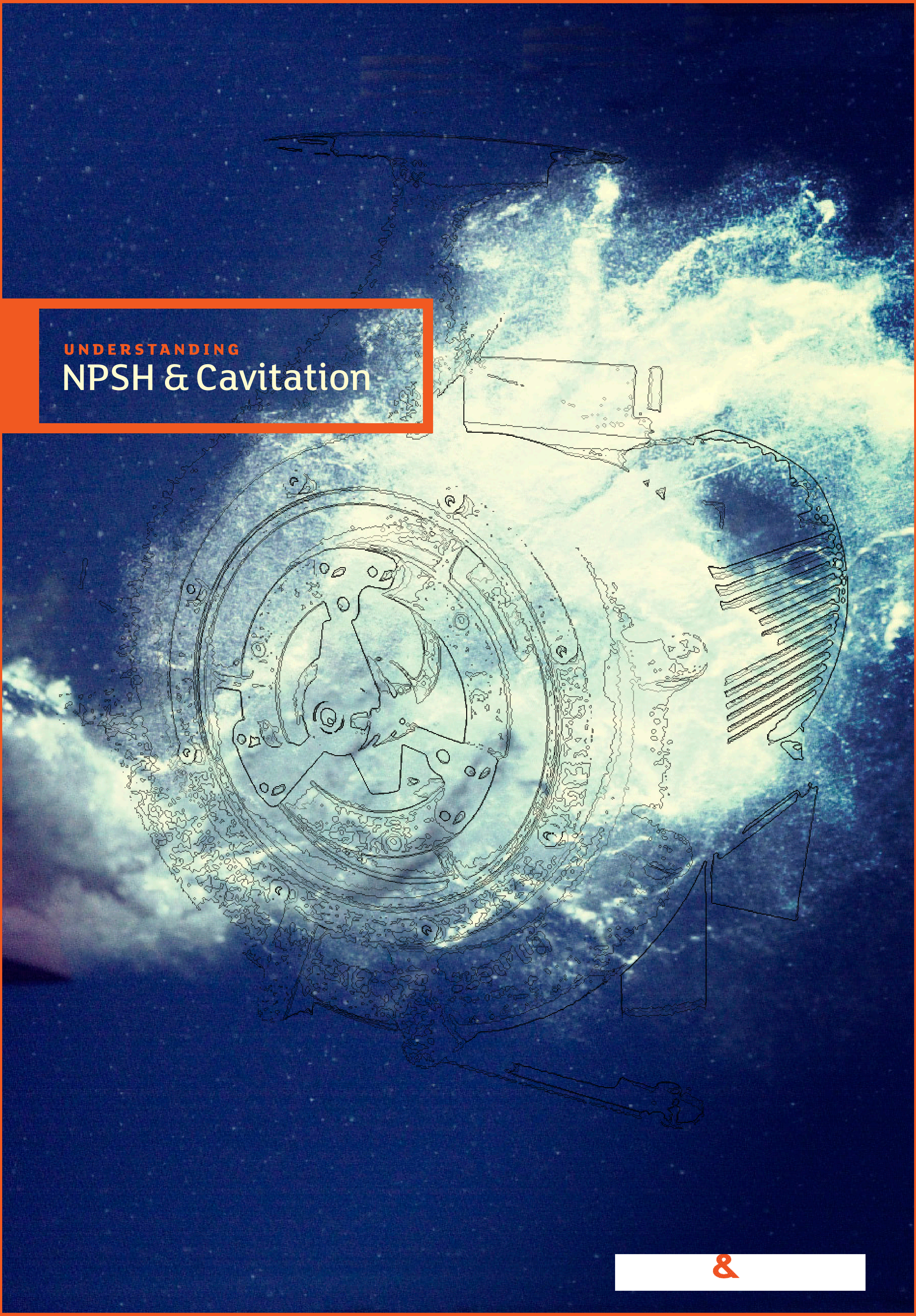
UNDERSTANDING

# NPSH & Cavitation



# UNDERSTANDING
# NPSH & Cavitation

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## Dear Reader,

People want to know about cavitation. At *Pumps & Systems* magazine, we hear it time and again. Our stories about NPSH are among the most popular on our website. More than 3,000 people registered for our recent Grundfos-sponsored webinar titled "How to Read a Pump Curve." End users want to know how to determine the best efficiency point (BEP) and how to keep their pumps operating in that sweet spot.

Cavitation damage can be a nightmare. It can raise or lower flow rate, cause seal failure and destroy the impeller, among other serious –and costly– issues.

Through the years, many of our experts have written about the dangers of cavitation and have offered great advice on how to avoid it. We are sharing some of those articles with you in this e-book. In these pages you will learn how to calculate net positive suction head (NPSH) and how to troubleshoot a system to keep its performance in its optimal zone.

We appreciate your interest in this topic and your support of our authors and editors. Please let us know if there are any other specific subjects that you feel would make good reading for a future e-book. Check our website, www.pumpsandsystems.com, for upcoming features about NPSH and cavitation, as well as other topics to help you run your pumping system as efficiently and safely as possible.

Happy reading!


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# Understanding NPSH: **NPSH Definitions**

BY **Terry Henshaw, P.E.**

Definition of NPSH —The margin of pressure over vapor pressure, at the pump suction nozzle, is Net Positive Suction Head (NPSH). NPSH is the difference between suction pressure (stagnation) and vapor pressure.

In equation form:

$$NPSH = P_s - P_{vap}$$

Where:

NPSH = NPSH available from the system, at the pump inlet, with the pump running

$P_s$ = Stagnation suction pressure, at the pump inlet, with the pump running

$P_{vap}$ = Vapor pressure of the pumpage at inlet temperature

Since vapor pressure is always expressed on the absolute scale, suction pressure must be in absolute terms.

In U.S. customary units, both pressures must be in psia. Gauge pressure is converted to absolute pressure by adding atmospheric pressure.

In equation form:

absolute pressure = gauge pressure + atmospheric pressure

The above equation provides an answer in units of pressure (psi). This can be converted to units of head (feet) by the following equation:

$$h = 2.31p/SG$$

Where:

h = Head, feet

p = Pressure, psi

SG = Specific gravity of the liquid

**Problem No. 1: NPSH**

Stagnation suction pressure is determined to be 1-psig at a sea level installation. The vapor pressure of the liquid is 8-psia. Calculate NPSH in PSI and feet

$$NPSH = P_s - P_{vap} = 1 + 14.7 - 8 = 7.7 \text{ PSI}$$

$$NPSH = 2.31p/SG = (2.31)(7.7)/0.9 = 19.8 \text{ FEET}$$

**Velocity Head is Included**

Note that suction pressure is stagnation pressure (total pressure); it includes velocity head. Adding velocity head puts all pumps on the same basis, otherwise a pump would require different amounts of NPSH when tested with different sizes of suction lines (assuming that suction pressure is measured in the suction line, which is normally the case).

It should also be noted that the velocity head is normally quite small, relative to the NPSH, so it can usually be ignored.

**Units of NPSH**

For centrifugal pumps, NPSH values are expressed in units of specific energy (equivalent column height) such as feet or meters. For displacement pumps (rotary and reciprocating), NPSH values are normally expressed in pressure units such as pounds per square inch (psi), kilopascals, or bars.

NPSH values are neither gauge pressures nor absolute pressures. The g in psig means that the pressure is measured above atmospheric pressure.

The a in psia means that the pressure is measured above absolute zero, a perfect vacuum. NPSH is a measurement of pressure above vapor pressure, so the units of NPSH (in the U.S.) are just psi or feet.

**What Symbol Should We Use?**

Because units of pressure are typically used to express the value of NPSH for a displacement pump, some authors, and companies, use symbols such as NPIP (for net positive inlet pressure) and NIP (for net inlet pressure), because the units are pressure units, not head units. For simplicity, I'll stick with NPSH, regardless of the units used.

**Suction Pressure: The First Half of the NPSH Equation**

Suction pressure must be determined at the pump suction nozzle when the pump is running.

If suction pressure is measured with a gauge, the atmospheric pressure (at the pump location) must be added to the gauge reading

**Definition of NPSH —The margin of pressure over vapor pressure, at the pump suction nozzle, is Net Positive Suction Head (NPSH).**

to convert the reading to absolute pressure. The elevation of the gauge must also be added (if the gauge is above datum) or subtracted (if the gauge is below datum).

Although often negligible, the velocity head in the pipe at the gauge connection should be added to obtain total (stagnation) pressure. For a reciprocating pump (and some rotaries), the acceleration head must be subtracted. (More on acceleration head later.)

### Vapor Pressure: The Second Half of the NPSH Equation

Vapor pressure is more difficult to determine than suction pressure. It is a measure of the "desire" of a liquid to boil to a gas. Some liquids, such as butane and ammonia, have high vapor pressures.

They must be kept under pressure, or they will boil (flash). An open container of pure ammonia would quickly boil away, filling the area with noxious ammonia gas.

Cool water has a low vapor pressure. An open container of cool water, on the earth's surface, would not boil, but would evaporate slowly over a period of days.

The desire of cool water to boil is therefore low.

If we were to place that same open container of cool water on the surface of the moon, it would boil away, similar to the ammonia.

Why? The atmospheric pressure on the moon is zero, a perfect vacuum. The vapor pressure of pure, air-free water at 80-deg F is about 1/2-psia. This means that if the pressure on the water is reduced below 1/2- psia, the water will boil.

### A Function of Temperature

Vapor pressure is a function only of temperature. As the temperature of the liquid increases, its vapor pressure increases until the critical temperature is reached. At the critical temperature, vapor pressure vanishes. Above the critical temperature, there is no distinction between a liquid and a gas. It is all fluid.

### Boiling Reestablishes Equilibrium Conditions

Any liquid at its vapor pressure is on the verge of boiling (flashing). In such a condition it is said to be in equilibrium, at its bubble point or saturated.

If the pressure is reduced slightly, it will start to boil. If the temperature is held constant (which requires heat input) and the pressure held constant (below the vapor pressure), the liquid will continue to boil until it has all flashed to vapor.

If heat is not provided to the liquid, the portion flashing to vapor will cool, and will also absorb heat from the remaining liquid, causing the liquid temperature to drop. The lower temperature will result in a lower vapor pressure. The boiling will continue only until the vapor pressure drops to the pressure which is imposed on the liquid.

When that vapor pressure is reached, and the boiling stops, the liquid-vapor mixture is again in equilibrium.

This is what happens in the suction passage of a pump. Cavitation will cool the liquid and stop the cavitation. Otherwise, all the liquid would flash to vapor.

### NPSH Available: A System Characteristic

NPSHA stands for NPSH Available from the system. It can be calculated by measuring suction pressure at the pump suction nozzle, correcting to datum, adding atmospheric pressure, adding velocity head and subtracting vapor pressure. In equation form:

$$NPSHA = P_{sg} + P_z + P_{atm} + P_{vel} - P_{vap}$$

Where:

NPSHA = NPSH available to the pump, psi

$P_{sg}$ = Gauge pressure measured at suction nozzle, psig

$P_z$ = Elevation of gauge above pump centerline, converted to pressure units, psi

$P_{atm}$ = Atmospheric pressure, psia

$P_{vel}$ = Velocity head, convened to pressure units, psi

$P_{vap}$ = Vapor pressure of the pumpage, at the pump suction nozzle, psia

If desired, all units can be convened to head (feet) prior to plugging into the equation.

If the system has not been built, it is necessary to calculate the NPSHA by starting with the pressure in the suction tank. Add atmospheric pressure, add (or subtract) the liquid level above (below) datum, subtract all losses from the tank to the pump and subtract vapor pressure. With reciprocating pumps it is also necessary to subtract acceleration head, a term which will be explained later. Inequation form:

Flow Area of Pipe = 3.14 x 1.52 = 7.07 square inches

VEL = 0.321 x Q/A = 0.321 x 100/7.07 = 4.54 feet/sec

$H_{vel}$ = V2/2G = 4.542/64.4 = 0.3 feet

$$NPSHA = H_{sg} + H_z + H_{atm} + H_{vel} - H_{vap}$$

$$= (p_{sg} + p_{atm} - p_{vap})(2.31/SG) + H_z + H_{vel}$$

$$= (152 + 14.0 - 163)(2.31/0.5) + (-2) + 0.3$$

$$= 13.9 - 2 + 0.3 = 12 \text{ feet}$$

**Problem No. 2: NPSHA**

A suction gauge with its centerline 2-feet below the centerline of a centrifugal pump reads 152-psig. Atmospheric pressure is 14.0-psia. The pipe is 3-in standard weight steel.

Capacity is 100-gpm. Vapor pressure is 163-psia. SG is 0.5. Calculate the NPSHA in feet.

Because the desired answer is in feet, rather than PSI, we will convert all pressure units to feet.

[Note: A new 300-psi gauge, used to measure the suction pressure, normally has an accuracy of ± 1 percent of full scale, or ± 3-psi (14-ft). Therefore, the error in the gauge could be more than the calculated NPSHA.]

[Also note that the velocity head was negligible, and could have been ignored.]

**System Requirement**

For proper operation of the pump, it is necessary that NPSHA > NPSHR. The system must provide more NPSH than the pump requires. ■

For more information about NPSH, visit pumpsandsystems.com

**Terry Henshaw** wrote a series of 14 articles on NPSH for Pumps & Systems magazine in 2010-2011. Henshaw, now deceased, was a retired consulting engineer with more than 30 years experience at Ingersoll-Rand and Union Pump. All of his NPSH articles, as well as educational material on other topics, are available at pumpsandsystems.com.

# Net Positive Suction Head: NPSHR and NPSHA

By **Joe Evans, Ph.D.**

In Pumps & Systems January 2007, I wrote an article about cavitation and how a collapsing water vapor bubble can damage an impeller. Since then, I have received a number of requests to address Net Positive Suction Head (NPSH) and its relationship to cavitation. Here it is in a very simple, Pump Ed 101 perspective.

The process of boiling is not as simple as it may seem. We tend to think that it is all about temperature and often forget that pressure has an equal role in the process. The point at which water boils is proportional to both its temperature and the pressure acting upon its surface. As pressure decreases, so does the temperature required to initiate boiling.

The onset of cavitation also follows this rule. When water-at some ambient temperature-travels through an area of low pressure, it can undergo a change of state from liquid to vapor (boiling). As it progresses into an area of higher pressure, it will return to the liquid state (cavitation). The bubbles that form and collapse during this process are those of water vapor-not air. Although dissolved or entrained air can affect pump performance, it produces a totally different kind of bubble than the one produced by boiling.

The fact that boiling is proportional to both temperature and pressure is the reason cavitation is such a persistent problem. Simply stated, water can boil at virtually any temperature. At sea level, where atmospheric pressure is about 14.7-psi (34-ft), it takes 212-deg F. Increase that elevation to 6,000-ft and it drops to around 200-deg F because the corresponding atmospheric pressure decreases to 11.7-psi (27-ft). If we introduce a vacuum and continue to reduce pressure to about 0.2-ft, it will boil at its freezing point. Well, so what? We don't usually operate a pump in a vacuum, and even at the top of Mt. Everest we still have almost 5.2-psi (12-ft) of atmospheric pressure!

Well, it turns out that all centrifugal pumps produce a partial vacuum. If they did not, they would be unable to pump water from a lower level. During normal operation, the area of lowest pressure occurs near the impeller vane entrances, and if the pressure in this area drops to about 1-ft, water will boil at 75-deg F! For a pump to operate cavitation free, an excess of pressure energy is required of the water entering this area. We typically refer to this requirement as NPSHR, or the NPSH required. Where does this pressure energy come from? It is a combination of several different forms of energy that exist, at various levels, on the suction side of the pumping system. We refer to this available pressure energy as NPSHA, or the NPSH available.

## NPSHA

The NPSH available to a centrifugal pump combines the effect of atmospheric pressure, water temperature, supply elevation and the dynamics of the suction piping. The following equation illustrates this relationship. All values are in feet of water, and the sum of these components represents the total pressure available at the pump suction.

NPSHA = Ha +/- Hz - Hf + Hv - Hvp

Where:
Ha is the atmospheric or absolute pressure
Hz is the vertical distance from the surface of the water to the pump centerline
Hf is the friction formed in the suction piping
Hv is the velocity head at the pump's suction
Hvp is the vapor pressure of the water at its ambient temperature

Ha is the atmospheric or absolute pressure exerted on the surface of the water supply. Atmospheric pressure is the pressure due to the density of the earth's atmosphere at some elevation. It develops its greatest pressure (14.7-psi) at sea level (where it is most dense) and approaches zero at its upper boundary. We seldom think about this pressure because, out of the box or on the work bench, the typical pressure gauge reads 0-psi. These gauges are calibrated to something we call "gauge" scale (PSIG) and ignore atmospheric pressure. Gauges calibrated to the "absolute" scale (PSIA) include atmospheric pressure and will read 14.7-psi at sea level. The figure below compares these two scales. On the absolute scale, 0-psi equates to a perfect vacuum, but on the gauge scale it equates to atmospheric pressure.

If the water source is a reservoir or an open (or vented) tank, Ha is simply the measured atmospheric pressure. It takes on another dimension if the supply is an enclosed, unvented tank. In this case, Ha becomes the absolute pressure or the sum of the measured atmospheric pressure plus or minus the actual gauge pressure of the air in the tank. Hz takes into account the positive or negative pressure of the water source due to its elevation. If it is above the pump, Hz is a positive number and if it is below, Hz is negative. Hf is simply the friction generated due to flow in the suction piping and is always a negative number. It is a function of the pipe length and diameter plus the fittings and valves it incorporates.

Hv and Hvp may be a little less familiar to some of us. Hv, or velocity head, is the kinetic energy of a mass of water moving at some velocity V. It is equivalent to the distance that water would have to fall in order to reach that velocity. It can be calculated by determining the velocity in the suction piping from a velocity table and substituting that value for V in the equation "h = V2/2g" (where g is the universal gravitational constant, 32-ft/sec2). It is usually small-at a velocity of 7-fps, Hv is just 0.765-ft-and is often ignored if Ha and Hz are sufficiently large.

Hvp represents the pressure that is required to keep water in the liquid state at some ambient temperature and is obtained from a vapor pressure table. At 50 deg F, just 0.41-ft is required, but at 160-deg F that requirement increases to 11.2-ft. Since this pressure must be reserved for its stated purpose, Hvp is always a negative number.

At first glance, the equation for NPSHA looks pretty static, but it is actually quite dynamic. All of the variables can be in a continuous state of change. Velocity head and suction line friction vary as a function of flow. Likewise, atmospheric pressure can vary by several feet depending on weather conditions. Water supply elevation and temperature can vary seasonally. Usually the "worst case" values for each of these components are used when calculating NPSHA.

## NPSHR

As mentioned earlier, NPSHR is the suction pressure necessary to ensure proper pump operation. It is purely a function of the pump design, and although it can be calculated, it is more accurately determined by actual testing. Why does a pump require a positive suction head? Quite simply, it is impossible to design a centrifugal pump that exhibits absolutely no pressure drop between the suction inlet and its minimum pressure point, which normally occurs at the entrance to the impeller vanes. Therefore, all pump systems must maintain a positive suction pressure that is sufficient to overcome this pressure drop. If the pressure is not sufficient, some of the water will change state (liquid to vapor) and cavitation is initiated. Like NPSHA, NPSHR is also a dynamic quantity and increases substantially with pump flow.

You would think that the NPSHR, measured by the pump manufacturer, would be the suction pressure required to prevent cavitation. That used to be the definition, but it is currently defined as the suction pressure at which a particular pump's hydraulic performance is degraded by 3 percent. This raises some concern since this degradation is actually due to cavitation, and at the 3 percent level, it has the potential to be damaging. The Hydraulic Institute's standards stipulate that each of the points on a pump manufacturer's NPSHR curve must reflect this 3 percent value. There are rumors that the term NPSHR will eventually be changed to NPSH3, which more accurately describes its true meaning.

Depending on the pump design, HI recommends an NPSHA / NPSHR margin of 1.1 to 2.5. Some pump experts recommend even more. It is a good idea to check with your pump manufacturer for its specific margin requirement as it relates to a particular pump model and its application.

A new term, NPSHI (inception), was recently developed to define the suction pressure required that will suppress all cavitation. The cavitation that occurs between NPSHI and the point where damage occurs is called incipient cavitation. This form of cavitation appears to cause little, if any, damage in normal pumping applications. There is some ongoing debate as to whether the cavitation that occurs due to a 3 percent performance degradation should be regarded as incipient cavitation. ■

**Joe Evans** is a retired pump engineer who has written extensively on educational topics for *Pumps & Systems*. This article first appeared in the magazine in 2011. You can read more of his educational articles at pumpsandsystems.com—many of which remain at the top of viewed stories for the website.

# Rethinking NPSH

Understanding this complex topic can help end users avoid common pitfalls.

By **Jim Elsey**

Net positive suction head (NPSH) and its two main components—$NPSH_R$ and $NPSH_A$—are an often misunderstood mystery to a large percentage of people in the pump industry. I have studied and catalogued more than 150 technical articles on NPSH in the last 40 years, and most have begun with comments about the complexity of the topic. A common statement in the pump industry is that 80 percent of all pump problems are on the suction side of the pump. I would state that, with the exception of operating the pump away from the best efficiency point (BEP), the percentage is much higher.

## Rethinking the Concept

The responsibility and purpose of the centrifugal pump is to receive the liquid that the suction system delivers and move it downstream. The suction-side system, if properly designed and operated, delivers the fluid to the pump. The pump does not reach upstream and retrieve the fluid, nor is it capable of doing so.

The common misconception is that the pump will "suck" the fluid from the suction system into the pump.

Perhaps if liquids had tensile strength characteristics, that could be remotely possible (I acquiesce that the impeller does create a small differential pressure at the eye), but the suction-side system must have adequate energy to deliver the fluid to the pump. Using the analogy of a cellphone, if the suction-side system does not have enough "signal strength" (bars of energy), then the "call" will be dropped or be of poor quality—in other words, the pump will cavitate.

## Suction Pressure

One of the most common errors I witness is confusing suction pressure with net positive suction head available ($NPSH_A$). Even people with decades of pump experience and education seem to make this mistake. A common comment is, "I do not need to calculate NPSHA because I have 135 psig of suction pressure."

What they fail to understand is that the temperature of the fluid in this case is 350 degrees F. (Please assume water as the fluid for all examples in this article.)

The formula for $NPSH_A$ indicates that 100 percent of the negative head caused by the vapor pressure of the 350 degree fluid negates the positive head contributed by the pressure of 135 psig. After accounting for the losses that result from friction head, the only positive head available to make up the remaining energy (bars of signal strength) is the static head. Static head is the energy (bars) contributed by the elevation of the fluid over the centerline of the impeller. (Note: This article does not account for velocity head because of the fractional

### 7 TIPS FOR CALCULATING $NPSH_A$

The formula for calculating $NPSH_A$ is:

$$NPSH_A = h_{abs.prs} - h_{vpr.prs.} - h_{static} - h_{fric}$$ (For a suction lift)

$$NPSH_A = h_{abs.prs} - h_{vpr.prs.} + h_{static} - h_{fric}$$ (For a flooded suction)

Where:

- $h_{abs.prs}$ = head due to absolute pressure converted to feet
- $h_{vpr.prs.}$ = head loss due to the vapor pressure of the fluid
- $h_{static}$ = head due to static pressure; can be negative or positive
- $h_{fric}$ = head loss due to fluid friction in the pipe and all components

1. I suggest you convert all factors to feet (meters) and work in absolute values.
2. I have not included the fifth factor of velocity head ($h_{vel.}$) because it is typically so small. If present, it would be a positive factor.
3. Vapor pressure and friction never work in your favor.
4. Static head will be negative and works against you in a lift situation.
5. Static head will be positive and works for you in a flooded situation.
6. If you have $NPSH_A$ problems, use the formula as a road map to look for solutions.
7. Using a pump of lower speed, dual suction or different impeller geometry can also resolve NPSH issues.

contribution and, in this case, flooded suction.)

Pump users must also remember that NPSH is not pressure. Pressure is a force, but head is an energy level, and the suction pressure is only one of numerous components in the total makeup of NPSH.

Another comment I often hear in the field is, "I do not need to calculate the $NPSH_A$ because I have a flooded suction." Again, these individuals are not taking the negative factors of friction and vapor pressure into account.

## Submergence

Submergence is the vertical distance from the top surface of the fluid to the centerline of the pump intake line. Submergence is applicable to both flooded and lift situations. If the submergence is not positively sufficient, then the velocity of the fluid in the suction line will create a vortex. The captured air will be ingested into the pump. Centrifugal pumps are not designed to pump (or compress) air, and the average centrifugal pump will drop performance quickly even with small amounts of entrained air.

While certain designs, such as recessed impeller pumps, can handle up to 24 percent entrainment, just 12 percent will stall most pumps. This is vital because many people in the field confuse cavitation with air binding/entrainment.

Every pump suction-side installation has a minimum submergence below which air will be ingested. The flow rate for a pipe of a given size, geometry and material makeup has a corresponding fluid velocity. The resultant velocity corresponds with an amount of required submergence (distance) to prevent the formation of a vortex. Keep in mind that just because you cannot see the vortex with the naked eye does not mean the vortex phenomenon is absent.

## Vacuum

At the bottom section of most steam condensers is a collection area, usually a tank-shaped reservoir for the condensate commonly known as the hot well. In these applications, end users commonly make errors determining the correct absolute pressure when making the $NPSH_A$ calculations. Pumps are subject to vacuum on the suction side in many other instances as well.

The error is in the assumption that the vacuum level is equal to the absolute pressure. Consider a condenser with a vacuum level of 28 inches of mercury (Hg). Inexperienced users might incorrectly assume that they need to convert the vacuum level to a corresponding head, which they determine is the absolute value (see Equation 1). In reality, the actual absolute pressure is the difference between the existing vacuum and what would be the perfect vacuum or zero absolute pressure. Think about it as how much pressure remains if the vacuum is at some level, X, (as in this case of 28 inches Hg). A perfect vacuum would be 14.69 (atmospheric pressure at sea level) x 2.31 (the conversion factor) = 33.933 (rounded to 34 feet).

At sea level, the atmospheric pressure typically supports a mercury column not more than 29.92 inches high. Therefore, the standard for atmospheric pressure at sea level is 29.92 inches Hg, which translates to an absolute pressure of 14.69 psia, which is usually rounded to 14.7 psia.

So the true absolute pressure (to be converted to head) is really the difference between the two (see Equation 2). The correct absolute pressure converted to head is 2.22 feet not 31.78 feet.

At some point, you will be required to calculate the value for NPSH available. Why not be ready to do it the right way and avoid the unnecessary drama and expense? ■

**Jim Elsey**, of Summit Pump, is a mechanical engineer who has focused on rotating equipment design and applications for the military and several large original equipment manufacturers for 43 years in most industrial markets around the world. Elsey is a columnist for *Pumps & Systems* magazine whose work consistently ranks among the most popular with magazine readers. This article first appeared in July 2015.

**Equation 1** (*Incorrect approach*)
28 in/Hg vacuum x 1.135 conversion, in/Hg to feet of water = 31.78 feet

**Equation 2** (*Correct approach*)
34 - 31.78 = 2.22 feet
(Note: I have rounded off and assumed sea level for the example)

# Pressure Instrumentation Critical for Troubleshooting

Pressure gauges are inexpensive components that can predict the causes of poor reliability in centrifugal pumps and prevent costly repairs and downtime.

By **Brandon Rudy, WIKA Instrument**

In today's industrial facilities, using reliability-centered maintenance as the primary approach to reduce maintenance costs and operational downtime is more commonplace. This approach may be hindered because most petrochemical facilities were built before this maintenance strategy became a priority. Even today, expansion projects planned to reduce costs often under-instrument equipment at the expense of losing the capability to effectively troubleshoot and predict issues.

For rotating equipment, field instrumentation serves three purposes:

1. Operators are often required to make decisions based on the parameters measured directly in the field.
2. Maintenance and engineering professionals often use gauges to troubleshoot problematic equipment to determine the root cause of failure.
3. Instrumentation can predict the causes of poor reliability before repeat equipment failures.

This article discusses the critical issues/parameters that should be managed to maximize reliability, with recommendations to utilize local pressure instrumentation to aid in predictive maintenance and troubleshooting.

## Pump Operating Point

Pumps are designed to achieve a specified design flow rate and differential head at which they should operate. Running within 10 to 15 percent of its best efficiency point (BEP) allows the equipment to minimize the vibrations associated with imbalanced internal forces. Note that the percentage off of BEP is measured in relation to the BEP flow rate. As shown in the pump curve in Figure 1, reliability suffers the farther a pump is operated from its BEP.

A pump curve works as a law for where the equipment can operate—if it is undamaged. The operating point of a properly performing pump can be predicted by using either the suction and discharge pressures or the flow rate. If damage to the equipment occurs, all three parameters must be known to accurately measure the performance of the pump. However, determining if any damage to the pump has occurred is difficult without measuring the aforementioned values. This makes the installation of flow meters and suction and discharge pressure gauges critical.

After the flow rate and

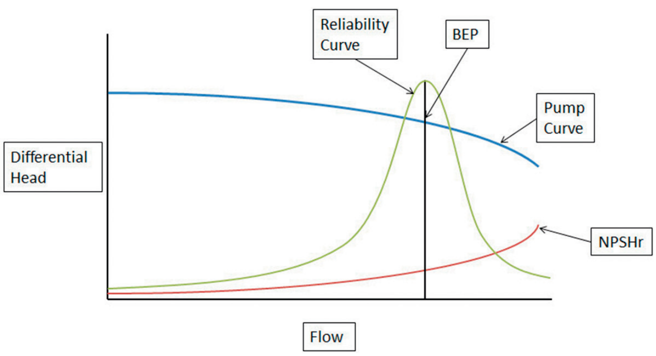
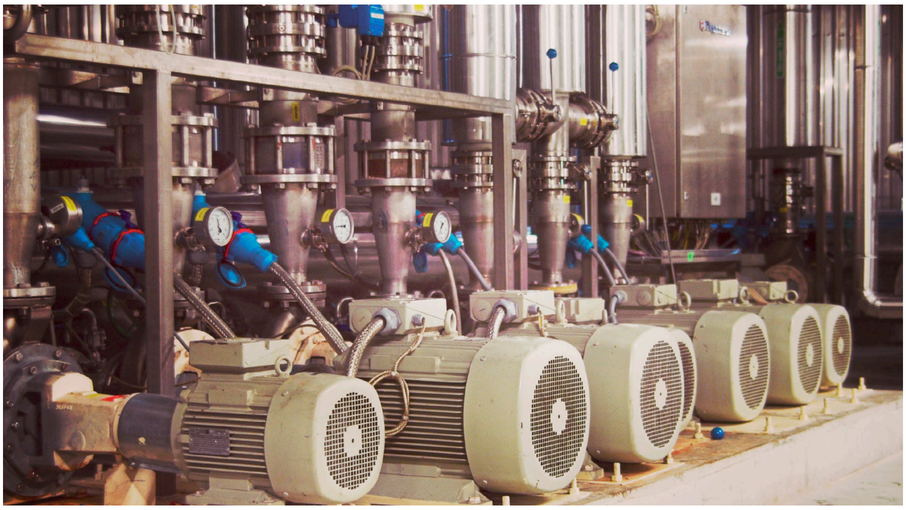



Figure 1. Sample pump curve

Pressure instrumentation can aid in predictive maintenance and troubleshooting.



differential pressure/head are known, plot the two on the graph. The plotted point is likely to be close to the pump curve. If so, how close to BEP the equipment operates can be determined immediately. If the point falls below the pump curve, it can be determined that the pump is not performing according to design and likely has some form of internal damage.

If a piece of equipment often operates to the left of its BEP, it may be considered oversized. Some solutions include trimming the impeller, slowing the pump if a VFD is installed or reducing downstream hydraulic restrictions.

A pump that habitually runs to the right of its BEP may be considered undersized. Possible solutions include increasing the impeller diameter, increasing the pump speed, throttling the discharge valve (if lower flow rates are acceptable) or replacing the pump with one designed to generate greater flow rates. Operating a pump near its BEP is one of the best ways to guarantee a high level of reliability.

**Net Positive Suction Head**

Net positive suction head (NPSH) is a measure of a fluid's propensity to stay in a liquid state. At zero NPSH, the liquid is at its vapor pressure or boiling point. Centrifugal pumps have a net positive suction head required (NPSHr) curve that defines the suction head required to prevent the fluid from vaporizing while going through the low pressure point at the eye of the impeller.

The net positive suction head available (NPSHa) must be greater than or equal to the NPSHr to prevent cavitation, a phenomenon in which vapor bubbles form at the impeller eye and then collapse violently, resulting in material removal and vibrations that can cause bearing and mechanical seal failure in a fraction of their typical operating life. The NPSHr value on the included pump curve increases exponentially in high-flow conditions.

A suction pressure gauge is the most practical and accurate way to measure NPSHa. Low NPSHa has many different causes. However, the most common are clogged suction piping, a partially closed suction valve and clogged suction strainers. Additionally, operating to the right of a pump's BEP will increase the NPSHr for the equipment. Upstream restrictions can be identified by installing suction pressure gauges and adding them to operator rounds.

**Suction Strainers**

Many pumps utilize suction strainers to keep debris from entering and damaging the impeller and volute. The problem is that they clog with time. As they clog, the pressure drop across the strainers increases, which decreases the overall NPSH available to the pump. A second suction pressure gauge can be placed upstream to be compared with the pump's suction gauge to determine if the strainer is clogged. If the two gauges do not read equal pressure, it will be obvious that there is a strainer blockage.

**Inappropriate Seal Support Pressure**

Although mechanical seals are not always the root cause, they are widely considered the most common failure point of centrifugal pumps. API seal support piping plans are used to maintain proper lubrication, temperature, pressure and/or chemical compatibility. Maintaining piping plans is critical to maximizing reliability. Therefore, close attention must be paid to instrumenting seal support systems. External flushes, steam quenches, seal pots, circulators and gas panels should all have pressure gauges. In the case of seal pots, consider how far the observer will be from the gauge. Using 4.5-inch gauges on seal pots is recommended to ensure visibility from a distance.

**Conclusion**

Instrument audits have revealed that suction gauges are installed on less than 30 percent of centrifugal pumps. However, no amount of instrumentation can prevent equipment failure if the data is not observed and used properly.

Whether specifying instrumentation on the front end of a new project or facility or retrofitting, ensure that current and future engineers and operators will have the opportunity to troubleshoot and operate their critical equipment appropriately. ■

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