PDHonline Course M124 (4 PDH)

Understanding Net Positive Suction Head

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Understanding Net Positive Suction Head

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Randall W. Whitesides, P.E.

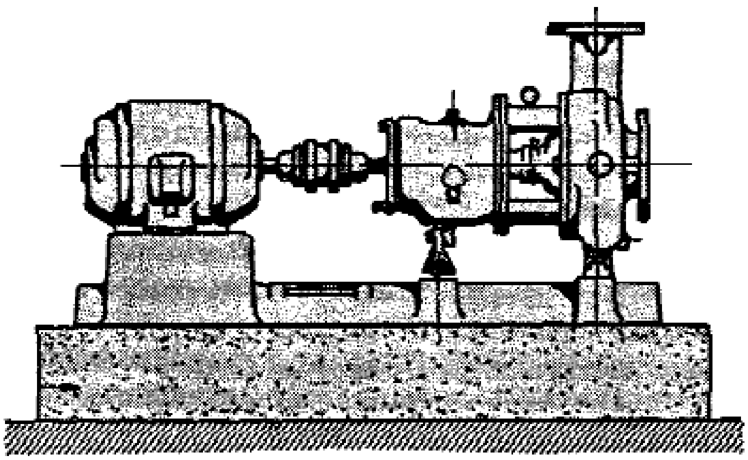
Introduction and Overview

A very large part of a pump installation's longevity has to do with selection of the proper pump for the application. Improper selection leads to premature pump failure, increased repair costs, unnecessary downtime, and in the case of a manufacturing environment, higher production costs. One critical aspect of determining the pump application is the basis for this course: the analysis of Net Positive Suction Head. Net Positive Suction Head is an important element in the proper selection of both centrifugal and positive displacement type pumps and each type has its own set of considerations. This course is limited to the study of centrifugal pumps.

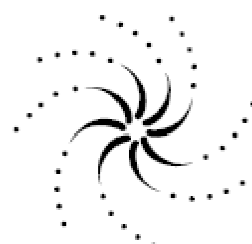
For a very good reason, we will begin our discussion of Net Positive Suction Head by first addressing a directly related problematic phenomenon known as cavitation. Liquid cavitation has a deleterious effect on a pump's internal parts and as a result reduces the pump's efficiency, performance, and ultimately, reliability. One might initially think this course should be re-titled *Understanding Liquid Cavitation in Centrifugal Pumps*, but be assured, the main purpose of this course is to fully understand Net Positive Suction Head by defining, identifying, and quantifying the concept.

We will learn that Net Positive Suction Head exists in two forms and that the numerical comparison of these forms is a useful tool in the prediction of potential liquid cavitation conditions. Moving from a predictive viewpoint to a reactive one, we will learn to identify some of the root causes, and possible solutions, when faced with pump cavitation.

Centrifugal Pump Fundamentals



Pumps are broadly classified as kinetic or positive displacement. One of the subclassifications of the kinetic pump branch is the centrifugal type. It consists of the "wet end" which is made up of a rotating impeller within a casing with inlet and outlet connections, which is coupled to either a constant or variable speed drive. Of all of the types of pumps, the centrifugal pump is the most commonly used. It has found favor because of its many advantages: simple construction, low relative cost, low maintenance, quiet operation, and reliability. Unfortunately, centrifugal pumps experience difficulty when handling liquids with large quantities of vapor or entrained gases.



Liquid is conveyed by the centrifugal pump by virtue of the kinetic energy imparted to the liquid by the rotating impeller. For a given diameter impeller at a given speed, a finite amount of energy (foot pounds) is transferred to each pound of liquid pumped regardless of the weight (density) of the liquid. This fact gives rise to the axiom that the resulting fluid height produced from this pumping operation, but not the pressure developed at the base of this fluid column, is identical irrespective of the liquid pumped. Liquid heights are referred to as *heads*. More on this later.

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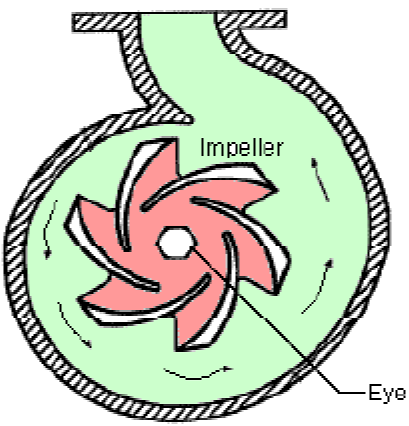
Liquid Cavitation



A pressure reduction occurs when a liquid moves from the pump inlet (suction connection) to the point at which it receives energy from the impeller. You may recall that liquids can vaporize (boil) at very low temperatures when they are subjected to low pressures. *Liquid cavitation* is the sudden formation and collapse of low pressure bubbles (cavities) in the pumped liquid caused by the mechanical rotation of the pump impeller. Other terms for cavitation are partial vaporization and liquid flashing. It is well documented that this process causes noise, vibration, and damage to many of the pump's internal components. Liquid cavitation has been acoustically characterized as the sound produced by a centrifugal pump attempting to convey small rocks in fluid suspension. The resulting noise and vibration range from barely discernible to quite loud and violent. In order to determine if cavitation will occur, the reduced pressure at the pump inlet must be compared to the vapor pressure of the pumped liquid.

Interesting facts (and myths) about cavitation are presented in PDHcenter.com course number M225.

INTERESTING FACT:
In centrifugal pumps the incoming liquid is most likely to vaporize in the vicinity of the vane tips in the eye of the impeller.

INTERESTING FACT:
In addition to the destructive characteristic of cavitation is the fact that a pump's performance suffers because it is attempting to convey a binary mixture of liquid and vapor.

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SUMMARY
- Pumps are kinetic or positive displacement.
- The most prevalent kinetic pump type is the centrifugal.
- Pumps have trouble conveying liquid/vapor mixtures.
- Liquid cavities can be created by a spinning pump impeller.

Liquid Cavitation

Before we can begin a discourse on Net Positive Suction Head there are other fluid properties and terms that must be fully understood. These are:

1. Vapor pressure;
2. Absolute pressure;
3. Specific gravity.

Vapor pressure is defined as that pressure exerted by the gaseous state of a liquid, that is in equilibrium with its liquid phase. Better still, try this definition: Vapor pressure is that pressure at which a liquid begins to vaporize, *i.e.* boil. Vapor pressure is usually given in units of millimeters of mercury (mm Hg) or pounds per square inch but must be converted to feet of liquid absolute in order to maintain consistency in the Net Positive Suction Head formula that will be presented shortly. (See the section entitled Conversion of Pressure Units to Feet of Liquid on page 10). How do we determine the vapor pressure of pumped liquid? If water is being pumped the method is relatively simple. Absolute pressure for water vapor at any temperature can be found in the ASME steam tables. If a liquid other than water is being pumped, published technical references and physical property data for the particular fluid should be consulted to accurately ascertain the correct vapor pressure. The vapor pressure of liquids varies directly with temperature.

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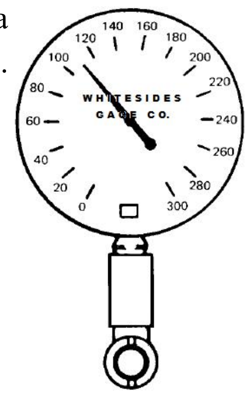
IMPORTANT CONSIDERATION

When a range of liquid temperatures will be encountered during the pumping process, the most elevated temperature should be used in order to account for corresponding higher value of vapor pressure.

A DIFFERENT PERSEPCTIVE

Vapor pressure is a measure of the propensity of a liquid to boil (evaporate). An example of a low vapor pressure liquid is lube oil; a highly volatile liquid is diethyl ether.

Absolute pressure is an observed pressure (say by means of a pressure gage) that has been corrected for ambient atmospheric pressure. In its classical form it is expressed:



$$P_{ABS} = P_{GAGE} + P_{ATMOS}$$

The units denoted by the letters ***P*** in the above expression are pounds per square inch (psi) but any system of consistent units, such as pounds per square foot (psf) or feet of fluid, are just as applicable. In many cases, and for practical considerations, the atmospheric pressure value is taken as standard at sea level, or 14.7 psi, which for clean water at 60° F converts to 33.9 feet of liquid. As the local altitude increases, the lower atmospheric pressure must be taken into consideration in order to properly evaluate Net Positive Suction Head.

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INTERESTING FACT:
The atmospheric pressure reduces approximately 1.2 feet of H_2O for every increase of 1,000 feet of elevation.

Liquid specific gravity, denoted by ***S***, is the dimensionless ratio of any liquid's weight density at a specific temperature to that of water at 60° F.

SUMMARY

- A liquid begins a phase change at its vapor pressure.
- When atmospheric pressure is added to gage pressure, absolute pressure results.
- Specific gravity is a measure of a liquid's density.

Net Positive Suction Head Defined

There are really two approaches that can be taken to effectively define Net Positive Suction Head:

1. A semantic approach whereby we examine the words that comprise the term and,
2. A classical or mathematical approach whereby we explore the numerical components of a simple linear equation.

It is recommended that the student progress through both of the following sections; however, those students who are familiar with hydraulics may wish to move directly to the more classical explanation which is presented below in the course section under the heading Classical Definition of Net Positive Suction Head.

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Semantic or Literal Definition

Net Positive Suction Head exists in two forms: **Available** and **Required**. For now, we will limit our discussion to the former and will explain in detail later in the course the difference between the two types.

Let's take a look at the phrase *Net Positive Suction Head* by breaking the expression down and defining each word in reverse sequence:

Head

Although used extensively within the hydraulic engineering community, the term *head* is a somewhat archaic word whose etymology is from the Middle English. Its original meaning was literally a body of water kept in reserve at a height. Today the dictionary definition is:

1. *The difference in elevation between two points in a body of fluid;*
2. *The resulting pressure of the fluid at the lower point expressible as this height; broadly, pressure of a fluid..*

Source: www.science.nasa.gov

Head is simply a pressure unit that is commonly used in hydraulic engineering that is expressed in feet of pumped fluid. That is to say, it is the pressure that is exerted from the weight of a height of a given liquid; hence the unit of feet. There are numerous forms and references to hydraulic head, such as,

1. Fluid friction head;
2. Static suction head;
3. Pump discharge head.

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For a better understanding of hydraulic head, let's digress momentarily from the suction aspects of a pump arrangement and discuss what may be a more common consideration: pump discharge pressure. It is convenient to conceptualize discharge head by visualizing a single vertical pipe, infinitely long, connected to the outlet of a centrifugal pump. When operated, this pump's developed discharge pressure would "lift" the pumped liquid to an equilibrium height in the vertical pipe, identical to the pressure that would be produced by the weight of that same column of liquid.

ADDITIONAL INFORMATION
Hydraulic static heads are referred to a common datum: the centerline of the pump suction nozzle or the pump drive shaft.

Suction

In pump hydraulics, suction refers to the inward movement of liquid through a conduit, such as a section of pipe, into the pump and ultimately to the eye of the impeller. Suction is the negative pressure induced by the rotating impeller that draws the pumped liquid to a point such that energy may be imparted to it from the impeller vanes. The opposite of suction is discharge. The word suction is used as an adjective in many hydraulic terms, all of which of course refer to the inlet side of a pumping system.

Positive

In the context of centrifugal pump suction side analyses, positive refers to the fact that while the resulting overall evaluated pressure quantity can mathematically be less than zero, desirably it will always be greater than zero.

Net

As an adjective, this means the remainder after all deductions have been taken. In a hydraulic sense, this word is derived from the fact that differences in pressure are being examined. That is to say, the helpful (additive) aspects of components of the suction system are being combined with the subtractive (negative) aspects to arrive at an overall (or net) condition.

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So, combining these individual definitions yields an overall definition of Net Positive Suction Head that can be summarized as:

Net positive suction head is a pressure, associated with the intake of a pump, expressed in feet of pumped liquid, resulting from the algebraic evaluation of both the accretive and depletive aspects of that suction system.

Net Positive Suction Head is almost universally denoted by the expression:

NPSH

and this abbreviation will be utilized throughout this course content when it is appropriate. This term should not be confused as the product of separate variables as is customary in mathematics.

Classical Definition of NPSH

According to the latest edition of the Hydraulic Institute Standards, Net Positive Suction Head available ($NPSH_A$) is defined as:

The total suction head in feet of liquid absolute, determined at the suction nozzle and corrected to datum, less the vapor pressure of the liquid in feet absolute.

In somewhat simpler terms, $NPSH_A$ is the absolute pressure in feet of liquid at pumping temperature available at the pump suction flange, above vapor pressure. Mathematically this looks like,

$$NPSH_A = \pm h_S - h_L + h_A - h_V$$

Where,

h_S = Static suction head (+) or static suction lift (-), feet
h_L = Suction line losses (friction, entrance and fittings), feet
h_A = Absolute pressure at the liquid's free surface, in feet of liquid pumped
h_V = Vapor pressure of liquid at pumping temperature, converted to ft. of liquid

IMPORTANT CONSIDERATION
With regards to the calculation of $NPSH_A$ it is important that liquid density be considered when considering those terms that involve the liquid's weight density, namely, h_A and h_V.

SUGGESTION
It is always good to include the adjective **minimum** with $NPSH_A$ to re-inforce the fact that all possible suction arrangement scenarios that would yield the lowest value have been considered.

Conversion of Pressure Units to Feet of Liquid

Consistent pressure units in feet absolute of liquid pumped are required in the NPSHA equation. To convert pounds per square inch (psi) to feet of liquid use the following relationship:

$$h = \frac{2.31\,P}{S}$$

To convert millimeters of mercury (mm Hg) to feet of liquid use the relationship:

$$h = \frac{P}{22.4\,S}$$

Net Positive Suction Head Required

The technical definition of Net Positive Suction Head required ($NPSH_R$) is: *The reduction in total head as the liquid enters the pump.* $NPSH_R$ is experimentally determined by several methodologies. One procedure is operate the pump under study with clear water while incrementally reducing $NPSH_A$ by throttling a suction valve. The on-set of cavitation is then observed and recorded at controlled flow rates. How do we accurately determine the on-set of cavitation? It is an approximation at best, but has been officially defined as corresponding to a 3% drop in total developed pump pressure, *i.e.,* discharge head. Obviously there is sufficient cavitation that is already occurring to produce this 3% reduction in discharge pressure. The actual start of cavitation is known as incipient cavitation and it always occurs well before the point of $NPSH_R$ is reached.

An important consideration with respect to the evaluation of $NPSH_R$ is that of the liquid's vapor pressure. Pump performance curves plot $NPSH_R$ versus flow; these data points are experimentally determined by conducting tests utilizing water. If in the practical application the fluid being pumped exhibits a vapor pressure exceeding that of water, it should be intuitively obvious that $NPSH_R$ values provided on the pump manufacturer's standard performance curve cannot be considered reliable.

> INTERESTING FACT:
> Limited tests have indicated that in some cases a reduction in $NPSH_R$ can be considered with liquids at elevated temperatures, *i.e.,* elevated vapor pressures.

Examples of liquids with high vapor pressures are:

1. Hydrocarbons;
2. Condensate (hot water);
3. Solvents.

The relationship of $NPSH_R$ to a pump's capacity (flow) is depicted in Figure 1.

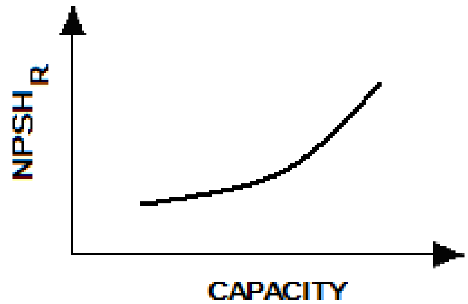

Figure 1

The method used by pump manufacturers to present $NPSH_R$ data on pump performance curves is not standardized. In some cases this information could resemble Figure 1. In contrast, some manufactures plot constant values of $NPSH_R$ for a given pump on performance curves. These are usually a family of curves, really usually parallel dashed negatively sloped straight lines, that are superimposed over all the other proliferation of data and plots shown on a typical pump curve. Take a look at the typical pump performance curve in Figure 2 and see if you can find the lines of constant $NPSH_R$ values.

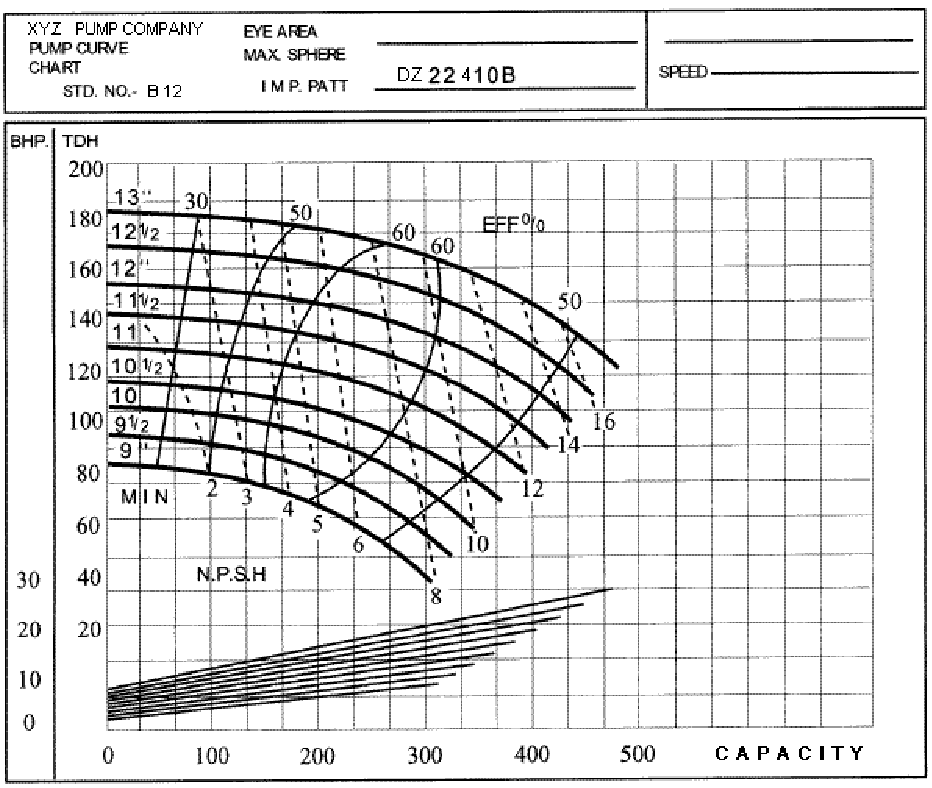

Figure 2

To a limited extent, changes in the value of $NPSH_R$ can be estimated when a pump's variables are manipulated. **See PDHcenter.com course number M125 for more information on this topic.**

OBSERVATION
Pump manufacturer's performance curves provide an abundance of data usually condensed into a small space. In addition to a family of multiple impeller diameter head and capacity curves plotted on a cartesian coordinate plane are: plots of hydraulic efficiencies; lines of constant $NPSH_R$; and brake horsepower. At first glance a pump performance curve can be quite intimidating especially when it is presented in a tight grid background.

SUMMARY

- Head is a pressure term expressed in liquid height.
- Pressures must be converted to heads to properly analyze $NPSH_A$.
- Specific gravity is a measure of a liquid's density.
- $NPSH_R$ is dictated by the equipment. It is relatively easy to determine; it is provided by the pump manufacturer.
- $NPSH_A$ is defined by the system within which the pump operates. It is more difficult to determine; it must be calculated.

The Desired Inequality of $NPSH_A$ and $NPSH_R$.

Theoretically, to preclude liquid cavitation,

$$NPSH_A \geq NPSH_R$$

Practically, in order to compensate for system variations and incorrect analytical assumptions,

$$NPSH_A >> NPSH_R$$

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It has been recommended in some technical circles that a differential of 1 to 2 feet between the two net positive suction heads be considered as a minimum to introduce a margin of safety against liquid cavitation when pumping water and water-similar liquids. Margins of 20% to 30% are not uncommon when the properties of the liquid being pumped are doubtful or unknown.

The American National Standards Institute (ANSI) and the Hydraulic Institute collaborated to produce a guidance document in 1998 entitled *Centrifugal and Vertical Pump NPSH Margin* (standard 9.6.1) that addressed this subject. Unfortunately this standard was "withdrawn" in 2003 as a result of that organization's periodic 5 year review policy. Until a replacement standard is issued, the information contained in the withdrawn version is still felt to be useful, considering the limited availability of information on the matter.

Note: A considerable amount of information regarding NPSH margins is provided in PDHcenter.com course number M225, "Interesting Facts (and Myths) about Cavitation".

Examples

Let's take a look at the various pump suction arrangements that can exist and see how the $NPSH_A$ is calculated for each arrangement.

Shown on the next page in Figure 3, is a typical pump and tank arrangement that is often encountered: a tank whose contents are open to the atmosphere and from which the pump takes suction. Because the liquid level is above the reference datum, *i.e.* suction nozzle centerline, the value of $\boldsymbol{h_S}$ is positive and is referred to as the **Static Suction Head.** The pump shown in the arrangement of Figure 3 is said to have a flooded suction.

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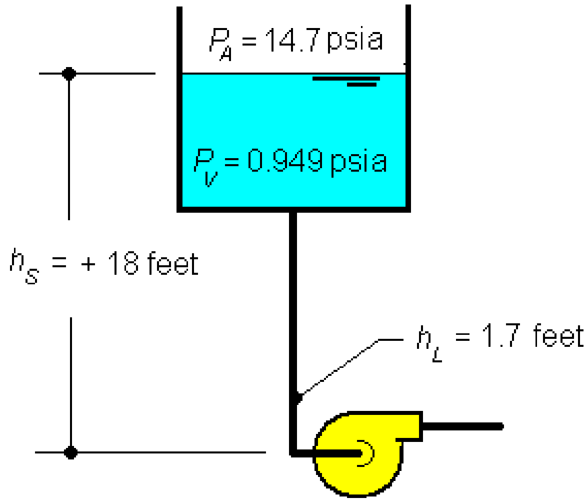

Figure 3 – Flooded suction open top tank

EXAMPLE 1 (Static Suction Head-Open Top Vessel)

Given:
Arrangement: Figure 3
Liquid: Water
Temperature: 100°F
Static Suction Head: 18 feet
Altitude: Sea level
Calculated Line Losses: 1.7 feet

Find: (1) The Net Positive Suction Head available ($NPSH_A$).
(2) The maximum acceptable Net Positive Suction Head required ($NPSH_R$).

Solution:
All the necessary information is provided to calculate $NPSH_A$ using the standard equation:

$$NPSH_A = \pm h_S - h_L + h_A - h_V$$

The first step is to determine the vapor pressure of water at 100°F. Referring to the ASME Saturated Steam Temperature Table corresponding to a temperature of 100°F shows that the vapor pressure is 0.94924 psia. In order to maintain unit consistency, we must convert this to feet of water thus,

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$$h_V = \frac{2.31\,P}{S} = \frac{(2.31)(0.94924)}{0.994} = 2.2 \text{ feet}$$

Note: The specific gravity of water at 100°F is 0.994.

Next we need to convert the atmospheric pressure to feet of water. Because we are at sea level, a standard pressure of 14.7 psia will be used,

$$h_A = \frac{2.31\,P}{S} = \frac{(2.31)(14.7)}{0.994} = 34.2 \text{ feet}$$

With the necessary pressures converted we are ready to calculate $NPSH_A$,

$$NPSH_A = \pm\, h_S - h_L + h_A - h_V$$

$$NPSH_A = +\,18 - 1.7 + 34.2 - 2.2$$

$$NPSH_A = 48.3 \text{ feet}$$

Because the liquid involved is H_2O at a moderate temperature, and there is no mention of entrained gases or other suction conditions that would infer unusual circumstances, we can proceed with:

$$NPSH_A = NPSH_R + 2$$

$$NPSH_R = 48.3 - 2 = 46.3 \text{ feet}$$

In the above example situation at least, we would search for a pump whose capacity and total dynamic head are satisfied and whose $NPSH_R$ would not exceed 46.3 feet.

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PRACTICAL CONSIDERATION
Since comparisons of **available** versus **required** Net Positive Suction Heads are made in units of whole feet, it makes little sense to calculate these values to an accuracy of finer than ± 0.1 feet.

Now let's look at another situation that might be encountered. In Figure 4 a railcar unloading system is diagrammatically depicted. The car contains a 50% concentration of sodium hydroxide at 86°F. At its lowest point, the liquid level in the car reaches an elevation 9 feet above the centerline of the unloading pump. In order to prime the pump and to insure a vacuum is not formed, the railcar is pressurized to 15 psi with an air blanket. Here again we have a static suction head present. What is the $NPSH_A$ with this pump arrangement?

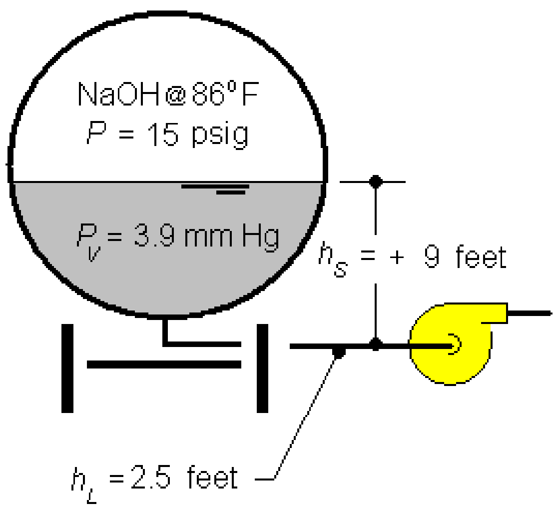

Figure 4 – Pressurized vessel

EXAMPLE 2 (Static Suction Head - Pressurized Vessel)

Given:

Arrangement:	Figure 4
Liquid:	50% Sodium Hydroxide
Temperature:	86° F
Static Suction Head:	9 feet
Altitude:	Sea level
Blanket Pressure:	15 psig
Calculated Line Losses:	2.5 feet

Find: (1) The Net Positive Suction Head available ($NPSH_A$).
(2) The maximum acceptable Net Positive Suction Head required ($NPSH_R$).

Solution:

All the necessary information is provided to calculate $NPSH_A$ using the standard equation:

$$NPSH_A = \pm h_S - h_L + h_A - h_V$$

The first step is to determine the liquid's physical properties at the pumping temperature of 86°F. There are many sources to find this type of information. Particularly useful is product manufacturer's literature which generally contains tables and graphs of the various physical properties. Consulting such a source for 50% sodium hydroxide at 86°F provides the following information:

Vapor pressure: 3.9 mm Hg
Specific gravity: 1.514
Viscosity: 42 cP

Note: The significance of the viscosity value will be examined momentarily.

Next we need to convert the liquid's vapor pressure to feet of 50% sodium hydroxide solution absolute,

$$h_V = \frac{P}{22.4\ S} = \frac{3.9}{(22.4)(1.514)} = 0.1 \text{ feet NaOH}$$

Finally we need to convert the railcar blanket pressure to an absolute value and then to feet of 50% sodium hydroxide solution absolute. Because we are at sea level, a standard pressure of 14.7 psia will be used,

$$h_A = \frac{2.31P}{S} = \frac{(2.31)(15 + 14.7)}{1.514} = 45.3 \text{ feet NaOH}$$

With the necessary pressures converted we are ready to calculate $NPSH_A$,

$$NPSH_A = \pm h_S - h_L + h_A - h_V$$
$$NPSH_A = +9 - 2.5 + 45.3 - 0.1$$
$$NPSH_A = 51.7 \text{ feet}$$

While this liquid has a very low vapor pressure we still need to take into consideration the fact that it is moderately viscous at the pumping temperature. The exact effect of viscosity on $NPSH_R$ generally is not available in technical literature but it is known to increase the value of $NPSH_R$. As stated earlier, values for $NPSH_R$ provided on pump performance curves are for water. We may therefore want to increase the margin of safety to say maybe 10 feet to rule out any potential for cavitation. Keep in mind that there exists no precise engineering rules for assigning a value to head margin.

$$NPSH_A = NPSH_R + 10$$
$$NPSH_R = 51.7 - 10 = 41.7 \text{ feet}$$

In this situation at least, we would search for a pump whose $NPSH_R$ would not exceed 41.7 feet at the required capacity.

Here is another example. As part of a hot water heating system, a pump and tank are arranged as shown in Figure 5.

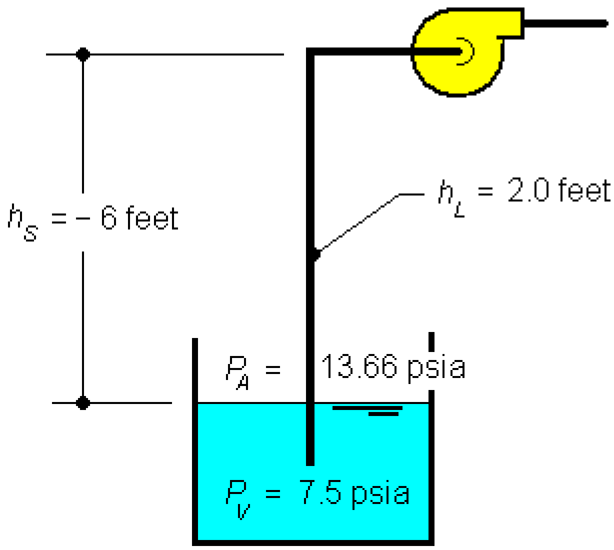

Figure 5 – Hot water tank with suction lift

Here is what the analysis would look like:

EXAMPLE 3 (Static Suction Lift – Open Top Hot Water Tank)

Given:

Arrangement:	Figure 5
Liquid:	Hot water
Temperature:	180° F
Static Suction Lift:	6 feet
Altitude:	+ 2,000 MSL
Calculated Line Losses:	2.0 feet

Find: (1) The Net Positive Suction Head available ($NPSH_A$).
(2) The maximum acceptable Net Positive Suction Head required ($NPSH_R$).

Solution:

All the necessary information is provided to calculate $NPSH_A$ using the standard equation:

$$NPSH_A = \pm h_S - h_L + h_A - h_V$$

The first step is to determine the vapor pressure of water at 180°F. Referring to the ASME Saturated Steam Temperature Table corresponding to a temperature of 180°F shows that the vapor pressure is 7.5 psia. In order to maintain unit consistency, we must convert this to feet of water:

$$h_V = \frac{2.31P}{S} = \frac{(2.31)(7.5)}{0.97} = 17.9 \text{ feet}$$

Note: The specific gravity of water at 180°F is 0.97.

Next we need to convert the atmospheric pressure to feet of water. Because we are at an elevation substantially above sea level, we need to convert the lower atmospheric pressure of 13.66 psia which exists at +2,000 MSL. (Data, graphs, and charts are readily available in the open literature on standard atmospheric pressure values at various altitudes above sea level).

$$h_A = \frac{2.31P}{S} = \frac{(2.31)(13.66)}{0.97} = 32.5 \text{ feet}$$

With the necessary pressures converted we are ready to calculate $NPSH_A$,

$$NPSH_A = \pm h_S - h_L + h_A - h_V$$

$$NPSH_A = -6 - 2 + 32.5 - 17.9$$

$$NPSH_A = 6.6 \text{ feet}$$

Because the liquid involved is H_2O at a moderate temperature, and there is no mention of entrained gases or other suction conditions that would infer unusual circumstances, we can proceed with:

$$NPSH_A = NPSH_R + 2$$

$$NPSH_R = 6.6 - 2 = 4.6 \text{ feet}$$

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Selecting a suitable pump for the low $NPSH_A$ presented by the configuration of this last suction arrangement example would present a challenge.

> **ADDITIONAL INFORMATION**
> Normally centrifugal pumps are not recommended for atmospheric suction lifts > 20 feet because they experience difficulty in maintaining prime regardless of $NPSH_A$. Loss-of-prime and "vapor lock" are common terms used by operations personnel to describe the cessation of flow. Pumps especially designed for extremely low $NPSH_A$ are purposely situated below suction sources so that in the event of momentary loss-of-prime they can recover prime by virtue of gravity flow.

Causes of Inadequate $NPSH_A$

It is one thing to identify a potential cavitation problem because of inadequate $NPSH_A$, and then quite another to identify measures that can be taken to rectify the problematic situation. To get an answer or develop a list of solutions, let's first list the causes of inadequate $NPSH_A$. We have already mentioned most of them.

We only have to look at the right side of the classical $NPSH_A$ equation to begin an understanding of contributing factors to inadequate $NPSH_A$. If one or more of the negative terms, *i.e.,* static suction lift (h_S), suction line loss (h_L), or liquid vapor pressure (h_V) are excessive, the resulting $NPSH_A$ will be reduced. Of course the simplest method to eliminate a documented problem with inadequate $NPSH_A$, albeit radical and certainly expensive, is to substitute a suitable pump. In essence, of course, what is being accomplished here is the effective substitution of a lower alternative $NPSH_R$.

Manipulating the System Variables

Obvious physical system changes than might be possible, before a compete pump change-out is undertaken are:

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1. Raise the liquid level in the suction vessel or, alternatively, lower the pump's elevation;
2. Decrease the fluid's operating temperature, *i.e.*, vapor pressure of the liquid;
3. If applicable, increase the superimposed pressure in the suction vessel vapor space;
4. Increase the suction line size or shorten its length, thereby lowering the frictional head losses.

Suction Line Frictional Head Loss

A detailed treatment of the calculation of suction pipe line frictional pressure loss is beyond the scope of this course. The open technical literature abounds with various methods to make this determination. These range from simple empirical approximation equations to rigorous iterative processes. Numerous "calculators" of this component of $NPSH_A$ are available on the Internet. Suffice it to say that suction line frictional head losses are attributable to:

1. Contractions and expansions;
2. Strainers and foot valves;
3. Valves and pipe fittings and;
4. Straight line length fluid friction.

In all cases, the line losses vary directly as a function of the square of the mean fluid velocity, $h_L = f(V^2)$. Let's look at one of the classic frictional head loss functions, the Darcy-Weisbach formula:

$$h_L = f \frac{L}{D} \frac{V^2}{2g}$$

Where, f = Colebrook friction factor
L = pipe line length
V = mean fluid velocity
D = pipe diameter
g = gravitational constant

It is readily apparent from this expression that reducing line length or reducing the mean fluid velocity, or increasing the suction line size, or any combination of these variations, would result in a lower value for h_L. Reducing the value of the h_L component in the $NPSH_A$ formula in turn results in an increase in the numerical quantity of $NPSH_A$.

A detailed treatment of practical pump suction arrangements is presented in PDHcenter.com course number M134.

Alternative Pump Designs

Very briefly, the $NPSH_R$ can be significantly reduced by the use of slower rotational speeds as a result of a concept that was developed in 1937-8 known as **Suction Specific Speed**. **A full explanation and detailed treatment of Suction Specific Speed is presented in PDHcenter.com course number M136.** It is defined as,

$$N_{SS} = \frac{N\sqrt{Q}}{NPSH_R^{0.75}}$$

Where, N = pump rotational speed, rpm
Q = pump capacity, gallons per minute

Historically, a knowledge base has been developed that indicates that cavitation usually occurs when values of N_{SS} exceed ~10,000 and that for a given application, a pump that results in a lower calculated suction specific speed should be considered over that of higher value, all other conditions being equal.

It has been demonstrated that double suction designs can offer reductions in $NPSH_R$ of over 20%. Use of a larger impeller eye reduces $NPSH_R$ by reducing the entrance fluid velocities.

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Summary

One of the most important considerations in selecting and applying a centrifugal pump is the conditions existing in the pump's suction system. Too often in the centrifugal pump selection exercise, disproportionate attention is given to satisfying the parameters of total dynamic head (TDH) and capacity. The significance of suction conditions is frequently discarded and gives rise to pump operational problems. The determination of a pump's Net Positive Suction Head is the analytical tool for ascertaining suitability to suction conditions.

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