Net Positive Suction Head (NPSH) in Centrifugal Pumps

An Online Continuing Education Course for Engineers

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Net Positive Suction Head (NPSH) in Centrifugal Pumps

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Introduction

Pumps are specified based on what they need to deliver to a system. The focus is generally on the outlet or discharge of the pump. For example, an engineer could specify a pump that generates 100 gallons per minute (gpm) of flow at 100 feet of head. The flow rate is generally established by the end use of the fluid, such as a heat exchanger or condenser. Pressure, or head, requirements are the result of the system design. A pump needs to generate enough head to drive the flow through the entire system.

In addition to what comes out of the pump, engineers need to be concerned with what goes in. This course will focus on the conditions at the inlet, or suction, of the pump, and specifically focus on Net Positive Suction Head (NPSH) in centrifugal pumps. The one-sentence takeaway of this course is that that there needs to be enough head at the pump suction for it to function properly. If the suction pressure of the pump is too low, the pump will not operate properly and could become damaged.

This course will introduce the concept of "head" as a measurement of fluid pressure. Using this concept, Net Positive Suction Head (NPSH) will be defined in terms of the piping system and the pump. The piping system will be analyzed to determine the Net Positive Suction Head Available (NPSHA) and the capabilities of the pump will determine the Net Positive Suction Head Required (NPSHR). To ensure the pump operates as intended, the NPSHA will need to be greater than the NPSHR for all operating conditions.

Please note that all examples in this course will use the English unit system, but the concepts conveyed are independent of the unit system.

Head

The term "head" is often used interchangeably with pressure in industries where fluid flow is present. If this is your first exposure to the term, it may be confusing. You may be wondering, why not use pounds per square inch (psi) instead? The short answer is that it makes conveying centrifugal pump performance and system hydraulics much easier. At the end of this section this idea will be revisited, but first, there will be a brief review of hydrostatics.

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Hydrostatic pressure is defined as the pressure a fluid exerts on an immersed object or container walls [1]. When considering an immersed object, the concept of head is easy to understand. If you have an object that is 20 feet below the surface of a pool filled with water, then the static head the object experiences is 20 feet of water. It can be seen in the equation below that the static pressure is directly proportional to the depth below the fluid surface. Therefore, the deeper an object is below the surface of a liquid, the more pressure it experiences. For example, the depth a submarine can dive below the surface is dictated by the pressure its hull can withstand. Beyond a certain depth, the water pressure will overcome the hull strength and crush the submarine.

$$p = \frac{\rho g h}{g_c} \qquad [1]$$

Where:

p = hydrostatic pressure

ρ = fluid density

h = depth below fluid surface

g = acceleration of gravity = 32.2 $\frac{ft}{s^2}$

g_c = gravitational constant = 32.2$\frac{lb_m \times ft}{lb_f \times s^2}$

When considering the second scenario of container walls, such as a pressurized pipe, visualizing head is not as intuitive. The idea of converting pressure perpendicular to a pipe wall into a one-dimensional distance requires some critical thinking. Let us consider the static pressure at the centerline of a pressurized pipe. Figure 1 shows a cross-section of a pressurized pipe with an "L" shaped static pressure gauge. The gauge is attached to the center line of the pipe and is open to the atmosphere at the other end. At the gauge, the pressure that was previously acting against the pipe wall is now free to lift the water against the force of gravity until an equilibrium is reached. The height of the water at equilibrium is the static head. If the static head measured in Figure 1 is 20 feet, the centerline of the pipe is experiencing the same static pressure as the submerged object discussed above.

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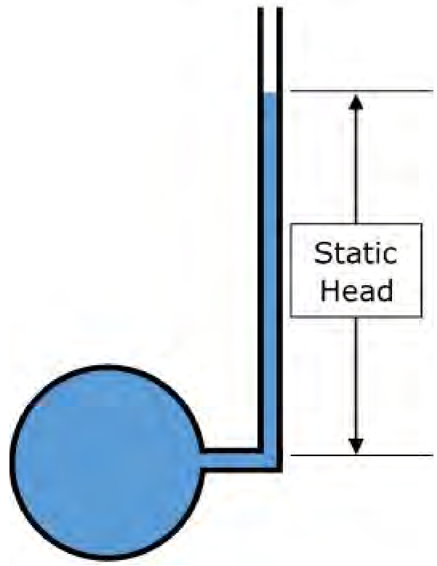

Figure 1

Rearranging the equation above to solve for "h" yields an equation that is useful for converting the pressure of a liquid into a head value.

$$h = \frac{pg_c}{\rho g}$$

Below is an example converting water at 10 psi and 60°F to a static head value. Note that the density of water at 60°F is 62.37 lb_m / ft^3, and that the answer has the units: *feet of water*. Heads are assumed to have units of the liquid being measured unless specified otherwise.

$$h = \frac{pg_c}{\rho g} = \frac{10\,\frac{lb_f}{in^2} \times \frac{144 in^2}{1 ft^2} \times 32.2\,\frac{lb_m \times ft}{lb_f \times s^2}}{62.37\,\frac{lb_m}{ft^3} \times 32.2\,\frac{ft}{s^2}} = 23.1\ ft\ of\ H_2O$$

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One important thing to notice about the equation above is that the static head is dependent on the fluid pressure and density. This is a subtle but important point that can lead to confusion for the following reasons:

1. Two fluids can have the same *static head* but different *static pressures*
2. Two fluids can have the same *static pressure* but different *static heads*

This concept is understood far easier visually than by reading the above sentences. Figure 2 shows two fluids that have the same static head but different pressures. The pressure at the bottom of the tank on the right is twice the pressure of the tank on the left. This is because its density is twice the density of the tank on the left. Remember, for a given head; pressure is directly proportional to density.

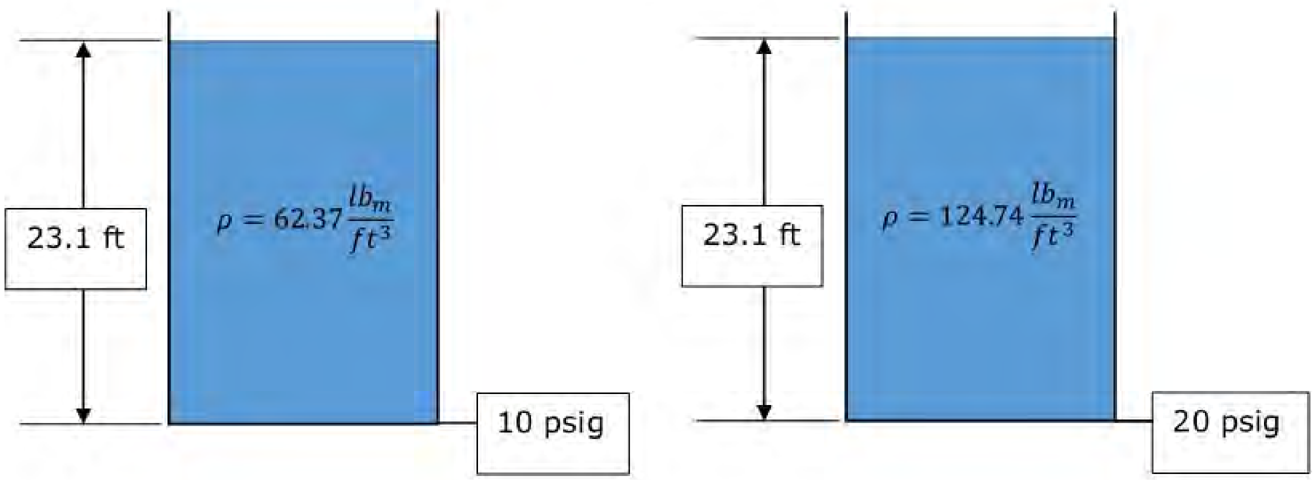

Figure 2

Figure 3 shows two fluids that have the same pressure at the bottom their tanks, but their static heads are different. The tank on the left has twice the head of the tank on the right. This is because its density is half the density of the tank on the right. From the equation above, head is inversely proportional to the density at a given pressure.

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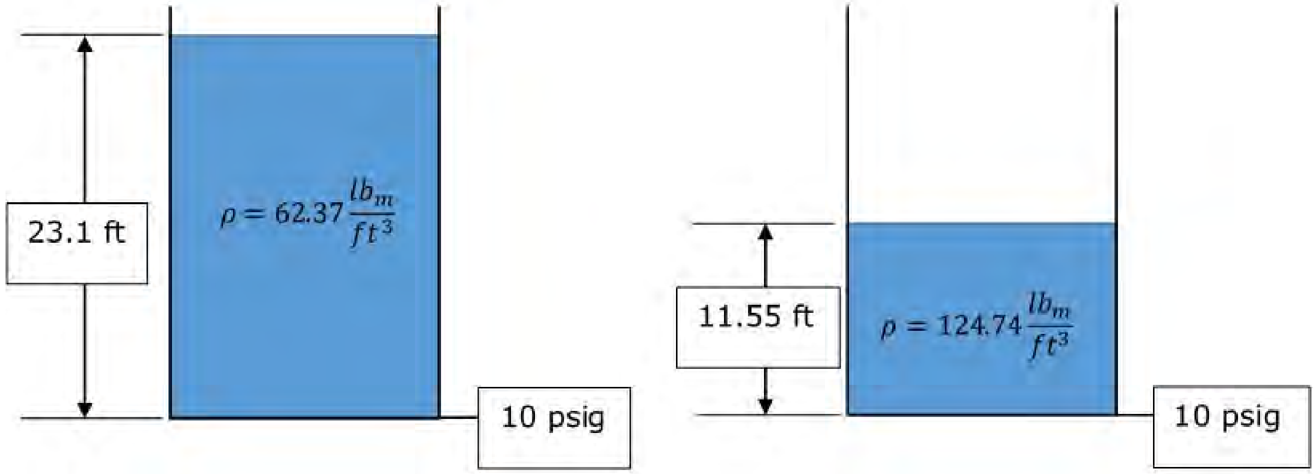

Figure 3

Earlier in this section, it was stated that head makes conveying centrifugal pump performance much easier. Pump performance is typically shown on pump curves, which are plots of pump head versus flow. For reasons not explained in this course, the head added by a pump is independent of fluid density. Therefore, one pump curve is applicable to all fluids. This greatly simplifies communicating pump performance from a manufacturer's perspective. Alternatively, if pump curves plotted pressure versus flow, different fluids would require different curves due to their varying densities. Further, multiple curves would be required for each fluid due to changes in density over a range of temperatures. Head versus flow is the better option.

Note: The section above applies to Newtonian fluids that are assumed to be incompressible. Liquid water, in nearly all pumped conditions, behaves as an incompressible Newtonian fluid. Additionally, the pressures and heads discussed above are gauge pressures, as opposed to absolute pressures.

Net Positive Suction Head Available

Now that the concept of head has been explained, it is time to move on to Net Positive Suction Head Available. Before the equation for NPSHA is introduced, it is important to understand why engineers should care about NPSHA. As stated previously, if there is not enough NPSHA in the system, pump performance is decreased and damage inside the pump can occur. The cause of these problems happens when the fluid entering the pump drops below its vapor pressure. In a phenomenon known as cavitation, vapor bubbles form and then collapse quickly.

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The cavitation causes noise, vibrations, and in some cases physical damage to the pump itself, in the form of pitting. A reduction in performance is caused by vapor bubbles blocking flow to the pump impeller vanes. Clearly, this is a situation that should be avoided.

The definition of NPSHA is the total suction head at the impeller less the vapor pressure of the liquid being pumped [2]. Intuitively, this makes sense because the fluid pressure at the pump suction needs to be above the vapor pressure to prevent the liquid from becoming a vapor. NPSHA is simply the excess pressure delivered to the pump suction beyond the vapor pressure. This excess pressure is required because pumps add kinetic energy to the fluid in the form of increased velocity, which is then converted to increased fluid pressure. As Bernoulli's principle states, increases in velocity lead to decreases in pressure. Therefore, the pressure decrease from the increased velocity must be offset by the NPSHA to prevent cavitation.

The equation below is used to calculate NPSHA. The discussion that follows will explain each of the four terms in the equation and how it affects NPSHA.

$$NPSHA = h_a - h_{vpa} \pm h_{st} - h_{fs} \quad [2]$$

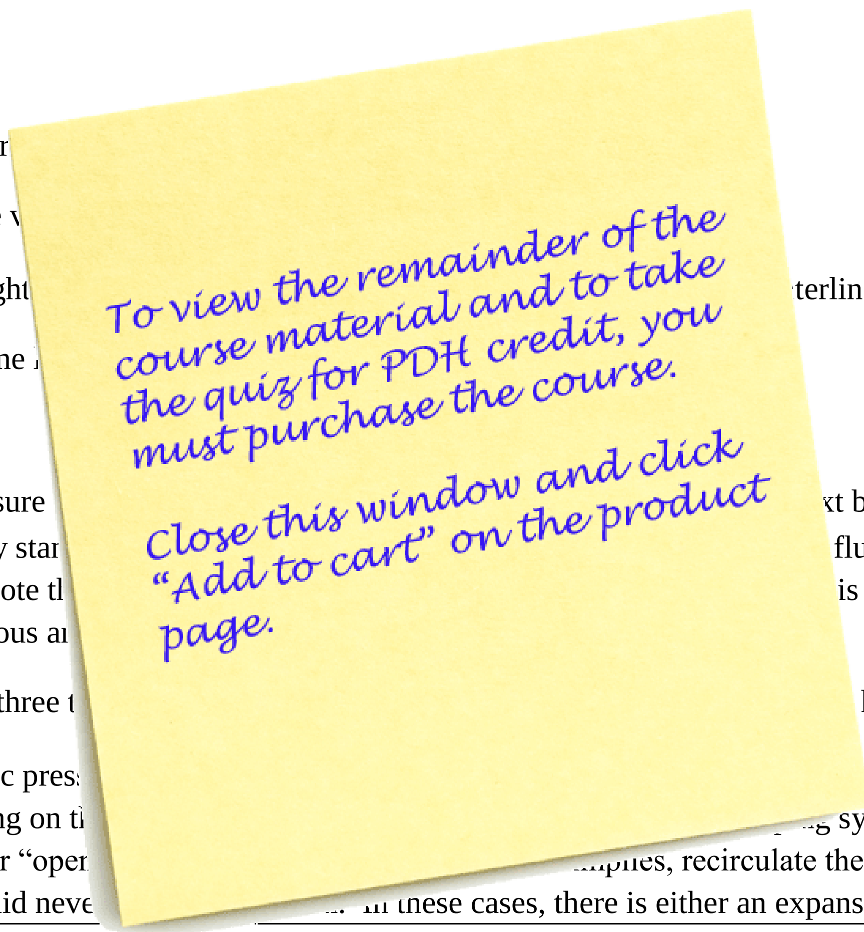
Where:

h_a = absolute pr

h_{vpa} = absolute v

h_{st} = static height ... terline

h_{fs} = suction line



The vapor pressure ... xt books or various industry star ... fluid temperature. Note tl ... is term will result in erroneous ai

The remaining three t ... head.

The atmospheric pres ... ifferent places depending on ti ... systems, "closed loop" or "oper ... mples, recirculate the fluid in a loop and the fluid neve ... In these cases, there is either an expansion tank or a

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