Understanding Net Positive Suction Head

Atmospheric Pressure

Until the early 17th century air was largely misunderstood. Evangelista Torricelli, an Italian scientist, was one of the first to discover that air, like water, has weight. He once said, "We live submerged at the bottom of an ocean of the element air." The weight of this "ocean" of air exerts a force on the Earth's surface called atmospheric pressure. Torricelli went on to develop the mercury barometer which now allowed for quantifiable measurement of this pressure.

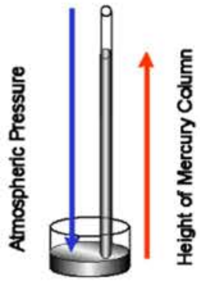

Figure 1
Operation of a mercury barometer

A mercury barometer *(figure 1)* uses a complete vacuum at the top of a glass tube to draw mercury up the tube. The weight of the column of mercury is equal to the weight of the air outside the tube (the atmospheric pressure). For this reason, atmospheric pressure is often measured in mmHg or inHg, corresponding to the height of the mercury column. This atmospheric pressure controls the weather, enables you to breathe, and is the cornerstone of pump operation.

Pump Operation

When asked how a pump operates, most reply that it "sucks." While not a false statement, it's easy to see why so many pump operators still struggle with pump problems. Fluid flows from areas of high pressure to areas of low pressure. Pumps operate by creating low pressure at the inlet which allows the liquid to be pushed into the pump by atmospheric or head pressure (pressure due to the liquid's surface being above the centerline of the pump). Consider placing a pump at the top of the mercury barometer above: Even with a perfect vacuum at the pump inlet, atmospheric pressure limits how high the pump can lift the liquid. With liquids lighter than mercury, this lift height can increase, but there's still a physical limit to pump operation based on pressure external to the pump. This limit is the key consideration for Net Positive Suction Head.

Net Positive Suction Head (NPSH)

NPSH can be defined as two parts:

NPSH Available ($NPSH_A$): The absolute pressure at the suction port of the pump.

AND

NPSH Required ($NPSH_R$): The minimum pressure required at the suction port of the pump to keep the pump from cavitating.

$NPSH_A$ is a function of your system and must be calculated, whereas $NPSH_R$ is a function of the pump and must be provided by the pump manufacturer. $NPSH_A$ MUST be greater than $NPSH_R$ for the pump system to operate without cavitating. Put another way, you must have more suction side pressure *available* than the pump *requires*.

Vapor Pressure and Cavitation

To understand Cavitation, you must first understand vapor pressure. Vapor pressure is the pressure required to boil a liquid at a given temperature. Soda water is a good example of a high vapor pressure liquid. Even at room temperature the carbon dioxide entrained in the soda is released. In a closed container, the soda is pressurized, keeping the vapor entrained.

Temperature affects vapor pressure as well *(figure 2)*. A chilled bottle of soda has a lower vapor pressure than a warm bottle (as anyone who's opened a warm bottle of root beer has probably already figured out). Water, as another example, will not boil at room temperature since its vapor pressure is lower than the surrounding atmospheric pressure. But, raise the water's temperature to 212°F and the vapors are released because at that increased temperature the vapor pressure is greater than the atmospheric pressure.

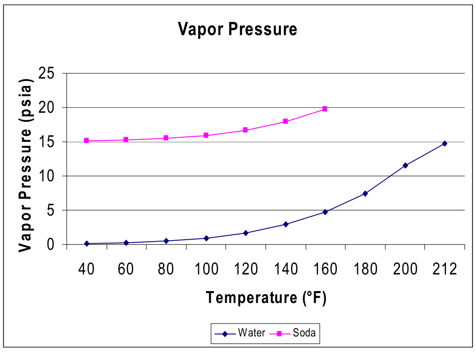

Figure 2
Vapor Pressure
versus Temperature

Pump cavitation occurs when the pressure in the pump inlet drops below the vapor pressure of the liquid. Vapor bubbles form at the inlet of the pump and are moved to the discharge of the pump where they collapse, often taking small pieces of the pump with them. Cavitation is often characterized by:

- Loud noise often described as a grinding or "marbles" in the pump
- Loss of capacity (bubbles are now taking up space where liquid should be)
- Pitting damage to parts as material is removed by the collapsing bubbles

Noise is a nuisance and lower flows will slow your process, but pitting damage will ultimately decrease the life of the pump.

Small dents on the surface caused by cavitation

Rotor cracked by cavitation

Calculating $NPSH_A$

No engineer wants to be responsible for installing a noisy, slow, damaged pump. It's critical to get the $NPSH_R$ value from the pump manufacturer AND to insure that your $NPSH_A$ pressure will be adequate to cover that requirement.

The formula for calculating $NPSH_A$:

$$NPSH_A = H_A \pm H_Z - H_F + H_V - H_{VP}$$

Term	Definition	Notes
H_A	The absolute pressure on the surface of the liquid in the supply tank	• Typically atmospheric pressure (vented supply tank), but can be different for closed tanks. • Don't forget that altitude affects atmospheric pressure (H_A in Denver, CO will be lower than in Miami, FL). • Always positive (may be low, but even vacuum vessels are at a positive absolute pressure)
H_Z	The vertical distance between the surface of the liquid in the supply tank and the centerline of the pump	• Can be positive when liquid level is above the centerline of the pump (called static head) • Can be negative when liquid level is below the centerline of the pump (called suction lift) • Always be sure to use the lowest liquid level allowed in the tank.
H_F	Friction losses in the suction piping	• Piping and fittings act as a restriction, working against liquid as it flows towards the pump inlet.
H_V	Velocity head at the pump suction port	• Often not included as it's normally quite small.
H_{VP}	Absolute vapor pressure of the liquid at the pumping temperature	• Must be subtracted in the end to make sure that the inlet pressure stays above the vapor pressure. • Remember, as temperature goes up, so does the vapor pressure.

All too often, these calculations are faulted by a simple unit discrepancy. Most often, it's easiest to work with feet of liquid. Adding the liquid name helps to be clear as well (feet of water, feet of gasoline, feet of ammonia, etc.). Also, make sure to include the specific gravity of the liquid. As discussed above, a 10" column of mercury and a 10" column of water exert very different pressures at their base.

Solving NPSH Problems

Let's be honest, many of us don't begin reading documents like this until after there's a problem. It would be wonderful if proper NPSH calculations had been run for every pump installation, but for thousands of cavitating pumps out there it's not too late.

The first step is to diagnose the pump. As discussed above, noise, capacity loss, and pitting are three major indicators, but direct measurement not only helps to confirm your suspicions, but also let's you know what your true $NPSH_A$ is. Install a compound gauge (one that measures both vacuum pressures as well as light positive gauge pressures) *(figure 4)* into the suction port of the pump (or as close as you can in the suction piping). When the pump is running, the reading from this gauge will be equal to your $NPSH_A$, less vapor pressure. If after subtracting vapor pressure this value is less than the pump's $NPSH_R$, you have confirmed that this is a cavitation problem.

Figure 4
A Compound Pressure Gauge

Diagnosing the problem is the easy part. Fixing the problem is usually much more difficult. Step by step, look at which of the $NPSH_A$ factors can be improved:

Term	Improvements
H_A	• Though you may use external pressure to feed the pump, this is usually atmospheric pressure and outside of your control.
H_Z	• If the pump only starts to cavitate near the end of emptying the supply tank, you may consider allowing for a higher level of liquid to remain. • Raising the tank, or lowering the pump helps, but may not be feasible.
H_F	• This factor is often the easiest to change. You can cut your frictional losses by: - Increasing the size of the suction piping or decreasing the length - Reducing obstructions such as valves, strainers, and other fittings. - For thicker liquids, heat tracing the lines will help to reduce the viscous losses - Hoses and corroded pipes have high losses. Consider replacing with new pipe
H_{VP}	• Control the temperature to make sure the vapor pressure doesn't get too high. Often tanks and pipes holding high vapor pressure liquids are painted light colors to avoid the sun heating them and raising the vapor pressure.

For example, a MasoSine pump generating 9.000l/h at 300rpm has a NPSHR of 3m of a product with 2.500cP. By switching to a larger pump running at 130rpm to generate the same 9.000l/h, the NPSHR drops to 1,3m for the same product. Slowing the pump allows more time for the rotor cavities to fill, allowing the pump to operate without cavitating even at a low suction pressure.

Just the Beginning

Hopefully you now feel more knowledgeable regarding NPSH and its importance when selecting a pump. A basic understanding can go a long way in identifying potential problems before they occur. Lifting liquids from underground tanks or rail cars, pulling thick liquids long distances or through hoses, handling high vapor pressure liquids such as LP gas or alcohol…these are just a few example cases of applications which pose the maximum risk of failure for the engineer who does not understand or account for NPSH.