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WHITE PAPER

NET POSITIVE SUCTION HEAD (NPSH)

by Steve Wilson

Net Positive Suction Head (NPSH) is one of the most misunderstood factors that impact pump performance and life cycle. In this White Paper, we will provide an overview of the factors impacting NPSH and how to enhance the decision-making process of selecting a pump and troubleshooting.

INTRODUCTION

Cavitation, which is the existance of "cavities" within the fluid in a pump, is unfortunately a common occurence. The term itself brings to mind destroyed impellers, systems that are not operating properly, and the sound of "pumping gravel." Cavitation, however, is not a problem but rather a symptom of a problem.

Two sources of cavitation exist, both of which constitute what forms the cavities. The first source is entrained air in the fluid. This condition exists because of the nature of the fluid being pumped (such as air laden water) or the nature of the pumping system into which the pump is installed (such as in a pump where vortexing draws air into the suction of the pump). Entrained air has nothing to do with NPSH and will not be discussed in this White Paper.

The second source is the presence of fluid vapor in the fluid. This vapor can, and does, exist when there is no air in the system. Since the very nature of a fluid is toward the gaseous state, external forces must be applied to maintain the liquid state. The amount of energy required varies with temperature and pressure and is called Vapor Pressure, which will be discussed in further detail later in this White Paper.

Since all liquids have a natural tendency to become gases, if allowed, these vapors can exist in all fluid systems. When the amount of these vapors (gases) exceeds an acceptable level, then problems arise. This source of cavitation associated with NPSH will be explained in this paper.

OVERVIEW

Before discussing NPSH, it's important to remember the centrifugal pump basics: a pump is a machine that adds energy to a fluid for the purposes of increasing the pressure or moving it along a pipeline.

A centrifugal pump accomplishes this through the actions of vanes. As fluid enters the vanes, energy is added in the form of velocity. Subsequently, the velocity is reduced and the energy is converted to pressure or head.

Therefore, the pump cannot add the velocity to a fluid that isn't "present." They do not add energy effectively to a gas nor to fluids outside the pump. The fluid must enter the eye of the impeller and be impacted by the vanes before the energy transfer can be started.

With centrifugal pumps, conditions outside the pump must "force" the fluid into the eye – there must be enough energy available to the fluid at the eye fo the pump to perform this and assure that the fluid remains a fluid. This type of energy is called Net Positive Suction Head Available, or NPSH (A) for short.

By design, each pump has certain characteristics (both physical and hydraulic) which determine the amount of energy needed to force the fluid into the impeller eye, ensure that is remains a fluid on its path through the impeller, and cause the amount needed to accomplish this. The nature of the pump eye, the structure of the impeller vanes, vane diameter, speed of operation, and where the pump is operating on its curve are just a few of the factors. The amount of energy needed by a pump is called Net Positive Suction Head Required, or NPSH (R).

The energy available must be equal to or greater than the amount of energy required, or the pump cannot do its job properly. The common NPSH rule has been stated as: NPSH (A) ≥ NPSH (R). A margin of safety should be given, and the rule is best stated as: NPSH (A) > NPSH (R). This will be discussed later in the paper.

What happens if there is not enough NPSH (A), or energy? The velocity of the fluid is increased upon entering the impeller, and, according to Boyle's law, pressure is decreased. The reduction in pressure will allow some of the molecules of fluid to reach the gaseous state and form "bubbles" (cavities) of vapor.

Pump performance is immediately reduced, and as these bubbles pass through the impeller they grow until the pressure inside the pump causes them to implode. The violence of the implosion is high, and this is what causes the characteristic "gravel" sound as well as the eroding of the impeller.

This series of actions – the vaporization of the liquid and the implosion of it back to a liquid – is called cavitation. Cavitation can and often does eventually cause catastrophic failure, which may happen quickly or slowly. In the meantime, there will be a loss of pump performance, and this performance loss may be pulsations in the pumpage and/or loss of pressure.

NPSH (R)

As previously stated, NPSH (R) is a function of pump design; there is little than can be done to change it after its designed. Inducers may be added, special first stage impellers placed on multistage pumps, etc. Make note that it is only the first stage which is impacted by NPSH problems as subsequent stages see the discharge from the first stage at their suctions.

Individual modification to the suction eye and vanes may be tried, but it is costly and highly unpredictable and typically not attempted until all other "cavitation stopping" methods have been employed.

NPSH (A)

NPSH (A) is a function of the system. Four basic factors in a system's design can impact NPSH (A), many of which may be controlled or changed. Understanding NPSH (A) is also important at the system design or modification stage to avoid pitfalls upon installation.

The amount of energy to the fluid at the pump suction is a net amount of the "positive energies" exerted on the fluid minus the "negative energies" that take away from the total. It is formulaically stated as:

$$\text{NPSH (A)} = H_a + H_s - H_{vpa} - H_f$$

Where:

NPSH (A) = Net Positive Suction Head Available

H_a = Absolute pressure on the fluid

H_s = Static suction pressure

H_{vpa} = Vapor pressure of the fluid

H_f = Friction losses in the suction pipe

H_a – ABSOLUTE PRESSURE ON THE FLUID

The absolute pressure is the pressure exerted onto the surface of the fluid by an outside source. In a closed system, this is the system pressure. In an open system, it is atmospheric pressure. At sea level, this pressure is given at "standard" as 29.92 in. of mercury, 14.696 psi, 1013.325 millibars, or 33.96 ft. of head (of any fluid having a specific gravity of 1.0, such as cool water).

In computing NPSH (A), it is important (as in all calculations) to assure that all units are in like form. Keep in mind, too, that as altitude increases, or atmospheric conditions change, H_a will change (*Table 1*). It is this pressure that "pushes down" on a fluid.

H_s – STATIC SUCTION PRESSURE

Altitude	Atmospheric Pressure	
(Above Sea Level)	Feet of Water	PSIA
0	33.9	14.7
1000	32.8	14.2
2000	31.6	13.7
3000	30.5	13.2
4000	29.4	12.7
5000	28.3	12.3
6000	27.3	11.8
7000	26.2	11.3
8000	25.2	10.9
9000	24.3	10.5
10,000	23.4	10.1

Table 1. *Atmospheric Pressure vs. Altitude*

The static suction pressure, or head, is the head above or below the suction of the pump. In other words, how high above or below the pump suction is the level of fluid. H_s is measured to the center of the pump suction eye on horizontal pumps or center of the discharge of the impeller on verticals. If the liquid level is above the pump, H_s will be a positive number. If if is below the pump, it will be a negative number.

Let's look at these two units (H_a and H_s) together, for example: We have a cooling tower located at sea level and the pump is located 10 ft. below the level of the sump.

The sum of $H_a + H_s$ will be 33.9 + 10 = 43.9 ft. If the pump were located 10 ft. above the level of the sump, it would be 33.9 +(-10) or 33.9 - 10 = 23.9. In order to ensure the pump maintained its prime when shut down, a foot valve would be required.

H_{vpa} – VAPOR PRESSURE OF THE FLUID

The vapor pressure of each fluid varies with the temperature. The higher the temperature, the higher the vapor pressure. Since the vapor pressure defines the point at which the liquid becomes a gas. Therefore, increasing the pressure elevates the boiling point and lowering the pressure decreases the boiling point.

Another way to explain vapor pressure is that the pressure at which a liquid and its vapor exist in equilibrium at a given temperature. At boiling, the vapor pressure equals the absolute pressure – they cancel each other out.

Vapor pressure tables for various liquids being pumped are available from a number of sources, and many engineering programs now include them. *Table 2* gives the vapor pressure of water. Note the vapor pressure at 212°F and compare it to the atmospheric pressure above: The vapor pressure equals the absolute pressure and the liquid boils.

Therefore, at low temperatures, the H_{vpa} portion of the NPSH (A) equation will be relatively low (for water), but at high temperatures it will be significant.

Vapor Presure		**Temperature (Degrees)**	
Ft. of Water	**PSIA**	**C°**	**F°**
0.2	0.0866	0	32
0.29	0.126	5	41
0.4	0.173	10	50
0.56	0.242	15	59
0.78	0.338	20	68
2.47	1.07	40	104
6.68	2.89	60	140
15.87	6.87	80	176
33.96	14.7	100	212
66.53	28.8	120	248
121.04	52.4	140	284
206.98	89.6	160	320
334.95	145	180	356
519.75	225	200	392
773.85	335	220	428

Table 2. *Vapor Pressure of Water (Absolute)*

H_f – FRICTION LOSSES IN THE SUCTION PIPE

The friction head loss in the suction pipe must be calculated through an application of Hazen Williams, D'Arcy, or other methods, such as the tabular "look up."

In design, the designer will often rely on statements made about available suction pressure to a pump as given municipalities. Those statements typically do not include losses through meters or valves, nor in the piping from the street to the mechanical room.

Those losses would need to be considered. As opposed to the other portions of the formula, the friction losses in the suction pipe will change with flow. Caution should be used at this point since friction losses increase with flow – as does NPSH (R) and if NPSH (A) is calculated at design flow and the pump runs out on its curve – and thus H_f will be higher than calculated.

Using the previous example, let's finish the NPSH (A) calculation: The water in the tower if 78°F. Using an online tool, we determine that the vapor pressure is .475 PSIA (1.097 ft.). An interpolation from *Table 2* would have yielded similar results.

In this case, the pump is located very close to the cooling tower, and losses are calculated at 1 PSI (2.31 ft.). With the pump located as in the first example, we find that we have the following NPSH (A):

$$43.9 - 1.097 - 2.31 = 40.493 \text{ ft.}$$

In the second example, we would have:

$$23.9 - 1.097 - 2.31 = 20.493 \text{ ft.}$$

If we were pumping hot water, the results would be quite different. For example: if the water temperature is 176°F, then the vapor pressure would rise to 15.87 ft. The two results would be:

$$43.9 - 15.87 - 2.31 = 25.72 \text{ ft.}$$

and

$$23.9 - 15.87 - 2.31 = 5.72 \text{ ft.}$$

We would need to compare those NPSH (A) results with the NPSH (R) on the pumps we intended to use to make sure we had sufficient energy available. If selections were otherwise excellent, we might have to modify the NPSH (A) factors to accommodate their use.

For example, we might relocate the pump, increase the suction pipe size, change the piping materials, modify valving, cool the temperature through cold water addition, or deepen the sump. In existing applications which exhibit NPSH induced cavitation, similar modifications might be indicated.

In either case, different pumps with lower NPSH (R) requirements might be the most advantageous solution.

CONCLUSION

Net Positive Suction Head deficiencies can cause severe pump and system problems and failure. The factors that impact NPSH (R) in the pump are relatively fixed and will vary from pump to pump.

The NPSH (A) factors in the system will vary with each system and are more susceptible to modification than are those in the pump. Because of variances in installation, atmospheric conditions, and values used in calculating, NPSH (A) should always be calculated to be greater than NPSH (R).

USA
GRUNDFOS Pumps Corporation
17100 West 118th Terrace
Olathe, KS 66061
Phone: (913) 227-3400
Telefax: (913) 227-3500

USA
PACO Pumps – National Headquarters
Grundfos CBS Inc.
902 Koomey Road
Brookshire, TX 77423
Phone: (800) 955-5847
Telefax: (800) 945-4777

CANADA
GRUNDFOS Canada Inc.
2941 Brighton Road
Oakville, Ontario
L6H 6C9
Phone: (905) 829-9533
Telefax: (905) 829-9512

MEXICO
Bombas GRUNDFOS de Mexico S.A. de C.V.
Boulevard TLC No. 15
Parque Industrial Stiva Aeropuerto
C.P. 66600 Apodaca, N.L. Mexico
Phone: 011-52-81-8144 4000
Telefax: 011-52-81-8144-4010

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