MORE ON WHAT IS CAVITATION?

Jacques Chaurette p. eng.,
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www.lightmypump.com

Cavitation begins as the formation of vapor bubbles at the impeller eye due to low pressure. The bubbles form at the position of lowest pressure at the pump inlet (see Figure 1) just prior to the fluid being acted upon by the impeller vanes; they are then rapidly compressed. The compression of the vapor bubbles produces a small shock wave that impacts the impeller surface and pits away at the metal creating over time large eroded areas and subsequent failure. The sound of cavitation is very characteristic and resembles the sound of gravel in a concrete mixer. You can hear this sound by downloading the cavitation sound file in mp3 format from the lightmypump web site www.lightmypump.com, go to the DOWNLOADS page.

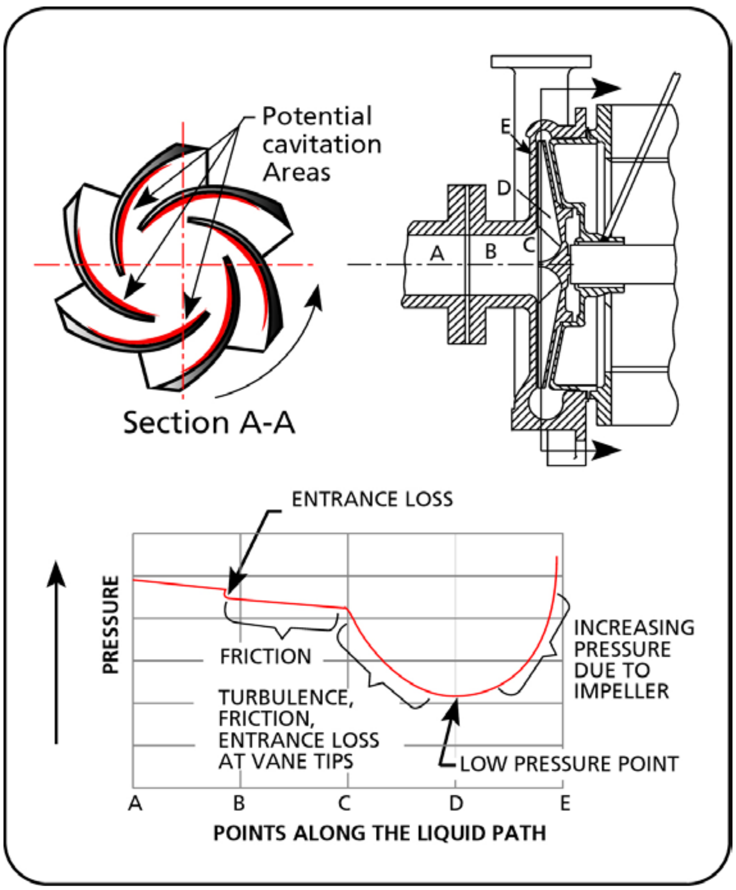

Figure 1 Pressure profile at the pump entrance.

As you can see from Figure 1 the pressure available at the pump inlet, which is the pressure that we would measure if we put a gauge at that point, can be reasonably high but still drop considerably as it makes it way into the pump. The pressure may be lowered enough that the fluid will vaporize and will then produce cavitation.

The same effect can sometimes be seen in control valves because they have a similar pressure drop profile, if the pressure is insufficient at the control valve inlet cavitation will also occur.

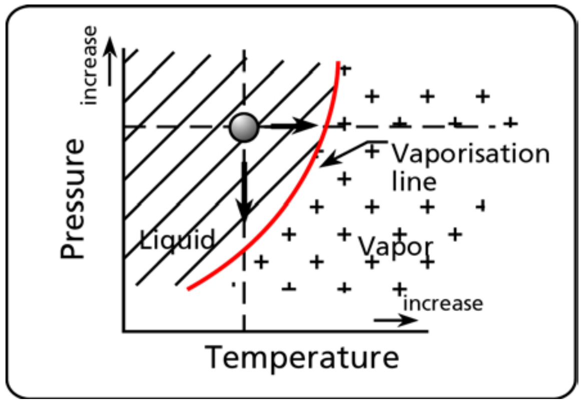

Figure 2 Vapor pressure vs. temperature.

Vapor pressure and cavitation

There are two ways to boil a liquid. One way is to increase the temperature while keeping the pressure constant until the temperature is high enough to produce vapor bubbles. In Figure 2 this is what happens if you take one point in the liquid phase and you move horizontally (that is at constant pressure) by increasing the temperature. Eventually you hit the vaporization line of the particular fluid and the fluid starts to boil or produce vapor bubbles. We do the same thing every day when we boil water in a pot.

The other way to boil a liquid is to lower the pressure. If you keep the temperature constant and lower the pressure the liquid will also boil. In Figure 2 this is what happens if you take one point in the liquid phase and you move vertically (that is at constant temperature) by decreasing the pressure. Again you hit the vaporization line of the particular fluid and the fluid starts to boil or produce vapor bubbles.

If the pot were covered and you had a source of vacuum (see Figure 3) by lowering the pressure in the pot you would be able to make the water boil at a lower temperature. When the pressure is 7.5 psia or (14.7 – 7.5 = 7.2) or 7.2 psi less than the atmospheric pressure the water will boil at a temperature of 180 °F and when the pressure is 1.5 psia the water will boil at 120 °F. This is what happens at the pump suction when the pressure is low enough to make the fluid boil or vaporize.

It is not unusual for industrial processes to operate at temperatures that are close or higher than 120 F. Therefore if the temperature is high and the pressure drops as the fluid enters the pump, it will be easier to produce cavitation because the pressure drop produced by the pump will have to be smaller to match a higher vapor pressure. If cavitation is occurring or suspected, two possible solutions are: to increase the pressure at the pump inlet or decrease the fluid temperature.

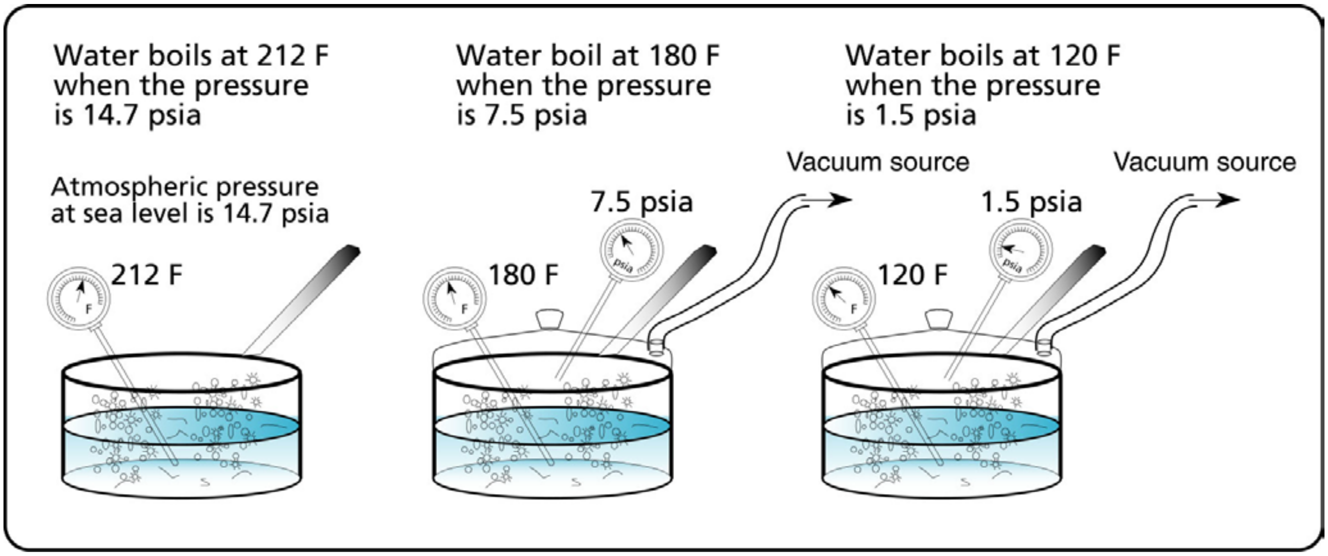

Figure 3 Making a liquid boil under low pressure.

The pressure at which the liquid vaporizes is known as the vapor pressure and is always specified for a given temperature. If the temperature changes, the vapor pressure changes.

HOW TO AVOID CAVITATION? CAVITATION CAN BE AVOIDED IF THE N.P.S.H. AVAILABLE IS LARGER THAN THE N.P.S.H. REQUIRED.

Net Positive Suction Head Available (N.P.S.H.A.)

The Net Positive Suction Head Available (N.P.S.H.A.) is the total energy per unit weight, or head, at the suction flange of the pump less the vapor pressure head of the fluid. This is the accepted definition that is published by the Hydraulic Institute's Standards books (see the HI web site at www.pumps.org). The Hydraulic Institute is the organization that formulates and promotes the use of common standards used for the pump industry in North America. The term "Net" refers to the actual head at the pump suction flange, since some energy is lost in friction prior to the suction.

Why do we need to calculate the N.P.S.H.A.? This value is required to avoid cavitation. Cavitation will be avoided if the head at the suction is higher than the vapor pressure head of the fluid. In addition, the pump manufacturers require a minimum N.P.S.H. to guarantee proper operation of the pump at the values of total head and flow rate indicated on the pump`s characteristic curves. They call this the N.P.S.H.R., where “R” stands for required.

To determine N.P.S.H.A., first we calculate the pressure head H_S at point S. A control volume is positioned (see Figure 4) to intersect the suction inlet of the pump and the fluid surface of the suction tank. The pressure head at point S is given by equation [1]:

$$H_S(ft\ \ fluid) = -(\Delta H_{F1-S} + \Delta H_{EQ\ 1-S}) + \frac{(v_1^{\ 2} - v_S^{\ 2})}{2g} + (z_1 - z_S + H_1) \qquad [1]$$

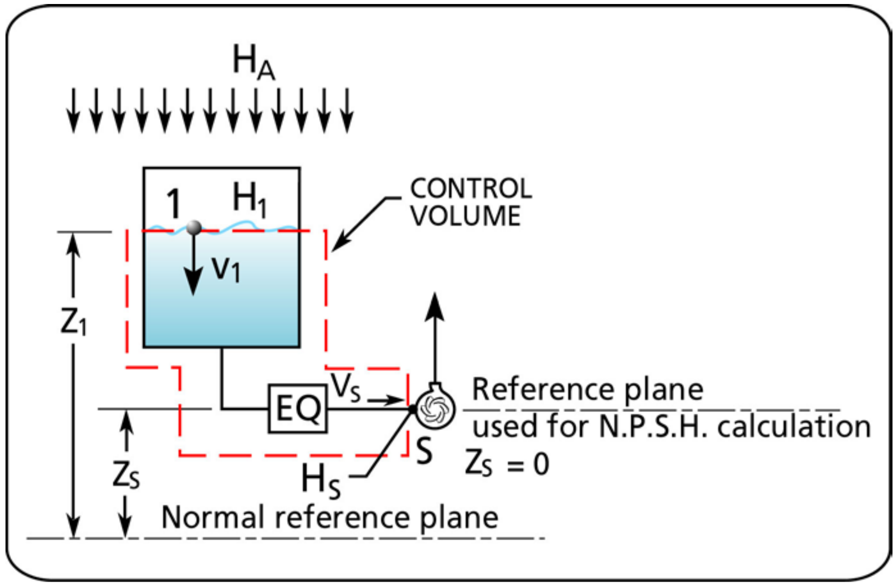

Figure 4 Using the control volume for calculating the pressure head at point S.

The specific energy or head $\overline{E}$ for any point in the system is the sum of the elevation (potential) specific energy, the velocity (kinetic) specific energy and the pressure specific energy. $\overline{E}$ is:

$$\overline{E} = H + \frac{v^2}{2g} + z \qquad [2]$$

And the head or specific energy at point S is:

$$\overline{E}_S = H_S + \frac{v_S^{\ 2}}{2g} + z_S \qquad [3]$$

By definition, the N.P.S.H available at the pump suction (point S) is based on a reference plane located at the pump suction centerline ($z_S = 0$). We can understand why since using any other reference will increase or decrease the specific energy level due to elevation at point S, which is obviously incorrect (see Figure 4).

And since $z_S = 0$ *then:*

$$\overline{E}_S = H_S + \frac{v_S^2}{2g} \qquad [4]$$

The head $\overline{E}_S$ is given in equation [4], the atmospheric pressure head (H_A) is added to H_S to convert $\overline{E}_S$ from feet of fluid to feet of fluid absolute. Therefore equation [4] becomes:

$$\overline{E}_S\,(\,ft\ \ fluid\ \ absol.\,) = H_S + \frac{v_S^2}{2g} + H_A \qquad [5]$$

The value of H_S in equation [1] is substituted in equation [5] to give:

$$\overline{E}_S\,(\,ft\ \ fluid\ absol.\,) = -\,(\Delta H_{F1-S} + \Delta H_{EQ\,1-S}) + \frac{v_1^2}{2g} + (z_1 - z_s + H_1) + H_A \qquad [6]$$

If the tank is not pressurized then $H_1 = 0$.

In order for the liquid to stay in a fluid state and not vaporize, the head at the inlet of the pump must be above the vapor pressure head of the fluid:

$$\overline{E}_S \geq H_{va}$$

where H_{va} is the vapor pressure head of the liquid. The Net Positive Suction Head Available (N.P.S.H.A.) is the difference between the head ($\overline{E}_S$) at the pump suction and the vapor pressure head (H_{va}).

$$N.P.S.H._{avail.} = \overline{E}_S - H_{va} \qquad [7]$$

By substituting the value of $\overline{E}_S$ from equation [6] into equation [7] then:

$$N.P.S.H._{avail.}(ft\ \ fluid\ absol.\,) = -\,(\Delta H_{F1-S} + \Delta H_{EQ1-S}) + \frac{v_1^2}{2g} + (z_1 - z_s + H_1) + H_A - H_{va} \qquad [8]$$

where H_A and H_{va} are in feet of fluid.

Vapor and atmospheric pressures are often given in pounds per square inch absolute (psia). The conversion of head in feet of fluid to pressure in psi is:

$$H\,(\,ft\quad fluid\,) = \frac{2.31}{SG} \times p\,(\,psia\,)$$

by substitution into equation [8]:

$$N.P.S.H._{avail.}(ft\ \ fluid\,absol.\,) = -\,(\Delta H_{F1-S} + \Delta H_{EQ1-S}) + \frac{v_1^{\,2}}{2g} + (z_1 - z_S + H_1) + H_B - H_{va} + \frac{2.31}{SG}\,(p_A(psia) - p_{va}(psia)) \quad [9]$$

The N.P.S.H. in equation [8] and [9] is in feet of fluid absolute and is a head term, head is independent of fluid density. Since the pump manufacturers use water as the fluid, the N.P.S.H. value they provide is in feet of water absolute.

The pump requires a minimum suction head in order to function properly and avoid cavitation. This is known as the N.P.S.H required which the pump manufacturer gives for a specific pump model, impeller diameter, speed and flow rate. In order to satisfy the pump manufacturer's requirements for proper operation the N.P.S.H available must be higher than the N.P.S.H required:

$$N.P.S.H._{avail.} \geq N.P.S.H._{req.}$$

Figure 5 shows typical relative proportions of the terms in equation [8].

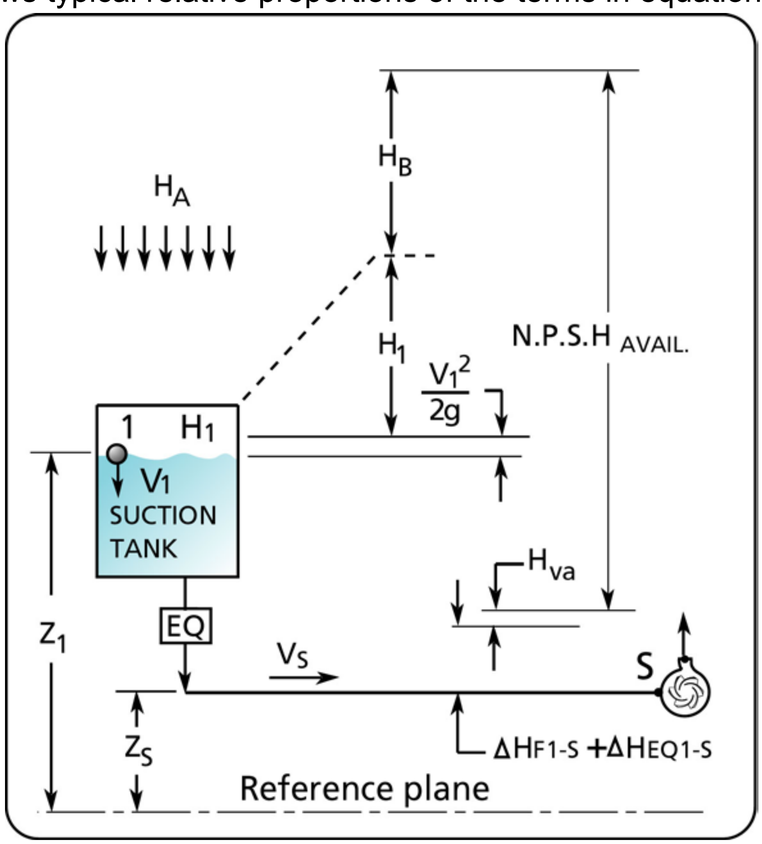

Figure 5 Relative sizes of N.P.S.H. components.