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Presentation Topic:	Calculating NPSHA in pumping – The Think Method
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Abstract:
There are a variety of different formulas available through different pumping resource materials to calculate NPSHA. Many of the formulas will vary depending if the system has a zero, positive, or negative tank pressure, positive suction head or suction lift. Through the years the author has found many of these equations to be confusing. The author offers what he believes to be a somewhat simpler approach to arriving at a formula through what he calls "The Think Method". Topics also discussed will be: vapor pressure, cavitation-what is it and why is it important, cavitation – what it is NOT. Dynamic photos illustrating surface air entrainment will be shown.

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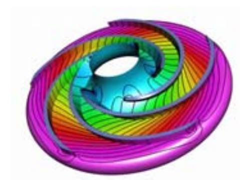
"Objectivity in pump selection, systems, trouble-shooting, & training"

Calculating NPSHA in Pumping – "The Think Method"

Many years ago there was a popular movie in the United States called "The Music Man" staring Robert Preston where he portrayed a music professor by the name of Harold Higgins. Harold Higgins was a self-proclaimed professor of music whose philosophy of teaching music was to not "read" music to play a musical instrument but to have the students "think" music in order to play. He believed that if the students could simply think the sounds required from the instrument that the sounds would then happen as the student would play the instrument.

I propose to apply that same basic philosophy to the understanding and calculating of Net Positive Suction Head Available, NPSHA, for centrifugal pumping systems.

Centrifugal pumps must have a certain amount of fluid energy at the pump suction to function correctly. We designate this energy as Net Positive Suction Head Required, or NPSHR. Pumps get this required energy from the system to which the pump is attached and we designate this system energy as Net Positive Suction Head Available, NPSHA.



Let's consider the analogy of a revolving door. Many buildings have revolving doors at their entrances to help provide some interior climate control. These doors require a certain amount of energy to function and rotate, analogist to our pump's energy need or NPSHR. This energy source usually comes from the people wanting to enter the building, analogist to the fluid system energy provided or NPSHA. If the people do not have sufficient energy to enter this revolving door, they will not get in the door. Pumps, like the revolving door, require a certain amount of hydraulic energy to function correctly and they source that hydraulic energy from the fluid entering the pump suction.

Our Absolute energies come from a variety of sources within our system. For this discussion we are only interested in what is happening on the suction side of the pump and thus we will focus our attention to only the pump suction side of our system. Referring to Figure #1 we will define our system terms.

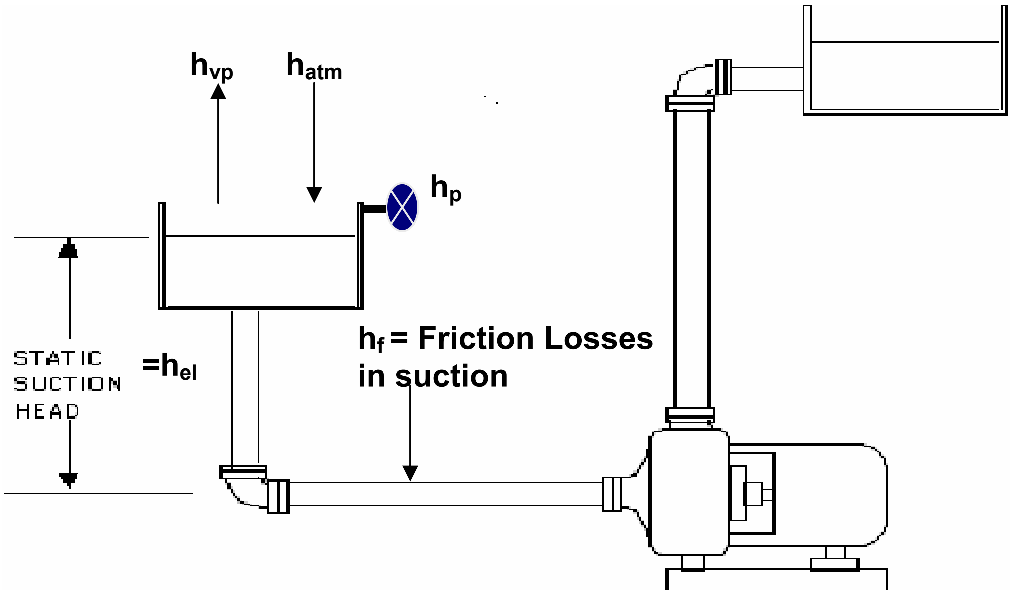


Figure #1 – Absolute System Energies in Basic Pumping System

h_{atm} = Absolute pressure of the atmosphere in feet of liquid.
h_p = Pressure in suction tank expressed in feet of liquid.
Open tanks $h_p = 0$.
h_{el} = Static liquid level height above/below pump suction centerline.
h_f = Friction/exit/entrance/all energy losses, incurred in suction line.
h_{vp} = Vapor pressure of the fluid expressed in feet of liquid.

Note: Feet of liquid = $\frac{PSIx2.31}{S.G.}$

Net Positive Suction Head Defined

Net Positive Suction Head Required (NPSHR) – Is defined as the ABSOLUTE energy, expressed in feet of liquid, that the pump needs at its suction to operate correctly. NPSHR is determined empirically in the pump manufacturer's lab with the criteria set by the Hydraulic Institute Standards for centrifugal pumps. NPSHR is reached when a centrifugal pump, operating at a constant speed and flow-rate, experiences a 3% reduction in its total head. This is referred to as insipient cavitation when a centrifugal pump will just begin to experience classic cavitation.

Net Positive Suction Head Available (NPSHA) – Is defined as the ABSOLUTE energy that the system furnishes to the pump at the pump suction.

NPSHA MUST BE GREATER THAN NPSHR! The energy supplied, or available, @ the pump suction from the system must be greater than the energy required by the pump.

NPSH & Cavitation

Why is NPSH so important? What will happen if NPSHA is not greater than NPSHR? Let's investigate.

One of the most often referred reasons for pumps performing poorly or having component failure is pump cavitation. One source reported that 40% of all pump related problems could be traced back to cavitation and insufficient NPSHA. What is cavitation, how does it occur, and what can we do to prevent it? Before we can discuss pump cavitation we must talk about Vapor Pressure.

Vapor pressure is that pressure exerted by the fluid upon its surroundings & is dependent upon the fluid's temperature. This pressure is a unique characteristic of every fluid and increases with temperature. When the vapor pressure within the fluid reaches the pressure of the surrounding medium, the fluid begins to experience a change of state from a liquid to a vapor. The liquid begins to vaporize or boil. The temperature at which this vaporization/boiling occurs will decrease as the pressure of the surrounding medium decreases. The following table will illustrate how vapor pressure fluctuates with temperature.

Vapor Pressure – Water

Temperature - ^{0}F	Vapor Pressure - psia
70	.363
100	.949
150	3.72
180	7.5
205	12.2
212	14.7

Atmospheric Pressure, the pressure of the surrounding medium, @ sea level = 14.7 psia (pounds per square inch absolute) and this is why water vaporizes or boils @ 212 ^{0}F.

Atmospheric Pressure @ Different Altitudes

Altitude - Feet	Atmospheric Pressure - psia
50	14.4
1000	14.2
3000	13.2
5000	12.2
10000	10.1

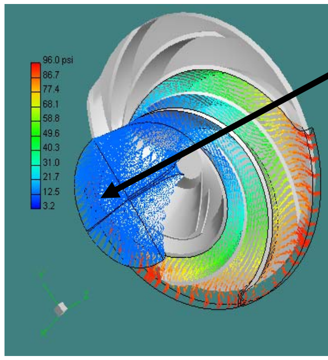
Vaporization/boiling begins when the atmospheric pressure pushing down on the liquid equals the vapor pressure of the liquid attempting to escape. For example, Denver, Colorado, USA is at an elevation of 5000 feet. The atmospheric pressure in Denver is 12.2 psia due to its elevation. When the water temperature in Denver reaches 205 ^{0}F, it will have a vapor pressure equal to the pressure of the surrounding medium, the atmospheric pressure. At that point vaporization/boiling will begin because of the pressures are now just barely at equilibrium and phase change begins. This is why water boils in Denver @ only 205 ^{0}F instead of 212 ^{0}F @ sea level.

If NPSHA IS LESS THAN NPSHR

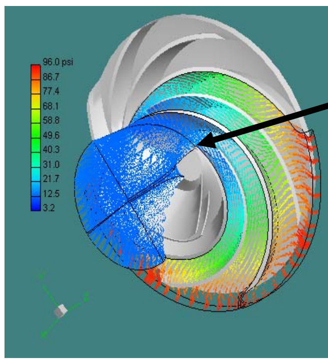
The statement was made previously that NPSHA must be greater than NPSHR. OK, what happens if NPSHA is not greater than NPSHR? When this occurs your system has reached that point where the pressure of the fluid is equal to or less than the pressure of the fluid's surrounding medium. What did we say results when that we have that condition? The fluid begins to experience a change of state from a liquid to a vapor. Vapor bubbles begin to form as the local pressure in the pump impeller vanes drops below the pump's required pressure of the liquid and the liquid begins to change state and begins to vaporize, & boil. Vapor bubbles are formed within the pump impeller. As the vapor bubbles continue through the impeller, they move to an area of higher & higher pressure within the pump until they reach a high enough pressure to collapse returning to a liquid state. This change of state is a violent reaction causing small jets of liquid @ extremely high localized pressure. The jets of water impinge on the impeller surfaces like a water jet cutter blowing small portions of the metal from the impeller surface. This phenomenon is called CAVITATION.

Cavitation

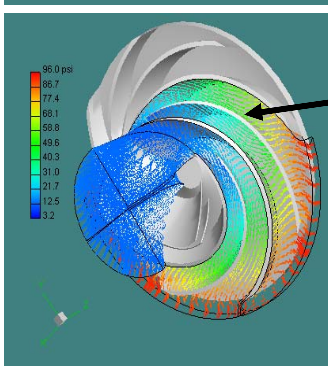
The implosion of these bubbles happens thousands of times per minute. Each little bubble implosion impinging on the metal causes the metal to fatigue and flake off. Damage can be extensive, eating holes through impellers, chipping mechanical seal faces, causing bearing failure. Localized pressure spikes have been calculated @ over 100,000 PSI.



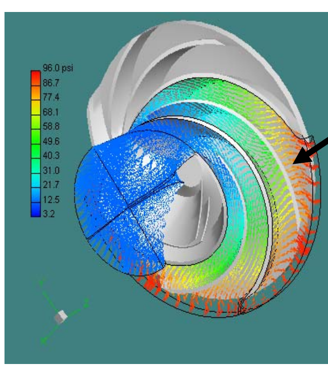
If NPSHA < NPSHR, the fluid will have a “change of state” and vaporize, typically @ the pump suction, the pump’s low pressure zone. Once vaporization begins, vapor bubbles begin to form @ the impeller eye.



These vapor bubbles formed @ the impeller eye are trapped by the fluid and carried along the impeller vane path.



As the vapor bubbles are carried along the impeller vane path, the bubbles are subjected to ever increasing pressures caused by the increasing pressure within the pump.



The vapor bubbles continue along the impeller vane path until the bubbles are subjected to sufficient pressures within the pump vanes to cause a reversal in change of state from a vapor to a liquid.

This reversal in change of state from vapor to liquid causes the vapor bubbles to implode. This implosion of bubbles happens thousands of times per minute. Each little bubble implosion blasts metal from the impeller vanes. Damage can be extensive, eating holes in impellers, damaging mechanical seal faces, causing bearing failure. The implosions send shock waves through the entire pump setting up vibrations resulting in reduced pump reliability.

Calculating Net Positive Suction Head Available – NPSHA

Net Positive Suction Head Available is the total sum of all ABSOLUTE system energies as measured/calculated at the pump suction. Now let us "think" about all of the energy sources available to the pump suction & simply add/subtract up all of them. We will identify and sum-up all positive & negative energies as determined at the pump suction. We will use a simple accountant's ledger to help "think' through & identify all energy sources and determine exactly what suction system energies will add to or subtract from our total absolute energies at the pump suction. Figure # 2 is a check sheet to help decide our suction energy sources and if they are an energy credit or debit to our suction energy account.

NPSHA – Accountant's Ledger

Energy Value	Energy Credit	Energy Debit
h_{atm}	YES	
h_p Positive Pressure	YES	
h_p Negative Pressure		YES
h_{el} Above Pump Suction	YES	
h_{el} Below Pump Suction		YES
h_f		YES
h_{vp}		YES

Figure # 2 – Accountant's Ledger to identify suction energy sources and if those energy sources are added (Energy Credit) or subtracted (Energy Debit) from our total absolute net positive suction head available at the pump suction.

Referring back to Figure #1 illustrating our various sources of energy when calculating NPSHA we now put our "think" method to work in formulating our equation to calculate NPSHA.

$$NPSHA = h_{atm} + h_p + h_{el} - h_f - h_{vp}$$

Note: $Ft. = \frac{PSIx2.31}{S.G.}$

h_{atm}= Atmospheric Pressure converted to feet of liquid.

h_p = Pressure in Suction Tank converted to feet of liquid.

- This number will be a POSITIVE if a POSITIVE pressure exists.
- This number will be a NEGATIVE if a VACUUM exists.
- Open tanks h_p = o.

h_{el}= Static liquid level height relative to the pump suction.

- This number will be a POSITIVE if liquid level is ABOVE pump suction.
- This number will be a NEGATIVE if liquid level is BELOW pump suction.

h_f = Friction/exit/entrance/all losses, incurred in suction line.

- This value will always be subtracted from our NET available energies because these energies are always considered energy LOSSES.

h_{vp} = Vapor pressure of the pumped fluid

- This value will always be subtracted from our NET available energies because if our NET energies equal our vapor pressure we know that we will cavitate.

$h_{vp\text{-}68}$ ^{o}F = .783 ft abs

Simply add up all the NET positive & negative absolute energies available to the pump as calculated @ the pump suction & you will have the NET POSTIVE SUCTION HEAD AVAILABLE, NPSHA to that pump.

Then make sure that your AVAILABLE energy value is sufficiently more than the energy value REQUIRED by the pump @ your pumping conditions, and you are good to go. The ratio of NPSHA/NPSHR is known as the NPSH margin. Many have simply used a 2 ft. margin as safe enough: NPHSA $\geq$ NPSHR + 2 ft. The Hydraulic Institute has a guide to NPSH Margin Values. A good rule of thumb for general industrial pumps is to have an NPSH margin of 1.3 as a minimum. Other high suction energy pumps have values as high as 1.6.

NPSHAvailable - Summary

$\sum$ NET positive & negative absolute energies available to the pump @ the pump suction and you will get your NET POSITIVE SUCTION HEAD AVAILABLE, NPSHA, to the pump.

Air Entrainment is NOT Cavitation

Air entrainment is not cavitation. Though air entrainment can be devastating to the performance of your pump; it is not cavitation. Often mis-taken for cavitation, air entrainment can be in many cases prevented and or remedied. Sucking air into the pumping system is not cavitation. Air introduced into the pumping system will have a great negative affect on the pumping capabilities with the air displacing volumes of liquid that would otherwise be pumped.

Air entrainment sources are as varied as there are components in a system.

- Supply tanks, pipes, fittings, gaskets, valves, gauges, meters, the pump itself.
- Air induced through free falling liquid onto the supply tank or sump liquid level surface driving air into the pump suction.
- Process itself can produce bubbles, foam or give off oxygen or other gases displacing the "liquid".
- Submergence-"Bathtub Drain Effect"-Insufficient liquid level above the pump suction can induce vortexing, pulling air into the pump suction.

Air Induced Into Pump Suction From Free Falling Liquid

Driving Air Into Pump Suction – DON'T!

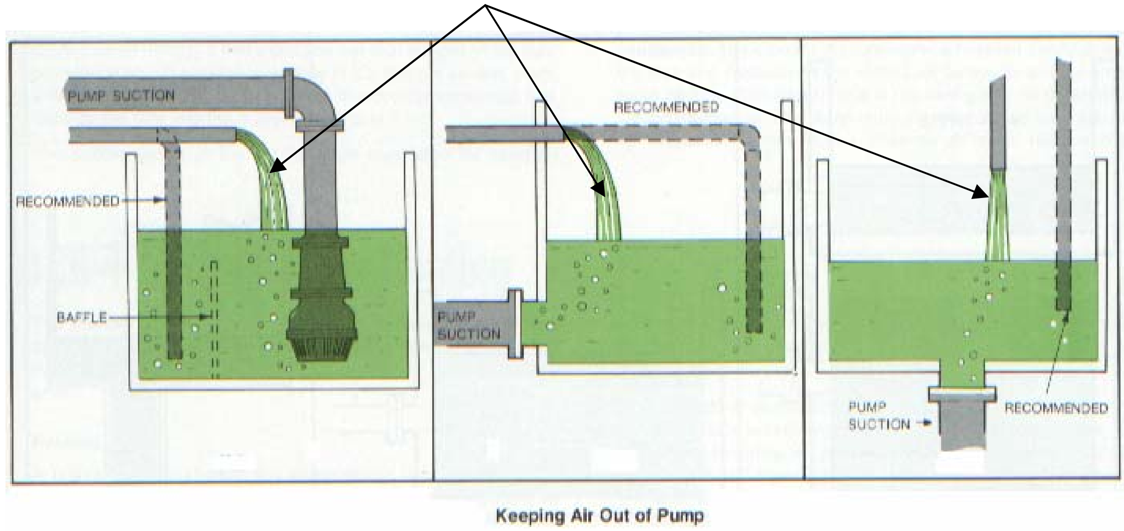


Figure # 3

Figure # 3 demonstrates some typical causes and cures of system induced air entrainment that can and should be prevented.

Air Induced Into Pump Suction From Surface Vortexing

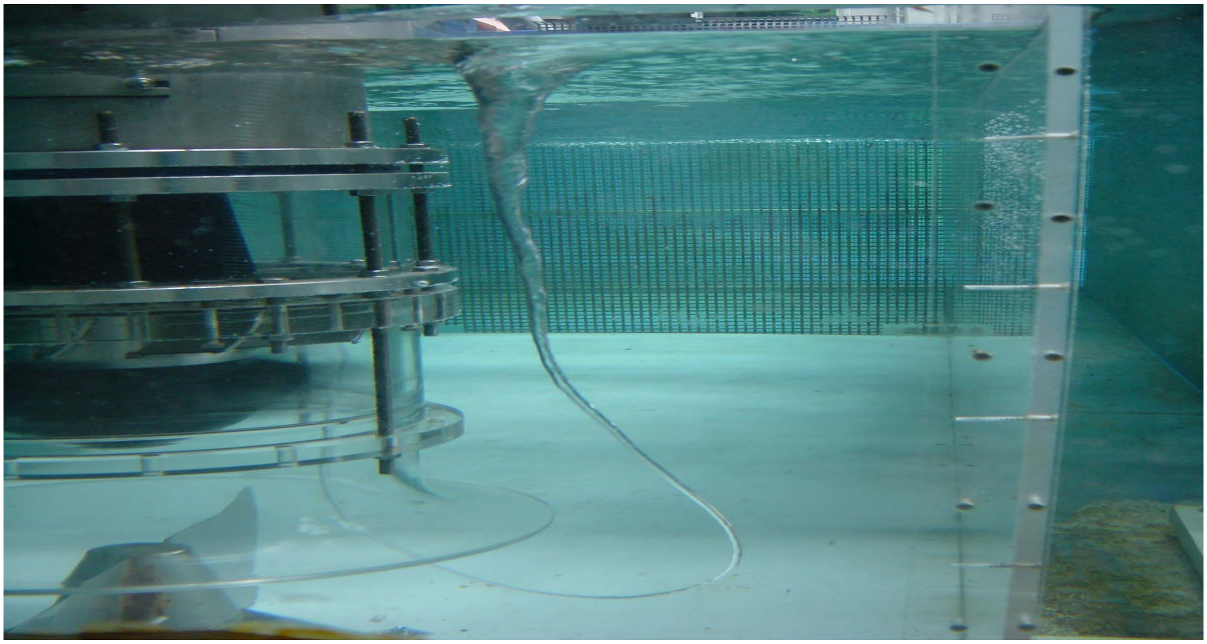


Figure # 4 – Surface Vortexing due to insufficient submergence or liquid level above pump suction. Image courtesy of: University of Kaiseralautem, Germany.

Figure # 4 clearly demonstrates how surface vortexing can drive huge quantities of air into your pump suction causing severe reduction in pump performance due to the air displacing liquid you want for production

Conclusion

By simply adding up the positive & negative absolute energies available to the pump @ the pump suction, you will get your NET POSITIVE SUCTION HEAD AVAILABLE, NPSHA, to the pump. Cavitation has been identified as one of the leading causes of reduced reliability in centrifugal pumps. Insufficient absolute system energy @ the pump suction, NPSHA, as compared to the energy required by the pump, NPSHR, results in cavitation and reduced pump reliability. Also, we have seen that air entrainment is not cavitation but is no less of a common cause for poorly performing pumping systems. Improve your pump suction system and eliminate air entrainment and you will dramatically improve your pumping capabilities.

I wish you successful pump ghost-hunting.

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References:

- American Trainco – Pumps & Pumping System Training Course, 2005
- Goulds Pumps – Website, 2005
- Hydraulic Institute
- University of Kaiseralautem, Germany.