2 NPSH, Net Positive Suction Head

Introduction

When someone turns on an electric light, the natural tendency is to look toward the light and consider the shine. We tend not to think about the electric wires and the current running through the light bulb. Equally, when someone starts an industrial pump, the tendency is to look toward the discharge piping and consider the pressure and flow. We tend not to think about the suction piping, or the liquid coming into the eye of the impeller. We need to emphasize the necessity to consider what's happening in the suction of the pump. This area is the source of problems, and probably is responsible for about 40% of all pumps going into the shop today.

This chapter is dedicated to NPSH, Net Positive Suction Head. NPSH is what the pump needs, the minimum requirement to perform its duties. Therefore, NPSH is what happens in the suction side of the pump, including what goes on in the eye of the impeller. NPSH takes into consideration the suction piping and connections, the elevation and absolute pressure of the fluid in the suction piping, the velocity of the fluid and the temperature. For the moment we can say that some of these factors add energy to the fluid as it moves into the pump, and others subtract energy from the fluid. There must be sufficient energy in the fluid for the impeller to convert this energy into pressure and flow. If the energy is inadequate we say that the pump suffers inadequate NPSH.

In simple terms we could say that NPSH is the reason that the suction nozzle is generally larger than the discharge nozzle. If there is more liquid leaving the pump faster than the liquid can enter into the pump, then the pump is being starved of liquid.

AUTHOR'S NOTE

Think about it this way. When we see a magician pulling a rabbit out of a hat, in all probability there's a rabbit hidden in a secret compartment inside the top hat, or the rabbit is hidden in the magician's coat sleeve. The rabbit does not appear spontaneously. Isn't it interesting that magicians all wear long sleeved topcoats? They always reach into a 'top hat' for the rabbit. When I see a magician pull a rhinoceros from a frisbee, then maybe I'll believe in magic. There is illusion, but there is no magic. Likewise with a pump, the energy must be in the fluid for the impeller to convert it.

Equally, if your body requires more oxygen than the available oxygen in the atmosphere, then you would be asphyxiated. There must be more oxygen available in the air than the oxygen you consume.

To express the quantity of energy available in the liquid entering into the pump, the unit of measure for NPSH is feet of head or elevation in the pump suction. The pump has its NPSHr, or Net Positive Suction Head Required. The system, meaning all pipe, tanks and connections on the suction side of the pump has the NPSHa, or the Net Positive Suction Head Available. There should always be more NPSHa in the system than the NPSHr of the pump. Let's look at them, beginning with what the pump requires:

Definition of NPSHr (required)

It is the energy in the liquid required to overcome the friction losses from the suction nozzle to the eye of the impeller without causing vaporization. It is a characteristic of the pump and is indicated on the pump's curve. It varies by design, size, and the operating conditions. It is determined by a lift test, producing a negative pressure in inches of mercury and converted into feet of required NPSH.

AUTHOR'S NOTE

An easy way to understand NPSHr is to call it the minimum suction pressure necessary to keep the pumped fluid in a liquid state.

According to the Standards of the Hydraulic Institute, a suction lift test is performed on the pump and the pressure in the suction vessel is lowered to the point where the pump suffers a 3% loss in total head. This point is called the NPSHr of the pump. Some pump manufacturers perform a similar test by closing a suction valve on a test pump and other manufacturers lower the suction elevation.

The definition of NPSHr may change in the future. A pump is in a definite state of cavitation with the 3% total head loss definition. Many pump users want a more explicit definition of NPSHr, and higher NPSHa safety margins to avoid inadequate NPSHa and cavitation altogether.

The pump manufacturers publish the NPSHr values on their pump curves. We're saying that the NPSH reading is one of the components of your pump curves. We'll see this in Chapter 7 on Pump Curves. If you want to know the NPSHr of your pump, the easiest method is to read it on your pump curve. It's a number that changes normally with a change in flow. When the NPSHr is mentioned in pump literature, it is normally the value at the best efficiency point. Then, you'll be interested in knowing exactly where your pump is operating on its curve.

If you don't have your pump curve, you can determine the NPSH of your pump with the following formula:

$$NPSHr = ATM + Pgs + Hv - Hvp$$

Where: **ATM** = the atmospheric pressure at the elevation of the installation expressed in feet of head.

Pgs = the suction pressure gauge reading taken at the pump centerline and converted into feet of head.

Hv = Velocity Head = $V^2/2g$ where: V = the velocity of the fluid moving through the pipes measured in feet per second, and 'g' = the acceleration of gravity (32.16 ft/sec).

Hvp = the vapor pressure of the fluid expressed in feet of head. The vapor pressure is tied to the fluid temperature.

The easiest thing to do is to get the pump curve from the manufacturer because it has the NPSHr listed at different flows. Nowadays, you can get the pump curve on the Internet with an e-mail to the manufacturer, you can send a fax, or request the curve in the mail or with a local call to the pump representative or distributor. If you wanted to verify the NPSHr on your pump, you'll need a complete set of instrumentation: a barometer gauge, compound pressure gauges corrected to the centerline of the pump, a flow meter, a velocity meter, and a thermometer. Definitely, it's easier to get the curve from your supplier.

Definition NPSHa (available)

This is the energy in the fluid at the suction connection of the pump over and above the liquid's vapor pressure. It is a characteristic of the system and we say that the NPSHa should be greater than the NPSHr (NPSHa > NPSHr).

As a general guide the NPSHa should be a minimum 10% above the NPSHr or 3 feet above the NPSHr, whichever is greater. Other books and experts indicate that the NPSHa should be 50% greater than the NPSHr, to avoid incipient cavitation. Again, be prepared for stricter definitions to NPSHr and higher safety margins on NPSHa.

The NPSHa is in the system. The formula is:

$$NPSHa = Ha + Hs - Hvp - Hf - Hi$$

Where: **Ha** = Atmospheric head (14.7 psi × 2.31) = 33.9 ft. at sea level. See Properties of Water I in this chapter that considers atmospheric pressure at different elevations above sea level.

Hs = Static head in feet (positive or negative) of the fluid level in the suction vessel to the pump centerline.

Hvp = the Vapor head of the fluid expressed in feet. It is a function of the temperature of the liquid. See Properties of Water II in this chapter.

Hf = Friction head or friction losses expressed in feet in the suction piping and connections.

Hi = Inlet head, or the losses expressed in feet that occur in the suction throat of the pump up to and including the eye of the impeller. These losses would not be registered on a suction pressure gauge. They could be insignificant, or as high as 2 feet. Some pump manufacturers factor them into their new pumps, and others don't. Also, changes occur in maintenance that may alter the Hi. If you don't know the Hi, call it a safety factor of 2 feet.

By observing the system, you can calculate the NPSHa within a one or two point margin. The main idea is to be sure the NPSHa is greater than the NPSHr of the pump. Remember that the NPSHa only deals with the suction side of the pump. Let's go back to that formula:

$$NPSHa = Ha + Hs - Hvp - Hf - Hi$$

1. To determine the Ha, atmospheric head, you only need observe the vessel being drained by the pump. Is it an opened, or vented atmospheric vessel? Or is it a closed and sealed vessel? If the vessel is open, then we begin with the atmospheric pressure expressed in feet, which is 33.9 feet at sea level. The altitude is important. The atmospheric pressure adds energy to the fluid as it enters the pump. For closed un-pressurized vessels the Ha is equal to the Hvp and they cancel themselves. For a closed pressurized vessel remember that every 10 psia of pressure on a vessel above the vapor head of the fluid will add 23.1 feet of Ha. To the Ha, we add the Hs.

2. The Hs, static head, is the static height in feet observed from the level in the vessel to be drained to the centerline of the pump. If the

Properties of water I – Atmospheric and barometric pressure readings at different altitudes

Altitude		Barometric pressure		Atmospheric pressure		Boiling point of water °F
Feet	Meters	In. Hg.	mm. Hg.	Psia	Feet water	
-1000	-304.8	31.0	788	15.2	35.2	213.8
-500	-152.4	30.5	775	15.0	34.6	212.9
0	0.0	29.9	760	14.7	33.9	212.0
+500	+152.4	29.4	747	14.4	33.3	211.1
+1000	304.8	28.9	734	14.2	32.8	210.2
1500	457.2	28.3	719	13.9	32.1	209.3
2000	609.6	27.8	706	13.7	31.5	208.4
2500	762.0	27.3	694	13.4	31.0	207.4
3000	914.4	26.8	681	13.2	30.4	206.5
3500	1066.8	26.3	668	12.9	29.8	205.6
4000	1219.2	25.8	655	12.7	29.2	204.7
4500	1371.6	25.4	645	12.4	28.8	203.8
5000	1524.0	24.9	633	12.2	28.2	202.9
5500	1676.4	24.4	620	12.0	27.6	201.9
6000	1828.8	24.0	610	11.8	27.2	201.0
6500	1981.2	23.5	597	11.5	26.7	200.1
7000	2133.6	23.1	587	11.3	26.2	199.2
7500	2286.0	22.7	577	11.1	25.7	198.3
8000	2438.4	22.2	564	10.9	25.2	197.4
8500	2590.8	21.8	554	10.7	24.7	196.5
9000	2743.2	21.4	544	10.5	24.3	195.5
9500	2895.6	21.0	533	10.3	23.8	194.6
10000	3048.0	20.6	523	10.1	23.4	193.7
15000	4572.0	16.9	429	8.3	19.2	184.0

level in the tank is 10 feet above the pump then the Hs is 10. A positive elevation adds energy to the fluid and a negative elevation (suction lift condition) subtracts energy from the fluid. To the sum of the Ha and Hs, we subtract the Hvp.

3. The Hvp, vapor head, is calculated by observing the fluid temperature, and then consulting the water properties graph in this chapter. Let's say we're pumping water at 50° F (10° C). The Hvp is 0.411 feet. If the water is 212° F (100° C) then the Hvp is 35.35 feet. The vapor head is subtracted because it robs energy from the fluid in the suction pipe. Remember that as the temperature rises, more energy is being robbed from the fluid. Next, we must subtract the Hf.

Properties of water II – Vapor Pressure

Temp. °F	Temp. °C	Specific Gravity 60 °F	Density	Vapor Pres. psi	Vapor Pressure* Feet Abs.
32	0	1.002	62.42	0.0885	0.204
40	4.4	1.001	62.42	0.1217	0.281
45	7.2	1.001	62.40	0.1475	0.34
50	10	1.001	62.38	0.1781	0.411
55	12.8	1.000	62.36	0.2141	0.494
60	15.6	1.000	62.34	0.2563	0.591
65	18.3	0.999	62.31	0.3056	0.706
70	21.1	0.999	62.27	0.6331	0.839
75	23.9	0.998	62.24	0.4298	0.994
80	26.7	0.998	62.19	0.5069	1.172
85	29.4	0.997	62.16	0.5959	1.379
90	32.2	0.996	62.11	0.6982	1.617
95	35.0	0.995	62.06	0.8153	1.890
100	37.8	0.994	62.00	0.9492	2.203
110	43.3	0.992	61.84	1.275	2.965
120	48.9	0.990	61.73	1.692	3.943
130	54.4	0.987	61.54	2.223	5.196
140	60.0	0.985	61.39	2.889	6.766
150	65.6	0.982	61.20	3.718	8.735
160	71.1	0.979	61.01	4.741	11.172
170	76.7	0.975	60.79	5.992	14.178
180	82.2	0.972	60.57	7.510	17.825
190	87.8	0.968	60.35	9.339	22.257
200	93.3	0.964	60.13	11.526	27.584
212	100.0	0.959	59.81	14.696	35.353
220	104.4	0.956	59.63	17.186	41.343
240	115.6	0.948	59.10	24.97	60.77
260	126.7	0.939	58.51	35.43	87.05
280	137.8	0.929	58.00	49.20	122.18
300	148.9	0.919	57.31	67.01	168.22
320	160.0	0.909	56.66	89.66	227.55
340	171.1	0.898	55.96	118.01	303.17
360	182.2	0.886	55.22	153.04	398.49
380	193.3	0.874	54.47	195.77	516.75

4. The Hf, friction head, can be calculated, approximated, or measured. The friction head can be calculated with the friction tables for pipe and fittings. You can consult the Hazen Williams formula, or the Darcy Weisbach formula mentioned in Chapter 8 of this book. The friction head can be measured with gauges using the

Bachus Custodio formula explained in Chapter 8. In most cases, the pump is relatively close to the vessel being drained by the pump. In this case the Hf is probably negligible. Hf is subtracted because friction in the suction pipe robs energy from the fluid as it approaches the pump.

5. The Hi, inlet head, is simply a safety factor of 2 feet. Some pumps have an insignificant Hi. Other pumps have inlet losses approaching 2 feet. The Hi is losses to the fluid after it passes the suction pressure gauge and goes into the impeller eye. In a maintenance function, you can't be precise about what's happening to the fluid in this part of the pump. Just call it 2 feet.

Now let's apply the hints and the formula to the following system figures and we can determine the NPSHa within one or two points. The important thing is that the NPSHa of the system is greater than the NPSHr of the pump. If the NPSHa should be inadequate, the pump is being starved, becomes unstable and cannot perform its duties. The inadequate NPSHa may lead to cavitation.

Remember that **NPSHa > NPSHr**

This open system pumping water is at sea level (Figure 2–1). Therefore the Ha is 33.9 feet. The level in the tank is 15 feet above the pump centerline, so the Hs_1 is 15 feet. The friction losses in the suction piping give us 2 feet. The water is 70° F so the Hvp is 0.839. The Hi is a safety factor of 2 feet.

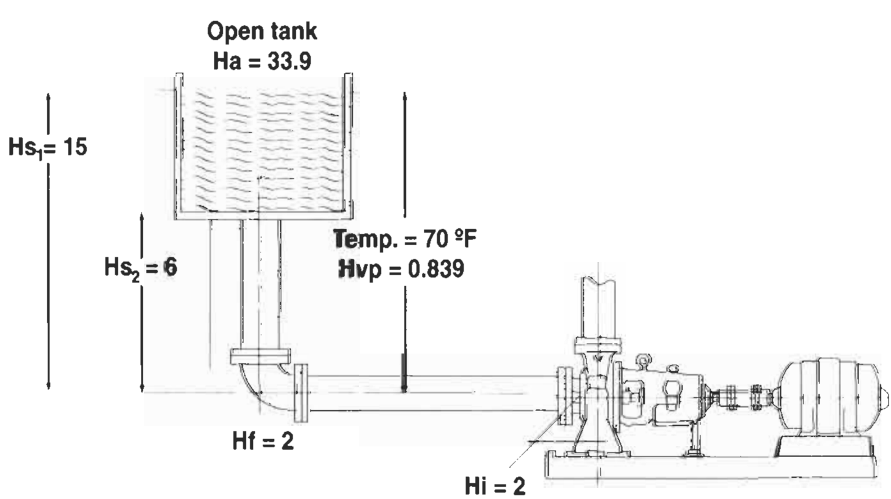

Figure 2–1

NPSHa = Ha + Hs_1 –Hvp – Hf – Hi
NPSHa = 33.9 + 15.0 –0.839 – 2.0 – 2.0
NPSHa = 44.061 feet

The curve of the pump in this service should show an NPSHr of less than 44 ft at the duty point. And the purpose of this pump is to drain this tank, lowering its level. If we don't want inadequate NPSHa and the possible resulting cavitation to start during the process we should consider a second Hs_2 with the tank empty. The other factors remain the same. At the end of the process, we have:

NPSHa = Ha + Hs_2 – Hvp – Hf – Hi
NPSHa = 33.9 + 6.0 – 0.839 – 2.0 – 2.0
NPSHa = 35.061 feet

To avoid stress from inadequate NPSHa during the draining process, we should consult the pump curve and be sure that the NPSHr is less than 35 ft at the duty point.

Now let's consider Figure 2–2. This is a pump in suction lift draining an opened tank that's 8 feet below the pump centerline. This pump is installed high on a mountain at 7,000 feet above sea level. The Ha is 26.2 feet. The Hs_1 is –8.0 feet. The water temperature is 50° F, so the Hvp is 0.411. The Hf is 1 foot and the Hi is 2.0. According to the information:

NPSHa = Ha + Hs_1 – Hvp – Hf – Hi
NPSHa = 26.2 + (–8.0) – 0.411 – 1.0 – 2.0
NPSHa = 14.8 feet

The curve of the pump in this service should show a NPSHr of less than 14 feet at the duty point. The purpose of this pump is to drain this tank down to 14 feet below the pump without cavitating. Let's consider a second static head, Hs^2, of –14 feet. The other factors would remain the same:

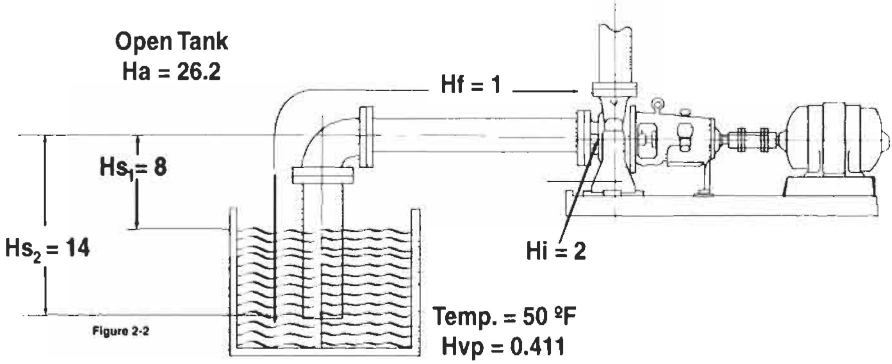

Figure 2–2

NPSHa = Ha + Hs_2 –Hvp – Hf – Hi
NPSHa = 26.2 + (–14.0) – 0.411 – 1.0 – 2.0
NPSHa = 8.8 feet

To avoid problems with this pump during the process, be sure the pump curve indicates NPSHr less than 8 ft at the duty point.

Many processes use sealed tanks and reactor vessels. For example, in a milk processing plant or a pharmaceutical plant, it's necessary to prevent outside air from contaminating the sterile product. In a beer brewery, you can't let the gas and carbonization escape from the process. In a closed un-pressurized vessel, the Ha is equal to the Hvp. And because the Ha adds energy and the Hvp subtracts energy, they cancel themselves. The formula is simpler:

NPSHa = Hs – Hf – Hi

The level in this sealed tank is 12 feet above the pump (Figure 2–3). The Hs_1 is 12 feet. The purpose of this pump is to drain this tank to a level 6 feet above the pump, so the Hs_2 is 6 feet. The Hf is 1.5 feet and the Hi is 2 feet.

NPSHa = Hs_1 – Hf – Hi
NPSHa = 12.0 – 1.5 – 2.0
NPSHa = 8.5

The curve of the pump that drains this tank should register an NPSHr

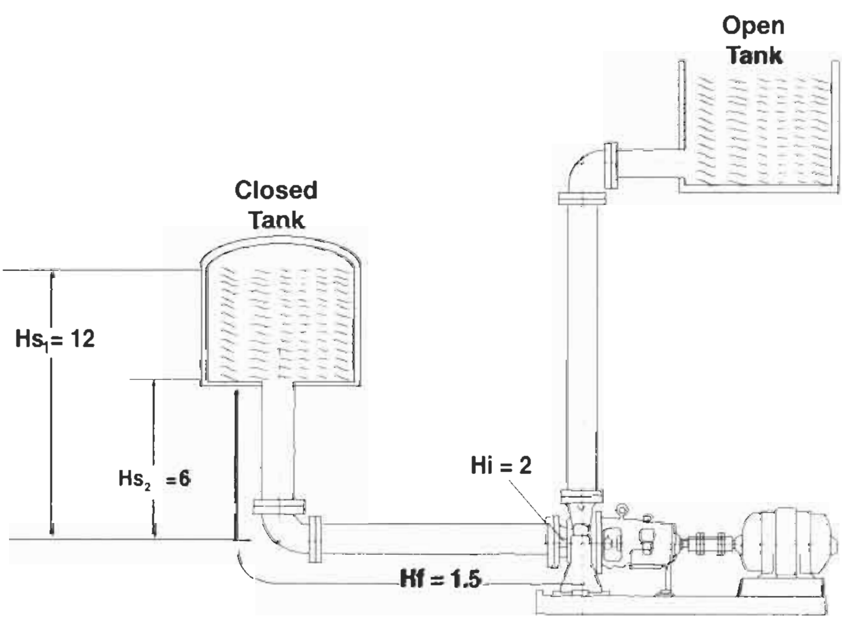

Figure 2-3

of less than 8 feet at the duty point. And, to be sure that problems don't arise during the process, we could calculate the NPSHa at the end of the process:

NPSHa = Hs_2 – Hf – Hi
NPSHa = 6.0 – 1.5 – 2.0
NPSHa = 2.5 feet

Now, it's one thing to say to use a pump with an NPSHr less than 2 feet. It's another thing to find a pump with this design parameter, that at the same time complies with the demands of the operation. Perhaps it will be necessary to modify the system to increase the Hs_2, reduce the Hf, or modify the pump to reduce the Hi. Other possible options are:

1. Pressurize the tank with air or a gas compatible with the liquid and process.
2. Turn off the pump and drain the tank by gravity.
3. Install a small booster pump that feeds the principal pump.
4. Operate the pump at a slower speed.
5. Survive the cavitation. (There's a discussion on this later in the book.)

As we've said numerous times before in this chapter, the important thing is that the NPSHa of the system is above the NPSHr of the pump by a sufficient amount to avoid stress and possible cavitation. If the NPSHa should be inadequate, there are ways to elevate it. Remember from the formula that five elements compose the NPSHa. Two of those elements, the Ha and the Hs, add energy to the fluid. And three elements, the Hvp, the Hf, and the Hi, subtract energy from the fluid. We must either increase the elements that add energy, or decrease the elements that subtract energy. To increase the NPSHa:

1. Raise the level in the tank if possible. This adds **Hs**.
2. Elevate the tank maybe with stilts. This adds **Hs**.
3. Maybe you can lower the pump. For example in many thermoelectric plants, the fuel oil pumps (#6 bunker fuel) are in a pit. This would permit draining the tanks down to the ground and still maintain 15 or 20 feet of NPSHa on the fuel oil pumps. This adds **Hs**.
4. Pressurize the tank if possible. This adds **Ha**.
5. Reduce the drag (Hf) in the suction piping. Change to larger diameter suction piping, or reduce the pipe schedule (change from 'schedule 40 pipe' to 'schedule 20 pipe' on the suction side). Investigate changing the pipe material. For example PVC pipe, and food grade Stainless, is rather slick on the ID. This reduces **Hf**.

6. Reduce the losses (Hf) of the connections and fittings in the suction piping. For wheel actuation valves, maybe globe valves could be converted into gate valves. For quarter turn valves, butterfly valves could be replaced with ball valves. A totally open butterfly valve still has the post and wings in the flow path. Maybe convert short radius elbows into long radius elbows. If you had two or three consecutive elbows, maybe you could use a flexible 'S' connection. This reduces **Hf**.
7. Eliminate some elbows. If the suction piping has multiple elbows, you can bet that some of those elbows are canceling themselves, and are not needed. This reduces **Hf**.
8. Lower the temperature of the fluid in the suction. This reduces the **Hvp**.

If you cannot increase the NPSHa of the system, maybe you could reduce the NPSHr of the pump, by:

1. Change to a pump with a larger suction diameter. For example, convert a 1 × 2 × 8 pump, into a 2 × 3 × 8 pump. The larger pump would have a reduced NPSHr. You need to keep the same impeller diameter (8 inch) to maintain the discharge head and pressures, but you would be converting the 2 inch suction nozzle into a 3 inch suction nozzle. This would reduce the fluid velocity entering into the pump, and therefore the **Hf** and **Hi**.
2. Install a small booster pump into the suction piping. The booster pump would have a reduced NPSHr for the system feeding it, and the discharge head of the booster pump would increase the **Ha** to the primary pump.
3. Increase the diameter of the eye of enclosed impellers. This reduces **Hi**.
4. Ream out and polish the suction throat and pathway to the impeller. This is normally the roughest casting inside the pump. Center the suction nozzle on a lathe and open the diameter of the pathway toward the impeller. This lowers the existing NPSHr of your pump, reducing the **Hi**.
5. Use an impeller inducer. An impeller inducer looks like a corkscrew device that fits onto the center hub of the primary impeller and extends down the suction throat of the pump. It is actually a small axial flow impeller that accelerates the fluid toward the primary impeller from further down the suction throat of the pump. Some inducers bolt onto the impeller and others are cast into the main impeller. The inducer has a low NPSHr for the system feeding it, and it increases the **Ha** to the primary impeller.

6. Convert to a pump with a double suction impeller. Double suction impeller pumps are for low NPSH applications.
7. Use two smaller pumps in parallel.
8. Use a larger/slower pump.

Inadequate NPSHa causes stress, vibration and maintenance on pumps because there is not enough energy in the fluid for the pump to perform its work. As you can see from the previous pages, the problems lie in system design and proper operating principles. When the NPSHa is below the NPSHr of the pump, the conditions are favorable for the pump to go into cavitation. Cavitation is the next chapter.