CENTRIFUGAL PUMP FAILURE SOLUTIONS

CONTROL SPECIALTIES, INC.

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Centrifugal Pump Failure Solutions
(Emphasis Boiler Feed and Condensate Pumps)

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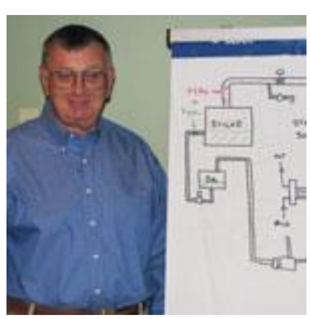
BIOGRAPHY OF EDWARD MOSCHETTI

Edward brings over 50 years of knowledge and experience to the manufacturing, medical, university, and commercial arenas. His education background includes a degree in physics from Muhlenberg College. The last 30 years have been devoted to providing solutions to industrial facilities geared around plant utilities and processes. He has spearheaded energy teams in major corporations resulting in the savings of energy dollars, as well as building/designing small to medium size boiler facilities.

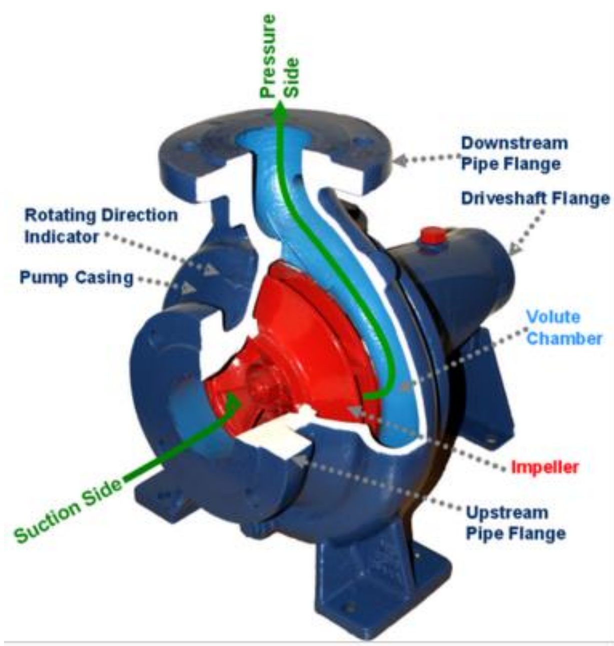


Preface

Centrifugal pumps are common in a wide variety of applications. We will focus on failures due to cavitation, which can be difficult to diagnose and correct. The formation and collapse of vapor filled bubbles is called cavitation. This process occurs in regions inside of a pump where the pressure drops below the vapor pressure of the fluid (the vapor pressure of the fluid is the pressure at which a fluid begins to boil or vaporize). Cavitation occurs when the Net Positive Suction Head Required (NPSHR) of the pump is not satisfied. This can result in significant damage to the pump.

Chapter 1 - Centrifugal Pump Basics

Centrifugal pumps are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. The fluid enters the pump impeller along, or near to, the rotating axis. It is then accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits. A centrifugal pump converts rotational energy, often from a motor, to energy in a moving fluid. A portion of the energy goes into kinetic energy of the fluid. Fluid enters axially through eye of the casing, is caught up in the impeller blades, and is whirled tangentially and radially outward until it leaves through all circumferential parts of the impeller into the diffuser part of the casing. The fluid gains both velocity and pressure while passing through the impeller. The doughnut-shaped diffuser, or scroll, section of the casing decelerates the flow and further increases the pressure.



The operating manual of any centrifugal pump often starts with a general statement, such as “Your centrifugal pump will give you completely trouble free and satisfactory service only on the condition that it is installed and operated with due care and is properly maintained.”

Despite all the care in operation and maintenance, engineers often face the statement “the pump has failed, i.e. it can no longer be kept in service”. Inability to deliver the desired flow and head is just one of the most common conditions for taking a pump out of service. There are other conditions in which a pump, despite suffering no loss in flow or head, is considered to have failed and has to be pulled out of service as soon as possible. These include seal related problems (leakages, loss of flushing, cooling, quenching systems, etc.), pump and motor bearings related problems (loss of lubrication, cooling, contamination of oil, abnormal noise, etc.), leakages from pump casing, very high noise and vibration levels, or driver (motor or turbine) related problems.

The list of pump failure conditions mentioned above is neither exhaustive nor are the conditions mutually exclusive. Often the root causes of failure are the same but the symptoms are different. A little care when the first symptoms of a problem appear can save the pump from permanent failure. Thus the most important task in such situations is to find out whether the pump has failed mechanically, if there is some process deficiency, or both. Many times when the pumps are sent to the workshop, the maintenance people do not find anything wrong on disassembling it. Thus the decision to pull a pump out of service for maintenance / repair should be made after a detailed analysis of the symptoms and root causes of the pump failure.

For more information on Centrifugal Pumps: Basic Concepts of Operation, Maintenance, and Troubleshooting see this great article from Plant Maintenance.Com

http://www.plant-maintenance.com/articles/centrifugalpumps.pdf

We will explore in this EBook the care and feeding of centrifugal pumps, and we will focus on failures due to cavitation as an often misunderstood cause of pump failures. This is especially true in pump applications where water or other fluids being pumped are near to the boiling point of that fluid. Also, not always understood, is that cavitation can occur when the fluid entering pump temperatures are substantially lower than the boiling point of the fluid, but the pump is approaching open flow rates. Open flow occurs when the pump is pumping against little downstream head, resulting in the pump running far to the right on the operating curve.

Cost to Operate a Pump

Electricity is the most expensive part of any pump - a simple fact often overlooked when purchasing a pump.

Total lifetime costs for operating a pump are about 15% to buy and maintain the pump. Electrical costs account for the other 85% of the total cost.

Electrical savings are significant; see the table below for typical savings.

Typical Application	Typical service per day	Operating hours per day	Average electrical savings
Water supply	350 gpm @ 85 psig	24 hours	18,500 kwh
Boiler feed	175 gpm @225 psig	15 hours	12,700 kwh
Water treatment	10 gpm @ 225 psig	15 hours	3,200 kwh
Industrial washing and cleaning	25 gpm@ 225 psig	5 hours	1,600 kwh
General plant pump application	25 gpm @ 145 psig	10 hours	2,200 kwh

Use this formula to calculate the cost to operate a motor driven pump.

$$\text{\$ per Hour} = \frac{\text{Gpm x Head in feet x .746 x KWH rate}}{\text{3960 x Pump efficiency x Motor efficiency}}$$

As a starting point, assume pump efficiency at 70% and motor efficiency of 90%.

As an example, assume a boiler feed pump is pumping 30 gpm at 150 psig (1 psig ~2.33' of head) and has an electrical cost of \$.08 per KWH. Cost to operate per hour would be as follows-

$$\$.251\ per\ Hour = (30\ x\ 349.5\ x\ .746\ x\ \$.08) \div (3{,}960\ x\ .70\ x\ .90)$$

If the pump operates 720 hours a month, cost to operate the pump works out to \$2,168.64 per year. Put another way, the operating cost of a single pump for one year is about 75% the cost of a new pump. Pump and motor efficiency can save you 20% a year in operating costs.

Electrical costs are a significant part of the cost to purchase and operate a pump. This simple fact is often overlooked when pumps and prices are compared. It may still come as a surprise to some to learn that the initial purchase price and maintenance costs account for less than 15% of the total cost of owning a pump. This means that electricity accounts for no less than 85% of the total cost! So if you want to save money, you should go for the lowest possible energy consumption.

Torque and Horsepower

Torque is the twisting force required to turn an item. The formula to calculate torque is-

$$\boldsymbol{Torque = (5,252\ x\ Horsepower) \div RPM}$$

Horsepower is calculated from-

$$\boldsymbol{Horsepower = (Torque\ x\ RPM) \div 5,252}$$

Notice that at RPM's less than 5,252, the horsepower generated by a motor or engine is a value less than the torque, and if greater than 5,252 RPM's it then becomes a multiplier.

Torque is force times distance (**T = F x D)** which is typically expressed in either ft-lbs or inch-lbs. When you wish to move something either horizontally or vertically, torque becomes the first issue you examine and then add in the desired speed to meet your requirements. Torque is king and horsepower becomes the tool required to generate the required torque. Gear boxes and motor drives become tools to convert motor horsepower to torque while also providing force multiplication. For electric motors, you can use the following conversions

Motor RPM-Poles	Inch-lbs torque per HP
3600 –2 pole motor	17
1750-4 pole motor	36
1200-6 pole motor	52
900-8 pole motor	70

Information Required in Selecting a Centrifugal Pump

If you are selecting or troubleshooting a pump application, then the minimum required information is as follows:

- What is the required pump flow?
- Is the flow required fixed or variable?
- What is the required discharge head?
- Is the discharge head variable?
- What is the suction head on the pump?
- Is the suction head variable?
- What fluid is the pump handling?
- What is the temperature of the fluid?
- What is the specific gravity of the fluid if it is not water?
- Are there any space limitations on the pump?
- What kind of motor will be required-OPD, TEFC, explosion proof, or other?

This information will become the basis for both the pump size as well as the control arrangement of the pump. The majority of applications for a pump can be accomplished with a run or not run control system such as an off/on switch, level control or other similar device. If the flows and discharge requirements for the pump vary, it would be wise to consider a VFD control to operate the pump. Inputs to the VFD controller are typically an analog pressure or flow signal.

Chapter 2 - Cavitation Defined

Chapter 2 Highlights - Notice that cavitation can occur with water or any fluid where the boiling point occurs inside the pump volute, due to insufficient head pressure on the suction side of the pump. Severe cavitation can damage a pump and its seals in less than 60 seconds. Cavitation typically sounds like marbles being shaken in a can. The sound level can be faint and intermittent or be very loud in severe situations.

- **Using the steam table in this chapter, note that the boiling point of water drops from 212°F at sea level to a range of values well under the 212°F boiling point.**
- **Review the vacuum units of measure chart to do conversions if required.**
- **Notice water will boil at a temperature of 162.24°F at a pressure of 5 psia (vacuum).**
- **The lower the pressure on the water, the lower the temperature the water will boil.**
- **As the water begins to boil, the resistance against the impeller drops off further aggravating the problem. The formation and collapse of vapor filled bubbles is called cavitation.**

- **To avoid cavitation, always make sure that there is enough pressure at the pump suction, (i.e. Net Positive Suction Head Available - NPSHA) so that the fluid does not boil or vaporize.**

Any pump's primary function is to move molecules of a fluid from a lower pressure to a higher pressure. Centrifugal pumps accomplish this process by allowing the fluid to enter the suction side of the pump. Then by spinning the molecules at high speeds, velocity is imparted to them which can be translated to an increase in pressure. Many amusement park rides use this centrifugal force by spinning to pin the rider to the outside wall, which holds the rider in position as the spinning portion is elevated.

In our park ride comparison, the ride is the impeller in the pump, and the rider is a molecule of water (if that is the fluid being pumped).

At sea level, water boils at a temperature of 212°F. As we rise above sea level the atmospheric pressure is reduced, which results in water boiling at temperatures less than 212°F. We find places on our planet which are below sea level where water will boil at a temperature less than 212°F.

A steam table shows the relationship between the water pressure and boiling point.

Properties of Saturated Steam
(Abstracted from Keenan and Keyes, THERMODYNAMIC PROPERTIES OF STEAM, by permission of John Wiley & Sons, Inc.)

	Col. 1 Gauge Pressure	Col. 2 Absolute Pressure (psia)	Col. 3 Steam Temp. (°F)	Col. 4 Heat of Sat. Liquid (Btu/lb)	Col. 5 Latent Heat (Btu/lb)	Col. 6 Total Heat of Steam (Btu/lb)	Col. 7 Specific Volume of Sat. Liquid (cu ft/lb)	Col. 8 Specific Volume of Sat. Steam (cu ft/lb)
Inches of Vacuum	29.743	0.08854	32.00	0.00	1075.8	1075.8	0.096022	3306.00
	29.515	0.2	53.14	21.21	1063.8	1085.0	0.016027	1526.00
	27.886	1.0	101.74	69.70	1036.3	1106.0	0.016136	333.60
	19.742	5.0	162.24	130.13	1001.0	1131.	0.016407	73.52
	9.562	10.0	193.21	161.17	982.1	1143.3	0.016590	38.42
	7.536	11.0	197.75	165.73	979.3	1145.0	0.016620	35.14
	5.490	12.0	201.96	169.96	976.6	1146.6	0.016647	32.40
	3.454	13.0	205.88	173.91	974.2	1148.1	0.016674	30.06
	1.418	14.0	209.56	177.61	971.9	1149.5	0.016699	28.04
PSIG	0.0	14.696	212.00	180.07	970.3	1150.4	0.016715	26.80
	1.3	16.0	216.32	184.42	967.6	1152.0	0.016746	24.75
	2.3	17.0	219.44	187.56	965.5	1153.1	0.016768	23.39
	5.3	20.0	227.96	196.16	960.1	1156.3	0.016830	20.09
	10.3	25.0	240.07	208.42	952.1	1160.6	0.016922	16.30
	15.3	30.0	250.33	218.82	945.3	1164.1	0.017004	13.75
	20.3	35.0	259.28	227.91	939.2	1167.1	0.017078	11.90
	25.3	40.0	267.25	236.03	933.7	1169.7	0.017146	10.50
	30.3	45.0	274.44	243.36	928.6	1172.0	0.017209	9.40
	40.3	55.0	287.07	256.30	919.6	1175.9	0.017325	7.79
	50.3	65.0	297.97	267.50	911.6	1179.1	0.017429	6.66
	60.3	75.0	307.60	277.43	904.5	1181.9	0.017524	5.82
	70.3	85.0	316.25	286.39	897.8	1184.2	0.017613	5.17
	80.3	95.0	324.12	294.56	891.7	1186.2	0.017696	4.65
	90.3	105.0	331.36	302.10	886.0	1188.1	0.017775	4.23
	100.0	114.7	337.90	308.80	880.0	1188.8	0.017850	3.88
	110.3	125.0	344.33	315.68	875.4	1191.1	0.017922	3.59
	120.3	135.0	350.21	321.85	870.6	1192.4	0.017991	3.33
	125.3	140.0	353.02	324.82	868.2	1193.0	0.018024	3.22
	130.3	145.0	355.76	327.70	865.8	1193.5	0.018057	3.11
	140.3	155.0	360.50	333.24	861.3	1194.6	0.018121	2.92
	150.3	165.0	365.99	338.53	857.1	1195.6	0.018183	2.75
	160.3	175.0	370.75	343.57	852.8	1196.5	0.018244	2.60
	180.3	195.0	379.67	353.10	844.9	1198.0	0.018360	2.34
	200.3	215.0	387.89	361.91	837.4	1199.3	0.018470	2.13
	225.3	240.0	397.37	372.12	828.5	1200.6	0.018602	1.92
	250.3	265.0	406.11	381.60	820.1	1201.7	0.018728	1.74

Using water as a common example of why cavitation can occur, even if the water temperature is well below the boiling point for the pressure, requires a quick review of the properties of steam and water.

Compare Columns 1 and 2 in the above table, which are measurements of the pressure on the water being pumped with column 3, which is the boiling point of water for a specific pressure. Notice that water will boil at a temperature of 162.24°F at a pressure of 5 psia (vacuum).

The lower the pressure on the water, the lower the temperature at which the water will boil.

When dealing with vacuum, a confusing array of measurements are used to define the level of vacuum. You will encounter units of measure such as psi, inches of water, inches of mercury, and other terms. Use this chart if you need to convert vacuum readings.

PSI	Inches Water	Inches Mercury	Mm Water	Torr (mm Hg)	Atmosphere
1	27.73	2.036	704.49	51.71	.06804
.03605	1	.0734	25.4	1.8627	.00245
0.49116	13.623	1	346.02	25.4	.03342
.00142	.03937	0.00289	1	.07341	.000097
.01934	.53632	.03937	13.623	1	.001316
14.696	407.61	29.921	10353	760	1

Pressure is a measure of molecules striking a surface. More molecules packed into an area will increase pressure, and a smaller quantity of molecules striking the surface will result in a lower pressure. In a total vacuum, like outer space, no molecules exist so there is no pressure.

Consider a room with a front and back door. If the front door is open people enter, and as the room fills to capacity, pressure will be exerted on the wall resulting in “people pressure”. If we open the back door and people exit, then the “people pressure” will go down.

The same idea occurs in a centrifugal pump with the people now being molecules. If the number of molecules being discharged from the pump exceeds the number entering the suction side of the pump, then the pressure in the pump housing (volute) will drop. If water is being pumped at 209°F and the pressure in the pump volute drops to 14.0 absolute pressure (psia), then water will boil inside the pump. Examine the steam table in this chapter to see how the temperature where water boils drops as the pressure inside the pump drops below 14.7 psia.

As the water begins to boil, the resistance against the impeller drops off; further aggravating the problem. The formation and collapse of vapor filled bubbles is called cavitation. This process occurs in regions inside a pump where the pressure drops below the vapor pressure of the fluid (the vapor pressure of the fluid is the pressure at which a fluid begins to boil or vaporize). Cavitation occurs when the Net Positive Suction Head Required (NPSHR) of the pump is not satisfied, and can result in significant damage to the pump.

To avoid cavitation, always make sure that there is enough pressure at the pump suction, (i.e. Net Positive Suction Head Available - NPSHA) so that the fluid does not boil or vaporize. Always make sure that the pump suction pressure is greater than the liquid vapor pressure, regarding the temperature. Note: If a pump is cavitating, you can close down the control valve on the discharge side of the pump to decrease the flow rate, and lower the NPSH required by the pump. Be sure to allow enough flow through the pump for proper cooling and lubrication.

Notice that cavitation can occur with water, or any fluid, where the boiling point occurs inside the pump volute, due to insufficient head pressure on the suction side of the pump. Severe cavitation can damage a pump and its seals in less than 60 seconds. Cavitation typically sounds like marbles being shaken in a can. The sound level can be faint and intermittent or be very loud in severe situations.

Chapter 3 - Pump Selection Basics

Chapter 3 Highlights - To summarize, cavitation occurs when the amount of fluid entering the pump on the suction side cannot keep up with the amount of fluid being delivered by the pump.

- **Selecting a pump requires that you know the flow rate, material you are pumping, temperature, required discharge pressure, and head pressure.**
- **Usually, the flow rate of liquid a pump needs to deliver is determined by the process in which the pump is installed.**
- **The total differential head a pump must generate is determined by the flow rate of liquid being pumped and the system through which the liquid flows.**
- **The total frictional head losses in a system are comprised of the frictional losses in the suction piping system and the frictional losses in the discharge piping system.**
- **The net positive suction head available (NPSHA) is the difference between the absolute pressure at the pump suction and the vapor pressure of the pumped liquid at the pumping temperature.**
- **Think of a pump curve as a graphical representation of what performance the pump can produce. Pumps are passive devices in the sense that the supply and discharge pressures govern the operation of the pump.**

To summarize, cavitation occurs when the amount of fluid entering the pump on the suction side cannot keep up with the amount of fluid being delivered by the pump. Depending on the fluid being pumped and its boiling point as compared to pressure on the fluid, cavitation can occur at temperatures well under 200°F. We will focus our attention on water as a typical example of how to avoid cavitation.

Selecting a pump requires that you know the flow rate, material you are pumping, temperature, required discharge pressure, and head pressure. Generally the flow rate, liquid, and temperature parameters are known for an application. Temperature and material being pumped are important in selecting the pump type, materials of construction, and shaft seals.

Getting at the pump discharge pressure may require a few simple calculations. For water, a column 2.31’ high is equal to 1 psig of pressure. For materials other than water, you would divide by the specific gravity to adjust the column height for what is referred to as the **elevation head.**

The **pressure head** is the difference between the point you are pumping from and the point you wish to pump the liquid to.

The **friction head** is the pressure lost due to the resistance of the pump the liquid is being pumped through.

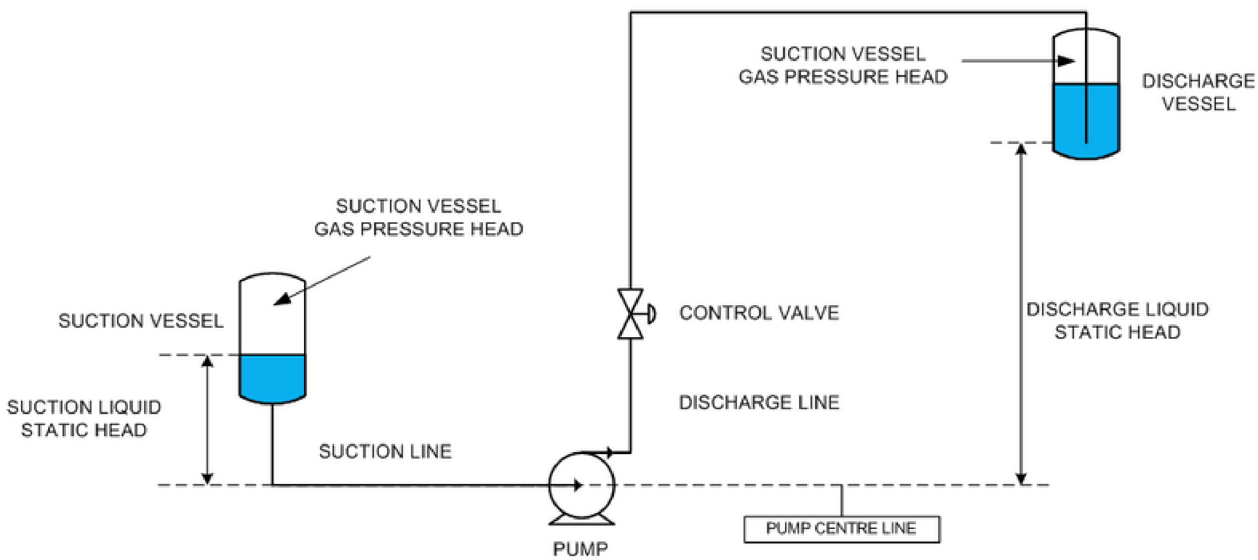
From a great website called Engineering Tool Box, here is a friction head table for water.

Pressure Friction Head Loss *(ft H_2O/100 ft pipe)*												
Volume Flow		Nominal Pipe Diameter (inches)										
Gallons Per Minute *(GPM)*[1)]	Gallons Per Hour *(GPH)*[2)]	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	6
		Nominal Inside Diameter *(inches)*										
		0.493	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	4.026	6.065
1	60	3.3	1.1	0.3								
2	120	11.8	3.8	1.0	0.3	0.1						
4	240	42.5	13.7	3.5	1.1	0.3	0.1					
5	300	64.2	20.7	5.3	1.6	0.4	0.2					
6	360		29.0	7.4	2.3	0.6	0.3					
8	480		49.5	12.6	3.9	1.0	0.5	0.1				
10	600		74.7	19.0	5.9	1.6	0.7	0.2	0.1			
20	1200			68.6	21.2	5.6	2.6	0.8	0.3	0.1		
30	1800					11.8	5.6	1.7	0.7	0.2		
40	2400					20.1	9.5	2.8	1.2	0.4	0.1	
50	3000						14.4	4.3	1.8	0.6	0.2	
60	3600						20.1	6.0	2.5	0.9	0.2	
70	4200							7.9	3.3	1.2	0.3	
80	4800							10.2	4.3	1.5	0.4	
90	5400							12.6	5.3	1.9	0.5	
100	6000								6.5	2.3	0.6	0.1
125	7500								9.8	3.4	0.9	0.1
150	9000									4.8	1.3	0.2

As an example, assume the pump is going to deliver 50 gpm (3000 gph) to a point 100' higher than an open sump and into a tank with a pressure of 50 psig. The friction loss for this application, based on 1 ½" pipe, is 14.4' of head, as noted on the above table.

The friction and elevation heads total 114.4' (100'+14.4') which works out to 49.52 psig (115' / 2.31). The pressure head required on the pump is 50 psig, which means the total discharge pressure required from the pump is 99.52 psig (49.52+50). Rounding off our pump calculation would be 50 gpm at a discharge pressure of 100 psig.

Let's look at an example-



Flow Rate

Usually, the flow rate of liquid a pump needs to deliver is determined by the process in which the pump is installed. This ultimately is defined by the mass and energy balance of the process.

For instance, the required flow rate of a pump feeding oil into a refinery distillation column will be determined by how much product the column is required to produce. Another example is the flow rate of a cooling water pump circulating water through a heat exchanger, which is defined by the amount of heat transfer required.

Total Differential Head

The total differential head a pump must generate is determined by the flow rate of liquid being pumped, and the system through which the liquid flows.

Essentially, the total differential head is made up of 2 components. The first is the static head across the pump, and the second is the frictional head loss through the suction and discharge piping systems.

Total differential head = static head difference + frictional head losses

Static Head Difference

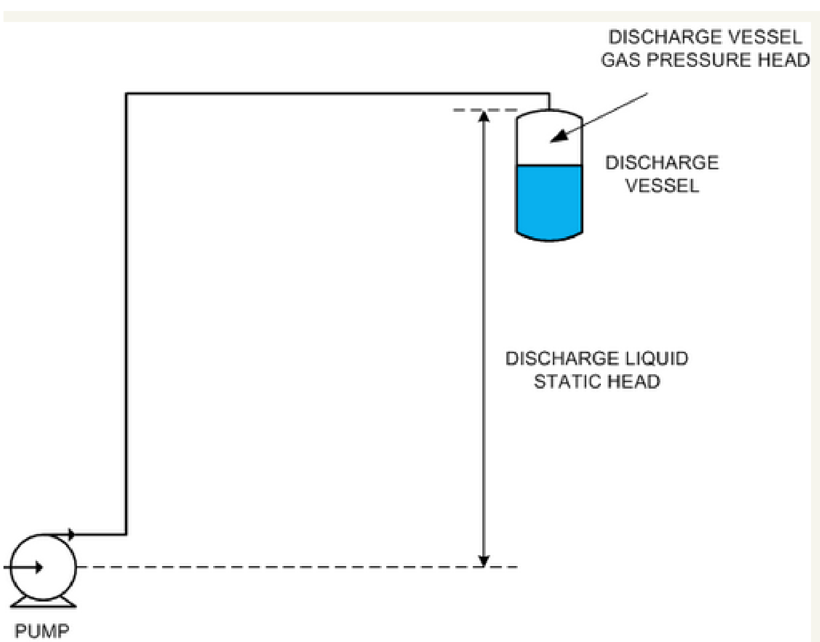
The static head difference across the pump is the difference in head between the discharge static head and the suction static head.

Static head difference = discharge static head – suction static head

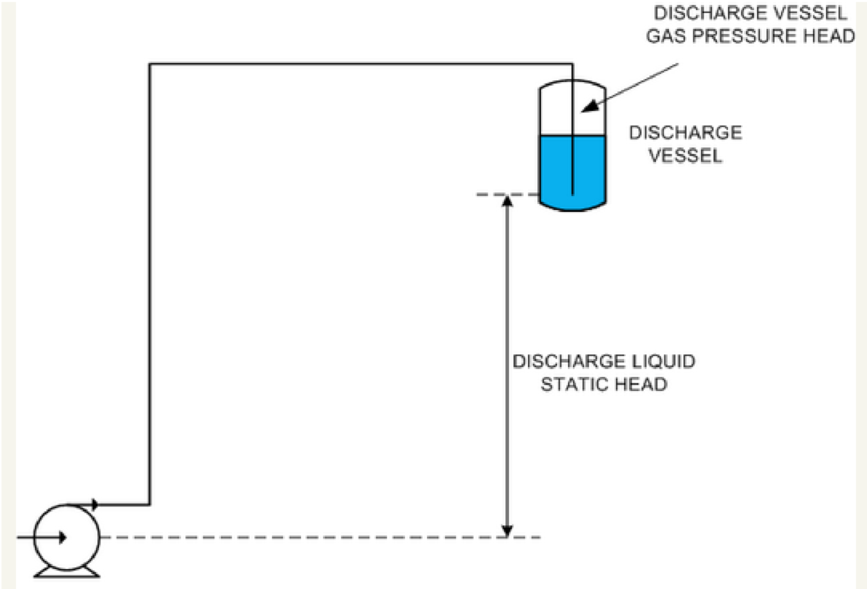
Discharge Static Head

The discharge static head is the sum of the gas pressure at the surface of the liquid in the discharge vessel (expressed as head rather than pressure) and the difference in elevation between the outlet of the discharge pipe and the center line of the pump.

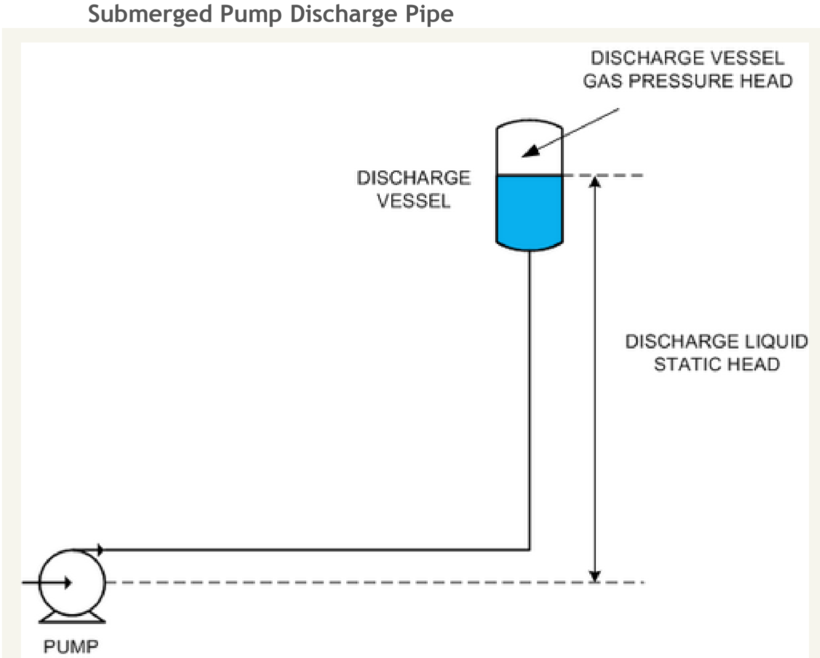
Discharge static head = discharge vessel gas pressure head + elevation of discharge pipe outlet – elevation of pump center line



Pump Discharge above Liquid Surface



Submerged Pump Discharge Pipe

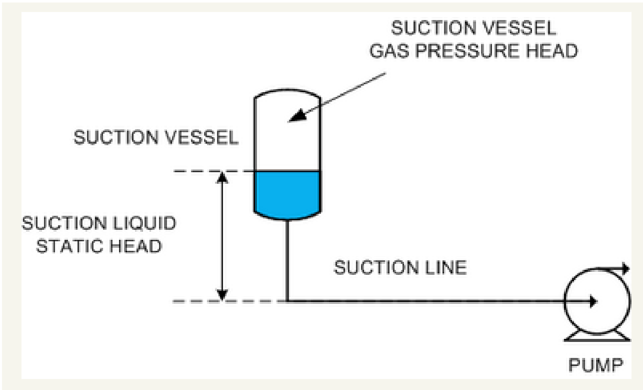


Discharge Pipe Enters the Bottom of the Vessel

Suction Static Head

The suction static head is sum of the gas pressure at the surface of the liquid in the suction vessel (expressed as head rather than pressure) and the difference in elevation between the surface of the liquid in the suction vessel and the center line of the pump.

Suction static head = suction vessel gas pressure head + elevation of suction vessel liquid surface – elevation of pump center line



Pump Suction

Frictional Head Losses

The total frictional head losses in a system are comprised of the frictional losses in the suction piping system and the frictional losses in the discharge piping system.

Frictional head losses = frictional losses in suction piping system + frictional losses in discharge piping system

The frictional losses in the suction and discharge piping systems are the sum of the frictional losses due to the liquid flowing through the pipes, fittings, and equipment**.**

Net Positive Suction Head Available

The net positive suction head available (NPSHA) is the difference between the absolute pressure at the pump suction and the vapor pressure of the pumped liquid at the pumping temperature.

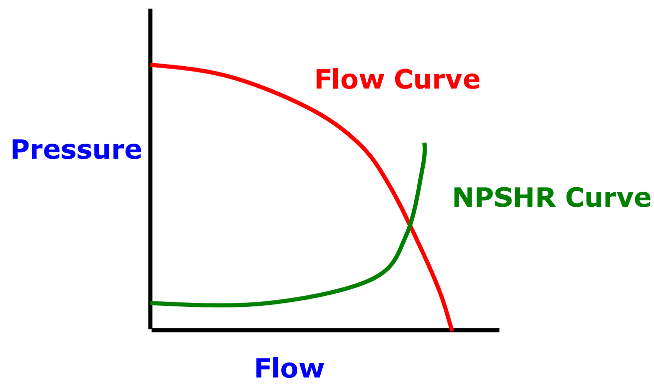
It is important to know this in order for the pump to operate properly. The pressure at the pump suction must exceed the vapor pressure for the pumped fluid to remain liquid in the pump. If the vapor pressure exceeds the pressure at the pump suction, vapor bubbles will form in the liquid. This is known as cavitation, and leads to a loss of pump efficiency, which can result in significant pump damage.

To ensure that the pump operates correctly, the net positive suction head available (NPSHA) must exceed the net positive suction head required (NPSHR) for that particular pump. The NPSHR is given by the pump manufacturer and is often shown on the pump curve.

Net positive suction head available = absolute pressure head at the pump suction – liquid vapor pressure head

Pump Curves

Think of a pump curve as a graphical representation of what performance the pump can produce. Pumps are passive devices in the sense that the supply and discharge pressures govern the operation of the pump.



The graph above represents a typical operating curve to describe pump operations.

The **red line** is the flow curve of the pump. If we close the discharge valve of the pump cutting off all flow, the pressure at the discharge will rise to its highest value which is the static discharge pressure of the pump. If we remove the discharge piping from the pump and turn it loose, the open flow is at the far right of the **red line** and occurs at no static pressure. The flow curve then allows us to predict the pump flow for any pressure difference between the inlet and discharge connections on the pump. Whenever you install a pipe, installing inlet and discharge gauges becomes very important to determine the pump's performance.

The **green line** is the net positive suction head (NPSHR) of the pump. A pump draws water by creating a reduced pressure, or suction, at the inlet of the pump. A good example is to think of a shop vacuum in operation. For the shop vacuum to operate, a blast of air discharges from the top or side of the unit to permit suction at the hose nozzle. A pump handling water or any fluid operates in the same manner. Water at atmospheric pressure boils at 212°F. As the pressure drops below 212°F, water can boil at temperatures well under 200°F. If insufficient suction head (NPSHR) is present at the pump inlet, then cavitation, which sounds like marbles, will occur in the pump, destroying seals and pump internals.

Chapter 4 – Cavitation Prone Applications - Boiler Feed Pumps

Chapter 4 Highlights - Cavitation will tend to occur more frequently when pumping water at temperatures above 180-200°F and with low suction heads or pressures. Steam boilers are widely used in many institutional and industrial applications and require boiler feed pumps to operate. We'll use a boiler feed pump as an example of selecting, installing, and starting a steam boiler. Much of what we will review in detail can then be translated to many other similar applications pumping water or other fluids.

- **Water at atmospheric pressure boils at 212°F. As the pressure on water increases, the boiling point rises. As the pressure drops to less than atmospheric values, the boiling point drops.**
- **A pump draws water from a point by suction, spins it with an impeller and generates pressure. The pump suction is generally at a pressure less than atmospheric pressure which means that hot feed water will "boil" inside the pump. This unloads the motor, generates cavitation, destroys seals, and quickly leads to a pump failure.**
- **The best way to understand the issues that need to be carefully considered is to look at a real world example to select a boiler feed pump. Remember that this example would fit any pump with hot water and low suction pressures.**
- **The pump selection specification is 41.1 gpm of water at 200°F, with a discharge pressure of 582' and a suction head of 8'.**
- **A pump is a "dumb" device given that it will pump as much fluid as the suction pressure will allow the pump to discharge into.**
- **Install on the discharge side of the pump in sequence a pressure gauge, globe valve, check valve, and another pressure gauge.**
- **Sufficient flow through a pump is required to ensure that adequate cooling and lubrication of the pump is maintained at all times. Inadequate cooling and lubrication will result in overheating, bearing wear, friction between the seal faces, seal leakage, and ultimately cause premature pump failure. A bypass line should be installed if there is any possibility the pump may operate under its minimum flow requirements.**

Cavitation will tend to occur more frequently when pumping water at temperatures above 180-200°F and with low suction heads or pressures. Steam boilers are widely used in many institutional and industrial applications and require boiler feed pumps to operate. We will use a boiler feed pump as an example for selecting, installing, and starting up a steam boiler. Much of what we will review in detail can then be translated to many other similar applications pumping water or other fluids. Our comments are based on personally selecting, installing, and starting up hundreds of pump and boiler installations over the years. We will be sharing what we have learned over many years dealing with this difficult application. We will now proceed to the math and details to select and install a steam boiler feed pump.

One of the most critical applications for any pump is feeding water to a boiler. We've seen boiler feed pumps which have lasted many years and many pumps which survive a few months at best. The issue is less related to pump brand and more related to application issues.

Typically a boiler feed pump is required to transfer feed water in a range of 200-230°F from a deaerator or boiler feed system to a boiler operating at pressures of 15-300 psig depending on the boiler specifics. The purpose of a deaerator is to condition the water chemically, remove dissolved gases, and heat the feedwater to at least 200°F to prevent doing thermal shock damage to the boiler. Deaerators come in two basic versions; atmospheric and pressurized. An atmospheric deaerator is a vented vessel and uses chemicals to condition the water.

Atmospheric deaerators typically operate in the 190-205°F temperature range with no pressure in the vessel.

Steam is typically used to heat the tank. In most installations two feedwater pumps are used to provide back up in the event of the primary pump failing, which is quite common. Controls are typically an alternator to spread the wear and operation over both pumps. The suction head to the feedwater pumps is the static head only since the tank is vented. This means that the static head or suction head on the feedwater pumps is very low and measured in feet of head pressure.

A pressurized deaerator uses a closed or pressure vessel to allow the water temperature to be raised to 225-227°F and at a pressure of 5-7 psig to condition the boiler feed water. Chemicals are used to adjust the feedwater to proper levels, and the boiling process of the feedwater is used to drive off the dissolved gases present in the cold water.

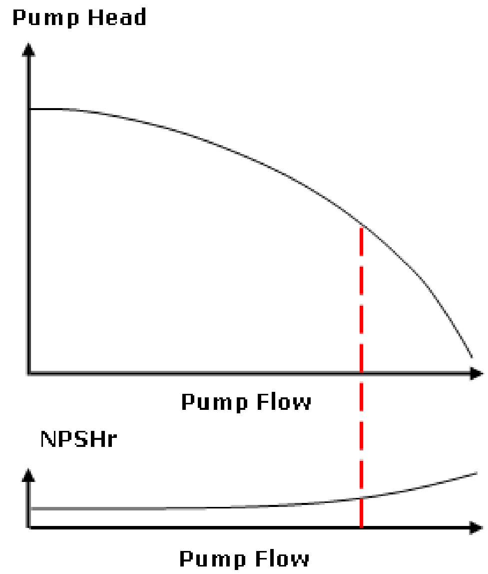
As with the atmospheric deaerator, typically two pumps are utilized to provide primary and secondary options with an alternator based control panel. From a pump selection point of view, the selection of the pump based on the discharge requirements is identical, but the suction specifications are different. Water temperatures are now in the 225-227°F range, but we now have the pressure in the deaerator of 5-7 psig and the static head on the pump to help deal with the potential for cavitation to occur.

Water at atmospheric pressure boils at 212°F. As the pressure on water increases, the boiling point rises. As the pressure drops to less than atmospheric values, the boiling point drops. See the steam table below for details.

Properties of Saturated Steam
(Abstracted from Keenan and Keyes, THERMODYNAMIC PROPERTIES OF STEAM, by permission of John Wiley & Sons, Inc.)

	Col. 1 Gauge Pressure	Col. 2 Absolute Pressure (psia)	Col. 3 Steam Temp. (°F)	Col. 4 Heat of Sat. Liquid (Btu/lb)	Col. 5 Latent Heat (Btu/lb)	Col. 6 Total Heat of Steam (Btu/lb)	Col. 7 Specific Volume of Sat. Liquid (cu ft/lb)	Col. 8 Specific Volume of Sat. Steam (cu ft/lb)
Inches of Vacuum	29.743	0.08854	32.00	0.00	1075.8	1075.8	0.096022	3306.00
	29.515	0.2	53.14	21.21	1063.8	1085.0	0.016027	1526.00
	27.886	1.0	101.74	69.70	1036.3	1106.0	0.016136	333.60
	19.742	5.0	162.24	130.13	1001.0	1131.	0.016407	73.52
	9.562	10.0	193.21	161.17	982.1	1143.3	0.016590	38.42
	7.536	11.0	197.75	165.73	979.3	1145.0	0.016620	35.14
	5.490	12.0	201.96	169.96	976.6	1146.6	0.016647	32.40
	3.454	13.0	205.88	173.91	974.2	1148.1	0.016674	30.06
	1.418	14.0	209.56	177.61	971.9	1149.5	0.016699	28.04
	0.0	14.696	212.00	180.07	970.3	1150.4	0.016715	26.80
	1.3	16.0	216.32	184.42	967.6	1152.0	0.016746	24.75
	2.3	17.0	219.44	187.56	965.5	1153.1	0.016768	23.39
	5.3	20.0	227.96	196.16	960.1	1156.3	0.016830	20.09
	10.3	25.0	240.07	208.42	952.1	1160.6	0.016922	16.30
	15.3	30.0	250.33	218.82	945.3	1164.1	0.017004	13.75
	20.3	35.0	259.28	227.91	939.2	1167.1	0.017078	11.90
	25.3	40.0	267.25	236.03	933.7	1169.7	0.017146	10.50

A pump draws water from a point by suction, spins it with an impeller and generates pressure. The pump suction is generally at a pressure less than atmospheric pressure, which means that hot feed water will “boil” inside the pump. This unloads the motor, generates cavitation, destroys seals, and quickly leads to a pump failure.



All deaerators and boiler feed systems are mounted on a stand and the distance from the tank water line to the inlet of the pump is called the **Net Positive Suction Head (NPSH).**

If we examine the generic pump curve, notice as flow increases from the pump, the **Required Net Positive Suction Head (NPSHR)** increases. For most pumps this will occur in the 60-80% of maximum flow through the pump and the dashed red line represents the danger point which will lead to pump failure.

A pump operating to the left of the red line will give long service and a pump operating to the right can fail very quickly. Since flow and pressure requirements on a boiler feed pump can vary by quite a bit, moving to the right of the red line can occur quickly and without warning. A pump is a passive device in the sense that it will always want to pump as much water as possible, and the current draw on the pump will be a reflection of the amount of water moved by the pump.

The best way to understand the issues that need to be considered is to look at a real world example to select a boiler feed pump. Remember that this example would fit any pump with hot water and low suction pressures. To make the selection example relevant, we will use a Grundfos CR series multistage centrifugal pump since we have had first-hand experience with hundreds of installations. The approach we will use would be similar for any other brand of centrifugal pump.

To set the stage let's go to a specific example-

- Boiler size 300 HP
- Boiler output 10,350 lb/hr of steam
- Boiler operating pressure 125 psig
- Feedwater operation on the boiler is on/off (not modulating)
- Atmospheric deaerator at 200°F
- Stand height of 8' below a 300 gallon tank

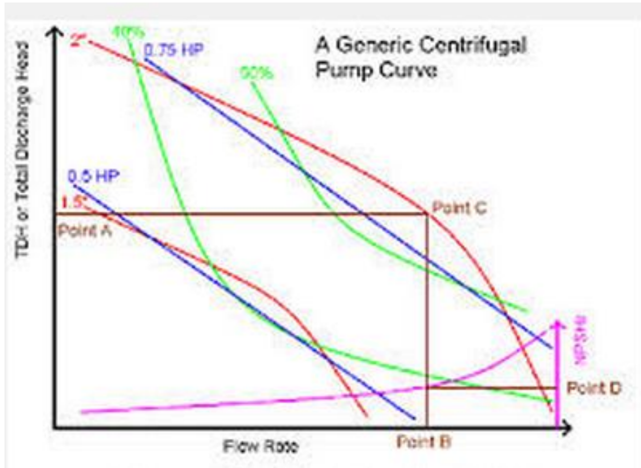
With this basic data let's proceed to break down the details to arrive at the specifications we need to select the feedwater pump which includes:

- The pump flow in gpm
- The pump discharge pressure in psig
- The minimum NPSHR required for the pump to avoid cavitation
- The installation details for the pump

We'll do some quick math to get at the pump specifications. You can, if you wish, skip the quick math to arrive at the pump selection if your application is not for a boiler feed pump. The quick math is as follows:

- 500 lb/hr = 1 gpm
- Boiler Evaporation Rate 10,350 lb/hr = 20.7 gpm (10,350/500)
- For an off/on boiler feed pump, the pump should be sized for 2:1 of the required boiler evaporation rate. For modulating feedwater control the ratio would be 1.5:1
- For on/off control the required maximum on the pump = 41.4 gpm (2 X 20.7)
- For on/off feedwater control the pump discharge pressure should be the operating pressure 2 times the boiler pressure (2:1). For modulating feedwater control it would be 1.5:1
- For our example the discharge pressure = 250 psig (2 X 125)
- 2.33' = 1 psig
- The discharge pressure of the pump = 582' (2.33 X 250)
- The suction head is 5' of elevation

The pump selection specification is 41.1 gpm of water at 200°F with a discharge pressure of 582' and a suction head of 8'.



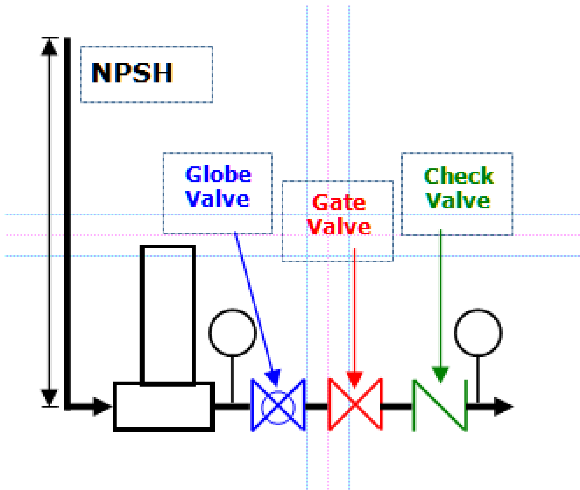
www.bphpumps.com "The Pump Specialists"

Our pump selection would be based on our sizing calculations. Boilers operate over a wide range of conditions from cold start up with no pressure in the boiler, to sudden demand surges, which during peak periods can exceed the boiler output. Notice that the pump, as selected, has an NPSH of 6-7’, so we are just below the minimum requirement of about 8’.

A pump is a “dumb” device given that it will pump as much fluid as the suction pressure will allow the pump to discharge into. On filling the boiler, the pump will go as far right as possible and pump in the region of 70-80 gpm of water. On a surge demand, which might drop the boiler pressure 5-10 psig, the pump output could increase and exceed the NPSH for our selection. This would allow the pump to cavitate, leading to seal or total pump failure.

To prevent the pump from going right on the curve, we need to limit its flow to no more than 40-42 gpm. Flow control devices can be purchased, which will accomplish that purpose. The option we’ve found over many years is simpler and works very well.

Referring to the sketch shown below, install on the discharge side of the pump in sequence a pressure gauge, globe valve, check valve, and then another pressure gauge. In our example, with both valves open and cold water flowing through the pump, gradually close the globe valve until the pressure gauge ahead of the globe valve reads 250 psig (585’ of head pressure). With the globe valve, we have provided a restriction on the discharge side of the pump limiting the flow of the pump, which keeps it within the limits of the NPSH curve. The gate valve can be used to isolate the pump for service and the globe valve should be tagged with a plate indicating “Do not open or close this valve”. In our installations we go one step further and remove the globe valve wheel handle. This insures that it won’t “accidently” be adjusted.



Having watched many boiler feed pumps fail over the years, we have learned the benefits of adding a globe valve in the pump discharge harness to deal with limiting the amount of water which can flow through the pump (under worst case conditions). This keeps the pump on the left hand side of the red line. You can go a step further, which we do, and measure the amp draw on the pump motor and compare it to the amp draw required by the pump for 40 gpm.

By studying the pump curve, knowing the NPSH dimension on the pump suction and the amp draw for a given pump, we can park the pump on the curve by throttling the globe valve to add artificial head on the discharge side of the pump. This limits maximum flows through the pump. This simple piping arrangement, along with pressure gauges and an amp meter, allow for a much better set up of your boiler feed pump.

Pump Bypass Lines

Sufficient flow through a pump is required to ensure that adequate cooling and lubrication of the pump is maintained at all times. Inadequate cooling and lubrication will result in overheating, bearing wear, friction between the seal faces, seal leakage, and ultimately cause premature pump failure. A bypass line should be installed if there is any possibility the pump may operate under its minimum flow requirements. The bypass line should run from the pump vent, or discharge pipe, back upstream of the pump as far as practical or into a tank to allow sufficient cooling of the liquid.

The liquid from the bypass line must have the opportunity to cool down before re-entering the pump in order to prevent its overheating. For this reason, never run the bypass line directly back to the pump inlet. A properly sized bypass is one that satisfies the pump's minimum flow requirement, as stated on the submittal data sheet for each pump. Grundfos offers bypass orifices, sized for each pump model and illustrates their installation in the Series C Installation and Operation manual included with each pump. Please note that during periods of full demand the combined flow through the system and bypass must not exceed the maximum flow rate of the pump.

Lessons Learned in Trouble Shooting

Have you ever been in a situation of trying to solve an impossible problem? Over many years, I have learned that trouble shooting and problem solving require that you think out of the box. Put another way, make a list of all of the probable causes, and then rule them either in or out, one at a time.

Of the many products which comprise a steam system, boiler feed pumps can be your best friend or your worst nightmare.

A boiler feed pump is the interface with the feedwater make-up system, the deaerator, and the condensate return system. Any hiccups in any of these systems, along with possible problems, will lead to boiler feed pump problems and failure.

After struggling with a boiler feed pump problem with a customer for more months than required, we spent a Sunday in the plant and ran a series of tests on the pump. We were able to determine that the pump, under certain situations, was running way off the right side of the curve. Put another way, a 60gpm pump was pumping close to 90gpm which then led to pump failure. Until I took the time to think outside of the box, we continually misdiagnosed the problem.

Lessons I learned included looking at **every possible cause** for a problem, and when boiler feed pumps prematurely fail, view it as a symptom of other possible system problems.

Chapter 5 – Cavitation Prone Applications – Condensate pumps

Condensate Recovery Equipment

Condensate recovery allows you to use all of the valuable BTUs within the steam system. Depending on the pressure, condensate leaving a trap contains approximately 20% of the heat energy transferred at the boiler in the form of sensible heat.

Condensate recovery systems help you reduce three tangible costs of producing steam:

- Fuel/energy costs
- Boiler water make-up and sewage treatment
- Boiler water chemical treatment

The workhorses in any condensate recovery system are condensate pumps. Their job is to move condensate, or other liquids, from low points, low pressures, or vacuum spaces to an area of higher elevation or pressure.

Condensate pumps usually run intermittently and have a tank in which condensate can accumulate. Eventually, the accumulating liquid raises a float switch that energizes the pump. The pump then runs until the level of liquid in the tank is substantially lowered. Some pumps contain a two-stage switch. As liquid rises to the trigger point of the first stage, the pump is activated. If the liquid continues to rise, (perhaps because the pump has failed or its discharge is blocked), the second stage will be triggered.

Often it's necessary to pump generated condensate from heat exchangers and other equipment that is widely distributed in the plant, back to the condensate receiver in the boiler house. A special challenge with hot condensate, which is often close to 212ºF, is cavitation of the pump and the pump impeller.

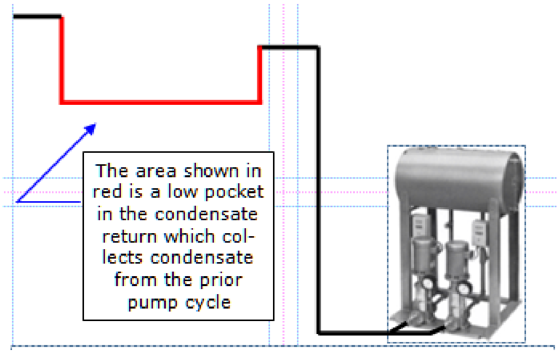
Centrifugal pumps generate lower pressure behind the wheels, and the hot condensate temporarily evaporates and expands on the back side of the vanes - before it implodes and condenses. Over time, this will erode and destroy the pump impeller.

Cavitation in motor driven centrifugal pumps is caused, as in boiler feed pumps, with issues of low NPSH on the suction side of the pump. On small receiver type condensate pumps, as shown in the above picture, the standard receiver is not large enough to provide enough suction head to prevent the pump(s) from cavitating.

Condensate Piping

We did a consulting project for a large plant last year which manufactures ATVs, golf carts, and jet-ski boats. The scope of the project was to improve the system and correct design errors in the original system.

Much of the equipment was installed by a contractor over the year-end holiday. I made a visit to review the system and do an overall check of the system installation. Along with a lot of steam equipment, the redesign involved four large motor operated condensate pumps. When checking the operation of one of the duplex condensate pumps, we got a pretty good bang in the discharge piping every time the pump was turned on. A closer look at the discharge piping revealed the following:



From the prior pump cycle, condensate collects in the low pocket. When the pump discharges on the next cycle, condensate slams into the water trapped in the low pocket. The solution was to eliminate the pocket by re-routing the return line. Condensate from pumps should always be pumped to the highest point, and then cascade downhill to the boiler room.

Electric Condensate Pumps

We carry a full range of electric and steam powered condensate pumps. Each has its application advantages and cost issues to consider. If cost is an issue, or you have fairly high amounts of condensate to pump (over 20-25 gpm), an electric condensate pump certainly has a substantial cost advantage. If properly selected, it will meet your performance requirements. For all electric pumps, NPSH requirements must be carefully considered as well as the construction and temperature ratings of the seals. Most inexpensive electric pumps use a 10-50 gallon square receiver and then mount one or two centrifugal pumps to the receiver. These pumps are low in cost, and for simple low pressure applications, can provide more than adequate service. Due to limitations of centrifugal pumps to deal with condensate above 200°F, seals and wear on the pumps can become a real maintenance headache.

Grundfos Boiler feed pumps are built to meet high temperature and demanding service requirements. Standard seals are rated 250°F and optional seals are offered to 350°F. This type of pump is an excellent choice for larger condensate pump applications and will generally cost 50% less over comparable steam powered pumps. We encounter many situations where other vendors will recommend a $15,000 plus steam powered pump package when a $7,500 duplex motor driven unit will meet the application requirements. I honestly believe these expensive units are in many cases sold to boost commissions and not for totally sound technical reasons.

We have sold a significant number of motor driven pump systems based around a 175 gallon receiver, two Grundfos multi-stage boiler feed pumps and a complete electrical panel with starters, HOA switches, and other electrical units to make the unit install at substantially less cost than a steam powered pump duplex package.

Chapter 6 - Trouble Shooting Tips for Centrifugal Pumps

The pump runs, but at a reduced capacity or does not deliver water-

- Wrong rotation—Check wiring for proper connections, correct wiring.
- Strainers check valves, or foot valves are clogged—remove strainer, screen or valve and inspect. Clean and replace. Reprime pump.
- Pump impeller or guide vane is clogged—Disassemble and inspect pump passageways. Remove any foreign materials found.
- Incorrect drain plug installed—If the proper drain plug is replaced with a standard plug, water will recirculate internally. Replace with proper plug.

Fuses blow or circuit breakers or overload relays trip-

- Pump is bound—Turn off power and manually rotate pump shaft. If shaft does not rotate easily, check coupling setting and adjust as necessary.
- If shaft rotation is still tight, remove pump and inspect. Disassemble and repair.

Noise in pump that sounds like gravel, pump is cavitating-

- Insufficient inlet pressure at pump—Choke back on pump discharge valve to attempt to lower NPSHR (net positive suction head required).
- Clogged strainers on pump inlet piping—Remove strainer, screen or valve and inspect. Clean and replace. Reprime pump.

The pump squeals when it starts and stops (vertical multistage pumps)

- Stack height adjustment is wrong—Disconnect power, remove coupling, loosen set screws in shaft seal, readjust stack height per installation and operating instructions, tighten set screws at shaft seal, reattach coupling.

Chapter 7 – Final Thoughts

In closing, we hope this eBook on Centrifugal Pump Failure Solutions has provided some practical data to enable you to trouble shoot pump failures in your facility. Cavitation can cause major issues to your pumps including seal or bearing damage to complete pump failure. The solution lies in thinking outside the box when practical ideas don't pan out.

Always consider the final operating cost when deciding electrical versus steam powered pumps, it includes much more than the price of the pump alone.

We hope this eBook has helped you; however, if you need further assistance, please give us a call or e-mail us for additional information at info@control-specialties.com.