CHAPTER 5

Operation at the Suction Side of a Pump

In a hydraulic system, much consideration is given to what is happening on the pressure side of a system. This is where all apparent action and work take place. The suction side of a pump is also a very important, but many times neglected, part of a system. We will concentrate on this area now.

pump location

Many times, pumps in an industrial hydraulic system are located on top of the reservoir which contains a system's hydraulic fluid. A suction or intake line connects the pump inlet with the liquid in the reservoir.

The liquid flowing from the reservoir to a pump can be considered a separate hydraulic system. But, in this system, the less-than-atmospheric pressure developed by the pump is the resistance to flow. Energy to move the liquid is applied by the atmosphere.

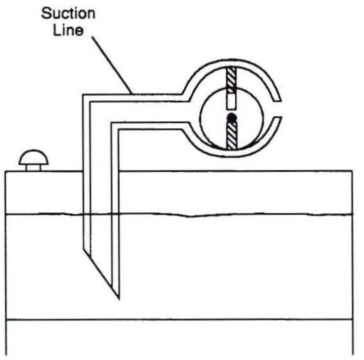
The atmosphere and fluid in the reservoir operate together as an accumulator.

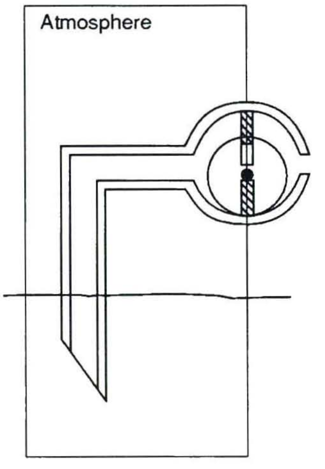
measuring atmospheric pressure

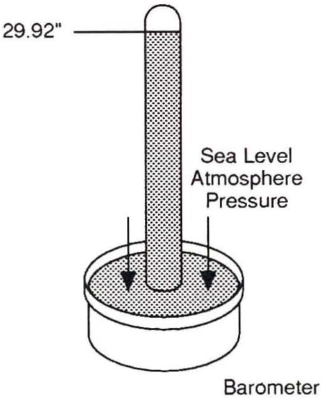
We generally think of air as being weightless. But, the ocean of air surrounding the earth does exert a pressure.

Torricelli, the inventor of the barometer, showed that atmospheric pressure could be measured by a column of mercury. Filling a tube with mercury and inverting it in a pan of mercury, he found that atmospheric pressure at sea level could support a column of mercury 29.92 inches (760 mm) high. Sea level atmospheric pressure, therefore, measures, or is equivalent to, 29.92 inches (760 mm) of mercury under standard conditions. Any elevation above sea level will of course measure less than this.

Hydraulic pressure is usually measured in units of psi or bar. But atmospheric pressure is typically measured in Hg or mm Hg. Vacuum pressures are also measured in in. Hg or mm Hg. Atmospheric pressure at sea level under standard conditions of 68°F (20°C) and 36% relative humidity is 29.92 in. Hg or 760 mm Hg. Those numbers are equivalent to 14.7 psia and 1.01 bar respectively. It is important to note that the bar is not defined as atmospheric pressure, but is defined as 100,000

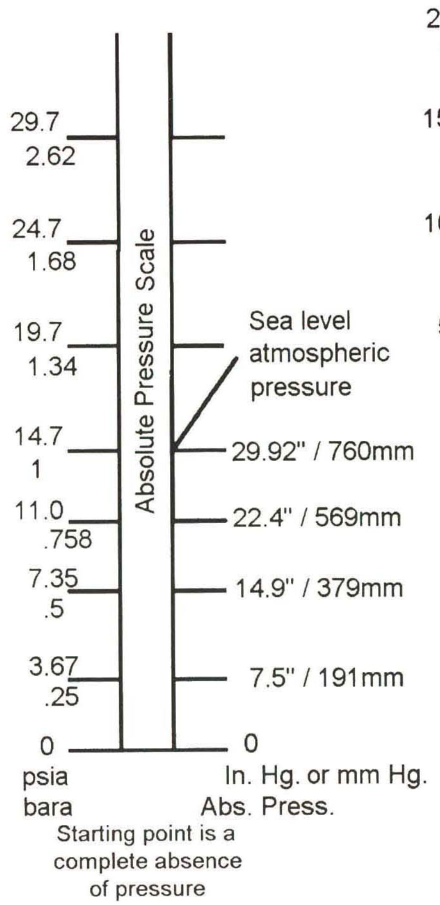


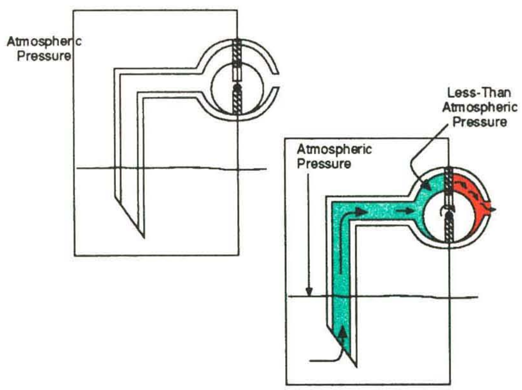




Barometer

Altitude Above Sea Level (ft.)	(m)	Barometer Reading (in. Hg.)	(mm)	Atmospheric Pressure (psi)	(bar)
0	0	29.92	760	14.7	1
1000	304.8	28.8	732	14.2	.966
2000	609.6	27.7	704	13.6	.925
3000	914.4	26.7	678	13.1	.891
4000	1219.2	25.7	652.7	12.6	.857
5000	1524	24.7	627.3	12.1	.823
6000	1828.8	23.8	604.5	11.7	.790
7000	2133.6	22.9	581.6	11.2	.762
8000	2438.4	22.1	561.3	10.8	.735
9000	2743.2	21.2	538.5	10.4	.707
10000	3048	20.4	518.2	10.0	.680





N/m² or 100 kPa. Standard atmospheric pressure is 101,000 N/m².

To convert between in. Hg and psia, notice that 1 psia is equal to 2.04 in. Hg. 1 bar is equal to 752 mm Hg. For approximation we can use 2 in. Hg per 1 psia and 750 mm Hg for 1 bar.

absolute and gage pressure scales

Either of two pressure scales are used to measure pressure in a hydraulic system--an absolute scale or a gage scale.

The absolute pressure scale begins at the point where there is a complete absence of pressure. The units of measurement can be either psi (bar) or inches of mercury (mm Hg).

The gage pressure scale begins at the point of atmospheric pressure. The units of approximate measurement are psi. To determine the absolute pressure from a gage, add standard atmospheric pressure to the gage reading. For example, if a pressure gage reads 100 psi (6.9 bar) and standard pressure is at 14.7 psi (1 bar), the equivalent absolute pressure is 114.7 psi (7.9 bar).

To differentiate between the two pressure scales, psig is used to denote gage pressure, and psia is used for absolute pressure.

operation at suction side of pump

When a pump is not operating, the suction side of a system is in equilibrium. A no-flow condition exists which is indicated by a zero pressure differential between pump and atmosphere. To receive a supply of liquid to its rotating group, the pump generates a less-than-atmospheric pressure. The system becomes unbalanced and a flow results.

use of atmospheric pressure

The pressure applied to the liquid by the atmosphere is used in two phases:

1. supplying liquid to the pump inlet.
2. accelerating the liquid and filling the rapidly moving rotating group, 1200, 1800 rpm, are standard speeds.

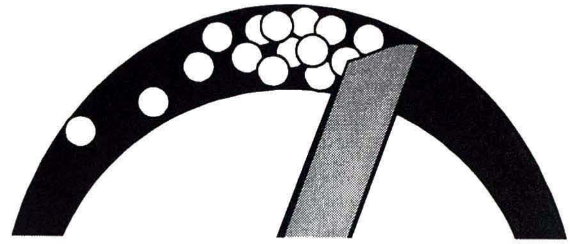
The largest portion of atmospheric pressure is used in accelerating the liquid into the pump. However, the action of supplying liquid to the inlet port makes use of atmospheric pressure first. If too much is used in this phase, not enough pressure will be available to accelerate the liquid into the rotating group. The pump will starve, and something known as cavitation will occur.

cavitation

Cavitation is the formation and collapse of gaseous cavities in a liquid. These cavities are harmful to pump life in two ways:

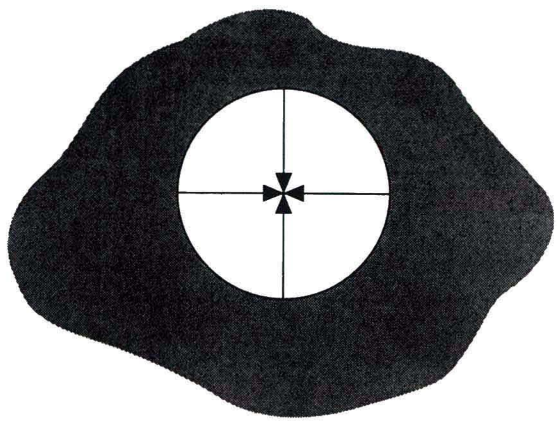
1. they interfere with lubrication.
2. they destroy metal surfaces.

Cavitation interferes with lubrication



On the suction side of a pump, bubbles form throughout the liquid. This results in a reduced degree of lubrication and an increased amount of wear.

As these cavities are exposed to high pressure toward the outlet of the pump, the walls of the cavities collapse and generate tons of force per square inch. The release of energy generated by the collapsing cavities "eat away" metal surfaces and has the same effect as a sculptor's hammer and chisel on stone. If cavitation is allowed to continue, the pump's life will be reduced, and pieces of the pump will migrate to other areas of the system, harming other components.



indication of cavitation

The most noticeable indication that cavitation is occurring is noise. The simultaneous collapse of cavities causes high-amplitude vibrations to be transmitted throughout the system, and a high shrieking sound to generate from the pump.

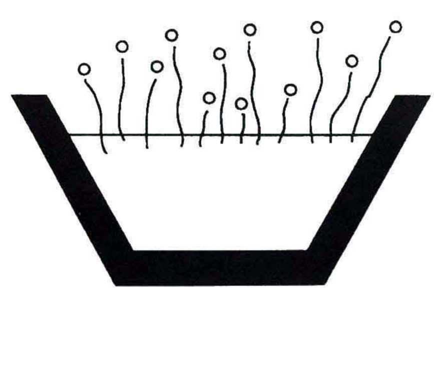
During cavitation, there is also a decrease in pump flow rate, because the pumping chambers do not completely fill with liquid, and system pressure becomes erratic.

cause of cavity formation

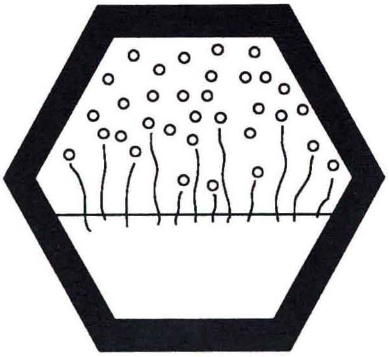
Cavities form within a fluid because the liquid is made to boil. The boiling in this instance is not caused by heating, but is brought about by reaching a low absolute pressure.

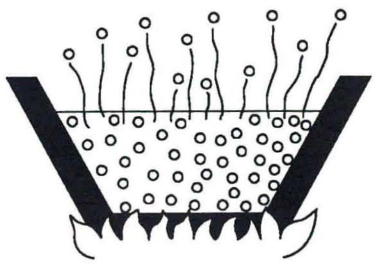
liquid vapor pressure

All molecules in a liquid are moving continuously, but not all at the same speed. Molecules of liquid which move quickly try to escape from the liquid despite the strong attraction of neighboring molecules. These speedier molecules exert a force to enter the atmosphere. This force is the liquid's vapor pressure.



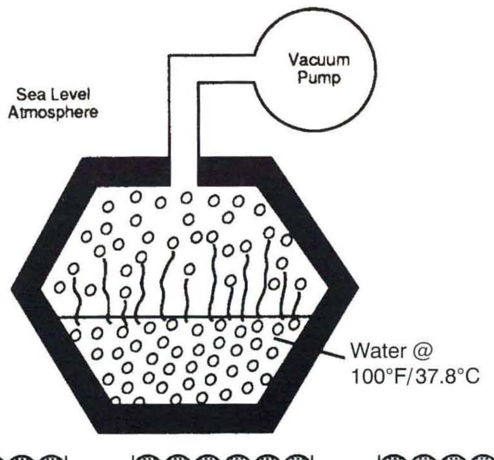
If a cover were placed on the liquid container, fast-moving molecules would enter the area above the

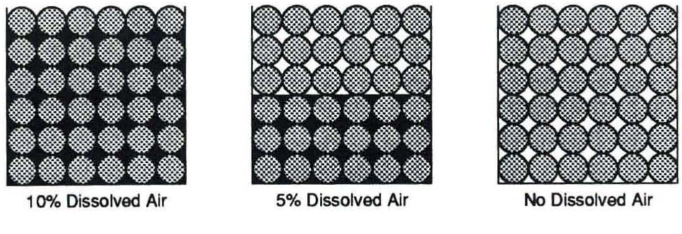




Vapor Pressure of Water

Temperature °F / °C		Vapor Pressure in in./mm Hg Abs. Press.	
100°F	37.8	2.0"	50.8 mm
110°F	43	2.6"	66.04 mm
120°F	49	3.5"	88.9 mm
130°F	54	4.5"	114.3 mm
140°F	60	5.9"	149.86 mm
150°F	66	7.7"	195.58 mm
212°F	100	29.92"	760 mm





liquid. When this area became saturated with vapor, molecules would collide with one another and be knocked back into the liquid. The action of molecules escaping from the liquid is evaporation. The action of molecules returning to the liquid is condensation. When the rate of evaporation equals the rate of condensation, the system will be in equilibrium. The pressure exerted by the vapor at this point will be the vapor pressure of the liquid. This pressure is often expressed in units of inches of mercury absolute pressure.

vapor pressure affected by temperature

The vapor pressure of a liquid is affected by temperature. With an increase in temperature, more energy is added to the liquid's molecules. The molecules move more quickly and the vapor pressure increases. When the vapor pressure equals the atmospheric pressure, liquid molecules freely enter the atmosphere. This is known as boiling.

The boiling point of water at sea level is 212°F (100°C). At this temperature the vapor pressure of water is equal to atmospheric pressure.

boiling affected by pressure

A liquid can also be made to boil by decreasing the pressure acting on it. When this reduced pressure equals the vapor pressure of the liquid, molecules of liquid will freely enter the area above the liquid.

Water has a vapor pressure of 2 in. Hg (0.068 bar) at 100°F (37.2°C). If a container of 100°F (37.2°C) water were connected to a vacuum pump, the water would boil when the pressure in the container reached 2 in. Hg (0.068 bar) Abs. Press. This boiling action takes place in a cavitating pump.

dissolved air

Hydraulic fluid at sea level is made up of approximately 10% air. This air is dissolved in the liquid. It cannot be seen and does not apparently add to the liquid volume.

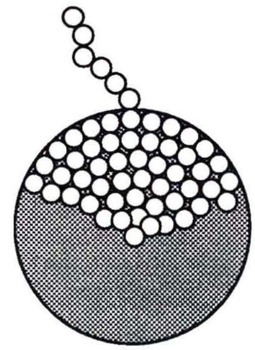
The capability of hydraulic fluid, or any liquid, to hold dissolved air decreases as the pressure acting on the liquid decreases. For example, if a beaker of hydraulic fluid, which has been exposed to the atmosphere, were placed in a vacuum chamber, the dissolved air would bubble out of solution.

Leading up to and during the action of cavitation, this dissolved air comes out of solution and contributes to the harm of the pump.

entrained air

Entrained air is air which is present in a liquid in an undissolved state. The air is in the form of bubbles.

If a pump happens to ingest fluid with entrained air, the air bubbles will have somewhat the same effect on a pump as cavitation. However, since this is not associated with a liquid's vapor pressure, we will refer to this action as pseudo-cavitation.



Entrained Air

Many times, entrained air is present in a system because of a leak in a suction line or a bad pump shaft seal. Since the pressure at the suction side of a pump is usually less than atmospheric, any opening at this point will result in air being sucked into the fluid and to the pump. Also, any entrained air bubbles, which were not allowed to escape while the fluid was in the reservoir, will find their way to the pump.

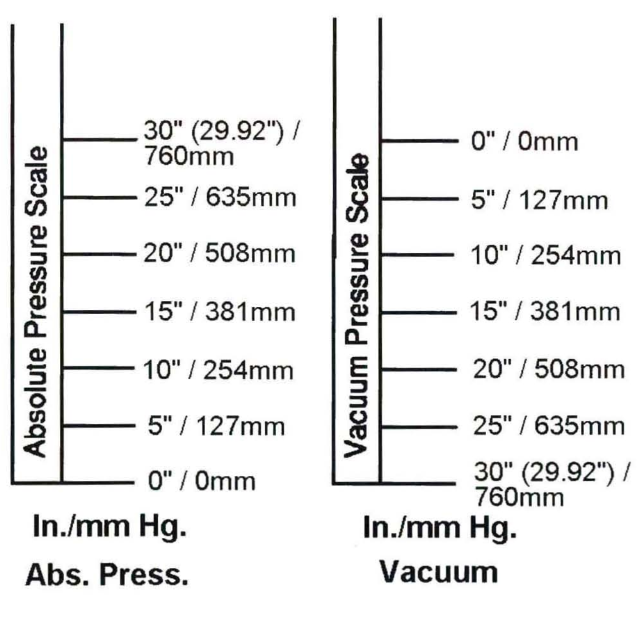
suction specification

Cavitation is very harmful to both pump and system. For this reason, manufacturers specify suction limitations for their pumps.

Manufacturers of positive displacement industrial hydraulic pumps usually specify the less-than-atmospheric pressure which must be present at the pump inlet to fill the pumping mechanism. However, this pressure specification is not given in terms of the absolute pressure scale, but in terms of the vacuum pressure scale.

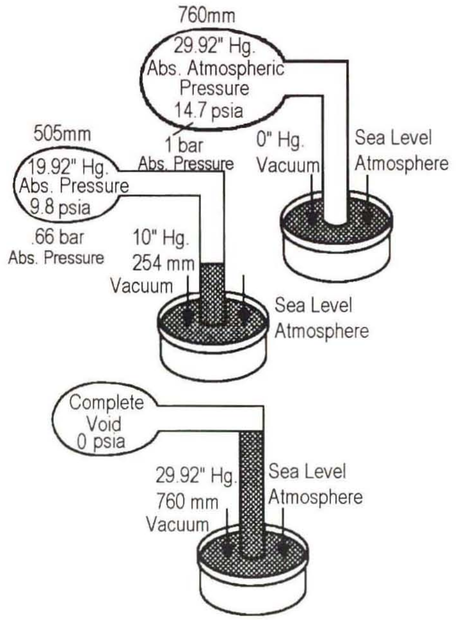
vacuum pressure scale

A vacuum is any pressure less than atmospheric. Vacuum pressure is a source of confusion since the scale begins at atmospheric, just as gage pressure, but works its way down in units of inches of mercury.



how vacuum is determined

In the illustration, a pan of mercury open to the atmosphere is connected by means of a tube to a flask which has the same pressure as the atmosphere. Since the pressure inside the flask is the same as the pressure acting on the pan of mer-



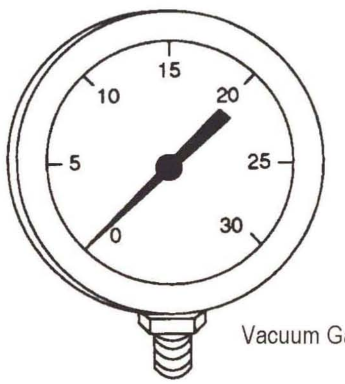
cury, a column of mercury cannot be supported in the tube. Zero inches of mercury in the tube indicates a no-vacuum condition in the flask.

If the flask were evacuated so that the pressure inside were reduced by 10 inches (254mm) of mercury, the atmospheric pressure acting on the mercury in the pan would support a column of mercury 10 inches high (254 mm). The vacuum would measure 10 inches (254mm) of mercury.

If the flask were evacuated so that no pressure remained and a complete void existed, the atmospheric pressure acting on the mercury could support a column of mercury 29.92 inches (760 mm) high. The vacuum would measure 29.92 in. Hg. (760 mm).

Zero inches (Zero mm) of mercury vacuum is atmospheric pressure or the absence of vacuum. 29.92 inches (760 mm) mercury vacuum indicates a perfect vacuum or zero absolute pressure.

vacuum gage



Vacuum Gage

A vacuum gage is calibrated from 0-30 inches of mercury (0-760 mm Hg). Each division is one inch of mercury.

At sea level, to determine an absolute pressure from a vacuum gage reading, subtract the vacuum in inches (millimeters) of mercury from 30 (760 mm). For instance, a vacuum of 7 in. Hg. (177 mm) is actually an absolute pressure of 23 in. Hg. (583 mm).

suspection specification given in terms of vacuum

Leading pump manufacturers give their suction specification in terms of vacuum as it relates to sea level. When the pump is to be used at an elevation above sea level, the barometric pressure at that level must be taken into account.

If a pump manufacturer specifies no more than a vacuum of 7 inches of mercury (177 mm Hg.) be present at the pump's inlet port, this means the pump manufacturer desires an absolute or barometric pressure at the inlet of at least 23 inches (583 mm) of mercury in order to accelerate liquid into the pumping mechanism. If the absolute pressure at pump inlet were anything less than 23 in. Hg. (583 mm), the pump may be harmed. Of course, this depends on the design factor built into the allowable vacuum specification by the manufacturer.

A suction specification is also given for a pump while it is operating at a specified RPM and using petroleum base fluid. The specification is altered if the pump is operating at another speed or pumping a different liquid.

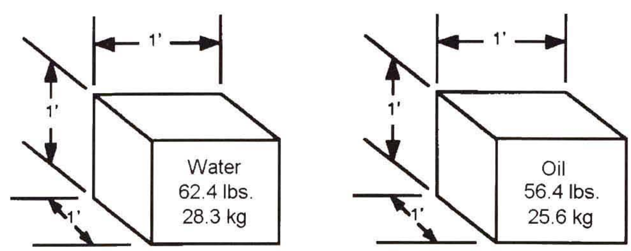
effects of different fluids on maximum allowable vacuum

A maximum allowable vacuum specification of a pump is affected by the fluid being pumped. A pump's suction specification is based on using petroleum base fluid which has a certain specific gravity and vapor pressure. If a fire resistant fluid is used, specific gravity and vapor pressure change affecting maximum allowable inlet vacuum.

high specific gravity affects maximum allowable vacuum

Specific gravity compares the weight of one liquid with another. More specifically, it is the ratio of weight between a volume of water and an equal volume of another liquid.

A cubic foot of water weighs 62.4 lbs. (28.3 kg) @ 60°F (15.6°C). A cubic foot of a common petroleum base hydraulic fluid weighs 56.4 lbs. (25.6 kg) @ 60°F (15.6°C). Dividing the weight of the hydraulic fluid by the water weight, we find that the weight of the oil is 90% of the water. The ratio of weights is 1 (water) to .90 (petroleum oil). The specific gravity (SG) of petroleum oil is then indicated as .90.



A pump's maximum allowable vacuum specification is based on using petroleum base fluid which has a specific gravity of approximately .87-.90. With a phosphate ester fire resistant fluid, specific gravity increases over 30% to approximately 1.15. Water base fluids have specific gravities ranging from .93 for an invert emulsion to 1.08 for water glycols. (See fluids chart in appendix.) With these heavier fluids, more pressure is required at pump inlet for fluid acceleration; consequently, maximum allowable vacuum may decrease appreciably.

high vapor pressure affects maximum allowable vacuum

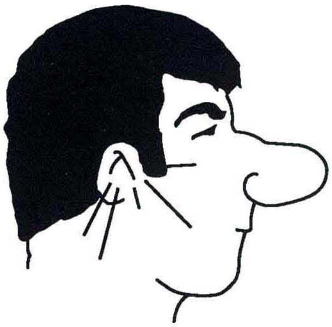
Petroleum base and phosphate ester fire resistant fluids have very low vapor pressures at the operating temperature of a common hydraulic system. However, this is not the case with a water base fluid.

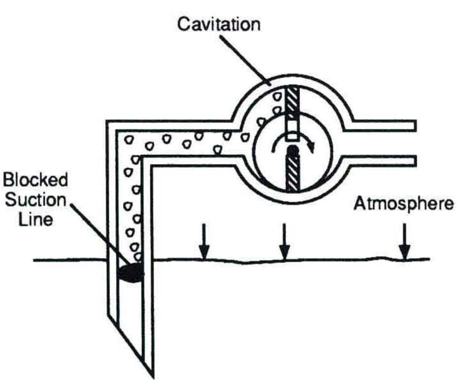
Typical Vapor Pressures of Water Glycol Fluids

Temp. °F	Temp. °C	Vapor Pressure in.Hg.	Vapor Pressure mm Hg.
100	37.8	1.3	33.02
110	43	1.9	48.26
120	49	2.5	63.5
130	54	3.3	83.82
140	60	4.1	104.14
150	66	5.5	139.7

Typical Vapor Pressures of Water-In-Oil Emulsion Fluids

		Vapor Pressure	
Temp °F	Temp. °C	in.Hg.	mm Hg.
100	37.8	1.9	48.26
110	43	2.6	66.04
120	49	3.5	88.9
130	54	4.5	114.3
140	60	5.9	149.86
150	66	7.6	193.04





Since they contain a large percentage of water, invert emulsions and water glycol fluids can have vapor pressures of several inches of Hg where petroleum and synthetic fluids would have vapor pressures of a fraction of an inch of Hg. For this reason, they have more of a tendency to vaporize and cavitate.

To avoid cavitation with a water base fluid, a pump manufacturer ensures that sufficient pressure is present at pump inlet to accelerate the liquid into the pump without ever going below the fluid's vapor pressure. This is accomplished by reducing maximum allowable vacuum.

check for pump cavitation

Maintenance men have the first opportunity to discover a cavitating pump or a pump which is sucking air. Being acquainted with their machinery, they receive the initial indication that something is wrong.

The most pronounced indication of a pump either cavitating or sucking air are high-pitched sounds, but they are of a slightly different character. A cavitating pump will have a steady, high-pitched sound which is probably due to collapsing bubbles of approximately the same size. On the other hand, a pump sucking air has somewhat of an erratic sound. If small amounts of air are finding their way to the pump, the noise may sound like a rattle or bad bearing. Large amounts of air will result in a very erratic banging and popping noise.

A more certain way to distinguish cavitation from air entrainment is to determine the absolute pressure at pump inlet by taking a vacuum gage reading and subtracting it from the barometric pressure. If this action indicates that insufficient pressure is available at pump inlet, cavitation may be occurring.

A new system with a cavitating pump is probably the result of poor suction line design or incorrect fluid viscosity. Changing to the appropriate viscosity or increasing the suction line size or reducing pressure differential will help the situation. A properly designed older system whose pump is cavitating may be the result of a plugged suction line due to a rag, newspaper, or animal. It may also be caused by a dirty filter without a bypass or an insufficient bypass.

pump priming

With respect to a pump, "prime" indicates that a pumping mechanism is filled with liquid. A pump which is not primed is filled with air or "air bound." Before pumping can occur, this air must be purged from suction line and pump cavities. If this is not done and the pump is allowed to operate in an unprimed condition for even a few minutes, it may be permanently damaged due to lack of lubrication.

At start up, a pump whose outlet is directly connected to tank through a directional valve, generally has an easy time of pushing trapped air to tank. A pump which must push its air over a relief valve has an impossible task; the reason being, an ordinary industrial hydraulic pump is a poor air compressor.

To release trapped air from an unprimed pump, a fitting at pump outlet can be loosened. The pump is then jogged until oil squirts out the fitting indicating the pump is primed. The fitting is then tightened. Trapped air may also be released by venting a relief valve.

Pump priming is frequently required on the new systems at start up and on systems with suction side leaks.

terms and idioms associated with the suction side of a pump

FLOODED SUCTION - situation in which pump inlet is below fluid level in reservoir.

HEAD PRESSURE - pressure exerted at the bottom of the fluid column. With a pump's inlet located below fluid level, head pressure is an additional source of energy to supply the pump. To calculate head pressure (in units of inches of mercury).

$$\text{head pressure (In. Hg.)} = \frac{\text{fluid column height (in.)} \times .036 \times \text{fluid specific gravity}}{.491}$$

$$\text{head pressure (mm Hg.)} = \text{fluid column height (mm)} \times \text{fluid specific gravity} \times .00288$$

LIFT - the height of a column or body of fluid below a given point expressed in linear units. To calculate lift pressure (in units of inches of mercury).

$$\text{lift pressure (mm Hg.)} = \frac{\text{fluid column height (in.)} \times .036 \times \text{fluid specific gravity}}{.491}$$

$$\text{lift pressure (mm Hg.)} = \text{fluid column height (mm)} \times \text{fluid specific gravity} \times .00288$$

SUCTION - act of the pump generating a pressure differential between itself and the atmosphere.

SUCTION PRESSURE - the absolute pressure of the fluid at the inlet pump.

exercise
operation at the suction side of a pump
50 points

INSTRUCTIONS: Comment on the following statements.

1. STATEMENT -
"We cavitated four pumps to death before we found the crack in the suction line." (Explain the difference between cavitation and the situation described by the statement).

2. STATEMENT -
"Here in Denver, the atmospheric pressure is usually around 12.1 psia (0.8 bar). The pump manufacturer's specification is 5 in.Hg. (0.17 bar). Since one inch of mercury is approximately a half psi, we have plenty of pressure to work with." (Clarify this erroneous statement).

3. STATEMENT -
"I don't understand what's wrong with my pump. It makes a high shrieking sound. And, I don't get the flow that is stated in the manufacturer's catalog. I thought the pump might not be developing enough vacuum, so I checked the vacuum with a gage. The gage reads 24 (0.81 bar) and the pump catalog says I only need 6" (0.204 bar). (What's happening to the pump? Clarify the last sentence in the statement).

4. STATEMENT -
"Purchasing bought a different brand of pump and it cavitated right off the bat. We can't determine why, since the flow rate through the suction line is exactly the same." (What's the problem?)

5. STATEMENT -
"Our machines were leaking like crazy so we switched to a heavier oil. Now the pump is noisy and doesn't last too long either." (What's happening to the pump and what caused the situation?)