PRESSURE — VACUUM TERMS, DEFINITIONS & DISCUSSION

Pressure - Vacuum: Two terms we are concerned with daily in pump application work. On occasion they are presented in unfamiliar terms and we find it necessary to do some digging to find a conversion or to make a logical interpretation.

Believing that this problem may also present itself to you, we felt it might be desirable to review some of the terms we encounter when dealing with pressure and vacuum.

We will list the terms, define them — using a textbook or standard definition when we can find one, or give the definition we use here at Viking when no more authoritative source can be found, and last, give some discussion on those terms that have proved particularly troublesome or have a peculiar significance when applied to pump applications.

We will break the terms down into four categories (1) those pertaining to pressure in general, (2) those encountered most frequently on the suction side of the pump, (3) those found on the discharge side, and (4) some applications to watch. See Figure 1 for the terms that will be defined.

(1) GENERAL TERMS

HEAD: One means of indicating the discharge pressure a pump must develop. Literally, head means the height of a column of liquid that will exert the same pressure at its base as a pump must develop at its discharge port to meet the requirements of the system. For applications involving positive displacement pumps, head is normally expressed in PSIG. For centrifugal pump applications, head is expressed in feet of the liquid being pumped (when converting to PSIG do not forget to consider specific gravity of the liquid). The term "head" when used alone is assumed to mean the total discharge head.

Friction Head: The head or pressure necessary to overcome the frictional resistance of a piping system to the flow of liquid through it. The term friction head is most frequently encountered in centrifugal pump applications. It is expressed in feet of liquid or PSI. Friction head is synonymous with the following terms which are more frequently encountered in positive displacement pump applications: pipe friction loss, line loss, and delta P (Δ P).

Static Head: The pressure or head at the pump ports when the liquid in the system is not flowing (is static). The value of the static head (expressed in feet of liquid or the equivalent PSI) is equal to the difference in elevation between the pump ports and the point where the liquid is exposed to atmosphere.

Total Head: The algebraic* sum of the head on the discharge and suction sides of the pump. It is synonymous with differential pressure and is expressed in feet of liquid or PSI.

**To add something algebraically is to take into account the plus and minus signs.*

Pages 510.3 and .4 of Engineering Section 510 of the Viking catalog also list the above-mentioned "head" terms and have additional diagrams illustrating them.

Velocity Head: The head or pressure possessed by a liquid because of its velocity or speed of flow. A term seldom used in positive displacement pump applications because of its small value compared to total head. It might possibly be of importance in a system involving a thin liquid and marginal available NPSH. Most frequently used with centrifugal pumps handling water. The units of velocity head are normally feet of liquid or PSI.

PRESSURE: The classic definition of pressure is $\frac{F}{A}$ where F equals force or "push" and A equals area. The force will normally be expressed in terms of weight: pounds, grams, tons . . .; the area in terms of square measure: square inch, square foot, square centimeter . . . The unit of pressure can take many forms, e.g., tons per square foot, kilograms per square meter. The main problem is to be able to convert the unit given to the one in which our data is expressed. Table 1 shows factors for converting between various units of pressure.

Absolute Pressure: Most of us are familiar with the term 14.7 PSI; this is atmospheric pressure at sea level. This implies that someplace in outer space there could be an atmosphere so "thin" that it would have a pressure reading of almost zero PSI (approaching a perfect vacuum). Any pressure reference

(1) GENERAL TERMS

Head
- Friction
- Static
- Total
- Velocity

Pressure
- Absolute
- Atmospheric
- Barometric
- Differential
- Gage
- Hydraulic
- System
- Working

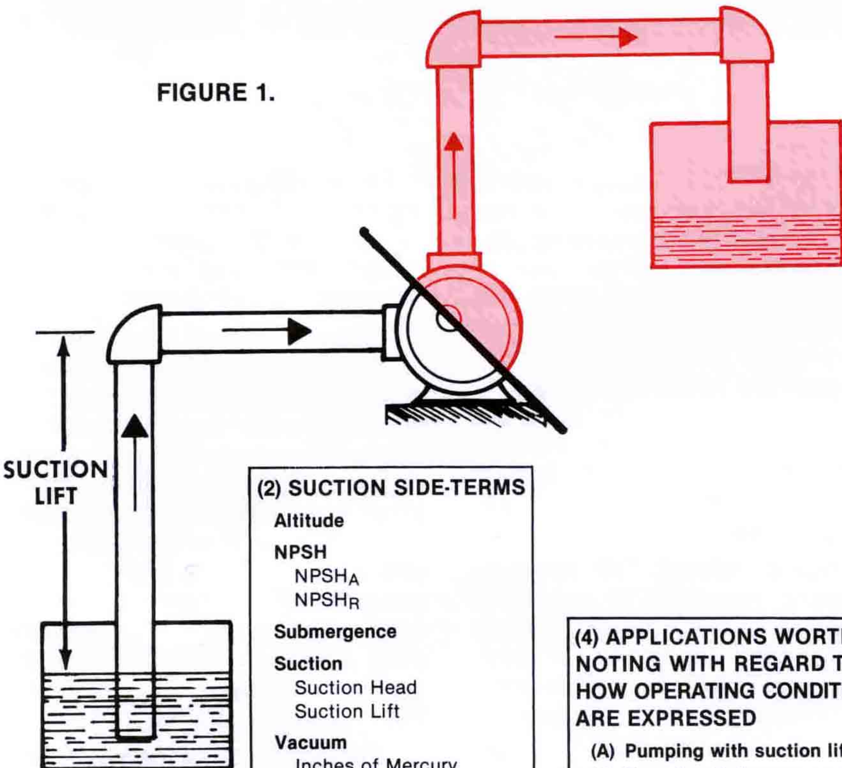
Pressure Drop

(3) DISCHARGE SIDE-TERMS

Discharge Head
- Static Discharge Head
- Total Discharge Head

Discharge Pressure
- Atmospheres
- Feet of water
- Kilograms per square centimeter
- Meters of water
- Pounds per square inch

FIGURE 1.



(2) SUCTION SIDE-TERMS

Altitude

NPSH
- $NPSH_A$
- $NPSH_R$

Submergence

Suction
- Suction Head
- Suction Lift

Vacuum
- Inches of Mercury
- Micron
- Millimeter of Mercury
- PSIA
- TORR

Vapor Pressure

(4) APPLICATIONS WORTH NOTING WITH REGARD TO HOW OPERATING CONDITIONS ARE EXPRESSED

- **(A) Pumping with suction lift**
- **(B) Pumping high vapor pressure liquid**
- **(C) Pumping from vessel under high vacuum**
- **(D) Pumping in a system having high internal pressure**

or reading that uses this zero as a starting point is known as "absolute" pressure.

Absolute pressure is expressed in pounds per square inch absolute, PSIA. Absolute pressure is equal to gage pressure plus 14.7 PSI. See Figure 2 for graphic comparison.

Atmospheric Pressure: The air or atmosphere surrounding the earth piles up, as it gets closer to the earth, exerting an ever greater pressure. This pressure is called atmospheric pressure; at sea level it amounts to 14.7 PSI. Probably the most frequent contact most people have with atmospheric pressure is in connection with weather reports in which the atmospheric pressure is given in inches of mercury. An equivalent for the 14.7 PSI when expressed in inches of mercury is 29.93. Common atmospheric pressure readings in our area (Cedar Falls, Iowa) run from 28.9 to 29.3 inches Hg. Another unit of atmospheric pressure measurement used occasionally is millimeters of mercury. The equivalent reading to 14.7 PSI when expressed in millimeters is 760. See Table 1 for conversion factors.

Atmospheric pressure is primarily dependent on the elevation or height above sea level, getting less as the air gets thinner at higher elevations. Table 2 shows atmospheric pressures at different elevations.

Suction conditions for a pumping application are not so critical that elevation has to be considered, but when working with thin liquids in mountainous areas it is well to keep it in mind. For example, the atmospheric pressure in the "mile-high" city of Denver, Colorado, is 12.1 PSI (24.7" Hg.) instead of 14.7 PSI.

Barometric Pressure: Pressure measured by a barometer and normally synonymous with atmospheric pressure. A simple form of barometer is made by filling a long tube with mercury and inverting it in a cup containing mercury. The column of mercury in the tube descends until it is balanced by the weight of the atmosphere. At sea level the height of the column is about 30 inches. The normal atmospheric or barometric pressure reading of around 30 inches of mercury.

Differential Pressure: Differential indicates difference. A difference in pressure exists between any two points in a system or circuit in which liquid is flowing. Differential pressure is normally understood to mean the difference in pressure across the pump, i.e., the difference between suction pressure and discharge pressure. See Figure 3. Differential pressure at Viking Pump is expressed in PSI. The pressure scale, absolute or gage, is ir-

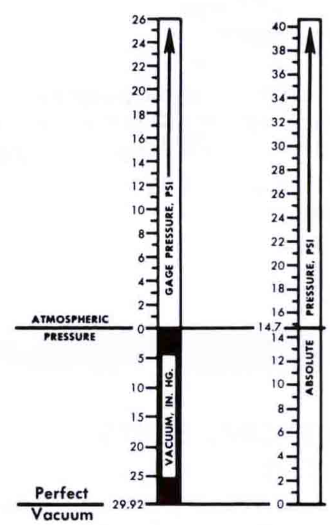


FIGURE 2. Comparison Between Absolute and Gage Pressure Scales

TABLE 1.
Factors For Converting* From One Pressure Unit To Another.

Pressure Unit	Atmospheres, Atmos.	Feet of Water, ' H_2O	Inches of Mercury, " Hg	Kilograms per square centimeters, Kg/cm^2	Millimeters of Mercury, mm Hg	Pounds per square inch, PSI
Atmos-pheres, Atmos.	1	33.9	29.9	1.03	760	14.7
Feet of Water, # ' H_2O	0.029	1	0.883	0.030	22.4	0.433
Inches of Mercury, " Hg	0.033	1.13	1	0.034	25.4	0.49
Kilograms per square centimeter, Kg/cm^2	0.968	32.8	28.9	1	736	14.2
Millimeters of Mercury, mm Hg	0.00131	0.0446	0.0394	0.00136	1	0.0193
Pounds per square inch, PSI	0.0680	2.31	2.04	0.0703	51.7	1

*To convert from a pressure unit in the left hand column multiply the numerical value times the factors in the vertical column showing the unit you are converting to. For example to convert 50 feet of water to PSI go horizontally to the right from the "Feet of Water" unit to the box under PSI, the factor is 0.433. The 50 feet of water would then be multiplied by 0.433 to get 21.6 PSI.
When working with liquids other than water multiply the conversion factors shown by the Specific Gravity of your liquid to get the correct factors.

TABLE 2.
Atmospheric Pressure and Barometer Readings at Different Altitudes

Altitude Above Sea Level in Feet	Atmospheric Pressure — Pounds Per Square Inch	Barometer Reading — Inches of Mercury
0	14.7	29.929
1000	14.2	28.8
2000	13.6	27.7
3000	13.1	26.7
4000	12.6	25.7
5000	12.1	24.7
6000	11.7	23.8
7000	11.2	22.9
8000	10.8	22.1
9000	10.4	21.2
10000	10.0	20.4

relevant since the value is the difference between two readings on the same scale.

Gage Pressure: Most pressure gages used on liquid transfer systems are those that show a zero reading when exposed to atmospheric pressure, i.e., when they are not in use.

Readings taken from gages having this zero point (atmospheric pressure) are known as gage pressure readings. The most common units are pounds per square inch gage (PSIG). Gage pressure is equal to absolute pressure minus 14.7 PSI. See Figure 2 for comparison between gage pressure and absolute.

Hydraulic Pressure: By dictionary definition hydraulic means "pertaining to fluids in motion, especially water". By popular usage it means transfer of power by the moving of liquid under pressure. Hydraulic pressure is pressure exerted by a liquid, resulting either from height (elevation) or a pump.

A system at rest will have pressure exerted on it at the low point. This is a function of the elevation of the liquid at its highest point and the specific gravity. This would be hydraulic pressure resulting from the "head" of liquid. It can be troublesome at times because of a packing leak. If leaking while the pump is idle, the system may drain itself through the pump (this can be especially bad if a siphon effect is created), or it may permit air to be pulled into a system.

Hydraulic pressure is frequently used in conjunction with hydrostatic pressure tests. Hydraulic pressure in this case is the pressure exerted on the liquid in a pump by an external means such as a hand piston pump to check the pump casing, gaskets, etc. for leakage.

Hydraulic pressure is also used in making pump efficiency calculations. The theoretical horsepower (hydraulic horsepower) or power contained in the liquid is a function of the pressure added to the liquid and the volume of liquid to which this pressure is added.

$$\text{THP} = \frac{\text{Pressure} \times \text{Volume}}{\text{Constant}}$$

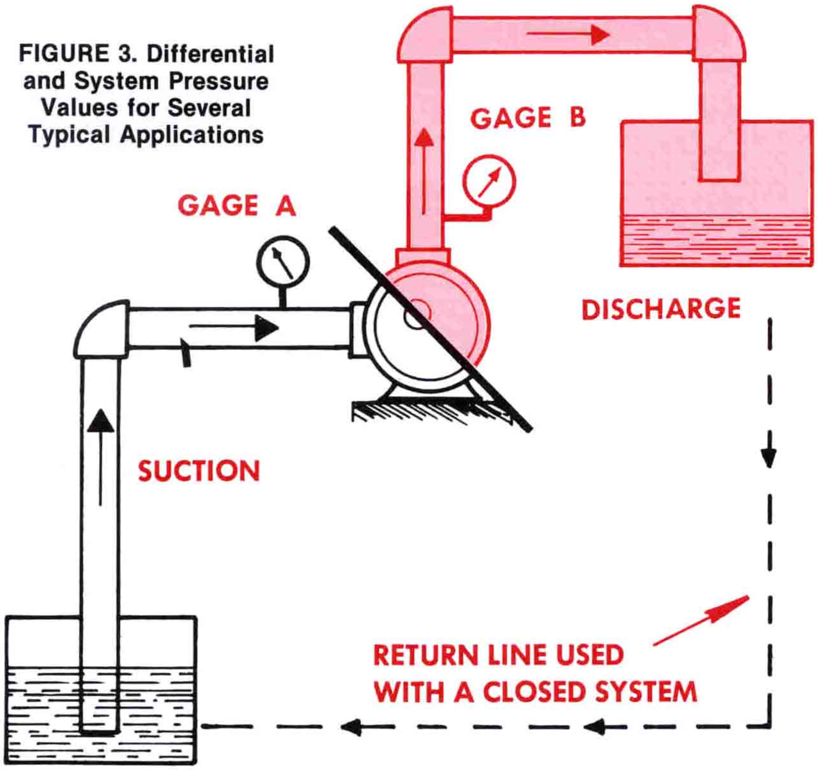
System Pressure: A system, when referring to pumps, includes the entire circuit of piping, valves, tanks, etc., that the liquid flows through. On most transfer applications the suction side is exposed to atmospheric pressure; thus there is no pressure being exerted on the system when it is at rest. This would be an "open" system. A closed system is one in which no point in the circuit is open to the atmosphere. Typical of closed systems would be ones handling high vapor pressure liquids such as LP-Gas, anhydrous ammonia, carbon dioxide, etc. Another example would be a "sampling" pump. This type application involves drawing liquid from a high pressure cross country pipe line, forcing it through an analyzer and then returning it to the pipe line again.

On applications with high system pressures, it is necessary to consider the pump as a pressure containing vessel even when it is not operating. This means special consideration must be given to the strength of the pump casing, tightness of gaskets, packing, "O" rings, etc. Special consideration must be given to any mechanical seals or thrust bearings used in the pump since they will be operating with abnormally high loads. Even for high system pressure applications, the job of the pump normally is still to transfer or circulate the liquid at a relatively low differential pressure. See Figure 3.

System pressure is expressed in pounds per square inch; the scale depending on the user.

Working Pressure: (A) Pump working pressure—This is the pressure the pump must develop or work against. It is synonymous with differential pressure and would be expressed in PSI; again the scale would make no difference since it would be the difference between two readings on the same scale.

FIGURE 3. Differential and System Pressure Values for Several Typical Applications



Application	Gage Readings		Differential Pressure (Pump working pressure)	System Pressure	System Working Pressure
	Gage A (Suction)	Gage B (Discharge)			
1. #2 fuel oil from storage to delivery truck.	0 PSIG	35 PSIG	35 PSI	0 PSIG	35 PSIG
2. Propane at 65°F from storage to truck	100 PSIG	150 PSIG	50 PSI	100 PSIG	150 PSIG
3. Soybean Oil from evaporator to storage	2 PSIA	50 PSIG	62.7 PSI*	2 PSIA	50 PSIG
4. Gasoline from pipeline to analyzer back to pipeline	500 PSIG	525 PSIG	25 PSI	500 PSIG	525 PSIG

*Note that suction is given in absolute and discharge in gage. It is necessary to get both readings to same scale before subtracting to get differential.

(B) System working pressure — This is the pressure on the high side or pressure side of a pump. In the case of an "open" system, the "system working pressure" would be the same as "pump working pressure". In the case of a "closed" system the "system working pressure" would be the suction pressure plus pump differential pressure. See Figure 3.

PRESSURE DROP: Pressure drop is as the words indicate a decrease or drop in pressure between two points in a pumping system. Most frequent use of the term is made in reference to the loss of pressure caused by pipe friction. Pipe friction is the resistance a liquid has to flow through a pipe. Pressure drops have been calculated and test checked for various capacities of different viscosity liquids through many pipe sizes. This testing has been conducted over the years by various pump companies and independent testing groups.

By knowing the piping layout, the capacity, the viscosity, and the specific gravity of the liquid, it is possible to predetermine the pressure drop by use of charts, tables, etc. Typical of the many tables available today are the ones on pages 510.13 thru 510.16 of the Viking General Catalog, Engineering Section 510. The pressure drop value plus any elevation change plus any pressure required at the point of delivery of the liquid determines the pressure a pump must develop. This permits accurate sizing of motors, relief valve settings, etc.

Pressure drop as we use the term is synonymous with pipe friction loss, friction loss and delta P (Δ P). It is normally expressed in PSI per foot or per 100 feet of pipe.

(2) SUCTION SIDE — TERMS

ALTITUDE: Altitude is not a term one automatically thinks of when considering the suction side of the pump, but it can be of importance in certain areas of the country. Atmospheric pressure, as mentioned during the discussion under general terms, is a function of the altitude or elevation of an installation. Table 3 shows the effect altitude has on atmospheric pressure. Usually altitude is not of major concern, but when working with installations in mountainous areas, it should be kept in mind, since there will be less atmospheric pressure to push the liquids into the pump.

TABLE 3. Effect of Altitude on Atmospheric Pressure and Barometer Readings

Altitude Above Sea Level in Feet	Atmospheric Pressure — Pounds Per Square Inch	Barometer Reading — Inches of Mercury
0	14.7	29.93
1000	14.2	28.8
2000	13.6	27.7
3000	13.1	26.7
4000	12.6	25.7
5000	12.1	24.7
6000	11.7	23.8
7000	11.2	22.9
8000	10.8	22.1
9000	10.4	21.2
10000	10.0	20.4

NPSH — Net positive suction head. Without question, NPSH is one of the most confusing and misapplied terms encountered in pump applications. In the past we have encountered NPSH most frequently as part of the information contained on specification sheets covering applications that can utilize centrifugal pumps.

Constantly coming to our attention are inquiries for positive displacement pumps to handle new applications, as well as familiar ones that have increasingly stringent service conditions. In some of these applications, such as pumping from a vessel under vacuum, filling aerosol cans with propellants, transferring solvents from underground storage, we have become aware that close attention to the suction conditions is a key to successful pump performance. We have always been concerned about suction conditions on applications involving our pumps, but those such as mentioned above require even more concern. Since net positive suction head is involved with conditions on the suction side of the pump, it is natural that we are becoming more aware of and involved with it.

Now that we can appreciate that NPSH should be of concern on at least some applications involving positive displacement pumps, let's see if we can define, discuss and illustrate it to a point where some of us might have a better inkling as to what it is. NPSH has been discussed and/or defined in textbooks, in many magazine articles, in the technical information of virtually all centrifugal pump manufacturers, and by several standards groups such as the Hydraulics Institute, American Institute of Chemical Engineers, and so forth.

As a basis from which to start learning what it is, let's consider the definition as found in many of the references. The definition is one taken from centrifugal pump references since NPSH is seldom discussed in positive displacement pump literature.

"Net positive suction head is the total suction head in feet of liquid absolute determined at the suction nozzle and corrected to datum, less the vapor pressure of the liquid in feet absolute." To get some of the centrifugal pump terms and references out of this definition, we offer the following as slightly easier to understand for people familiar with positive displacement pumps. "NPSH is the total suction head in feet of liquid absolute at the suction port, less the vapor pressure of the liquid."

Taking the phrase "net positive suction head" word by word may help shed some light on it.

Head — One means of indicating pressure, usually in feet of liquid being pumped.

Suction head — Head at the suction port of the pump.

Positive suction head — Positive or plus, as opposed to negative or minus, means that the suction head must always be a positive term. Since many applications involve a vacuum at the pump (negative gage pressure), we must always use the *absolute* pressure scale (a perfect vacuum equals zero absolute pressure) to assure a positive value. See Fig. 4.

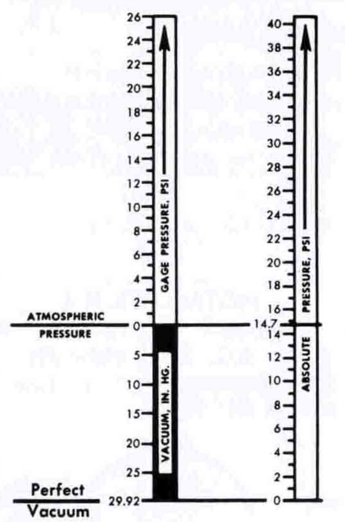


FIGURE 4. Comparison Between Absolute and Gage Pressure Scales

NOTE: To convert pressure in psi to feet of liquid multiply by 2.31 and divide by specific gravity of the liquid.

To convert inches of mercury to feet of liquid multiply by 1.13 and divide by specific gravity of the liquid.

Net positive suction head — Net, here as with your income, means what is left of a gross amount after certain deductions or additions. In the case of NPSH, the "gross" is the absolute pressure at the surface of the liquid in the supply tank. One deduction is the liquid vapor pressure; another is the pressure drop due to pipe friction losses in the suction line; a third deduction is the static suction lift (vertical distance in feet); if there is a static suction head it is an addition. After these deductions and additions we are left with the *net* positive suction head.

Since there are several terms tied together to make the phrase *net positive suction head*, it is easy to see where some of the confusion comes from. To make the situation even more resistant to clear understanding, we find that there are two types of NPSH — NPSH available ($NPSH_a$) and NPSH required ($NPSH_r$).

$NPSH_a$ — Net Positive Suction Head *available* is a function of the suction piping system, the operating conditions and the liquid pumped. For a system at the design stage or for one in existence, it can be calculated.

By formula

$$NPSH_a = H_a + H_z - H_{vp} - H_f.$$

Where

H_a = absolute pressure on the surface of the liquid in the supply tank expressed in feet of liquid pumped.

H_z = vertical distance in feet from the surface of the liquid in the supply tank to the centerline of the pump suction port. If liquid is below centerline, this value is negative.

H_{vp} = absolute vapor pressure of liquid at pumping temperature expressed in feet of liquid pumped.

H_f = friction losses in suction piping expressed in feet of liquid pumped.

Remember!!! All values *must* be expressed in the same units; feet of liquid pumped.

We will calculate the $NPSH_a$ for three typical installations to show how the formula is applied. Values for vapor pressures, line losses, etc. are approximate and meant for illustration only.

INSTALLATION 1.

$$NPSH_a = H_a + H_z - H_{vp} - H_f.$$

H_a = absolute pressure on liquid.

= atmospheric pressure in feet of liquid.

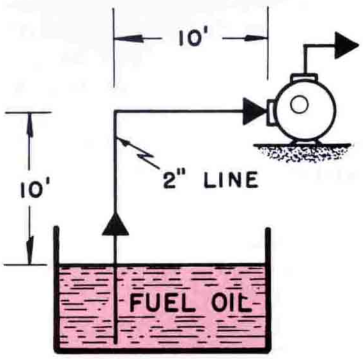
$$= \frac{(14.7\ PSIA)(2.31'\ H_2O/PSI)}{0.88\ S.G.\ of\ Fuel\ Oil}$$

$\underline{H_a}$ = 38.8 feet of fuel oil.

H_z = distance from liquid level to port center line. Liquid is below pump, so this value is negative.

$\underline{H_z}$ = − 10 feet of fuel oil.

INSTALLATION 1.
No. 2 Fuel Oil, 90 GPM, 75°F., sea level installation, S.G. 0.88, 38 SSU viscosity.



H_{vp} = vapor pressure of fuel oil at 75°F. in feet of fuel oil absolute.

$\underline{H_{vp}}$ = 1 foot of fuel oil (estimate).

H_f = suction line loss in feet of fuel oil.

$\underline{H_f}$ = 2.9 feet of fuel oil (see pressure loss charts in Sec. 510 of Viking General catalog).

$NPSH_a = H_a(38.8) + H_z(-10) - H_{vp}(1) - H_f(2.9)$.

$\underline{NPSH_a}$ = 24.9 feet of fuel oil.

INSTALLATION 2.

$NPSH_a = H_a + H_z - H_{vp} - H_f$.

H_a = absolute pressure at surface of liquid.

= atmospheric pressure + vapor pressure.

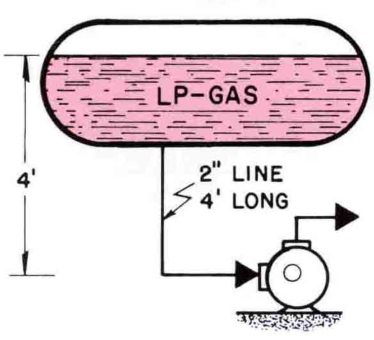
= 14.7 + 100.7 = 115.4 PSIA.

$= \dfrac{(115.4\ \text{PSIA})(2.31'\ H_2O/\text{PSI})}{0.50\ \text{S.G.}}$

$\underline{H_a}$ = 533 feet of LP Gas.

H_z = distance from liquid level to port centerline.

INSTALLATION 2.
LP Gas (Propane), 65°F, 30 GPM, S.G. 0.50, viscosity 0.1 cps, vapor pressure 100.7 psig.



$\underline{H_z}$ = 4'.

H_{vp} = vapor pressure of LP Gas at 65°F. in feet of LP Gas absolute.

$\underline{H_{vp}}$ = 533 feet of LP Gas.
H_{vp} equals H_a just calculated; they will cancel each other in the formula.

H_f = suction line loss in feet LP Gas.
= from typical LP Gas truck installation described in Viking TS-12A.

$\underline{H_f}$ = 1.5 feet of LP Gas.

$NPSH_a{}^* = H_a(533) + H_z(4) - H_{vp}(533) - H_f(1.5)$.

$NPSH_a$ = 2.5 feet of LP Gas

*Note that for a liquid at its boiling point the H_a and H_{vp} terms cancel each other and that $NPSH_a$ equals $H_z - H_f$. Difference in elevation minus line losses.

INSTALLATION 3.

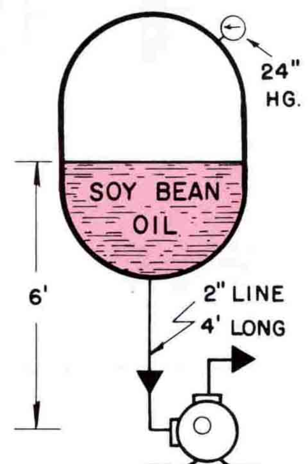
$NPSH_a = H_a + H_z - H_{vp} - H_f$.

H_a = absolute pressure at surface of liquid.

$= \dfrac{(''\text{Hg abs.})(\text{Ft } H_2O \text{ per } ''\text{Hg})}{\text{S.G.}}$

$H_a = \dfrac{(29.9 - 24.0)\ (1.133)}{0.88}$

INSTALLATION 3.
Soybean Oil, 240°F., 40 GPM, S.G. 0.88, viscosity 40 SSU, pumping from a vacuum still at 24" Hg.



$\underline{H_a}$ = 7.6 feet of soybean oil.

H_z = distance from liquid level to port centerline.

$\underline{H_z}$ = 6'.

H_{vp} = vapor pressure of soybean oil at 240°F.

$\underline{H_{vp}}$ = 1 foot (estimate) of soybean oil.

H_f = suction line loss in feet of soybean oil. Ref. Sec. 510 of Viking General Catalog for line loss charts.

$\underline{H_f}$ = 0.1 foot of soybean oil (approx.).

$NPSH_a = H_a(7.6) + H_z(6) - H_{vp}(1) - H_f(0.1)$.

$\underline{NPSH_a}$ = 12.5 feet of soybean oil.

The procedure followed in determining the $NPSH_a$ for these three typical installations gives an idea of how the data given on a pump specification sheet is arrived at. For a system in operation, $NPSH_a$ can be determined by taking pressure and temperature readings at the suction port flange, by then figuring head and vapor pressure, and plugging the information into still another formula. We will not go into this formula at this time.

Why all the fuss about NPSH *available?* Because: all pumps have an NPSH *required.* All pumps have, as a result of their particular principle and design, an internal pressure drop from their suction port into their pumping element(s).

If the pressure provided at the suction port by the system ($NPSH_a$) does not equal or exceed this internal pressure drop, the liquid in the pump will flash (pump will cavitate*). The pressure necessary at the pump suction port to keep the pump from cavitating is called the net positive suction head *required*, $NPSH_r$.

So, every pump has an NPSH required. The next logical question is "How much is required?" This can only be determined accurately by tests.

As indicated before, it is only recently that there has been a growing awareness of the need for NPSH *required* information on rotary pumps. (For more information on NPSH, refer to AD-19).

SUBMERGENCE: One of the technically correct definitions of submergence is "the vertical distance from the surface of a liquid to the suction port of a pump that is submerged in the liquid being

**Cavitation can cause a loss in capacity, noise, vibration and rapid wear.*

pumped." It is also used occasionally to indicate the height of liquid above the suction port when the pump is outside of the tank. We have heard of submergence being used in this way in connection with ammonia refrigeration systems, or on other systems involving a liquid with a high vapor pressure where it is necessary to have several feet of liquid above the pump to prevent cavitation.

SUCTION: Suction per se can have several definitions, (1) the inlet to a pump, (2) the movement of a liquid as the result of reducing the pressure over some part of its surface, (3) the entire system of piping, valves, etc. from the supply tank to the pump. Suction encompasses everything on the inlet side of the pump. To cover a specific facet of the inlet condition, suction is often used in conjunction with other terms, e.g., suction piping, suction port, suction head, suction lift, etc. The first of these terms are presumed to be self-explanatory; suction lift and suction head often take some explanation.

Suction Head: (static suction head) The vertical distance in feet between the liquid level in the supply tank and the centerline of the pump suction port when the liquid is *above* the pump. See Figure 5. This is the condition known as flooded suction. We expect flooded suction conditions to present no problems, *but*, even with a static suction head, we cannot neglect pressure drop through the piping. When pumping a viscous liquid it is possible even with a static suction head to starve the pump because of excessive pressure drop through the piping. *Total* suction head is equal to the static suction head minus the pressure drop through the line. It is our procedure when making suction head calculations to neglect velocity head because it is quite small. When figuring total suction head, be sure all factors are in the same pressure units.

Suction Lift: (static suction lift). The vertical distance in feet between the liquid level in the supply tank and the centerline of the pump suction port when the liquid is

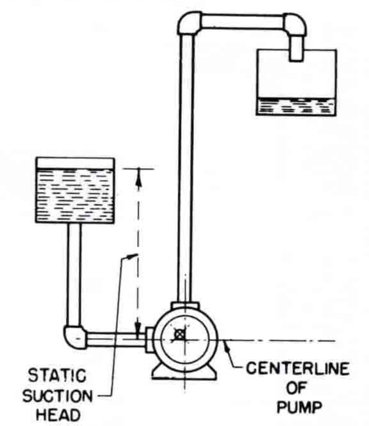


FIGURE 5. Static Suction Head

below the pump. See Figure 6. Under these conditions the pump has to "lift" the liquid to the suction port by creating a vacuum. In addition to the lift to overcome the difference in elevation, the pump must develop enough lift to overcome the pressure drop through the piping. These two combined are known as the *total* suction lift. Remember — everything has to be in the same units.

Engineering Section 510 of the General Catalog has some additional discussion on suction.

VACUUM: Nothing, in its truest sense; that which nature abhors; empty or devoid of matter, particularly air; a space, part of a piping system or a pump port that contains a pressure less than that of

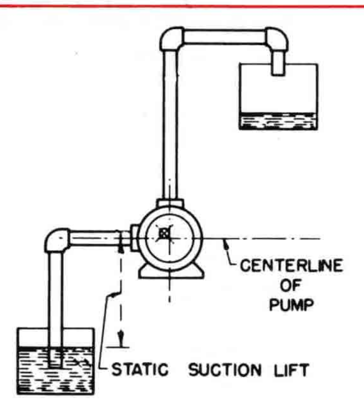


FIGURE 6. Static Suction Lift

the surrounding atmosphere. If a vessel or liquid is "under vacuum" it means that the pressure on the inside of the closed vessel or at the surface of a liquid in a closed vessel is less than that of the surrounding atmosphere.

A vacuum can be developed in many ways. Any one of you can develop a vacuum. As you suck a malt through a straw, you are creating a vacuum. The reduced pressure in your mouth lets the air pressure on the surface of the malt push some of it through the straw into the vacuum in your head. Some of us seem to be exceptionally well equipped to drink heavy malts. For industrial purposes there is a wide variety of devices for creating vacuums, e.g., rotary vane or rotary piston vacuum pumps, steam, water or air ejectors, diffusion pumps, etc. In a positive displacement gear pump the vacuum is created by the separation of the gear teeth. With close running clearances, the tooth spaces as the gears come out of mesh are devoid of matter; they create a vacuum. The amount of vacuum created is dependent on a number of factors, e.g., viscosity, pressure, speed, running clearances.

By what units is vacuum measured? This again is an area of some confusion since it can be measured from either end, i.e., from atmospheric pressure as a zero point, or from an essentially perfect vacuum as a zero point. Of the many units used to measure vacuum, the following are the most frequently used:

Inches of Mercury: ("Hg) — Zero point for the "Hg. scale is atmospheric pressure. Atmospheric pressure at sea level is equivalent to the pressure exerted by a column of mercury 29.9" high. If a vacuum is created in a closed vessel so that the pressure in that vessel will support a column of mercury only 28.9" high, a vacuum of 1" Hg. is said to exist. If a vacuum is created so that a column of mercury only 19.9" high is supported, a vacuum of 10" Hg. (29.9 minus 19.9) exists. This is the most common unit of vacuum measurement used by manufacturers of liquid transfer equipment. Most vacuum gages readily available to industry also use the "Hg. scale.

Micron: (micron of mercury, μ) — one millionth part of a meter, or one thousandth part of a millimeter. Micron is used as a unit of measure for only the very highest of vacuums, such as encountered in scientific or space investigation. The zero point for vacuum measurement using microns is a perfect vacuum. With present-day laboratory vacuum equipment it is possible to create vacuums in which the absolute pressure is less than 10^{-6} microns of mercury.

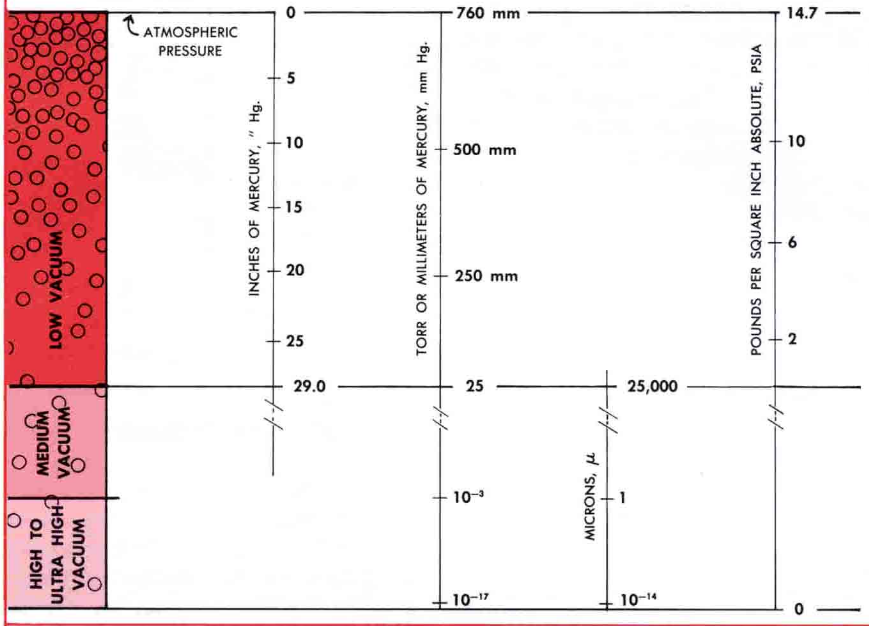
Millimeters of Mercury: (mm Hg.) — one thousandth part of a meter or one thousand microns. Millimeters of mercury are often used in weather bureau work to designate atmospheric pressure; 760 mm Hg. is normal (equal to 29.9″ Hg.). Zero point for the mm Hg. vacuum scale is a perfect vacuum; as the vacuum becomes greater, the mm Hg. value becomes less. Vacuums of 10^{-3} mm Hg. are quite common in some industries. Vacuums of 5 to 25 mm Hg. over the liquid in evaporators or deaerators are not uncommon in pumping applications. Often to eliminate any possible confusion the readings are given as mm Hg. absolute. Converting *mm Hg. to ″Hg. and then subtracting from 29.9 gives the vacuum in the vessel in ″Hg. A pump attached to a suction line drawing liquid from the surface of a vessel with 25 mm Hg. vacuum would have to develop a vacuum in excess of 28.9″ Hg. to get the liquid to flow to the pump. The only practical way to move the liquid from such a vessel is to locate the pump several feet below the surface of the liquid so there is a head of liquid above the suction port of the pump. For further discussion, see page 10—"Pumping from a Vessel under High Vacuum."

PSIA: (pounds per square inch absolute). Vacuums measured in PSIA use perfect vacuum as a zero point. 14.7 PSIA is atmospheric pressure. Occasionally all pressure units in a system are expressed in PSIA. Anything less than 14.7 PSIA is a vacuum; to get to ″Hg. vacuum, convert the **PSIA vacuum reading to ″Hg. and subtract from 29.9″ Hg.

Torr: a contraction of the name of Torricelli. Evangelista Torricelli, an Italian physicist (1608-1647), discovered the principle of the barometer. In his honor the mm Hg. pressure unit is known as the Torr. Any vacuum or pressure expressed as so many Torr is equivalent to the same number of mm Hg.

**25.4 millmeters = 1 inch.*
***1 PSI = 2.04″ Hg.*

TABLE 4. Relationship Between Various Vacuum Scales



CONVERSION FACTORS: 1 mm Hg. (Torr) = 1000 Micron; 1″ Hg. = 25.4 mm Hg.; 1 PSIA = 2.04″ Hg.

The degree or amount of a vacuum is sometimes broken down into rather general terms to give an indication of how high the vacuum is. A low or rough vacuum is anything between 760 and 25 mm Hg. (up to approximately 28.9″ Hg.), a medium or fine vacuum is anything between 25 and 10^{-3} mm Hg. and anything below 10^{-3} mm Hg. is a high or ultrahigh vacuum. Pumps used to transfer liquids are seldom involved with anything but low vacuums. Equipment specifically designed for creating a vacuum is used when medium and high vacuums are required.

Table 4 shows the relationship between the various vacuum scales.

VAPOR PRESSURE: the pressure exerted by the vapors of a confined liquid. This pressure is a function of the liquid and its temperature.

Liquids such as water and fuel oil that can be left in an open container at ambient temperatures have a vapor pressure less than atmospheric. This vapor pressure is normally expressed in mm Hg. Liquids such as LP-Gas and ammonia that must be stored in closed containers have vapor pressures greater than atmospheric. This vapor pressure is normally expressed in PSIG or atmospheres.

For fuel oil and like liquids, the vapor pressure can be measured by putting some of the liquid above the mercury in a barometer and noting the depression of the mercury column. For LP-Gas and similar liquids, the vapor pressure can be determined by reading a gage attached to the vapor section of a partially filled enclosed container.

The vapor pressure of several common liquids at 100°F. is as follows: xylene 16 mm Hg., water 47 mm Hg., toluene 54 mm Hg., acetone 391 mm Hg., butane 37 PSIG, and propane 170 PSIG.

An area where vapor pressure plays an important part in our everyday lives is in connection with automotive gasolines. The vapor pressure at 100°F. for a summer gasoline is approximately 9.5 PSIA, while for winter gasoline it is around 13.5 PSIA. The lower vapor pressure for summer gasoline tends to keep it from vapor locking in the summer heat. The higher vapor pressure for winter gasoline helps it vaporize in the carburetor at wintertime temperatures.

The vapor pressure of the liquid is of definite concern when considering a pumping installation. If the pump must create a vacuum that results in an absolute pressure less than the vapor pressure of the liquid, the liquid will tend to vaporize in the suction line and in the suction port of the pump. This formation of vapor on the suction side of the pump reduces capacity and can cause vapor lock. The subsequent collapse of the bubbles on the discharge side causes noise and vibration. This formation of vapor and its collapse as the liquid goes through a pump is known as cavitation. *Vapor pressure is of concern.*

(3) DISCHARGE SIDE — TERMS

Terms used in describing conditions on the discharge side of a pump are normally not as troublesome or difficult to understand as those on the suction side. Part of this, of course, is due to the fact that the limits within which we can expect good pump performance are much broader with regard to pressure.

Most of the discharge side terms have been at least partially defined under general terms or suction side terms, so we will not spend much time on them.

DISCHARGE HEAD — Discharge head is the discharge pressure expressed in feet of water (normally) or feet of liquid pumped that a pump must develop to meet the requirements of the system. In normal use, discharge head is synonymous with total discharge head.

Static Discharge Head — Pressure at the discharge port when the pump is not operating. This head or pressure is equal to the difference in elevation between the discharge port and the point of free discharge of the liquid and is expressed in feet of water, feet of liquid pumped or PSI. Any pump must be able to develop a pressure greater than the static discharge head before it can move any liquid through the system.

Total Discharge Head — Total discharge head is equal to the sum of the static discharge head and the friction head or line loss in the discharge piping. It is most frequently expressed in PSI for positive displacement pumps. In normal use, the term discharge head is understood to mean total discharge head.

DISCHARGE PRESSURE — Same as discharge head, i.e., pressure a pump must develop at its discharge port to meet the requirements of the system. Normally expressed in PSI.

Of the many units used to express discharge pressure, the following are some of the most common (see Table 1, Page 3 for the factors necessary to convert from one unit to another):

Atmospheres — Atmospheric pressure, earlier defined as being the absolute pressure of the atmosphere at sea level, has a value of 14.7 PSIA. Thus a discharge pressure expressed in atmospheres is actually being expressed in multiples of 14.7 PSI. Atmospheres can be converted to PSI by multiplying by 14.7. A discharge pressure expressed as 10 atmospheres is equal to a pressure of 147 PSI.

Feet of Water — A means of expressing discharge pressure by tying it to the pressure exerted by a column of water. A column of water 1″ on a side and one foot high exerts a pressure on the one square inch of area at its base of 0.433 PSI. This is frequently a convenient conversion factor to bring to mind. If you should forget, you can always recalculate it by remembering that a cubic foot of water weighs 62.4 pounds, and that this weight is supported by an area of 144 square inches. Thus, if the 62.4 pounds is supported by an area of 144 square inches, the 62.4 divided by 144 gives us the conversion factor of 0.433 mentioned above.

When making calculations on liquids other than water, it is necessary to multiply by the specific gravity of the liquid to convert to head in feet of water. A 100′ head of LP-Gas with a specific gravity of 0.5 is equivalent to a head of 50′ of water. Thus, you can see it is important when expressing head in feet that the particular liquid involved be known, or that the head be specifically stated as being feet of water.

A discharge pressure expressed as 100′ of water is equal to 100 × 0.433 or 43.3 PSI.

Kilograms per Square Centimeter — This is the normal means of expressing pressure in the metric or cgs system. A kilogram is equal to 2.2 pounds and there are 6.45 square centimeters per square inch, so the conversion from kilograms per square centimeter to PSI is Kg/sq. cm. × 14.2 = PSI. Thus 10 Kg/sq. cm. = 142 PSI.

Meters of Water — Another means of expressing pressure frequently used in Europe is the meter of water. This is the same idea as feet of water except the column is one meter (39.34″) high instead of one foot. The conversion factor for converting from meters of water to PSI is 1.42 (39.34 ÷ 12 × 0.433). Thus a discharge pressure expressed as 10 meters of water is equal to 14.2 PSI.

Pounds per Square Inch — Pounds per square inch is the most common unit of measure used for expressing discharge pressure when working with positive displacement pumps. Pounds per square inch or PSI is understood to be pounds per square inch gauge unless otherwise indicated. All Viking performance curves, catalog limitations, pressure drop charts, etc. are based on PSI (gauge). If the discharge pressure is expressed in pounds per square inch absolute, remember to subtract 14.7 PSI to get the pressure in PSIG.

(4) APPLICATIONS

The types of applications covered are listed in box (4), Figure 1, Page 2.

(A) **PUMPING WITH A SUCTION LIFT.** (See left-hand portion of diagram in Figure 1, Page 2).

What should we be concerned about when pumping with a suction lift? At least the following: actual distance in feet between the liquid level and the pump suction port (*static suction lift*),* the *vapor pressure* of the liquid at the pumping temperature, the diameter of the pipe, the number of fittings and valves in the pipe line, the length of horizontal pipe, the viscosity of the liquid (pipe size, pipe length, number and type of fittings and liquid viscosity, plus capacity would permit calculating *pressure drop*), the *altitude* of the installation, if any, etc.

While it often appears to be adequate for a customer to advise that there is a 10′ suction lift on his application, there are times when knowing only this much about the application can lead to difficulties because we have no information on the points listed above.

Common applications involving suction lifts are: (1) Pumping fuel oils and solvents from underground storage tanks. (2) Pumping oils, syrups, and fish solubles from storage tanks located on a floor below the pump.

General comments: (1) If the ability of a pump to lift the liquid from the bottom of a buried circular tank (long axis horizontal) is marginal because of the depth of the tank, we often consider that the bottom quarter of the tank diameter is below the normal liquid level, since the tank would be almost empty. If the customer should pump out this part of the tank and the pump was to be a little noisy, it would probably not be objectionable for the short period of time involved and would not be particularly harmful to the pump. (2) An item of concern when pumping from buried tanks is the temperature of the liquid. A buried tank does not have a very wide temperature range, but the pump often is exposed to atmospheric extremes. Depending on the liquid, the pump may have to start with an extremely viscous liquid in it during cold weather, or it may become vapor bound when starting in hot weather. (3) Regardless of how desirable it is to know all the details when working with a suction lift, often the time and effort spent in getting this information is not justified when reasonable assumptions can be made. Many times when the name of the liquid is given and a temperature can be approximated, we can determine the approximate viscosity and vapor pressure involved. In most instances it is safe to assume that the pipe size will be the same as the port size of the pump, and that the horizontal run does not exceed the vertical run of piping; also that there probably are no more than two elbows and one gate valve in the suction piping. If with these basic assumptions, calculations indicate that the pump is required to develop no more than 10 to 15″ Hg. vacuum, and that the liquid will not vaporize in the pump under the vacuum conditions calculated, we would feel reasonably safe in making a pump recommendation. It is wisest whenever there is any doubt on the details of the suction side conditions to get the exact information; where this is impractical, make logical assumptions and then state the assumptions on which the pump recommendation is based so there will be no misunderstanding.

Any italicized terms have been defined earlier in this article.

(B) **PUMPING HIGH VAPOR PRESSURE LIQUID.** (See Figure 7.)

What should we be concerned about when pumping a high vapor pressure liquid? At least the vapor pressure of the liquid at the pumping temperature, the viscosity, the *submergence* or the height (H) of the liquid level above the suction port, the size of the suction pipe, the length of pipe, the number and type of fittings in the suction line, the specific gravity of the liquid, the pressure on the discharge side of the pump (*system working pressure*), the *differential pressure* across the pump, etc. If the Net Positive Suction Head available ($NPSH_a$) is given, additional information about the suction side is not necessary.

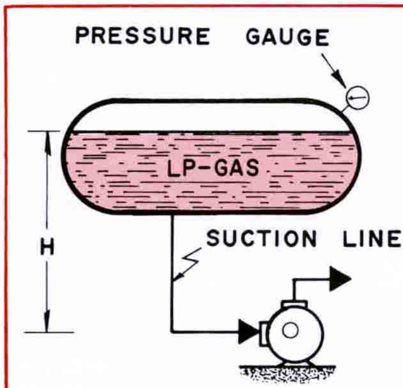


FIGURE 7.

If a customer was to call in and say he had a 4′ head of liquid on his pump and that it was noisy, we might be hard pressed to determine the cause unless he gave some details we should know about as outlined above. Too high line loss may be the problem. To paraphrase an old cliche, there's many a (pressure) drop between the sump and the pump.

Common applications involving pumping high vapor pressure liquids are: (1) Transfer of LP Gases such as propane and butane. (2) Low pressure transfer or recirculation of refrigeration ammonia. (3) Filling aerosol bombs with fluorocarbon propellants (such as Freon, Genetron, Isotron, etc.)

General comments. The main key to successful pump operation when handling a high vapor pressure liquid is to get the liquid to the pump without having it boil or vaporize. In other words, make sure the $NPSH_a$ is greater than *net positive suction head required.* Use piping larger than the pump port; use full open valves (never globe); if a strainer is used, be sure it is big enough so there is negligible pressure drop; keep the inlet to the suction away form turbulent spots in the sump or supply tank; avoid heat pickup from the atmosphere, from internal valves, or from excessive slip because of high operating pressure; bleed the lines before restarting a pump to keep from vapor binding the pump; where possible, provide 4 feet or more of liquid above the pump. All of these points are aimed at increasing the $NPSH_a$. Additional information on high vapor pressure liquid applications can be found in the Viking General Catalog Sections 420 and 440 and Application Data Sheets AD-2 and AD-19.

(C) **PUMPING FROM A VESSEL UNDER HIGH VACUUM.** (See Figure 8).

What's to be concerned about when pumping from a high vacuum? The height (H) of the liquid above the pump, the size, length and make-up of the suction line are of concern just as with high vapor pressure liquids. The vapor pressure is not normally of too much concern, since often the function of a vessel under a high vacuum is to remove vapor or boil or distill off a portion of the liquid; thus unless the pump has to develop a vacuum higher than that over the liquid, there is no chance of vaporizing at the pump. The viscosity is of importance on such applications since it can vary from very thin to highly viscous, depending on the nature of the process. And finally, the actual vacuum over the liquid in the vessel is of prime concern. It may be expressed in any one of several ways, e.g., ″Hg., μ, *mm*, etc.

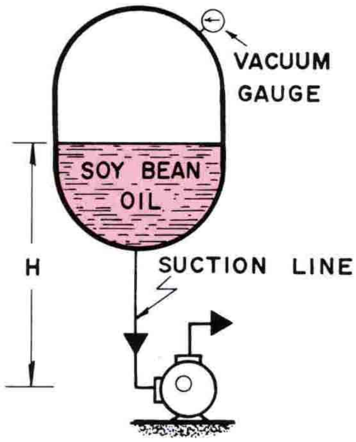


FIGURE 8.

It is not necessary to shy away from an application involving 28 or 29″ Hg. just because the pump may not deliver significant capacity when developing this vacuum. By understanding the system and how to locate the pump, this type application can be handled satisfactorily.

Typical applications involving pumping from a vessel under high vacuum are: (1) soybean oil processing, (2) removing the water vapor from syrups and candies, (3) degassing transformer oils, (4) dry cleaner stills.

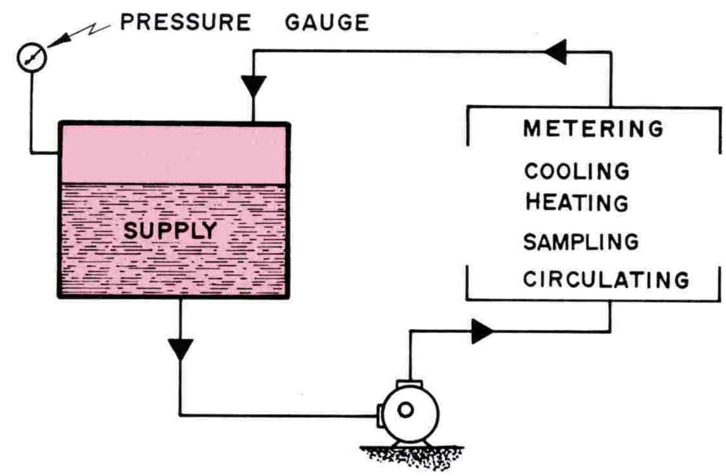


FIGURE 9.

General comments. (1) One point to remember when pumping from a high vacuum is that the pump is at the low point in the system and therefore is always wetted. It does not have to evacuate a line full of air or vapor as it does when pumping with a *suction lift*. With the pump always wetted and no appreciable danger of vaporizing at the pump, it is possible to operate satisfactorily with higher than what would be considered normal vacuum at the pump. (2) When pumping a viscous material from a vessel under vacuum, be sure that the pressure gained by evaluation is not more than offset by *pressure drop* through the line. This can be avoided by using sufficiently large pipe or lower flow rates.

(D) **PUMPING IN A SYSTEM HAVING A HIGH INTERNAL PRESSURE.** (See Figure 9).

What points should be given special attention when pumping with high system or high internal pressures? Basically the same points as when pumping high vapor pressure liquids, except there is no tie between the pressure and the particular liquid or temperature, since pressure is a function of some outside force rather than vapor pressure. Because the pressure may be higher than expected with a positive displacement transfer pump, particular attention should be given to the construction from the standpoint of pressure tightness and strength.

If a customer inquires about a pump for an application with only a 25 PSI *differential pressure*, but a 500 PSI system pressure, do not assume because of the low differential from suction to discharge that any pump can do the job. Before a pump could be considered for such an application it should at least have a balanced seal, "O" ring gaskets, plus possibly a heavier thrust bearing.

Typical applications involving a high system pressure are (1) pipe line sampling, (2) a system pressurized with gas or some other force with the pump being used to meter or circulate. A general comment on this type of system is: "Be Careful!!"