PDHonline Course M134 (3 PDH)

Practical Considerations in Pump Suction Arrangements

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Practical Considerations in Pump Suction Arrangements

Randall W. Whitesides, P.E.

Course Overview

An important aspect of pump hydraulic system design is the suction or inlet conditions. Disregard for proper allowances can result in vortices, cavitation, and loss of prime. Pumps do not force liquids through inlet or suction piping, but rather create lowered pressures at the suction nozzle which in turn *induces* the fluid to enter. Any design that impedes or lessens the efficient transport of this liquid will, of course, result in less liquid being handled. Any design that encourages the introduction of entrained gas or liquid voids will likewise result in a less efficient pumping operation. In addition to poor performance, truly bad designs can in some cases actually result in physical damage to the pump or its parts.

The study of pump suction system configuration can be broken down into two parts: (1) suction piping and (2) suction source. Critical consideration must be given to both in order to properly design an efficient system. Proper suction piping design and installation considerations consist of pipe and pipe fittings and their relationship, quantity, and relative location to the pump suction nozzle. Suction source design factors include the geometry of the source and the relative location of the suction entrance point(s) to suction liquid surface, source enclosure boundaries, and other suction entrance points. This course deals with both parts and is applicable generally to all types of pumps, since every pump's successful operation and useful life can be so dependent on a properly designed and thought-out suction arrangement.

Course Introduction

There are many factors that affect the operation of a pump. Important factors are total head, speed, liquid properties, and physical arrangement/system connection. Included in the category of arrangement and connection are the suction conditions. Excessive suction lift, shallow inlet submergence, or insufficient Net Positive Suction Head available ($NPSH_A$), all spell serious trouble from vibration, cavitation, lowered capacity, and reduced efficiency. While the Engineer may not have large control over some of the inherent process factors, with planning and foresight many times the pump suction conditions can be optimized in the design stage. This course offers ideas and summarizes generally accepted guidelines of practical consideration in pump suction arrangements.

Course Content

Do Pumps Suck?

True of False? There appears to be a continual disagreement on this subject. Actually, some purists would contend that a true state of absolute suction is impossible (except in the perfect vacuum of space) and that only varying degrees of flow-causing differential pressure exist. Rightly or wrongly, the term *suction* is firmly planted in hydrology as is evidenced with its extensive use as an adjective in pump terminology, *i.e.*, suction connection, suction line, suction lift, *etc*. Pumps create a partial vacuum letting atmospheric (or positive source) pressure force liquid into a lower pressure area of the pump; this is the definition of *suck*. What is important to know is the fact that any impedance to hydraulically balanced, unrestricted flow, induced by this *"suction"*, will be problematic.

In Order to Form a More Perfect Stability

The single most important function of a pump suction system is to supply an unencumbered, evenly distributed flow to the pump. This is true regardless if the intake configuration is a single pipe, an open sump, or a river. Secondly, the pump suction system should not promote the external introduction, or internal creation, of compressible flow elements, *i.e.,* air, vapor, or gas.

Improper design of the suction piping or sump, or inadequate pipe support exterior to the pump, can cause hydraulic disturbances that manifest in chronic and eventual destructive random frequency vibrations. Interestingly enough, internal pump problems such as bearing failures, seal failures, excessive erosion, excessive corrosion, excessive noise, and excessive vibration can many times be rooted to sources outside the pump itself and in the connected piping. Often times the trouble emanates from poor suction conditions and piping practices that encourage unbalanced hydraulic flow.

Promoting hydraulic stability is maintaining hydraulic balance on pump rotating elements. If at all possible, the direct connection of any type of pipe fitting to the pump suction nozzle should be avoided. Pipe fittings cause uneven flow patterns. In single end suction pump types, unbalanced flow axial to the pump shaft causes unequal liquid introduction to the impeller eye. This results in unbalanced thrust which increases bearing wear, reduced bearing life, and premature seal failure. Direct connection of elbows should always be avoided. In double suction pumps, if directly connected elbows can not be avoided, they should be installed such that the elbows are in a plane perpendicular to the pump shaft. **Figure 1** on the following page is an illustration of a single end-suction centrifugal pump piping arrangement typically witnessed in industry, with fittings installed in close proximity to the suction nozzle.

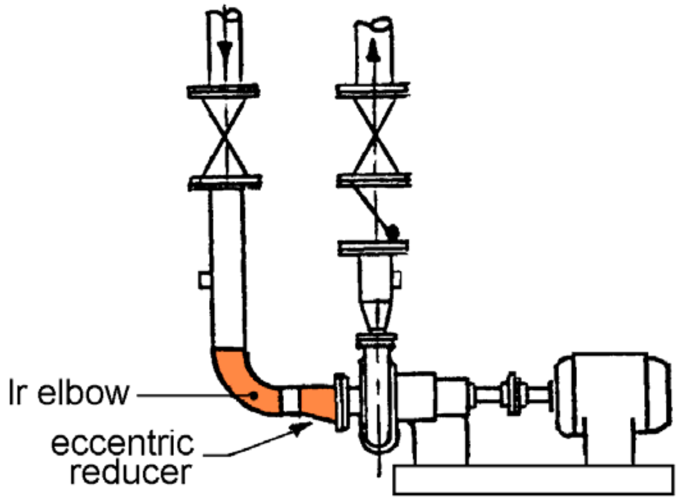
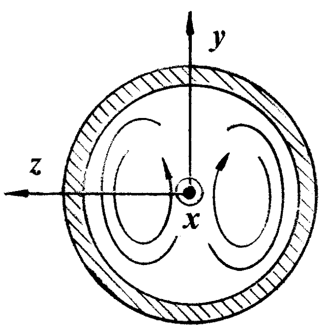
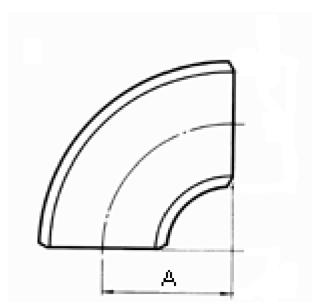


Figure 1 – Typical single end-suction piping arrangement



Beyond what would logically be surmised to be unbalanced flow attributable to the elbow, studies have determined that a secondary, rotating flow, is imparted in the fluid by elbows. This secondary rotating flow is superimposed and conveyed with the main momentum flow in the axial direction. In addition to an axial force in the *x* direction, ancillary forces are imparted to the surroundings in the *y* and *z* directions. This secondary flow, sometimes referred to as pre-rotational flow, is ultimately carried into the impeller imparting additional damaging turbulence and inefficient internal recirculation. Bottom line: Directly connected or closely placed elbows are detrimental to pump operation because of multiple and compounding reasons.

The Ninety degree (90E) elbow is commercially produced in two styles: short radius and long radius. The short radius elbow's center line radius (***A***) is equal to the nominal pipe diameter (***D***). In the long radius elbow, ***A*** is equal to ***1.5D***. Obviously, the long radius 90Eelbow is more "sweeping" and imparts less turbulence and unbalanced flow than that of the short radius; it should be used whenever suction elbows are unavoidable.



Following the Straight and Narrow

The ideal suction pipe approach to the pump's impeller eye is straight pipe. Field experience has shown that the ideal minimum length of full-size straight pipe, devoid of any obstructions to flow, immediately upstream of the pump suction connection, should be ***10D***. The absolute minimum length of full-size straight pipe, devoid of any obstructions to flow, immediately upstream of the pump suction connection, should be ***5D***. This is illustrated in **Figure 2**.

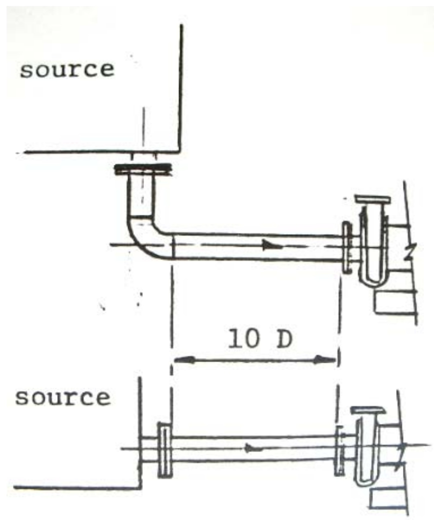
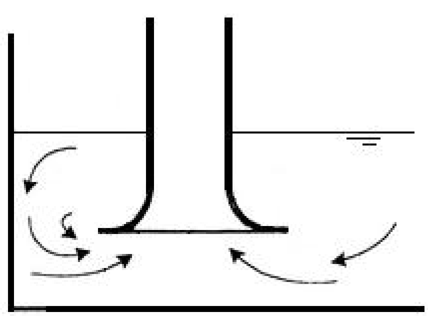


Figure 2 – The rule of 10D

Taking It Smooth and Easy

Pump inlet piping should be designed and installed to provide smooth and orderly flow to the pump.



The pump suction bell reduces the contraction entrance frictional losses by "smoothing" the flow by elimination of a sharp inlet edge. Entrance fluid frictional losses can be reduced by as much as 80% depending on the size of the rounding. The suction bell also reduces the approaching mean fluid velocity; it has been shown that minimum submergence depth varies directly with fluid velocity as it relates to vortex formation. (More on vorticies in a moment). Liquids undergoing sudden or sharp changes in cross-sectional flow area have intensified differential pressure losses which reduce flow.

Some Restrictions May Apply-Void Where Prohibited

Check valves are installed on pump *discharge* lines to prevent liquid flow reversal with the succession of pumping. In a similar fashion, a foot valve is simply a form of check valve, usually in a vertical position, usually incorporating a strainer, installed in the pump suction line (see **Figure 3**). The purpose of the foot valve is to preclude back-flow from the pump through the suction line. They are used to promote a liquid filled suction line that hopefully will allow the pump to maintain prime. Much like standard check valves, they are available in various styles and principles of operation. By necessity they create an obstruction to flow and, therefore, should not be employed unless is deemed absolutely necessary.

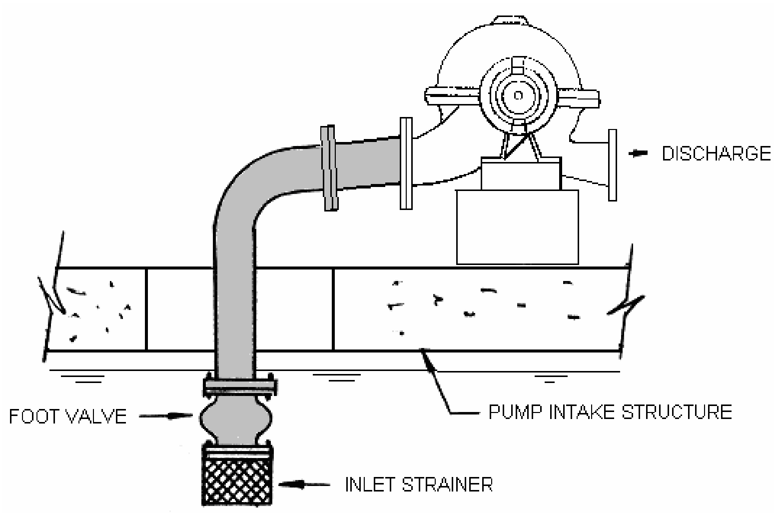


Figure 3 – Foot valve and suction strainer

The connection of a suction line to a larger pipe should be given special consideration. See **Figure 4** for the wrong and correct means of accomplishing this intersection. The correct method promotes streamline flow and reduces the fluid frictional contraction loss. A separate and dedicated suction line should be used in situations where multiple pumps are taking suction from a common header, *i.e.,* a manifold arrangement. **Figure 5** shows a plan view of the wrong and correct manner to make header connections. Note that the minimum distance between connections should be ***3D*** and that "y-branches" oriented in the direction of flow should be used in lieu of a right angle or "tee" configuration. **Figure 4** (the elevation view) again comes in to play in this situation to indicate the wrong and correct way to accommodate a size reduction from the header to the suction take-off line.

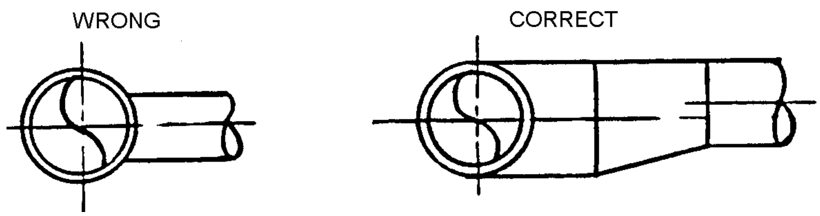


Figure 4 – Size reduction pipe intersection

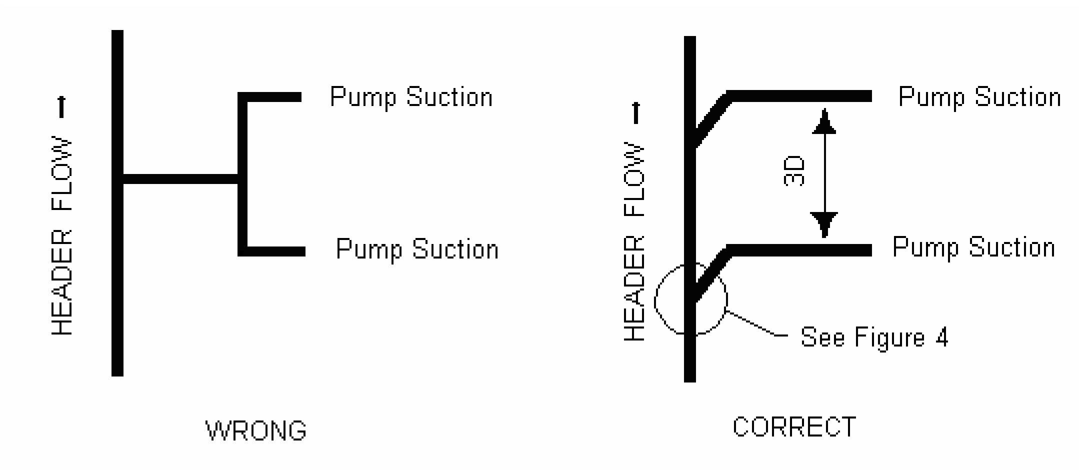


Figure 5 – Plan view of pipe manifold arrangement

Figure 6 is a plan view of a horizontal split case pump with several suction arrangement poor practices. They are: (1) A short-radius 90º elbow in the horizontal plane; (2) followed by a sudden contraction to accommodate the pump's nozzle size; (3) both located less than ***5D*** from the suction nozzle. In contrast, **Figure 7** illustrates an elevation (side) view of a double suction pump with two maybe not perfect, but nevertheless better, practices. They are: (1) A long-radius sweeping 90º elbow in the vertical plane, and (2) an eccentric reducer oriented with the flat at the top. (More on reducers and their implications momentarily).

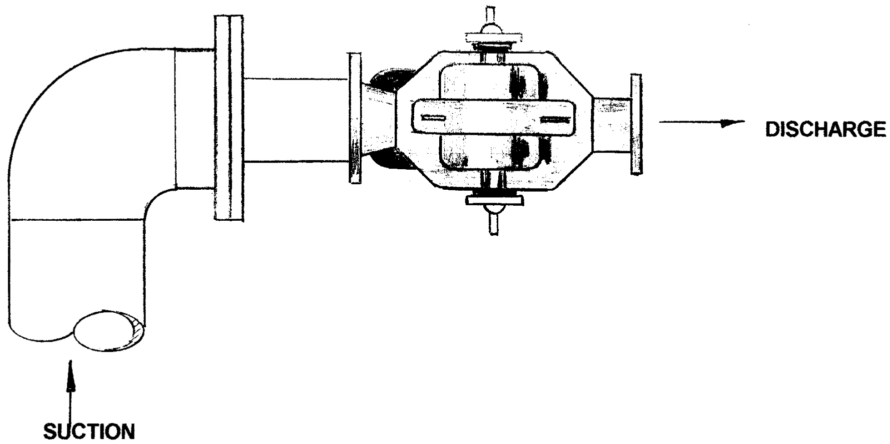


Figure 6 – Plan view of horizontal split case pump suction

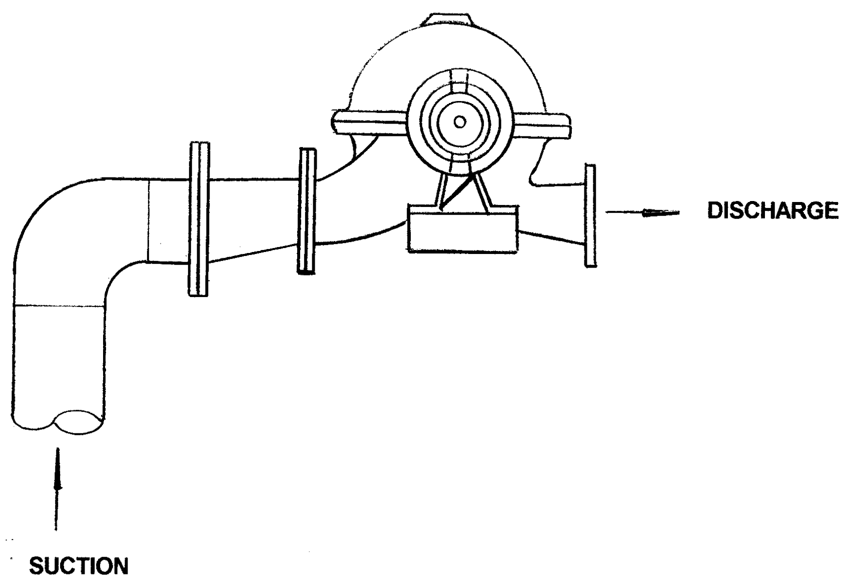


Figure 7 – Side view of horizontal split case pump suction

Confusion on Diffusion

Controversial opinions can be found on the subject which has become known as *suction diffusion*. Actually, diffusion means *to disperse or spread out*. A suction diffuser is a special pipe fitting, sometimes in the configuration of a tee or sharp elbow, which is installed directly on the pump's suction connection which contains, depending on the make, various configurations of *flow straightening* elements. Often these special fittings may also incorporate some type of straining feature. **Figure 8** shows a cut-away view of a typical diffuser attached directly to a pump suction. Manufacturers of suction diffusers state that they can be utilized to smooth, balance, and otherwise streamline liquid flow to the impeller eye when physical space is not available to accommodate the recommended ***5D*** to ***10D*** full-size straight pipe provision.

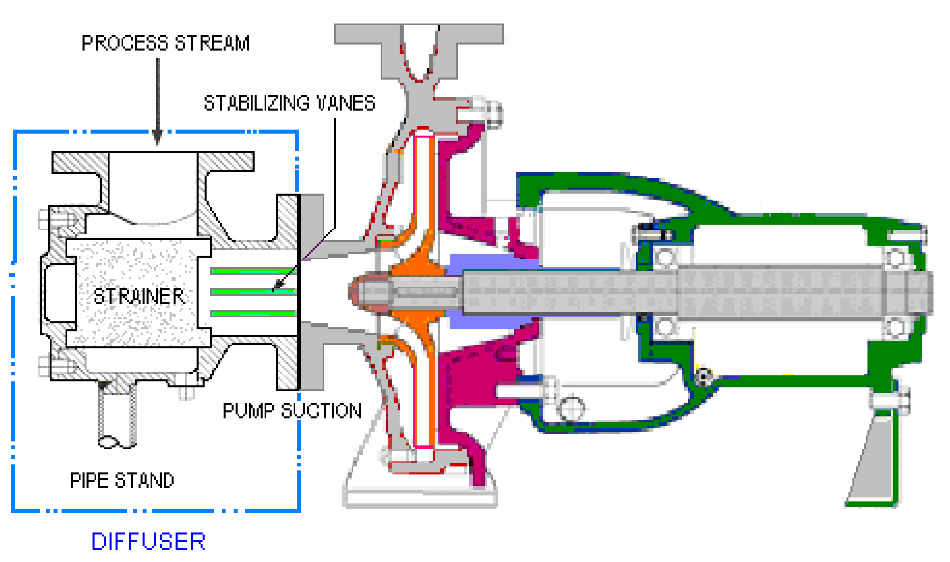


Figure 8 – Suction diffuser

The attribute of spatial compensation is somewhat debatable. A comparative examination of a number of commercially available diffuser models indicated that the average physical *take-out*, or length, plus the required space for the removal of the screen, was equivalent to ***5D***. This is identical to the recommended absolute minimum of ***5D*** normally sought. Even assuming that the diffuser has a space accommodating feature and that its use may produce the desired result, it introduces additional frictional resistance which may be problematic with limited $NPSH_A$. If a straining element is present in the diffuser, then routine observation and maintenance will always be in order. Suction diffusers with straining elements should be treated with the same careful consideration, that will be discussed shortly, given a suction strainer when deciding to install this type of device on the pump suction. With respect to diffusers, use them only when

the recommended minimum full-size straight pipe lengths can not be provided immediately upstream of the pump inlet port and certainly only after complete evaluation of the resultant flow characteristics.

A Suction Source by Any Other Name

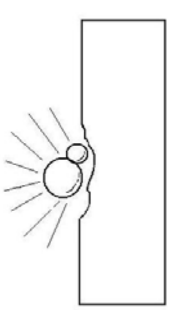
Theoretically, any suction system arrangement can be considered a pump intake structure. However, the term pump intake structure generally refers to a man-made, completely or partially enclosed or otherwise flow capturing contrivance, which hopefully promotes the smooth and efficient flow distribution to one or more pump suction inlets. Examples of pump intake structures would be a sump, a dam, or a channel. Little or no consideration to proper pump intake structure design and layout can produce stagnant flow areas, swirling eddy current type flows, uneven-flow distributions, and insufficient pump inlet submergence. All of these present problems for proper pump operation. Good design practices with regard to the suction source are provided throughout the remainder of the course. The fact of the matter is, these are just *guidelines.* There are many site-specific, geometric, and hydraulic constraints. In order to truly know, understand, and anticipate the circumstances of a particular suction application requires hydraulic model testing before final pump intake design is completed.

Going Through the Phases

As you will recall, the three phases of matter are liquid, solid, and gas. Two-phase flow is simply the simultaneous existence in a pumped fluid of two of the possible physical phases. Consequently, gas-liquid and liquid-solid binary mixtures constitute two-phase flow. The existence of two-phase flow can be problematic to pump operation.

Classical Gas

Pumps are not good (gas) compressors. Unfortunately, pumps encounter situations in which they are subjected to binary mixtures of liquids and gases. Even small amounts of entrained air or gas reduce pump

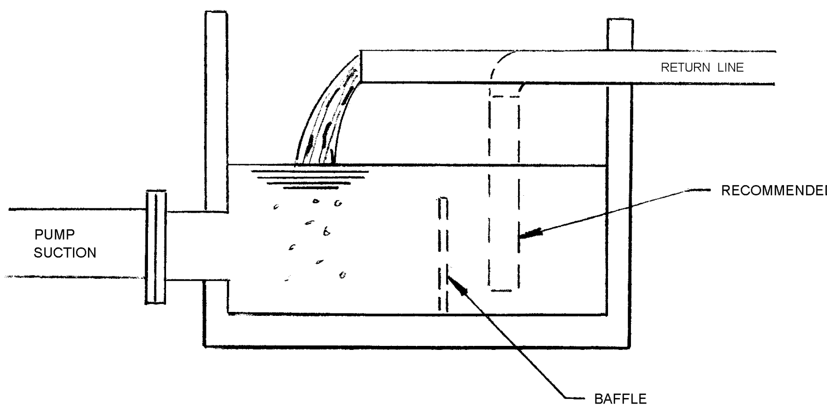


head, capacity, and efficiency. Collapsing gas bubbles are extremely long-term destructive to impellers and pump casing internals. Gas/liquid binary mixtures are caused by, (1) aeration, (2) vortexing, and (3) cavitation (vaporization). Within the context of pump terminology, aeration is the unintentional, and sometimes unavoidable, conditional introduction of compressible constituents in the pumped media. Aeration can be caused by the entrance of air into the vacuum condition of a suction line, or it can be created by excessive agitation or turbulence in the suction vessel. While generally not air, many

pharmaceutical and beverage fermentations are inherently plagued with entrained (and sometimes dissolved) gas as a result of normal chemical reaction products such as CO_2. This is also true of many petroleum liquids which naturally exist in binary phases of liquid/hydrocarbon gases and which exhibit very high vapor pressures. In all cases, these entrained and dissolved gases are carried into the pump's high pressure region where they collapse, or implode, releasing large amounts of energy which is dissipated with resultant destructive force and sometimes high temperature.

Even water has dissolved gases that can, under certain conditions, come out of solution. Clean, clear water contains the atmospheric gases consisting primarily of oxygen, nitrogen, and carbon dioxide. When the pump suction pressure approaches and reaches the vapor pressure of water, cavitation ensues. Interesting facts (and myths) about cavitation are covered in detail in PDHcenter.com course number M225.

Return pipe lines to sumps or tanks that allow the liquid to free-fall and impact on the suction reservoir's liquid surface can aerate the vessel's contents. Unless the process prevents such an arrangement, returned liquids should not be allowed to cascade, but rather should terminate below the liquid level in order to minimize turbulence, agitation, and the creation of entrained gas. In a similar fashion, return lines should not terminate in close proximity to the suction outlet.



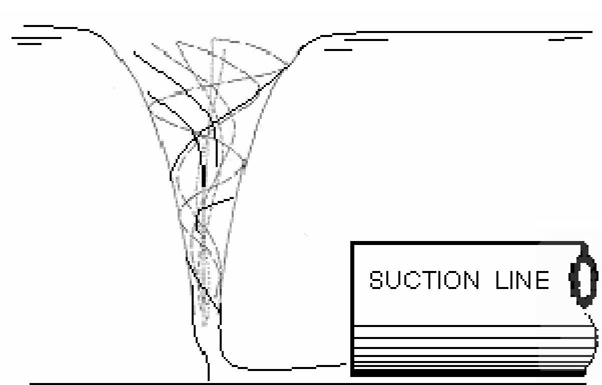
Feed lines for that matter, that could possibly introduce gas-entrained liquid to the sump or suction tank should be positioned to be physically distant from the suction point to alleviate the possibility of hydraulic short-circuiting. Doing so allows the freshly entering liquid important residence time in the suction vessel to dissipate gas. If this arrangement is not feasible, baffles can be installed in the sump to cause the liquid to have hold-up time before making its way to the pump suction port.

When the suction line is exceptionally long, or the pump is subjected to a large static suction lift, the suction pipe is more susceptible to external air leaks. Piping that employs non-positive connecting type joints, *e.g.*, bell and spigot joints, should be discounted as an acceptable alternative for suction lines. Screwed, flanged, or other pressure tight connections are the only recommended means of joining segments of long or high suction lift applications.

Its All Up Hill from Here

In applications of suction lift, resulting high points created in negatively sloped horizontal suction lines have a tendency to trap air. In order to prevent horizontal suction lines from becoming partially filled with air, the line should be installed dead level or with a slight elevation rise from suction line inlet to the pump suction connection. Likewise, valves or pipe fittings which are installed in the suction line whose configuration or design promotes the trapping of air should be avoided. Of particular interest are bonnet assemblies and valve stems of gate valves, these valves being necessary isolation components of good pump maintenance considerations. It is recommended that the axis of large gate valve stems be installed horizontally, as opposed to vertically, with respect to the axial plane of the suction pipe to reduce the possibility of trapped air. For this same reason, concentric reducers should not be used in horizontal pump suction lines. Use of eccentric reducers with the flat side oriented to the top dead center position will help eliminate air entrapment. Please refer back to **Figures 3** and **7** for illustrations of two of the points just made.

Rotating Funnel-Type Disturbances are not Limited to Kansas



A vortex is a smooth, roughly conical, rotating liquid void that forms in a fluid body as a result of a low pressure area. Vortices exist as both free-surface and sub-surface manifestations. Regardless of form, this liquid void spells trouble for pumps; it allows, and brings with it, air into the pump's suction. Fluidic studies have demonstrated that vortices collapse, otherwise break-up, or fail to form before entering a suction conduit, as the low pressure source's (inlet's) distance is increased vertically from the free liquid surface level. It is therefore important that proven and established minimum submergence depths be maintained based upon the amount of liquid being handled and the inlet fluid velocity. The graph following, **Figure 9**, shows the relationship between inlet fluid velocity (***V***) and the recommended minimum submergence depth (***H***) to avoid vortices. The approximate mathematical relationship of these two variables is:

$$H = 0.96e^{0.184V} \qquad [\text{ for } 3 \leq V \leq 10 \text{ }]$$

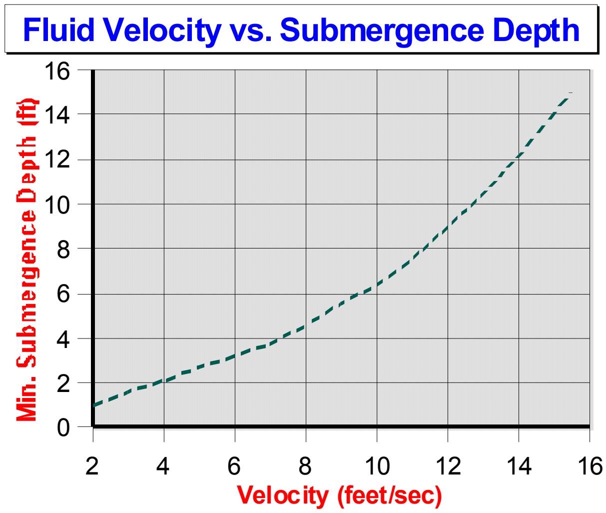


Figure 9

ADDITIONAL INFORMATION
For a detailed, but very interesting and understandable explanation of the fluid mechanics of vortex formation, go to http://www3/sympatical.ca/slavek.krepelka/ttf2.htm.

Breaking-Up is Hard to Do

Fluid baffles have also been successfully used to "break-up" vortices in sumps and tanks. The suppression of vortices in pump intake structures is not an exact science and great effort has been expended to understand this phenomena because vortices causes such undesirable hydraulic consequences.

Figure 10 illustrates three types of vortex breakers that have been successfully employed to suppress vortex formation.

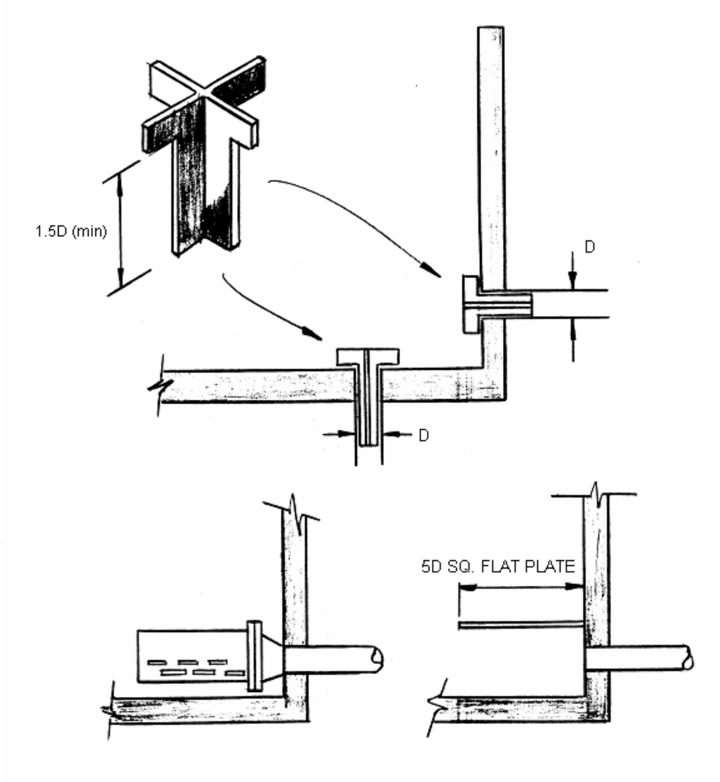
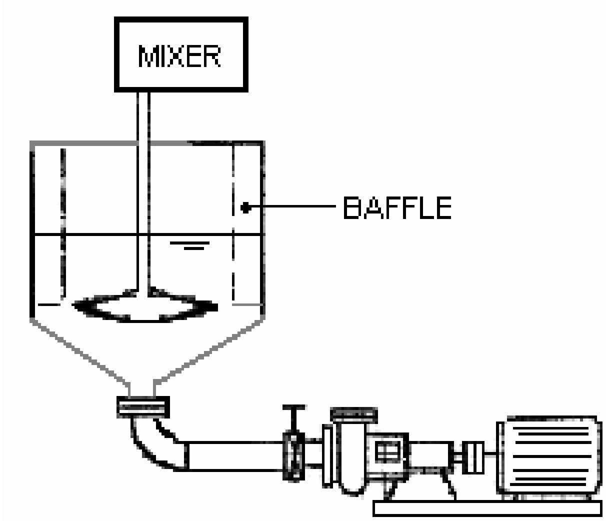


Figure 10 – Vortex breakers



Round suction source vessels can be problematic with regard to vortex formation. The swirling fluid mass that can be naturally set-up during liquid evacuation augments any already existing propensity for the formation of a vortex. Round vessels are sometimes equipped with vertical baffles to otherwise impede this rotational fluid mass. The addition of an agitator or mixer to the round vessel can exacerbate a vortex problem. Many batch processes require the complete emptying of a vessel and to accomplish this the bottom portion is fabricated in the shape of a cone. The conic bottom type of vessel can become a vortex creator depending on the geometric proportions of the cone and the rate at which the vessel is emptied. Combine all of the above conditions with a liquid that has a high vapor pressure and has entrained and dissolved gases, and a truly nightmarish suction condition can be created.

In the illustration just presented of a round, conical bottom, agitated vessel, note the proximity of the pump suction isolation valve to the pump inlet. Isolation valves are important operational and maintenance design necessities. If conditions warrant the installation of an isolation valve within the ***10D*** parameter, then consideration should be given to "on-off" valve types that promote unrestricted flow when in the open position. Acceptable valve types would be full-flow gate valves and full-port ball valves. Valve types that would not be acceptable would be globe valves or butterfly valves that exhibit a low C_V value.

There is Nothing XXX about NPSH

Net Positive Suction Head (NPSH) exists in two forms. NPSH available ($NPSH_A$) is the resulting pressure value of the liquid entering the pump. NPSH required ($NPSH_R$) is the resulting pressure drop produced as the liquid passes through the pump. $NPSH_A$ is defined by the system within which the pump operates; it must be calculated. $NPSH_R$ is a characteristic of the pump itself; it is determined from tests conducted by the pump manufacturer. A discussion of Net Positive Suction Head (NPSH) in essence is a discussion of cavitation. As fluid moves through the pump inlet its pressure is reduced. If the decrease in pressure results in the liquid equaling or going below its vapor pressure, then a portion of the liquid *boils* or vaporizes. As the now gas-entrained liquid enters the high pressure section of the pump these "bubbles" rapidly collapse releasing large amounts of damaging energy to pump internals. This process is known as *cavitation*. The greater the margin between $NPSH_A$ and $NPSH_R$, the lesser the possibility of cavitation. Therefore, pump suction designs which maximize $NPSH_A$ are superior to those that subject the suction liquid to pressure reductions which approach the liquid vapor pressure.

ADDITIONAL INFORMATION
It is recommended that the student study PDHcenter.com's course number M124 entitled *Understanding Net Positive Suction Head* for an in-depth treatment of this subject.

ADDITIONAL INFORMATION
Interesting facts (and myths) about cavitation can be found in PDHcenter.com course number M225.

DESIGN SIZE CONSIDERATION

Up to this point the importance of suction pipe line size has only been implied with the term *full-size* being mentioned. As it turns out, suction line size is important because it dictates mean fluid velocity for a given pump capacity (flow rate). Liquid velocity is important because the suction line frictional head loss varies directly with the square of its value, velocity itself depending on flow cross-sectional area, which is also a quadratic function ($A = \pi D^2/4$) in terms of line diameter. Therefore, line size changes result in exponential effects on frictional head loss. Suction line frictional head loss is a negative component in the determination of $NPSH_A$. General engineering practice holds that suction line mean fluid velocities should be limited to 5 to 8 feet per second, or alternatively, the suction line frictional head pressure loss should ideally be limited, if at all possible, to what would be equivalent to 2 to 3 feet of the pumped liquid.

One good method to minimize the possibility of cavitation is to elevate the suction source above the pump in order to create a *flooded suction*. A pump is said to have a flooded suction condition when the pressure in the connecting suction line and its vented source does not fall below the local atmospheric pressure with liquid flowing.

Inductive Reasoning

In the interest of improving (lowering) $NPSH_R$ limitations, the late 1960s saw the introduction and, still today, popular use of the centrifugal pump impeller inducer. In essence, an inducer is a helical screw arrangement immediately ahead of the normal impeller vanes or blades, that through pressure-ratio enhancements improves suction conditions. The inducer's effectiveness in reducing cavitation is a proven fact.

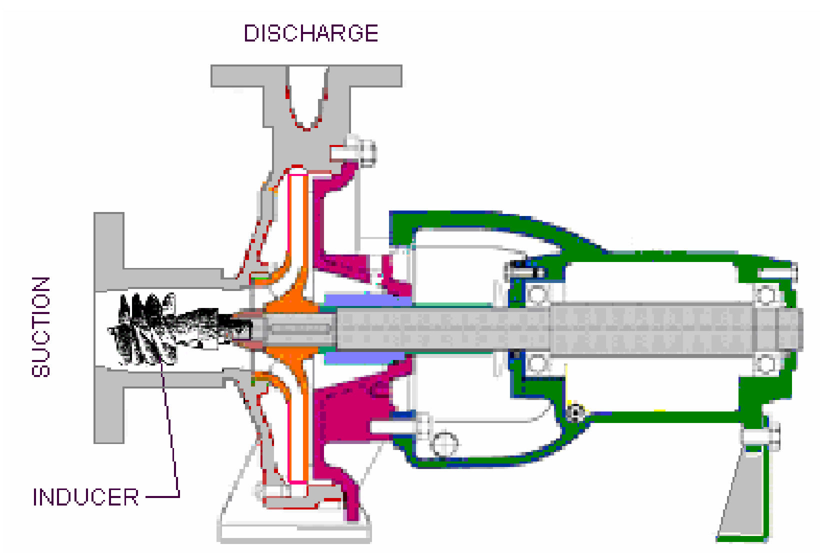


Figure 11 – Impeller inducer

Pumping on Solids Ground

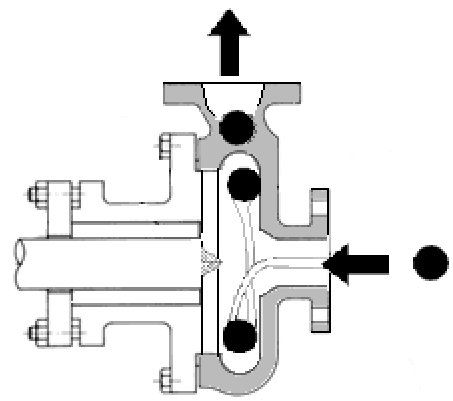
Depending on the percentage and nature of the mixture, pumping of liquids with solids in suspension can be problematic. In order to avoid clogged pipe lines, the Engineer should, through laboratory tests or technical data, determine and insure that the critical fluid velocity that precludes solids separation will be maintained in the suction line. Even though the suction line may not become completely blocked, the effective reduction in the internal diameter will ironically increase the mean fluid velocity, resulting in increased friction head and less Net Positive Suction Head available ($NPSH_A$). Settled solids that randomly "break-away" in the suction line may result in sudden excursions to normal pump operation vibration levels as the larger-than-normal mass attempts to make its passage through the pump. Even larger concentrations of "break-away" solids may completely clog the pump's impeller.

One special situation of liquid/solids mixtures occurs in the paper products industry and it is referred to as paper stock. A comprehensive treatment of paper stock fluid dynamics is beyond the scope of this course. Through industry's experience, the following paper stock suction piping design recommendations are offered: (1) The suction line size should be ample and as direct as possible to the pump suction connection; (2) Paper stock should be allowed to flow freely to the impeller; (3) Suction line frictional head losses should be calculated with a generous safety margin; and (4) Careful consideration should be given to the effects of pump head, capacity, and efficiency reduction associated with heavy paper stock.

To Strain or Not to Strain, That is the Question

Strainers are differentiated from filters generally by the size of the particle captured. Strainers can be thought of as large particle filters. Please refer back to **Figure 3** for a graphical representation of an inlet basket type strainer. Installation of true, say fine mesh, filters in suction lines should be avoided. Strainers create obstruction to flow and alternatives to strainers are pumps that are especially designed with a comminution (grinding) feature in the impeller. These are often referred to as grinder or chopper pumps and are popular in waste water treatment applications. Upstream comminution equipment and/or bar screens should be provided in waste water pump suction applications handling municipal and industrial influents, given the size and quantity of solids that can be encountered.

On the other end of the spectrum for the solution to handle solids are pumps which are designed to pass large particles, debris, and solids. Sometimes this is accomplished by simply fabricating the pump with larger than normal internal clearances between the moving and stationary parts. The vortex pump is a centrifugal type pump that contains a specially designed impeller which produces a vortex between the pump inlet port and the outlet port within the pump casing. This vortex should not be confused with the deleterious vortex (a vertical gaseous vena hyperboid) that develops in suction intake fluid bodies which has already been discussed. Large solids are carried through the vortex style pump via this internal vortex and are essentially unaffected by the centrifugal force generated by the rotating impeller. One manufacturer of vortex pumps states that fibrous materials such as hay, sugar cane stalks, and the like can be safely handled without build-up of solids on the impeller vanes. Advertised by some pump manufacturers are pumps that can handle liquids with suspended solids corresponding to spheres approaching 3½ inches in diameter.



To conclude, the important consideration of the installation of a suction strainer is to determine its effect on the suction pressure such that is does not fall below the value of $NPSH_R$ due to screen clogging. If a strainer is determined to be absolutely necessary, the suction pressure at the pump suction, and downstream of the strainer, should be carefully monitored via a properly maintained pressure indicating device (gage, *etc*.).

Don't Fence Me In

Suction piping misalignment is a common cause of excessive loads on the suction nozzle; this in turn can be transmitted through the pump, inducing pump/driver misalignment. This causes high vibration and bearing and seal wear.

Suction pipe attachment should be made in a manner that precludes other than normal strain on the pump connection(s). The American Standards Institute/Hydraulic Institute standard 9.6.2 *Allowable Nozzle Loads for Centrifugal and Vertical Pumps* is quite specific in the allowable superimposed stress on pump suction connections. The American Petroleum Institutes' (API) standard 610 also addresses this issue. Proper pipe fitting techniques with regards to any equipment would have the pipe installation proceed in a sequence that would result in an *outward* direction from the equipment's connection points. In other

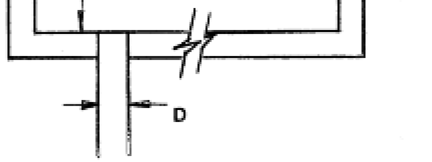
words, pump connection points should be considered as source points for the commencement of pipe installation runs.

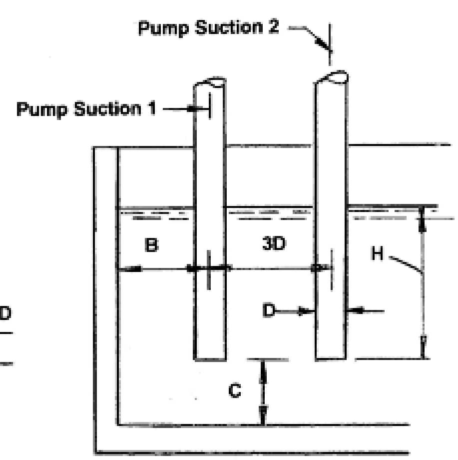
To eliminate undue combined external forces and moments on the pump suction connection and the casing itself, it is advisable to support and restrain the suction piping independently. Resultant forces due to expansion (and contraction) of connected suction piping through process temperature variations should be given full consideration. Anchorage of the suction line should generally be near the pump as opposed to the suction inlet in installations that have large temperature variations.

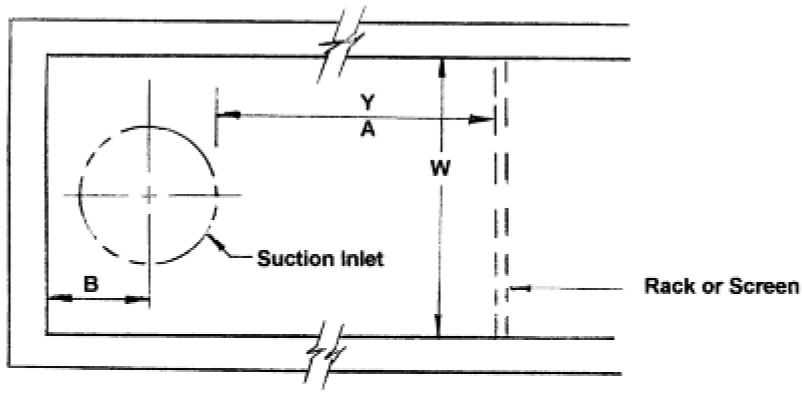
The suction piping should be designed so that a short section at the pump is removable in order to allow clearance for removal of the impeller.

Suction In-Take Design Guidelines

Proper sump, or intake structure design, deals primarily with maintaining certain critical dimensions and relational geometries to suppress vortices, provide evenly distributed flow, and avoid aeration. These widely published design suggestions (Goulds Pumps and the Hydraulic Institute among many others) have been developed through laboratory tests and field observation and are considered generally accepted engineering practice. For convenience, they are expressed in terms of the nominal size of the suction pipe, the flow capacity, or a fluid velocity. This makes the design guidelines flexible by allowing the intake structure to be easily scaled-up or scaled-down depending on the specific application. The best way to begin a discussion of the design guidelines of intake structure design is to just simply jump in. Here they are. Study the figures below and review the list of general guidelines that follows.







1. The recommended suction inlet size ***D*** should be $(0.0744\boldsymbol{Q})^{0.5}$, where ***Q*** is the flow in gallons per minute (gpm).
2. The minimum width ***W*** of the intake structure, per suction inlet, in the direction of flow, should be ***2D***.
3. The minimum unobstructed, full width, even flow, upstream approach distance ***Y*** to the suction inlet should be ***4D***. The optimum recommended upstream approach distance ***A*** should be ***$5D***.
4. The minimum vertical clearance ***C*** between the suction pipe end and the sump floor should range between ***0.3D*** and ***0.5D***.
5. The minimum suggested horizontal "stand-off" ***B*** of a suction pipe (the distance from the inside vertical surface of a sump wall to the 6 of the suction pipe) should be ***D***.
6. The minimum submergence depth ***H*** of the suction inlet below the liquid surface should be $\boldsymbol{D + 0.574Q/D^{1.5}}$. As presented earlier, an alternative to this guideline is $\boldsymbol{H = 0.96\, e^{0.184\,V}}$ where ***H*** is in feet and ***V*** is in feet/second.

The above listed guidelines are limited to a single inlet and barely touch on all of the possible arrangements that can be encountered. The student should refer to the sources cited under the section entitled **Additional Resources** for a more in-depth treatment of this subject.

Rules of Thumb and Myths?

Here are a few commonly held beliefs of good pump suction piping practice. None of these can be categorically classified as detrimental because there are so many varying conditions and applications. In reality, because there are no *absolutes,* each pump installation should be carefully studied to determine the optimum pump and interconnecting piping arrangement.

1. *The suction line size should always be one size larger than the pump suction connection size.* While this certainly insures a lower mean fluid velocity, it is contrary to the rule which promotes that pipe fittings should be eliminated (or at less minimized) in pump suction lines. A line size larger than the provided pump connection size necessitates the incorporation of a reducer at some juncture. Maybe a better rule of thumb would be that the suction line size should never be smaller that the pump suction connection size.
2. *Elbows installed directly on or near the pump suction entrance of a double suction pump are perfectly acceptable as long as they are in a vertical orientation at a right angle to the pump shaft.* The fact of the matter is that there is no truly desirable installation of an elbow directly on or near the pump suction, regardless of pump type.
3. *Pump suction lines should be as short as is practically feasible.* A supplement to this statement could be that a bare minimum length of straight full-size pipe equivalent to five pipe diameters should be allowed immediately upstream of the pump suction nozzle. This promotes streamlined balanced flow immediately upstream of the pump suction port.
4. *If Net Positive Suction Head available is greater than Net Positive Suction Head required, fluid cavitation will not occur.* Maybe so. However, some amount of cavitation is generally always occurring, notwithstanding the absolute value of the inequality stated above. It is extremely difficult to determine exactly when cavitation commences and it is easily confused with entrained vapor which has the same symptoms and debilitating effects.
5. *The benefits derived from the installation of a suction strainer far outweigh the risk of pump failure due to the entrance of damaging debris.* Again, maybe so. However, the installation of a strainer increases the pressure drop which reduces the Net Positive Suction Head available. Strainers require maintenance. The decision to install a strainer depends entirely on suction conditions, pump clearances, and the consistency of handled liquid. If the liquid is extremely contaminated with debris, alternatives to the strainer that are exterior to the suction pipe, such as racks, screens, and comminutors, should be given serious consideration.
6. *Because equipment is set before pipe fitting begins, the pump's position must be established and the connecting piping "brought" to it.* This often results in superimposed pipe forces and moments on pump connections. Contrary to the pipe fitter's viewpoint, it is far superior to pipe "away"from a newly set pump in order to eliminate the tendency for the pump to become an "anchor" to which pipe fitting workmanship shortcomings are accommodated.

Pump Suction Fault Diagnosis

The troubleshooting table that follows is necessarily filled with redundancy because many suction-inlet problems manifest in the same symptoms. Needless to say, the chart is not all encompassing.

PROBLEM (SYMPTOM)	PROBABLE CAUSE	CORRECTIVE ACTION
1. No Liquid Delivery		
	Excessive Lift.	(1) Reduce lift. (2) Change pump style.
	Clogged Strainer.	(1) Justify need. (2) Remove debris.
	Plugged Inlet.	Inspect and remove debris.
	Pipe Test Blanks inadvertently left in place.	Inspect and remove.
	Defective (inoperative) foot valve.	Inspect and replace.
	Loss of prime, air lock, vapor lock.	Check for aeration, cavitation, vortexing.
2. Low Liquid Delivery		
	Dirty Strainer.	(1) Justify need. (2) Inspect and clean.
	Undersized foot valve.	(1) Justify need. (2) Analyze and up-size.
	Partially plugged Inlet or Impeller.	(1) Inspect and clean. (2) Install strainer?
	Line solids/encrustation/scale restriction.	(1) Increase fluid velocity. (2) Replace line.
	Joint gasket flow restriction (encroachment).	Inspect and replace/realign.
	Liquid entrained air or gas.	Check for aeration, cavitation, vortexing.
3. Low Discharge Pressure		
	Dirty Strainer.	(1) Justify need. (2) Inspect and clean.
	Wrong impeller rotation.	Check and correct drive rotational direction.
	Excessive Lift.	(1) Reduce lift. (2) Change pump style.
	Inadequate inlet submergence.	Check for minimum $\boldsymbol{H} = \mathbf{0.96}\, \boldsymbol{e}^{0.184V}$
	Secondary (pre-rotational) flow.	(1) Maintain ***10D*** rule. (2) Install diffuser?
	Partially plugged Inlet or Impeller.	(1) Inspect and clean. (2) Install strainer?
	Inaccurate (defective) pressure gage.	Inspect and replace.
4. Excessive Noise, Vibration		
	Partially plugged Inlet or Impeller.	(1) Inspect and clean. (2) Install strainer?
	Secondary (pre-rotational) flow.	(1) Maintain ***10D*** rule. (2) Install diffuser?

	$NPSH_R > NPSH_A$	Correct. See PDHcenter.com course M124.
	Suction pipe misalignment nozzle strain.	Eliminate mechanical/thermal external loads.
	Pump/driver misalignment.	Check alignment; adjust.
5. Excessive Seal/Bearing Wear-Premature Failures		
	Unbalanced flow. Non-uniform flow.	(1) Maintain ***10D*** rule. (2) Install diffuser?
	Secondary (pre-rotational) flow.	(1) Maintain ***10D*** rule. (2) Avoid 90Eelbows
	Liquid entrained air or gas.	Check for aeration, cavitation, vortexing.
	Suction pipe misalignment nozzle strain.	Eliminate mechanical/thermal external loads.
6. Internal Casing and Impeller Pitting/Erosion-Uneven Wear		
	Unbalanced flow. Non-uniform flow.	(1) Maintain ***10D*** rule. (2) Install diffuser?
	Secondary (pre-rotational) flow.	(1) Maintain ***10D*** rule. (2) Avoid 90Eelbows
	Liquid entrained air or gas.	Check for aeration, cavitation, vortexing.
	$NPSH_R > NPSH_A$	Correct. See PDHcenter.com course M124.

INTERESTING FACT

Electric motor current draw is an excellent troubleshooting diagnostic tool. Inlet problems, which invariably result in less than desired liquid flow, also result in less than expected current flow. This is because a smaller amount of energy consuming mass is moving through the pump. This is true regardless of whether the problem stems from restricted or blocked flow or excessive gas entrainment due to aeration, cavitation, or vortexing.

Summary

A hierarchy of the practical considerations for pump suction piping design and installation presented in this course is:

1. The optimum length of full-size straight pipe, devoid of any obstructions to flow, immediately upstream of the pump suction connection, should be 10D.
2. The minimum length of full-size straight pipe, devoid of any obstructions to flow, immediately upstream of the pump suction connection, should be 5D.
3. Taking points 1 and 2 above into consideration, the suction line should be as short as possible.
4. The selected suction line pipe size should limit the mean fluid velocity to a maximum of 8 ft/sec understanding that more restrictive sizing criteria may govern, *e.g.,* National Fire Protection Association (NFPA) Chapter 20 or consideration for conservation of solids suspension.
5. The number of valves and fittings in the suction line should be minimized. Special examination and flow testing may be warranted for items such as strainers and suction diffusers.
6. Suction piping should be designed and installed to minimize entrapped air. This consists of positive sloped lines, avoidance of horizontal plane concentric reducers, proper orientation of eccentric reducers, and rotation of valve stems to oppose the axis of the pump shaft plane.
7. Directly connected elbows should be avoided and when absolutely necessary, should be of the long radius style oriented to minimize unbalanced flow to the pump impeller. If both a line size reduction and a piping direction change are required, consideration should be given to the reducing long radius elbow. Forty-five degree elbows should be favored over the 90E.
8. Suction line pipe joint designs should be air-tight. This is particularly true in long suction lines and in situations in which the suction lift is large.
9. The adherence to certain tried and true critical dimensions and relational geometries in suction intake structures are extremely important to suppress vortices, provide evenly distributed flow, and avoid aeration.
10. Sump or reservoir design can not be considered as a simple intuitive process of creating a hole in the ground, but rather, must be given due diligence.