Solving Pump Inlet Problems

Written by Gary L. Cornell, BLACOH Fluid Control, Inc.

Flow and pressure downstream are important, but inlet pump conditions also require attention during design.

Positive displacement pumps, specifically reciprocating and peristaltic types, create pulsating flow that results in damaging vibration and pressure spikes. These flow pulses occur because the pump's liquid chamber or chambers are repeatedly filled with liquid on the inlet stroke and then expelled on the discharge stroke.

Typically, the discharge flow from the pump is not linear. The flow from a piston or diaphragm pump for example, accelerates at the start of the pump stroke, reaches maximum velocity at midpoint and decelerates to zero flow at the end of the stroke. While the flow is accelerating and decelerating, the fluid pressure at the pump's discharge is increasing and decreasing.

Peak flow from the pump can be as much as 3.14 times the average or mean flow, creating an acceleration head phenomenon that must be considered when designing a liquid pumping system.

The design and construction of a liquid pumping system is often concentrated on ensuring that the desired pressure and flow are achieved downstream of the pump. This is critical, of course, but acceleration head is another important factor to consider.

Frequently, pump inlet conditions are not given proper consideration in system design. With positive displacement pumps, especially reciprocating types, it is crucial to include a complete design analysis of pump inlet conditions.

Two components of the inlet or suction side of a pump that must be considered to achieve the required system pressure and flow are net positive suction head required (NPSHR) and net positive suction head available (NPSHA). NPSHR is a function of the pump's design and determines the amount of NPSHA at the pump inlet required to prevent more than a 3 percent capacity drop in stated fluid flow, including consideration for acceleration head.

NPSHR must be supplied by the pump manufacturer. NPSHA is the absolute pressure above fluid vapor pressure available at the pump inlet. When dealing with positive displacement pumps, NPSHA is often expressed as net positive inlet pressure available (NPIPA) and net positive inlet pressure required (NPIPR). These terms reflect the use of pressure units rather than feet. Once feet of head are calculated, it is easily converted to psi.

This article explores acceleration head—a component that is frequently forgotten or given too little thought in calculating NPSHA. So, what is this often overlooked phenomenon? Remember, positive displacement pumps by design, especially reciprocating types, start and stop flow with every stroke. Depending on the number of pistons or chambers, complete stoppage can occur or some overlap can exist from chamber to chamber. The liquid mass in the suction line to the pump must be started and stopped with every pump stroke. The pump must expend energy to accelerate the liquid into the pump during the suction stroke and then stop the inlet flow on the discharge stroke.

This is the acceleration head component of NPSHA for reciprocating pumps and can be calculated using the generally accepted formula shown below. This equation is not inclusive enough to account for fluid compressibility or elasticity of components but will serve well in most applications.

$$ha = \frac{LVnC}{Kg}$$

where:

ha = Acceleration head in feet
L = Length of suction line in feet
V = Velocity in suction line in feet per second (fps)
n = Pump speed in cycles per minute (cpm)
*C = Constant (by pump type)

Constant	*Pump Type*
0.200	duplex single-acting (diaphragm pump)
0.115	duplex double-acting
0.066	triplex single or double-acting
0.040	quintuplex single or double-acting
0.028	septuplex single or double-acting
0.022	nonuplex single or double-acting

*K = A factor representing the reciprocal of the fraction of the theoretical acceleration head which must be provided to avoid a noticeable disturbance in the suction line

**K*	*Liquid*
2.5	Hot oil
2.0	Most hydrocarbons
1.5	Amine, glycol, water
1.4	De-aerated water
1.0	Urea and liquids with small amounts of entrained gases

g = Gravitation constant (32.174 ft/sec2)

The velocity component in the equation can be found in readily available tables or calculated as:

$$V = 0.4085 \frac{Q}{D^2}$$

where: V = Velocity in feet/second
Q = Flow rate in gallons per minute
D = Pipeline inside diameter

Acceleration head, sometimes referred to as inertia pressure, on the suction side of a pump can be positive, negative or both, but it must always be considered in several different ways.

Steady State Flow

As stated previously, positive displacement pumps have a maximum flow per stroke of more than three times the mean flow due to the nature of their pumping action. One of the biggest single mistakes made by system designers is to start NPSHA calculations by referring to standard pipe pressure loss tables and using mean flow numbers determined by system design requirements. These tables show pressure loss based on steady state flow. However, momentary peak flow rates will be higher on every stroke, and this higher rate should be used for friction loss determination.

The difference in loss on the discharge side of a pump can usually be overcome by added pump energy, but small differences on the inlet side can be critical to the limitations of NPSHA. Larger pipe diameter, elevated supply source or shorter suction piping may be required. This is a simple and common mistake that can have serious consequences to anticipated flow projections.

Cavitation

Because liquid in the inlet piping has been stopped during the discharge stroke of the pump, it must be accelerated by the pump on the inlet stroke. To do this, especially under low NPSHA conditions, a low pressure area at the pump inlet is created. If the acceleration pressure required lowers the inlet pressure below the vapor pressure of the liquid, then vaporization and subsequent cavitation can occur. NPSHA calculations must be made, including acceleration loss, because inlet systems have positive pressure under steady state conditions that can go negative at the start of the pump's inlet stroke.

Suction Lift

One of the advantages of positive displacement pumps is their ability to self-prime under suction lift conditions. Air-operated diaphragm and peristaltic pumps, for example, can self-prime up to as much as 20 feet of lift, while controlled volume metering pumps are usually limited to 3 to 5 feet.

Acceleration head loss under these conditions must be calculated carefully and may be the difference between being able to self-prime at all and requiring some sort of assistance—such as check or foot valves in the inlet piping. The size and interior surface finish of the inlet piping can also influence suction lift.

Multiple Chamber Pumps

Pumps with multiple pumping chambers, such as duplex and triplex pumps, typically have lower acceleration head losses primarily because, once liquid is in motion, at least theoretically, a small amount of continuous flow overlap exists as one chamber's inlet valve closes and the next chamber's inlet valve opens. Pump rpm and valve closure timing can have an impact on this.

Lack of complete pump chamber fill can occur as liquid is first accelerated to one chamber and then must be redirected to the next chamber. If sufficient time is not available for the stroke rate to allow each chamber to fill completely, pump damage can occur. An accumulator-type inlet stabilizer can usually minimize this condition by accumulating a quantity of liquid available at the pump's inlet.

Positive Inlet Pressure

While acceleration head on the inlet or suction side is generally a negative and subtracts from NPSHA, it can be positive. In fact, it can be too positive. Depending on pipe profile, supply tank elevations, pump speed and valve closure sequence, too much positive pressure can result.

Under most conditions of application, the pump's inlet valve(s) are quick closing valves. When a valve closes quickly against a flowing liquid, rapid velocity change occurs and a pressure spike, often referred to as water hammer can occur. The magnitude of the pressure spike is a function of the liquid's mass, flow rate velocity and the rate of the change in velocity. If the water hammer or pressure spike is of sufficient magnitude, it can damage system inlet components such as plastic pipe, gauges, seals and other components.

In duplex pumps, especially air-operated double-diaphragm pumps, this pressure spike can be particularly dangerous for the pump's diaphragms. As liquid flow is stopped by the closing of one inlet valve, the opposite chamber's inlet valve is opening. The pressure spike carried by the flow of diverted liquid rushes into the chamber being filled and slams into the diaphragm, stretching and weakening it until premature failure occurs. To minimize this pressure spike, the flow rate of the liquid must be held below a critical velocity for the system. To prevent the pressure spike from occurring in the first place, an inlet accumulator can be installed at the pump inlet to capture liquid during valve closure.

Minimize Acceleration Head

Other factors beyond this discussion should be considered when designing any pump's inlet configuration, but clearly, when positive displacement reciprocating pumps are involved, acceleration head is a critical factor that must be addressed. Minimizing the negative effects of acceleration head on the suction side of the pump can be accomplished in many ways. Some are discussed in this section.

Pumps and Piping
The following changes and additions to pumps and piping may influence acceleration head:

- Increase pipe diameter to reduce friction loss and liquid velocity.
- Make sure there is straight pipe for at least 10 to 15 pipe diameters at the pump inlet to minimize turbulence.
- Move the pump as close as possible to the source of supply to reduce mass that must be reaccelerated on every stroke and to reduce friction loss.
- Eliminate as many turns and elbows in the suction line as possible. Use sweeping elbows rather than 90-degree elbows.
- Use a larger pump to allow for slower stroke speed. (This can be an expensive solution.)
- Use suction piping 1.5 to 2 times the size of the pump's inlet port to reduce friction loss and help ensure an adequate supply of liquid into the pump chamber(s). *Caution: Larger suction piping can adversely affect suction lift.*
- Use pumps with multiple chambers to reduce acceleration head loss. This is an expensive fix, and multiple chamber pumps may raise cavitation concerns.

Standpipes
Standpipes can be used to help control acceleration head by providing an area of accumulation and release of pumped liquid as the pump's inlet valve alternately opens and closes. The standpipe needs to be at least 1.5 times the diameter of the pipe it is mounted on and, generally, as tall as the supply tank to the pump. It must be mounted within 25 pipe diameters from the pump's inlet (preferably within 10 pipe diameters).

It must also be capped and typically vented to the supply tank. Standpipes can never be used in a suction lift application because air could be sucked into the supply piping. The other disadvantage of standpipes is that they can become waterlogged and rendered ineffective when trapped air at the top becomes entrained in the liquid accumulated in the standpipe.

Inlet Stabilizers
Essentially a pulsation dampener, an inlet stabilizer has a flexible internal diaphragm or bladder to prevent mixing of the system liquid with the stabilizer's gas charge. Properly sized and installed in a tee within 10 pipe diameters of the pump inlet, it can usually reduce acceleration pressure loss to less than 3 or 4 psi. It does this by accumulating liquid during the pump's discharge stroke and releasing the liquid back into the suction line during the pump's inlet stroke.

In effect, the inlet stabilizer uses the stored energy of the compressed gas to reaccelerate the liquid back into the suction line. It will only have an effect on the liquid between it and the pump's inlet so proper location is critical.

An inlet stabilizer essentially operates for free because the energy expended by the pump to stop flow by closing the inlet valve on the discharge stroke is returned when that same energy stored in the stabilizer's compressed gas pushes accumulated liquid back into the suction line as the inlet valve of the pump opens. This, of course, minimizes the pump's job of reaccelerating the liquid in the suction line. Pulsation and pressure fluctuations are minimized, and a near constant flow of liquid is available at the pump inlet.

Traditionally, both standpipes and inlet stabilizers have required positive pressure available to the pump, but neither was particularly effective in suction lift applications. However, inlet stabilizer models are now available that can be used in both positive pressure and suction lift applications. These models have a venturi control arrangement that can either direct pressure into the inlet stabilizer for positive pressure applications or create a partial vacuum to assist in suction lift applications.

In suction lift applications, liquid can move away from the pump inlet as the inlet valve closes. The vacuum on the gas side of the stabilizer will pull product into the unit and momentarily hold it until the inlet valve opens on the pump's suction stroke.

Again, the idea is to accumulate liquid close to the pump inlet so that the entire column of liquid does not have to be accelerated. This type of inlet stabilizer will not assist in initial pump priming but will reduce pump energy once the pump is primed.

As a general rule, a pulsation dampener at the pump discharge must be at least 15 times the volume of the pump's liquid chamber, depending on the number of pumping chambers. An inlet stabilizer must be at least the same size and preferably 1.5 times the size of the pulsation dampener. The inlet, or nozzle, on the stabilizer must be at least the same size as the pipe on which it is mounted. The gas charge on the inlet stabilizer will be determined by the specific application according to guidelines provided by the manufacturer.

Conclusion
This article is meant to be a general guideline to make the reader aware of factors that must be considered when designing the layout of inlet piping for positive displacement pump systems, particularly those applications using reciprocating and peristaltic pumps. Acceleration head, often overlooked and misunderstood, was emphasized.

While no attempt was made to give specific engineering guidelines for designing inlet systems, the goal was to provide useful information on design criteria for efficient and effective liquid handling systems.

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Gary Cornell is Chairman/CEO of BLACOH Fluid Control, Inc., a manufacturer of pulsation dampeners, surge suppressors, inlet stabilizers and other fluid control products and based in Riverside, Calif. With a BS degree from California Polytechnic University, Cornell has worked in the reciprocating pump industry for more than 35 years and is a member of the Hydraulic Institute and the American Society of Mechanical Engineers. For more information, contact BLACOH at 951-342-3100 or 800-603-7867 (toll free), or visit www.blacoh.com.

BLACOH Fluid Control, Inc.
601 Columbia Ave, Bldg D
Riverside, CA 92507 USA
951.342.3100 or 800.603.7867
Sales@blacoh.com
www.blacoh.com