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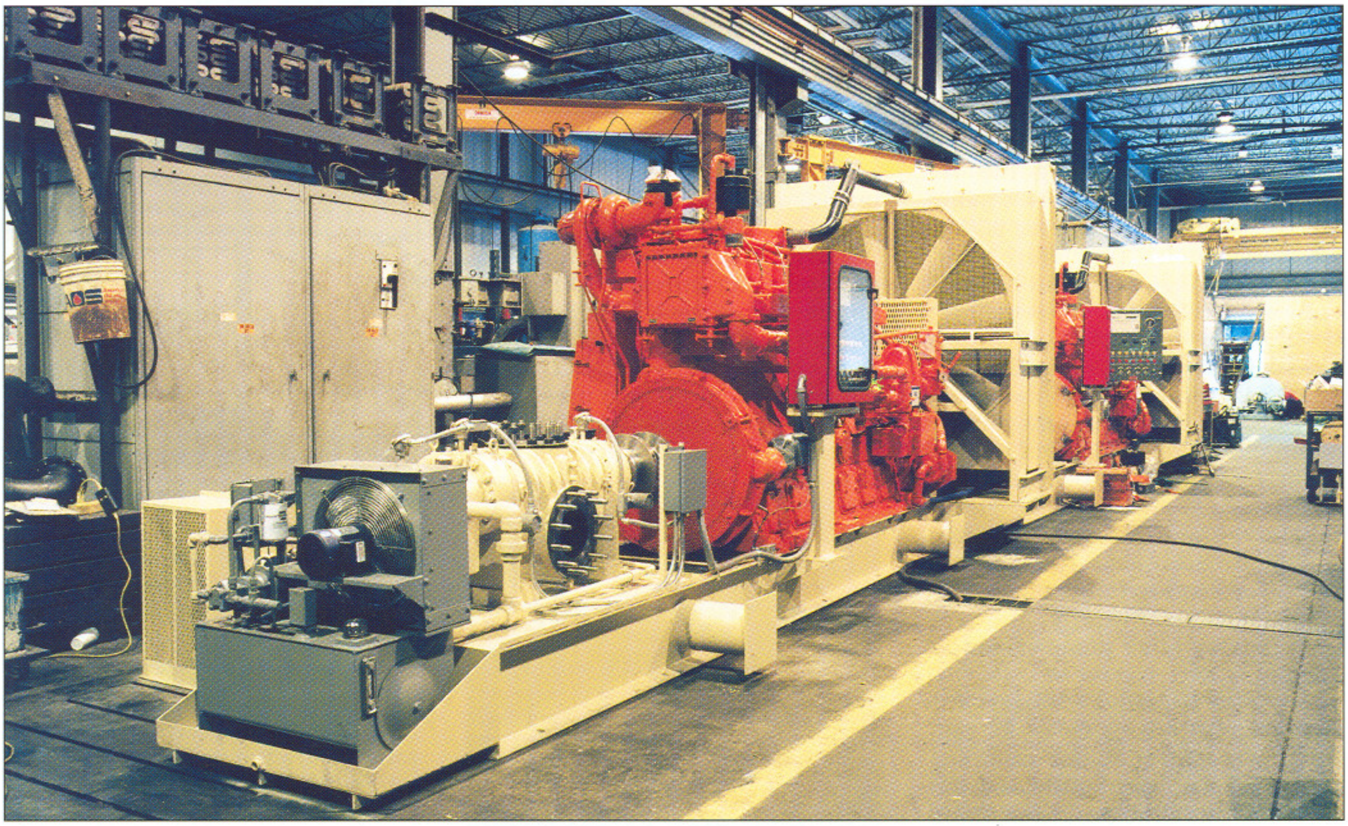

Rotary Pump Inlet Pressure Requirements

Shedding light on one of the least understood yet most important aspects of a successful pump installation.

By James R. Brennan

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By James R. Brennan, Imo Industries Inc.

Incorrectly specifying the required inlet pressure for a pump will result in either poor performance, noise, premature wear, high operating and maintenance expenses and failures, or a seemingly excellent installation that costs a good deal more than it should.

Rotary pumps handle the broadest range of liquids of any generic pump classification – from molten metal, food, liquefied petroleum gas and sewage to asphalt, fuels, chemical slurries and plastics, polymers and pharmaceuticals. Capabilities and user expectations for rotary pumps are significantly different from those of other pump classifications.

In the United States, the Hydraulic Institute is the major controlling organization for pumping definitions, and each of the centrifugal, rotary and reciprocating pump manufacturers have its own set of similar but not necessarily identical standards. Inlet pressure requirements for rotary, positive displacement pumps are similar to NPSHr (Net Positive Suction Head Required) for centrifugal pumps. For rotary pumps, pressure units are normally in force per unit area (psi, bar, MPa) rather than elevation difference (feet or meters).

The variety of labels used for this parameter, as well as an astonishingly long list of units of measure and reference scales, perpetuates misunderstanding of required inlet pressure. The purpose of this article is to provide a basic physical understanding such that the various scales and units do not, at least initially, intrude on our ability to grasp the principles.

Every pump has a minimum required inlet pressure. What that minimum pressure is depends on pump type, size, speed and the viscosity of the fluid pumped. If the minimum required inlet pressure is not made available to the inlet side of the pump, cavitation will result. Cavitation is the incomplete filling or feeding of the pumping elements with liquid. This results in a reduction of flow and, if the condition is severe, noise, vibration, instability, internal erosion and catastrophic failure can result. Cavitation must therefore be avoided. Pure cavitation is the partial vaporization of the pumped liquid caused by allowing the fluid pressure to fall below its vapor pressure at the pumping temperature. Pseudo-cavitation can occur if the liquid contains dissolved gas or air – a not uncommon condition. The dissolved gas will expand as the fluid pressure is reduced and cause exactly the same symptoms as pure cavitation. Entrained gas or air in the fluid, such as can be found in some restricted or poorly designed lubrication systems, will also cause pumps to exhibit cavitation symptoms, as will an air leak in a pump inlet line below atmospheric pressure.

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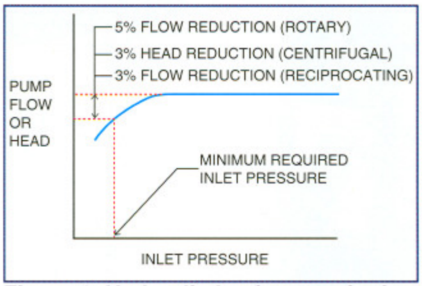

Figure 1. Hydraulic Institute cavitation definitions

The Hydraulic Institute defines minimum inlet pressure as that pressure, for a specified pump and set of operating conditions, that will result in a flow loss of 3% for reciprocating pumps, and 5% for rotary pumps and a 3% head loss for centrifugal pumps while all other operating conditions are held constant. Most pump manufacturers accept these fairly arbitrary definitions as a condition that their pumps will tolerate indefinitely (Figure 1). It is, however, operation in a very mildly cavitated condition. Figure 2 illustrates what is happening to the pump above and below this min-

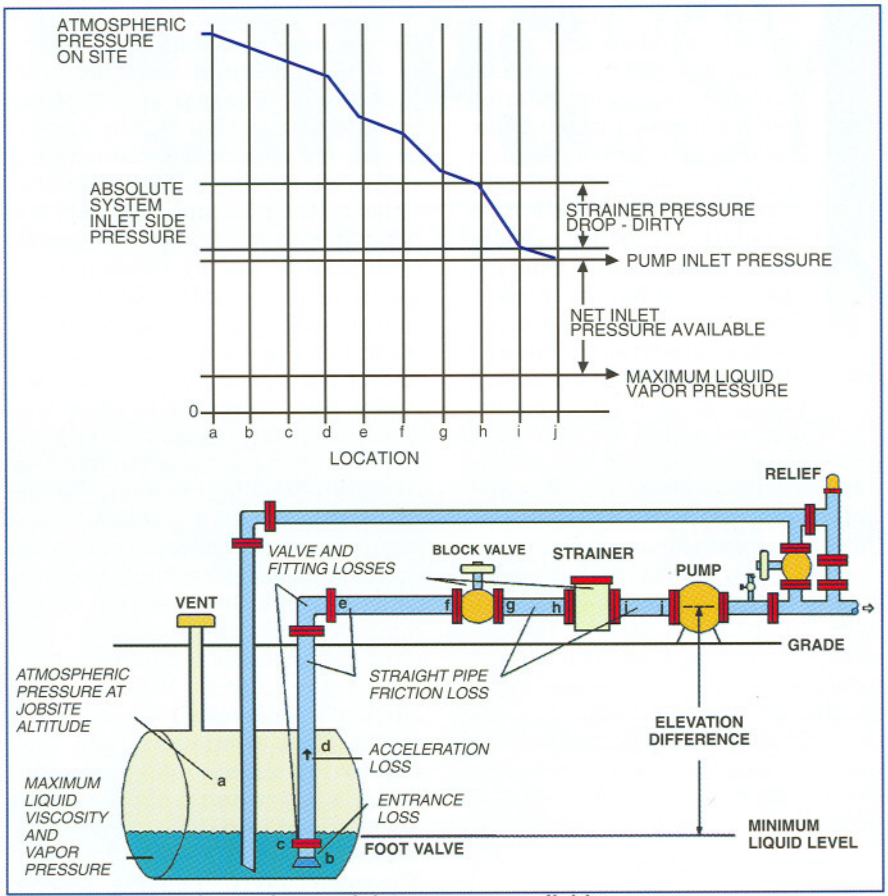

Figure 2. Factors impacting net inlet pressure available

imum inlet pressure. The lower case letters in the diagram correspond to the horizontal axis locations in the graph. Pump manufacturers have conducted extensive tests and determined the empirical equations used to calculate the required minimum inlet pressures for their products.

So from where does the required minimum inlet pressure come? It comes from either an upstream pump or atmospheric pressure pushing on the free surface of the fluid upstream of a pump in question. Atmospheric pressure can be the natural pressure exerted by the column height of air above the pump, or it can be the artificially maintained pressure above the fluid surface, such as a deliberately maintained vacuum or pressure in a process vessel. If natural atmospheric pressure is used, then the job site altitude above sea level is an important factor. Figure 3 illustrates the reduction in atmospheric pressure with altitude. Higher elevations have less pressure available for use in pushing fluids into a pump, and this often overlooked factor can make or break an application. The idea that a pump can "suck," while seemingly obvious, is in fact incorrect. The pressure reduction at the inlet of the pump is simply the result of frictional pressure loss due to the flow of fluid from its source to the pump and into the pumping element(s).

If fluids always remained in their liquid state, establishing the minimum required inlet pressure would be somewhat simpler. However, many liquids exhibit a vapor pressure of sufficient magnitude at pumping temperature – a factor that must be taken into consideration for proper pump operation (Figure 4). Vapor pressure is the inverse of boiling temperature. As we all learned long ago, water boils at 100°C (212°F). This boiling temperature is only correct when the water is at a pressure of one atmosphere (one international atmosphere is equal to 101,325 Pascals, 1.01325 bar, 1.03323 kg/cm^2, 14.696 psi). At an elevation of 3000 meters (9842 feet), the atmospheric pressure is only 69% of what it is at sea level. At this reduced pressure, water will boil at about 90°C (195°F). The inverse way of looking at this is to say that the vapor pressure of water is 1 atmosphere at 100°C (212°F). If you wish to pump water in its liquid state and the water happens to be at a temperature of 100°C (212°F), the inlet side of the pump must not be exposed to a pressure below 1 atmosphere or the liquid will begin to convert to a gas (steam) and the pump will enter a cavitating region of operation, a very undesirable condition. If liquid water is to be pumped at 160°C (320°F), then the inlet side of the pump must be maintained at or above the 6.1 atmospheres that represent the vapor pressure of water at this temperature.

Many liquids handled at their normal pumping temperature exhibit such a low vapor pressure that this factor can be ignored for all practical purposes. Refined lubricating oils, for example, at normal operating

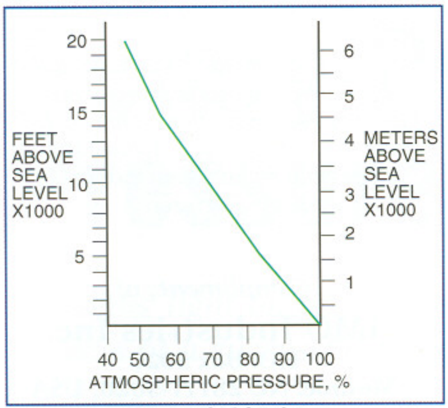

Figure 3. Effects of altitude on atmospheric pressure

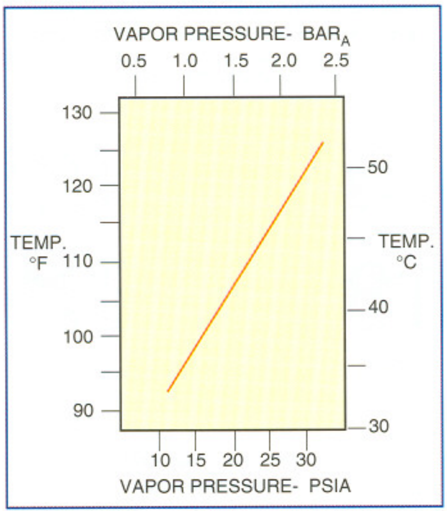

Figure 4. Effect of temperature on vapor pressure

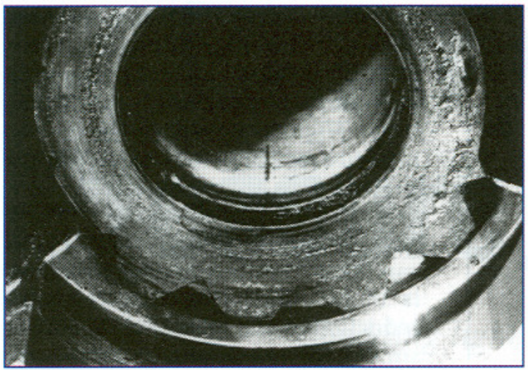

Photo 1. High pressure gear pump destroyed by severe cavitation

temperatures up to 82°C (180°F) have vapor pressures in the range of 0.01 atmospheres. On the other hand, volatile liquids such as gasoline and alcohol will readily evaporate (boil) at ambient temperatures. Propane is kept liquid at ambient temperature only because it is stored in a pressure vessel. The vessel must contain the propane's vapor pressure at the vessel's temperature. Vapor pressure invariably increases with temperature. It is this very fact that is put to use in refining petroleum and in many other petrochemical and chemical processes. While it is almost always important to know a fluid's minimum vapor pressure at the maximum pump suction temperature, the pumping of high temperature fluids should involve a careful analysis of the possible impacts of vapor pressure.

Some fluids will exhibit multiple vapor pressures. Raw crude oil is an example. This fluid is composed of many different complex molecules. It is a mixture and, as such, its component fluids will each have its own vapor pressure. The lowest discernible component vapor pressure is the one to use for net inlet pressure calculations if pumping this fluid. Alcohol mixed with water will exhibit two vapor pressures: that of alcohol and a different one for water. The way to separate these two liquids is to apply heat. The alcohol will boil first at a lower temperature than water's boiling point. The alcohol can be collected as a gas, then cooled to its liquid state. This process, called distillation, is a good example of vapor pressure at work.

Cavitation causes its damage by the abrupt, violent compression of the vapor (gas) back into liquid at the pump discharge. This compression occurs very rapidly as an implosion. There is enough energy to erode minute metal particles from the rotating and stationary pumping elements. Such erosion is frequently visible on outboard marine engine propellers in which the propeller velocity exceeds the water velocity, thus cavitating the blades. Given enough time, a blade failure is inevitable. Photo 1 shows cavitation damage to a pump. Most rotary positive displacement pumps use incremental pressure staging within the pumping elements to withstand differential pressure. Examples of this staging include multiple wraps of screw pump thread, multiple teeth on gear pumps and multiple vanes in vane pumps. This staging is only effective if the fluid pumped is nearly incompressible, i.e., a liquid. Introduction of gas, air or vapor causes the fluid's compressibility to increase, and this compressibility defeats the staging benefits. Most of the pressure rise across a pump handling compressible fluids occurs at the last stage, overloading the unit.

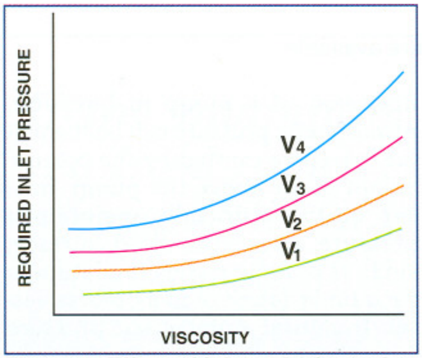

Figure 5. Effect of inlet velocity and viscosity on required inlet pressure

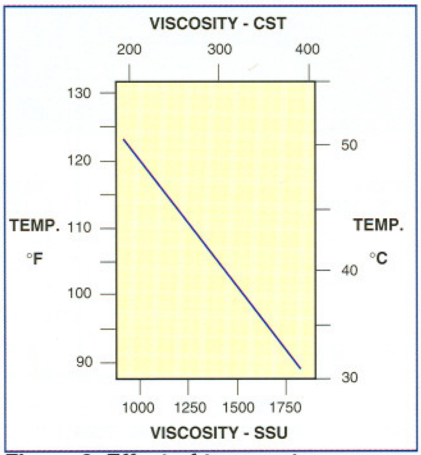

Figure 6. Effect of temperature on viscosity

The minimum required inlet pressure of a pump also depends upon its size and speed. The product of size and rotational speed is velocity. Fluids moving at high velocities entering the pumping elements will consume more energy (pressure) than slower moving fluids. Consequently, large and/or high speed pumps will require a higher minimum inlet pressure than smaller and/or low speed pumps. Fluid viscosity (fluid resistance to shear) will also adversely affect minimum required inlet pressure. Friction losses within the pump suction side casing (minimal) and friction losses entering the first pumping chamber increase with increasing viscosity. Thus, pumps will require higher minimum inlet pressures when handling higher viscosity fluids. Figure 5 shows the effect. Velocities are labeled V_1 increasing in magnitude to V_4. One solution to the high required minimum inlet pressure is to use a larger pump operating at a lower speed to reduce the internal velocity.

The price paid is, of course, a larger, more expensive pump and a more expensive driver.

Getting the inlet side of the pump correctly specified, and providing as much net inlet pressure as possible, will result in an optimally sized, minimum cost pump selection that can be expected to operate well for a long time. Excessively conservative inlet pressure specifications will result in larger, slower and more expensive – and perhaps even less efficient – pumps.■

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His responsibilities include worldwide marketing and technical support for pumping applications. He is a 1973 graduate of Drexel University in Philadelphia and a member of the Society of Petroleum Engineers.

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