Positive Displacement Pump Basics

A. Definitions and Terms

Density

Density is the mass of a substance per unit volume. Generally, we express density in units of pounds per cubic inch.

Specific Gravity

Specific gravity is used to compare the density of a product to the density of water. The specific gravity of a product is expressed as its density divided by the density of water. This number will have no units, because it is simply a ratio.

Brix

Also called degrees Brix (°Brix), it is a hydrometer scale for sugar solutions. It is expressed as grams of soluble solids per 100g of liquid and is temperature corrected. Sugar content is approximately proportional to the °Brix value, with sugars contributing 55 to 75% of the °Brix.

Viscosity

Viscosity is a measurement of a product's resistance to flow. Low viscosity products (i.e. water) have little resistance to flow, while higher viscosity products have a greater resistance to flow. It is key to positive pump sizing and operation because it affects slip within the pump as well as the pressure required to overcome frictional loss in the lines. The product's resistance to flow produces system backpressure and heat. It will be explained later that the increased resistance to flow can be seen in the relationship between the frictional pressure loss (psi / foot tubing), flow rate (gpm), and product viscosity (cps) in the pressure loss charts shown on pages 42-47. It will also be explained that this same resistance to flow, by higher viscosity products, can be seen in reduced product slip inside the pump.

Newtonian vs. Non-Newtonian Fluids

A Newtonian fluid will have the same viscosity whether or not it is in motion. Examples of this type of fluid would be water and high fructose corn syrup (HFCS). A non-Newtonian fluid will have a different viscosity depending on the velocity of its flow. The majority of fluids are of this type, some examples would be ketchup, orange juice concentrate and shampoo.

Thixotropic Fluids

A thixotropic fluid is a type of non-Newtonian fluid that will become less viscous as the shear rate increases. This is also known as shear thinning, ketchup is a good example of this type of fluid. While the product is static, or standing still, the viscosity can be very high. As the fluid begins to flow it becomes less viscous and starts to run like water. After it sits again, it becomes very viscous. This thinning is due to shear in the fluid. As the fluid begins to move, the molecules will slide over each other and require less force to stay in motion. This force causes a shear stress in the fluid.

Apparent Viscosity

As previously explained, non-Newtonian fluids have less viscosity in motion, than at rest. The viscosity of a product in motion is known as its apparent viscosity. When a non-Newtonian fluid is in motion the apparent viscosity should be used for calculating the pressure drop. The apparent viscosity can be measured using a viscometer and plotting the results as a "Viscosity vs. Shear Rate" curve. This curve can be used with a shear rate curve for the tubing that is used in the system, to determine the apparent viscosity.

1. Find the product's flow rate (75 gpm) on the "Flow Rate vs. Shear Rate" curve for tubing.

2. Draw a line to the right until it intersects the 3" tubing diameter.

3. Follow the line down to find the shear rate. Shear rate=125

4. Find the shear rate on the "Viscosity vs. Shear Rate" curve for the product.

5. Move up until you intersect the line.

6. Move left to find the apparent viscosity. Apparent viscosity = 1500 cps.

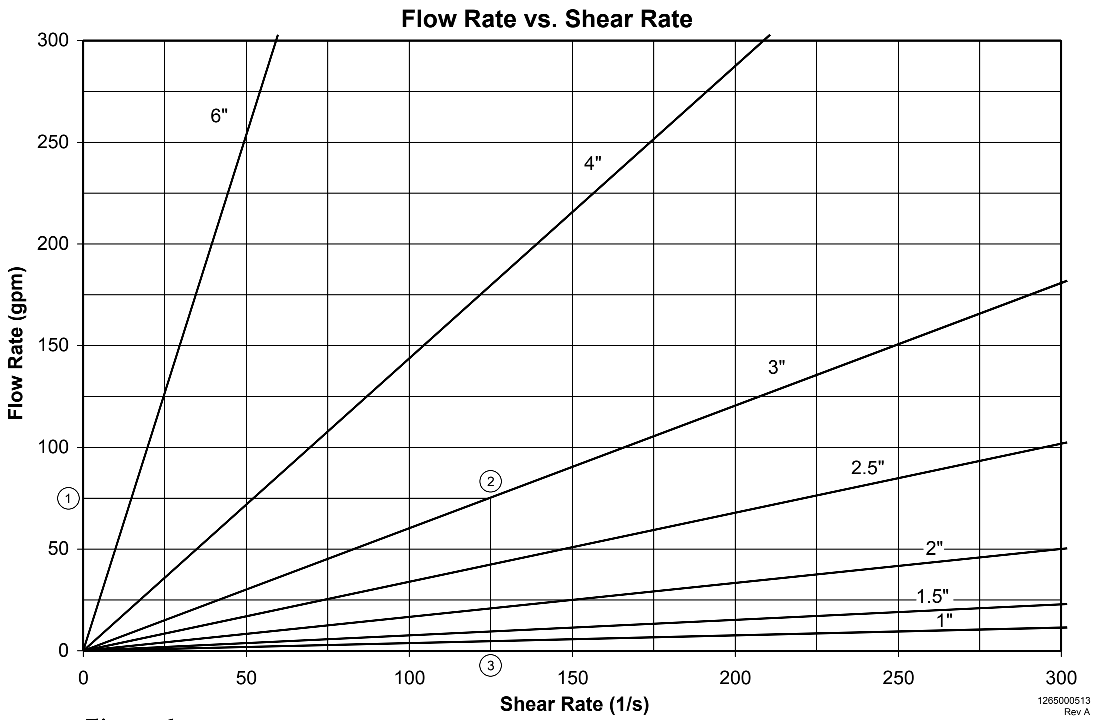


Figure 1

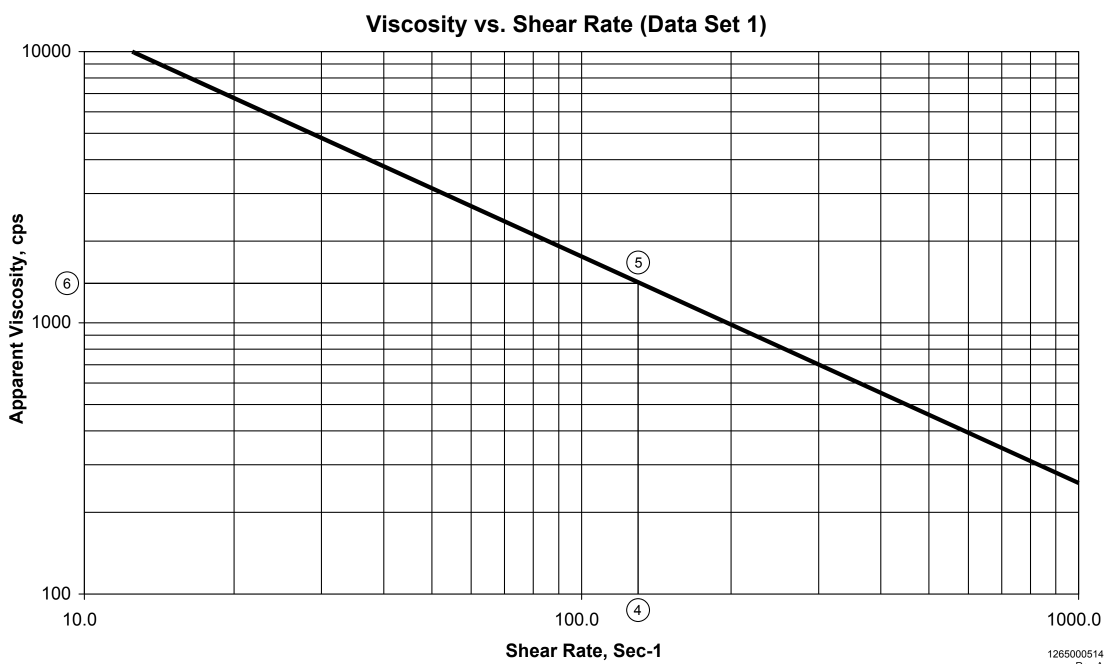


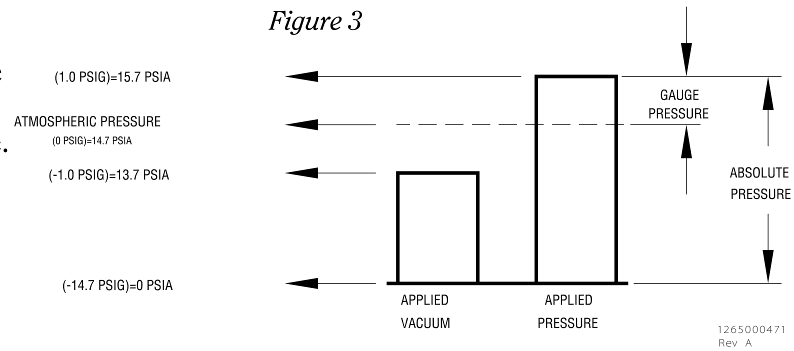
Figure 2

Atmospheric Pressure

Atmospheric pressure is the force exerted by the weight of the atmosphere. At sea level, the average atmospheric pressure is 14.7 pounds per square inch (psia). Refer to Table 2 (page 48) for the average atmospheric pressure at different elevations.

Gauge Pressure

Gauge pressure is the pressure read on a gauge installed in a system. At sea level the average atmospheric pressure is 14.7 psia, this would be equal to 0 psi gauge pressure. This is measured in units of pounds per square inch gauge or psig.



Absolute Pressure

Absolute pressure is calculated by adding the atmospheric pressure to the gauge pressure. This is measured in units of pounds per square inch absolute or psia.

Static Pressure (Head)

Static pressure is the pressure exerted by a column of liquid above the centerline point of measurement.

$p_z = (Z / 2.31) \times sg$

p_z = static pressure (psia)

Z = liquid level (ft)

sg = specific gravity (product)

2.31 = conversion factor (dimensionless)

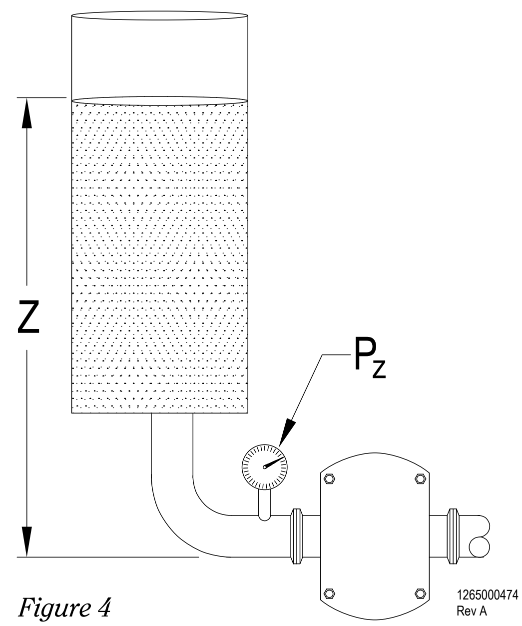


Figure 4

Vacuum

Vacuum refers to a pressure that is below the normal atmospheric pressure. If the tank feeding the inlet of a pump is at an absolute pressure less than atmospheric, the tank is said to be under vacuum. Vacuum is typically measured in units of inches of mercury (inches Hg). This number must be converted to psia, for NIPA calculations. For the conversion, see Table 6 on page 50.

Vapor Pressure

The vapor pressure of a fluid is the pressure required at a given temperature to keep the fluid from turning to vapor. Water at 210°F has a vapor pressure of 14.123 psia. See Table 1 for the water vapor pressure on page 48.

NIPR – Net Inlet Pressure Required

NIPR is the pressure required by a pump to perform smoothly without cavitating. NIPR is measured in psia.

NIPA – Net Inlet Pressure Available

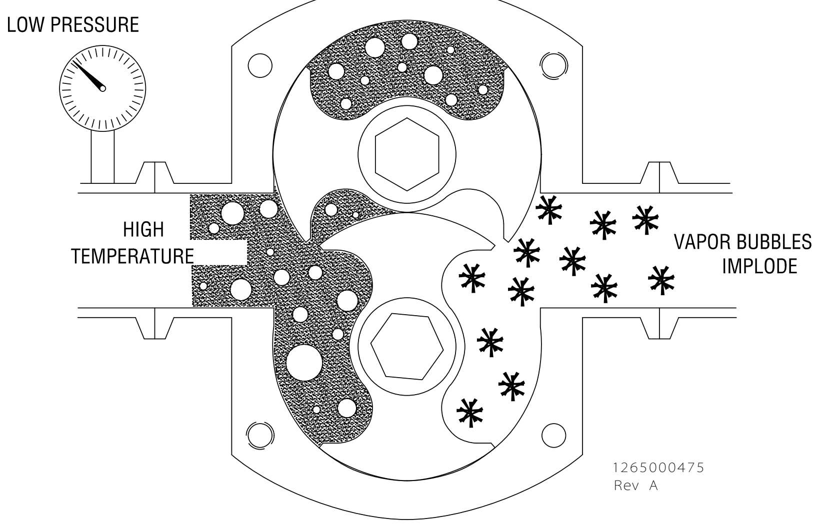
NIPA is the absolute pressure available at the inlet of the pump. NIPA is measured in psia.

Cavitation

Cavitation is the formation of vapor bubbles due to insufficient pressure at the inlet of the pump. High product temperature and/or low pressure on the inlet side of the pump can lead to insufficient pressure. Over time, cavitation can seriously damage a pump. Additional pressure energy would be required to supply the pump with the energy it requires to keep from cavitating. Four ways to increase NIPA are raise the level of the product in the tank, pressurize the tank, lower the pump or decrease the product temperature.

If the NIPR of the pump is greater than the NIPA in the system, the pump will cavitate. If the NIPR is less than the NIPA, the pump will not cavitate.

Figure 5

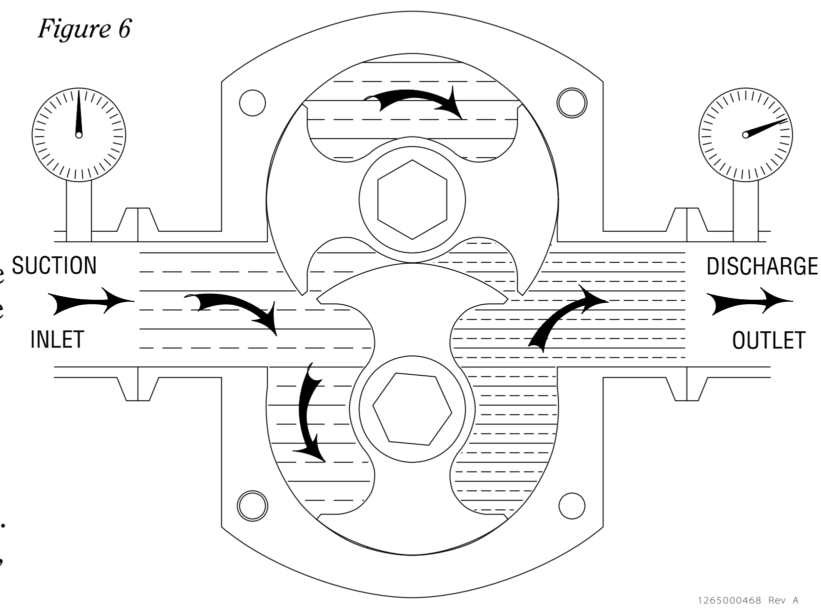


B. How a Positive Pump Operates

Positive Displacement Pump Operation (assuming sufficient NIPR)

Positive displacement pumps use two opposing, rotating elements (rotors) to displace product from the suction side of the pump to the discharge side of the pump. As the rotors rotate, the chamber formed between the rotors, housing and cover collects the product on the inlet side of the pump and carries the product to the discharge side of the pump.

Figure 6



Slip and Efficiency -

Positive pumps sometimes do not pump the full displacement for which they are rated because of a phenomenon called slip. To allow a positive pump's rotors to rotate, small clearances must be maintained between the rotors and housing. At lower viscosities these clearances allow some product to slip from the discharge side to the inlet side as the pump operates. The product that slips by will partially fill the inlet cavity. This amount of product must be "repumped" preventing the pump from reaching its full rated capacity and decreasing its volumetric efficiency.

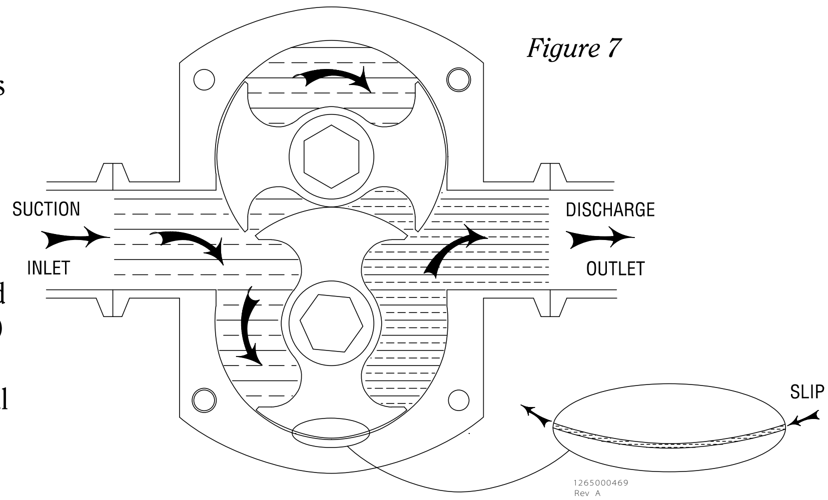
• Internal clearances – The tighter the clearances, the less slip occurs.
• Viscosity – The amount of slip varies inversely with viscosity. The thicker the product, the less slip will occur. This reduction in slip eventually reaches a point called "zero slip".
• Zero slip – Zero slip is the point at which the product is thick enough that it will no longer flow past the rotors. This point varies depending upon the internal clearances of the pump. The FKL reaches zero slip at 200 cps and the FL II achieves it at 500 cps. At these points the amount of differential pressure no longer becomes a factor.

Volumetric Efficiency = Actual Flow/Flow at Zero Slip

Full volumetric efficiency is achieved on all products with viscosities above the zero slip point.

Actual flow for products between one and the zero slip point will depend on the interaction of product viscosity and the differential pressure. At a constant product viscosity below zero slip, increasing the discharge pressure increases the product slip. At a constant discharge pressure, decreasing the product viscosity increases the product slip.

Figure 7



For products with a viscosity between 1 and 200 cps for the FKL and between 1 and 500 cps for the FL II the flow rate is dependent on the product viscosity and the differential pressure. At a constant product viscosity below zero slip, increasing the discharge pressure increases the product slip. At a constant discharge pressure, decreasing the product viscosity increases product slip. As the slip increases, the volumetric efficiency of the pump decreases because the full volume of the suction chamber is not available for new product.

Slip = (Flow @ 0 psi) – (Flow @ 10 psi)

Slip = 100 gpm - 70 gpm

Slip = 30 gpm

VE = 70%

Figure 8 shows the effect that increasing the discharge pressure has on slip and volumetric efficiency. At 0 psi, the volumetric efficiency is 100%. As the pressure increases, product slips from the discharge side of the pump to the suction side.

$$\text{Volumetric Efficiency} = \frac{\text{Flow @ 10 psi}}{\text{Flow @ 0 psi}}$$

$$\text{VE} = \frac{70\ \text{GPM}}{100\ \text{GPM}} \times 100$$

Figure 8

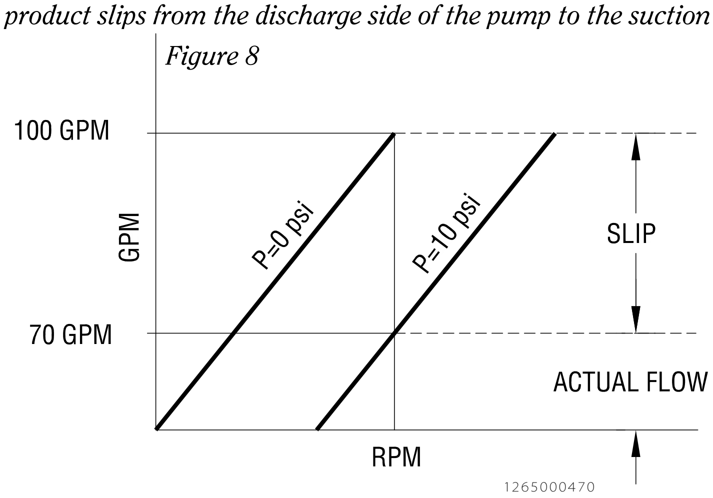


Figure 9

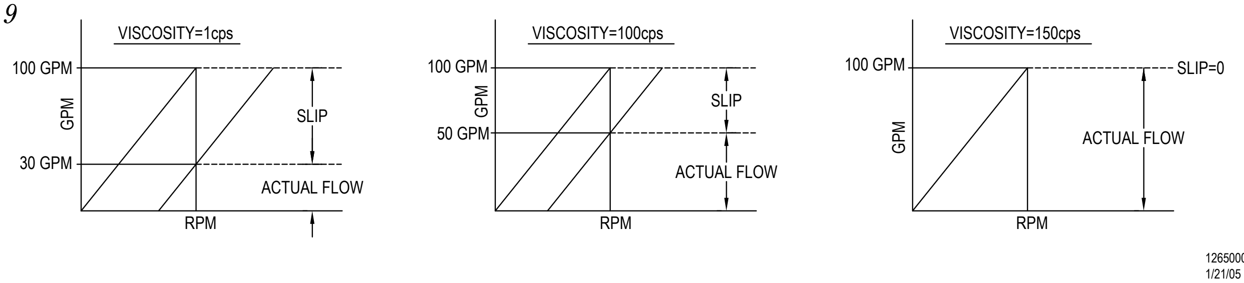
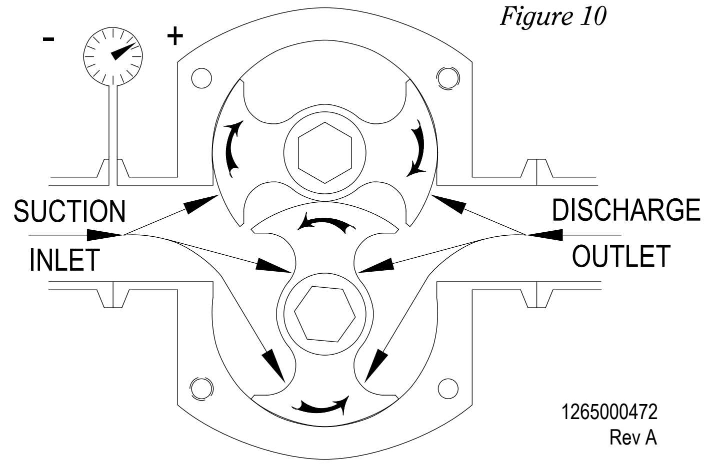


Figure 9 shows that as product viscosity increases, slip decreases. As product slip decreases, volumetric efficiencies increase. At 200 cps the slip is zero and volumetric efficiency is 100%, assuming that the net inlet pressure of the pump is satisfied. At 200 cps, the zero psi pressure line is used for sizing the FKL.

Differential Pressure

The differential pressure that the pump must generate is key to sizing. Differential pressure is the total pressure against which a pump must work. Generally the suction pressure is negligible and the discharge pressure makes up nearly all of the differential pressure. If the suction gauge pressure is positive, the differential pressure across the pump is the discharge pressure minus the suction gauge pressure.

Figure 10

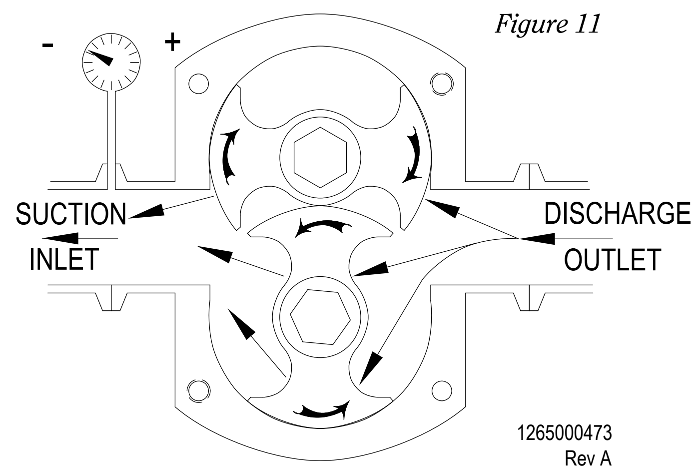


Differential Pressure (psi) = Discharge Pressure (psi) – Suction Pressure (psi)

The pressure gradient inside the pump shows that the positive pressure on the suction side (Figure 10) of the pump assists the rotor movement and reduces the product slip inside the pump. Pressurized tanks and product levels above the pump on the suction side contribute to positive suction pressures.

The pressure gradient inside the pump shows that the negative pressure on the suction side (Figure 11) of the pump pulls against the movement of the rotors and increases product slip inside the pump. A vacuum drawn on a tank and frictional losses in inlet piping contribute to negative suction pressures.

Figure 11



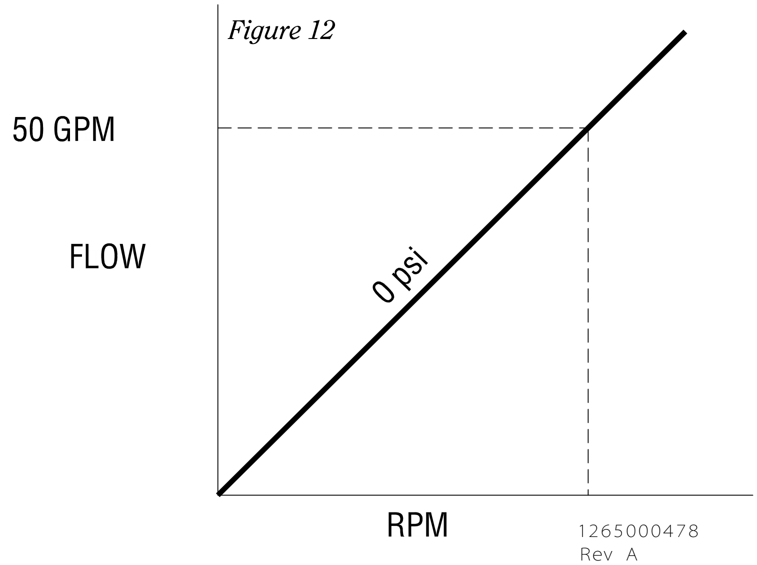
Pump Speed

Pump speed is affected by product viscosity and the differential pressure. At zero slip, the pump speed will be directly related to the flow rate and displacement. The zero psi line on the pump curves may be used to determine the pump speed. In the FKL pump the slip stops at a product viscosity of about 200 cps and in the FL II pump it stops at about 500 cps.

For water like products with a viscosity of one cps, calculate the differential pressure. Select the curve labeled with that differential pressure to determine the pump speed required.

If the product viscosity falls in between 1 cps and zero slip, you need to use a viscosity correction to determine the pump speed. The FL II viscosity adjustment curve is on page 32.

Figure 12



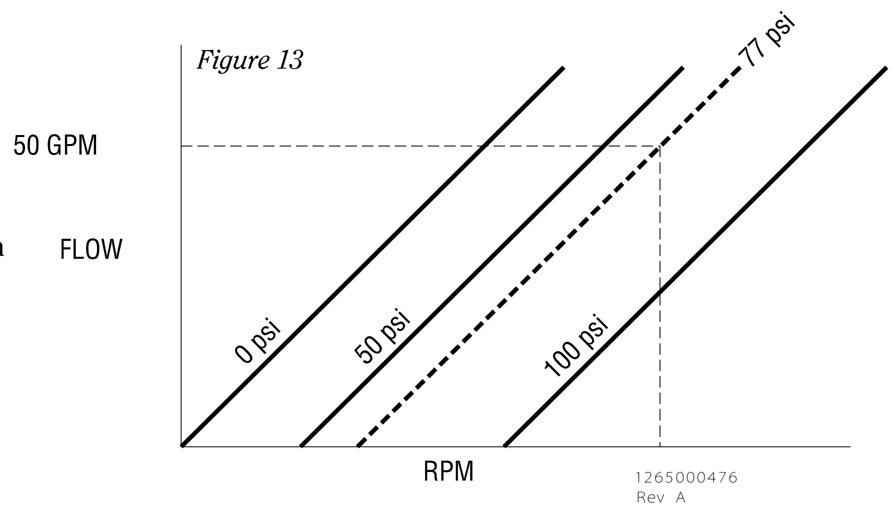
Work Horsepower (WHp)

The power required to pump the product through a system. This is based on the pump speed and the pressure against which it is working.

Viscosity Horsepower (VHp)

The power required to move product through the pump. This is based on the pump speed and the viscosity of the product as it passes through the pump. The measurement is take with zero backpressure on the pump.

Figure 13



C. Frictional Losses through Sanitary Tubing

Friction loss is the loss of pressure energy through the interaction between the product and the tubing. The higher the product viscosity, the more pressure energy is lost through friction. This manual contains six graphs on pages 42-47 that can be used to calculate the system pressure drop through 1 ½”, 2”, 2 ½”, 3”, 4” and 6” tubing. Use the product’s apparent viscosity and required flow rate to determine the frictional pressure drop through 1 foot of tubing, then multiply by the length of tubing in your system to obtain the total tubing frictional loss.

Examples 1, 2 and 3 show the effect of product viscosity and tubing size on frictional loss.

Example 1 – Determine the pressure loss resulting from 50 gpm of water at 1 cps flowing through 100 ft. of 1 ½” tubing. (see figure 14)

Directions:

1) Locate the product viscosity on the horizontal axis.

2) Move up vertically until you intersect the system flow rate.

3) Move horizontally and record the pressure loss in psi / foot tubing.

Given:

p_f = tubing frictional loss (psi) = f × L

f = frictional pressure loss (psi/ft tubing)

L = tubing length (ft)

Refer to figure 14:

f = 0.1 psi/ft

L = 100 ft

p_f = 0.1 psi/ft × 100 ft

p_f = 10 psi

Example 2 – Now determine the pressure loss resulting from a flow rate of 50 gpm of 300 cps product flowing through 100 ft. of 1 ½” tubing.

f = 1.1 psi/ft

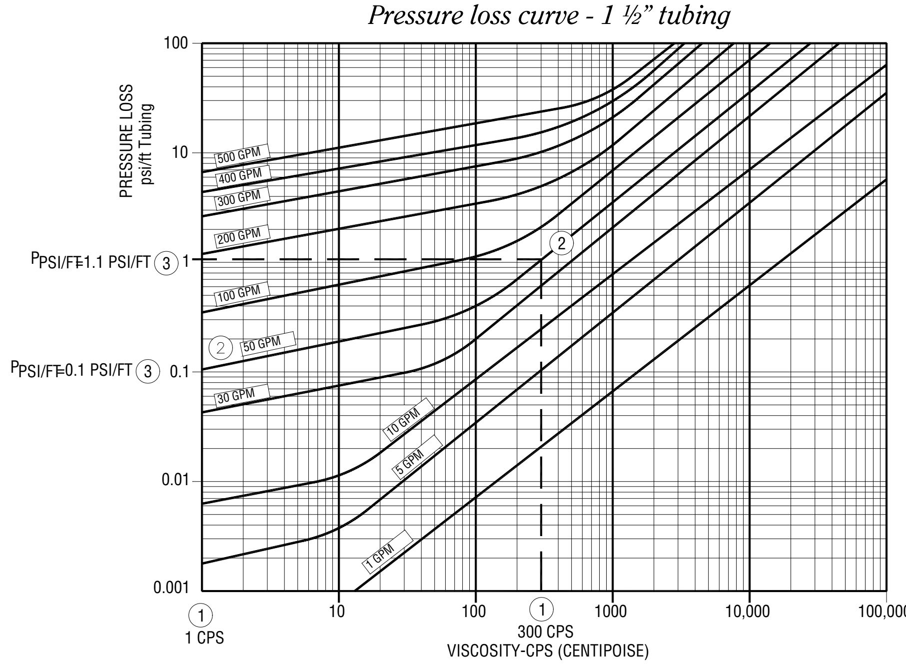
L = 100 ft

p_f = 1.1 psi/ft × 100 ft

p_f = 110 psi

Increasing the product viscosity from 1 cps to 300 cps increases the frictional pressure losses from 0.1 psi/ft to 1.1 psi/ft.

Figure 14 - Example 1 & 2 - Pressure loss curve - 1 ½” tubing



Example 3 – (see figure 15) Increasing the tube size will reduce pressure loss through the piping system. 300 cps viscosity product flowing at 50 gpm through 1 ½” tubing will develop 110 psi of system backpressure. Now repeat the example using 2” tubing and compare the result.

$f = 0.32$ psi/ft

$L = 100$ ft

$p_f = 0.32$ psi/ft $\times$ 100 ft

$p_f = 32$ psi

Increasing the tubing diameter from 1 ½” to 2” decreases the pressure loss by 0.78 psi / foot of tubing.

Figure 15 - Example 3 - Pressure loss curve - 2” tubing