Positive Displacement Pumps

Positive displacement pumps are those in which volumes of the inlet fluid are periodically captured mechanically and transported to the discharge at a higher pressure where they are released. They have the advantage that they deliver a particular flow rate relatively independent of the head rise.

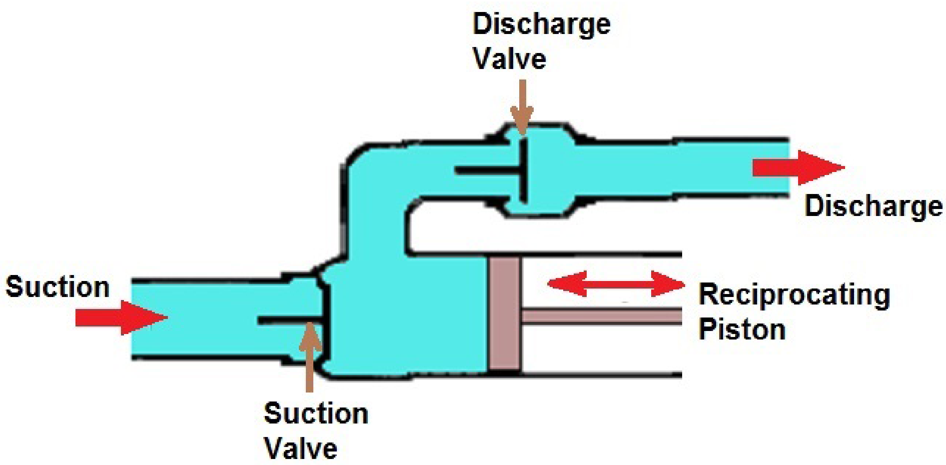

Figure 1: Schematic of a simple positive displacement pump.

Positive displacement pumps come in different types: many are driven by a reciprocating mechanism with passive suction and discharge valves to prevent backflow as illustrated in Figure 1. Another classic type is the peristaltic pump (which mirrors the action in animal intestines) comprised of a flexible tube that is squeezed by the action of a mechanical device that acts to move the liquid (or deformable solid/liquid) along the tube as depicted in Figure 2 (right). The advantage of such a pump is that the liquid only contacts the tube and this has great advantages as a pump for sterile medical applications or for processes handling corrosive or dangerous liquids. Disadvantages are the inability to pump against a substantial pressure increase and a low efficiency due to leakage; in addition peristaltic pumps require regular maintenance due to the finite life of the flexible tube. The performance of a peristaltic pump is highly dependent on the size

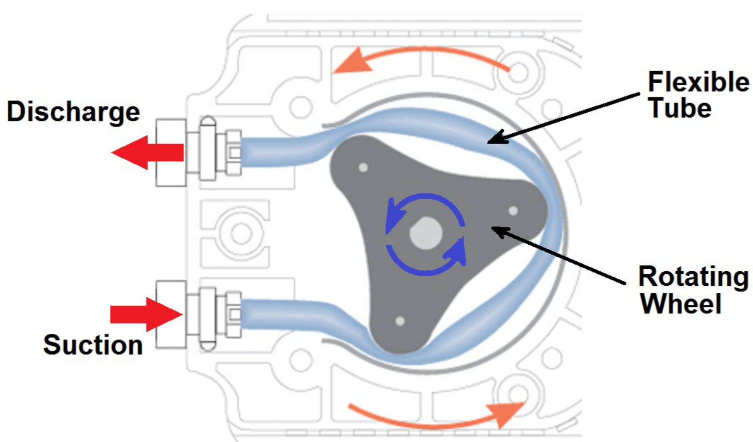

Figure 2: Schematic of a typical peristaltic pump.

and flexibility of the installed tubing. The flowrate is essentially linear with the speed of rotation though it also depends to some extent on the viscosity of the fluid being pumped. The flow rate does decrease with the head rise though the deficit decreases as the flexibilty of the tube increases.

Another common type of positive displacement pump is the gear pump shown in Figure 3. These, too,

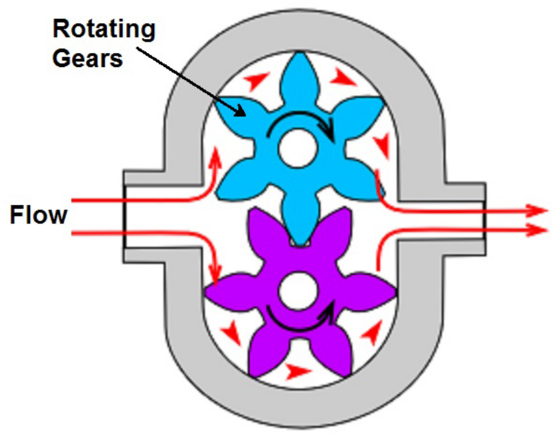

Figure 3: Schematic of a typical gear pump.

come in a wide variety of designs for the rotors; as another example we feature here the performance of the AMPCO positive displacement pumps whose rotor design is exemplified in Figure 4.

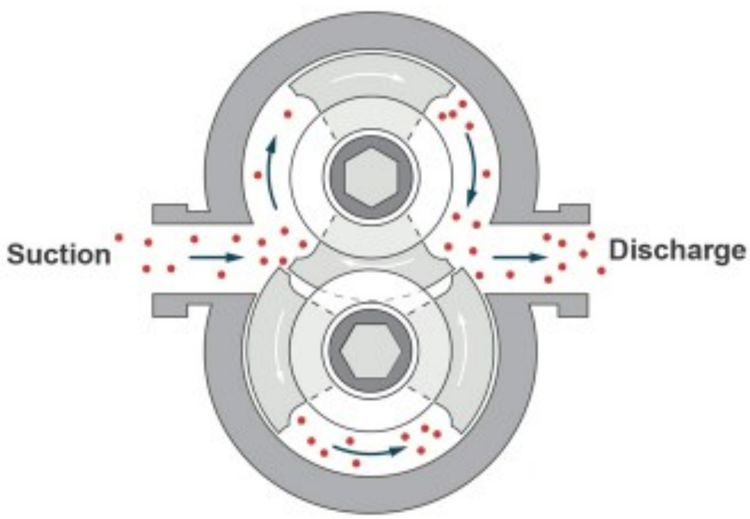

Figure 4: Geometry of the AMPCO ZP1 positive displacement pumps.

We present here the non-dimensional performance of these APMCO "circumferential piston pumps". A dimensionless head coefficient, ψ, is defined as

$$\psi \quad = \quad gH/R^2\Omega^2 \tag{Mbj1}$$

and the dimensionless flow coefficient, ϕ, is defined as

$$\phi \quad = \quad Q/R^2L\Omega \tag{Mbj2}$$

where the total head rise across the pump is denoted by H (in m), g is the acceleration due to gravity (in m/s^2), Q denotes the volume flow rate through the pump (in m^3/s), Ω denotes the rotation rate of the rotors (in $radians/s$) and R and L are respectively the rotor radius and axial length (respectively $0.067m$ and $0.0439m$ for the ZP1-130 pump with a shaft spacing of $0.114m$). The above definitions for head and flow coefficients roughly parallel those used for centrifugal and axial flow pumps in section Mbbc.

The data in Figure 5 is derived from dimensional information presented in the AMPCO webpage (http://www.ampcopumps.com) on a series of ZP1 pumps with rotors ranging in size from $R = 0.0388$ to $0.1047m$.

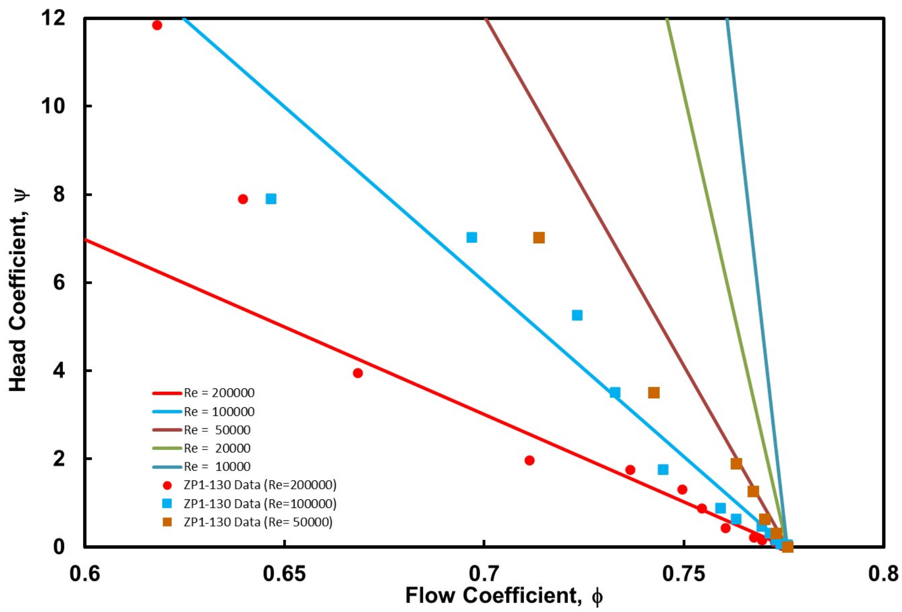

Figure 5: Non-dimensional performance of the AMPCO ZP1-130 positive displacement pump. The data points for three different Reynolds numbers were derived from dimensional information presented in the AMPCO webpage. The lines are the theoretical performance curves from equation (Mbj6) for five different Reynolds numbers as indicated.

A theoretical performance can be constructed as follows. In the absence of any pressure rise, the flow rate, Q_0 (in m^3/s), is simply given by the volume of liquid, D, captured during one rotor revolution (known as the "displacement") multiplied by the revolutions per second, $\Omega/2\pi$ (note that for a particular rotor geometry $D \propto R^2L$). We denote this zero pressure rise flow rate by $Q_0 = \Omega D/2\pi$. At non-zero pressure rise, the leakage flow, ΔQ, back through the narrow passages surrounding the rotor can be approximately evaluated using the analysis of section (Bib) for viscous flow between parallel plates as

$$\Delta Q \quad = \quad \kappa_1 \, \rho g H \; R^2 L/\mu \qquad \text{(Mbj3)}$$

where μ is the dynamic viscosity in kg/ms and κ_1 is some dimensionless constant to be determined. The combined flow rate, Q, is then

$$Q \quad = \quad Q_0 \; - \; \Delta Q \quad = \quad \Omega D/2\pi \; - \; \kappa_1 \, \rho g H \; R^2 L/\mu \qquad \text{(Mbj4)}$$

Then utilizing the definitions of ϕ and ψ and defining a Reynolds number, $Re = \rho\Omega^2 R/\mu$, it follows that the estimated dimensionless performance is given by

$$\phi \quad = \quad Q_0/\Omega R^2 L \; - \; \kappa_1 \, \rho g H R^2 L/(\mu R^2 L \Omega) \quad = \quad D/(2\pi R^2 L) \; - \; \kappa_1 \, \psi \, Re \qquad \text{(Mbj5)}$$

We denote the geometric ratio $D/(2\pi R^2 L)$ by κ_2 so that the dimensionless performance is given by

$$\phi \quad = \quad \kappa_2 \; - \; \kappa_1 \; \psi \; Re \tag{Mbj6}$$

The value of κ_2 for the ZP1 pumps is 0.776; values for κ_1 from the tabulated test data for the ZP1 pumps are more scattered but lie between 0.66×10^{-7} and 2.5×10^{-7} for a wide range of flow conditions and Reynolds numbers. The performance curves for the pump ZP1-130 according to equation (Mbj6) for five different Reynolds numbers are plotted in Figure 5.