Technical definitions

Technical definitions for pumps – part three

Many people who write about or discuss pump topics don't fully understand pumps and don't realize how important all the details are. However, it's the details that are assumed, rather than quantified, that cause a lot of the problems, warns pump consultant Brian Nesbitt. In this third of a series of articles, he continues his explanation of pump terminology.

Let us consider what pumps do. The first 'fact' discussed in any pump application is "What is the flow and head"? At face value, this seems obvious and accurate – but there are hidden problems. Initially, all pump applications are discussed using rotodynamic pump terms (head) but there are always pressure implications.

Flow

Pump flow is assumed to be 100% liquid because pumps are generally designed to handle liquids. This is always true unless the manufacturer's designation or application descriptions state otherwise. The hidden factor is that this is inlet flow; that is, liquid flow into the pump inlet connection. The 'inlet' limitation is not usually a problem because most pumps don't operate with a large differential head and hence there is no significant change in liquid density. Without a change in liquid density, the outlet flow is the same as the inlet flow, thus specifying the 'inlet flow' is not a process restriction.

However, sometimes there is a change in liquid density and this can lead to other problems not associated with 'flow'. Remember that pumps are flow machines not mass machines; pumps are concerned with volumes. If mass flow is important for the process then the pump user is responsible for the conversion from 'mass' to 'volume'. Even if there is a change in liquid density, the mass flow at the outlet will be the same as the mass flow at the inlet, possibly less by small leakage allowances. Internal recirculation and parasitic losses within the pump don't affect process flows or mass flow.

Consider rotodynamic pumps as 'constant energy machines'; this is why a range of flows is possible with a fixed-speed pump. This concept cannot be realized in practice because of the physical design and operating variable problems and is shown in the variation of pump efficiency. Consider positive displacement pumps as

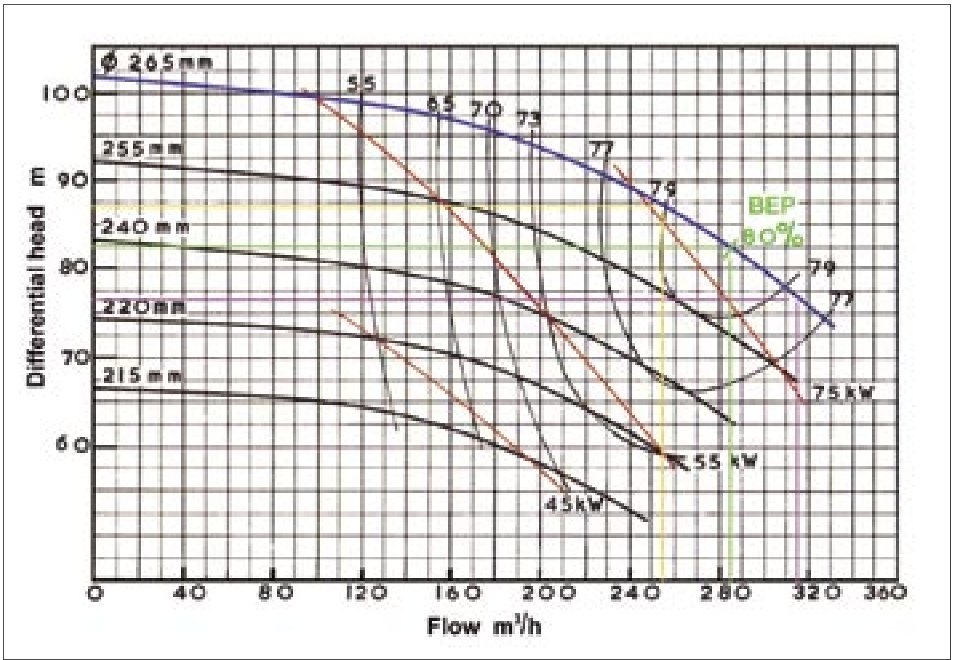

Figure 1. *A typical centrifugal pump performance curve.*

'constant flow machines'; this is why fixed-speed pumps don't have a flow range. Some pump designs can achieve this concept – under specific operating conditions.

Units

Flow is specified in many units and some are not explicit. The SI unit of flow is m^3/s but m^3/hour is very popular. Small flows may be specified as litre/minute or litre/hour. When old-fashioned imperial units are used, the gallon is very popular; but there are two different gallons! The original imperial gallon, as used in the UK, is about 277.418 cubic inches (4.546 litres), whereas the Americans use a USgallon, which is 231 cubic inches (3.785 litres). Oilfield applications may specify flow in barrels; but, again, there is more than one barrel! The most popular barrel in the oilfields is 42 USgallons but there are also 48 USgallon and 55 USgallon barrels.

For those really interested, the UK inch is exactly the same size as the American inch – 25.4 mm – though this hasn't always been the case. Standards were rationalized in the mid 20th century when it was thought that SI would conquer the whole world. About 20% of world trade is still resisting the metric system and SI.

A cautionary note

SI values supplied on American documentation should be treated with suspicion as it seems that many misunderstandings concerning the correct use of SI terms are still prevalent among American engineers. For example, the importance or reasoning behind the use of upper-case letters for some units often does not seem to be understood. It is essential that people who provide technical information do so in terms and units that are familiar to them; others may subsequently convert to different units – at their own risk!

Rated flow

The pump inlet flow, which will be measured, and guaranteed, when the pump is tested. Rated flow is associated with rated differential head for rotodynamic pumps, and rated outlet pressure for positive displacement pumps. For a fixed-speed rotodynamic pump, the pump is capable of operating at a range of flows with corresponding differential heads (Figure 1). The ideal application selection would have the pump operating at its best efficiency point (BEP). But the flow can be adjusted easily by changing the differential head; throttling the pump outlet is common practice although very inefficient. The orange and mauve lines in Figure 1 indicate changes of ±10% flow. The flow can be reduced by 10% by increasing the differential head by 5.5% and increased by reducing the differential by just over 7%. Notice the pump efficiency is reduced in both cases. The absorbed power can be judged by reference to the red 75 kW line. Even though the pump performance curve shows head and flow for 'zero' flow, the pump manufacturer doesn't expect the pump to operate there; notice where the efficiency and power curves finish. Operating a pump away from its BEP has incidental affects that impact on life and reliability.

Throttling

Introducing a pressure drop in a fluid circuit. Throttling is commonly performed using globe valves. It converts 'head' or pressure into heat, which increases the temperature of the liquid.

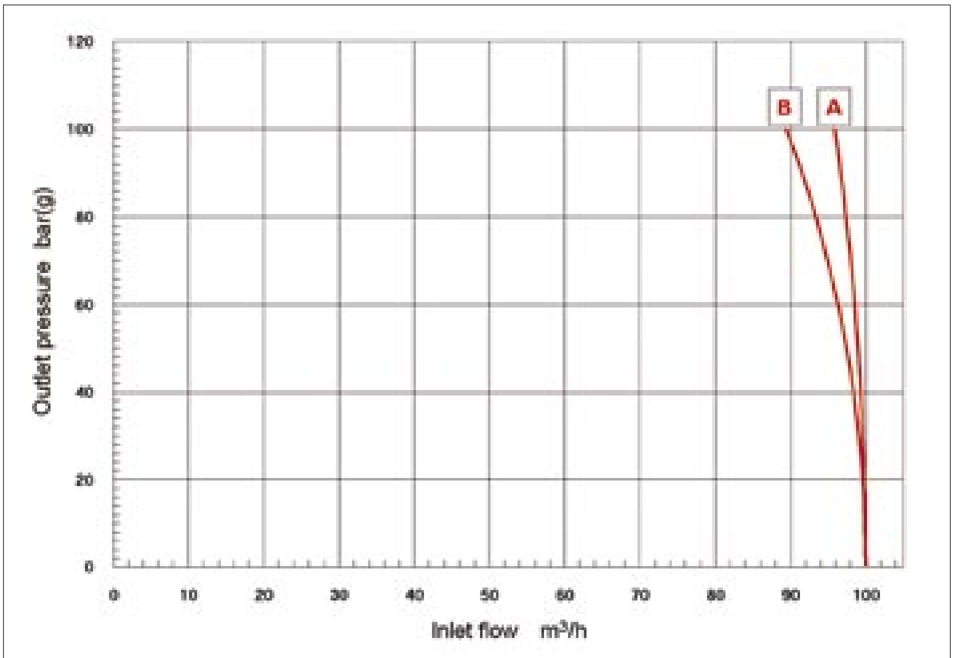

Figure 2. *A plunger pump 'head-flow' characteristic.*

Runout

If a rotodynamic pump is operated with very low differential head, it is likely the flow will increase dramatically and so will the absorbed power. Pump drivers may need to be oversized to accommodate 'runout', which may occur during start-up.

Positive displacement pumps have very different 'head-flow' characteristics, as seen in Figure 2. This is a plunger pump characteristic showing the effects of two different pump designs or two different liquids. The actual shape of the 'curve' is dependant upon the pump design, the operating conditions and the liquid properties. Notice particularly that the flow doesn't approach zero. Plunger pumps and piston pumps have one of the steepest characteristics of all pumps. Rotodynamic pumps tend to have a shallow characteristic (close to horizontal) and positive displacement pumps tend to have steep characteristics (close to vertical). However, generalizations are sometimes counterproductive: axial-flow rotodynamic pumps have quite steep characteristics; peristaltic pumps have a very shallow characteristic.

Figure 2 shows that curves can be unsuitable for positive displacement pump selection. Figure 3 shows a magnified version of the active portion of the curve. High-pressure positive displacement pumps are generally selected by calculation rather than graphically. High pressure is a very dangerous term and I apologize for using it. A high-pressure peristaltic pump might be 20 bar(g); a high-pressure plunger pump might be 4000 bar(g). The blue lines in Figure 3 indicate the efficiency of a representative, well-designed pump.

In Figure 3, characteristic A shows the inlet flow varies by about 4% for a 100 bar(g) change in outlet pressure. Characteristic B is slightly shallower, showing more than 10% flow reduction. These steep characteristics indicate why piston and plunger pumps make very good metering pumps.

Looking at Figures 1, 2 and 3, and ignoring the characteristic differences, there is another significant distinction. Figure 1 uses 'metres' while Figures 2 and 3 use 'bar(g)'. Rotodynamic pumps use 'metres' because they convert kinetic energy into static head. Positive displacement pumps use pressure units directly as there is no kinetic energy involved. There is a direct relationship between head and pressure, as shown in Equation 1:

$p = \rho gh$ [Equation 1]

where p = pressure; ρ = density; g = gravitational acceleration; and h = head. The product of density and g gives specific weight, a term rarely used with pumps.

Note that g is shown as a variable; this is because SI provides an equation for the accurate evaluation of local terrestrial values of gravitational acceleration, as shown in Equation 2:

$$g = 9.7803(1+0.0053\sin^2\varphi) - 3\times10^{-6}z$$ [Equation 2]

where φ is the latitude in degrees and z the altitude in metres.

It is easy to see from Equation 1 that a rotodynamic pump head can produce many different pressures depending on the liquid density and the pump location.

Head

A useful term in the context of rotodynamic pumps but complicated because it can define different properties: elevation (static head), energy (potential and kinetic), and an abstract 'pressure'. Head is mostly used as an abbreviation of differential head or static head.

It should be noted that the difference in elevation between the pump inlet and outlet connections is not usually significant in calculations, but can be very significant in large, low differential head applications.

Pressure

The force per unit area exerted by a fluid. The SI unit of pressure is the pascal (Pa), defined as a force of one newton (N) applied to one square metre. The pascal is an ideal theoretical unit and allows easy integration into calculations. Unfortunately, the pascal is far too small to be a useful industrial unit. Industry has safety concerns regarding confusion created by the use of different pressure multiples for inlet and outlet streams; kPa would be useful for inlets and MPa for outlets, but an MPa is a thousand times bigger than a kPa. In industrial operations, the bar is preferred as the common pressure unit; 1 bar ≡ 100 000 Pa.

1 bar ≡ 14.5038 lb/in^2 (1 lb ≡ 0.453592 kg)

1 kg/cm^2 ≡ 14.2233 lb/in^2

1 ata = 1 kg/cm^2(a)

1 atu = 1 kg/cm^2(g)

Atmospheric pressure

The pressure exerted by atmospheric air. Unfortunately, this is a variable, not a constant value. Atmospheric pressure is dependant upon the location and the weather! SI has defined a 'standardized' sea-level absolute atmospheric pressure of 1.01325 bar(a). In average locations, weather can cause pressure variations of ±4% but in extreme conditions the pressure can be reduced by −13%. Elevation above sea level produces a reduction in atmospheric pressure. At 1000 m the pressure is reduced to about 89%, and at 2000 m the pressure is about 78% of that at sea level.

Remembering that liquids have a very low tensile strength and cannot be pulled, and depending upon the type of system, atmospheric pressure provides all or part of the 'push' to get liquids into the pump inlet.

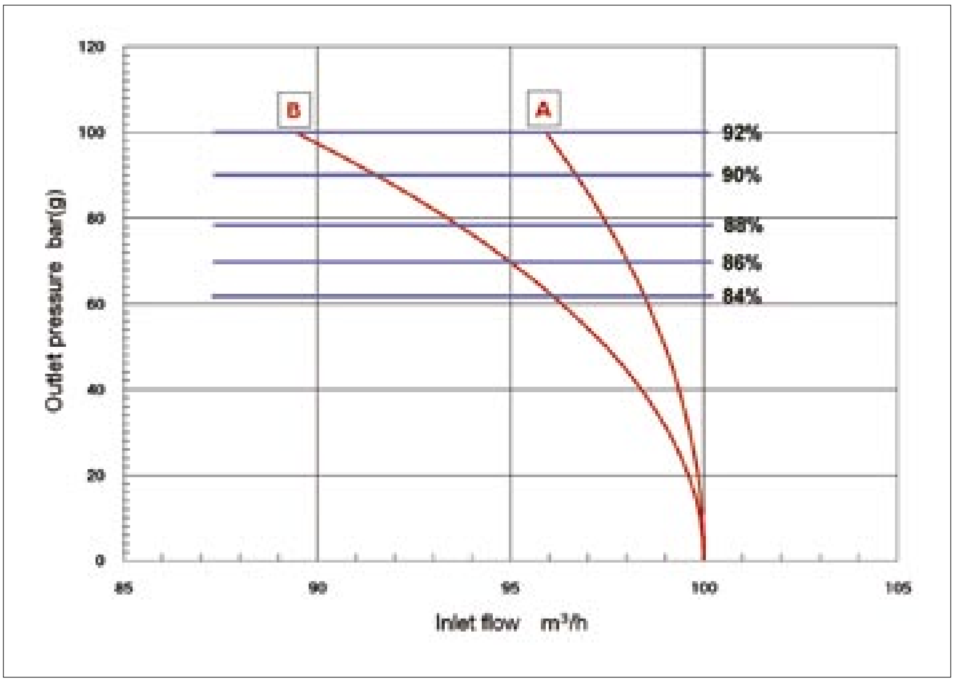

***Figure 3**. Magnified section of the plunger pump 'head-flow' characteristic from Figure 2.*

Absolute pressure

Pressure can be specified relative to two different reference points. Absolute pressure is a pressure measurement scale where 'zero' pressure corresponds to a complete vacuum.

Gauge pressure

Gauge pressure measures relative to atmospheric pressure; a 'zero' reading corresponds to atmospheric pressure. Thus gauge pressure is not a specific pressure because atmospheric pressure is a variable. Most industrial instruments measure gauge pressure. Manometers, used for low pressure measurement in many pump tests, measure 'gauge head' or 'differential head'.

It is important to define pressure values correctly. For high pressures, the difference between 'absolute' and 'gauge' is insignificant. For low pressures, particularly on pump inlet systems, the difference can be critical. It is common practice to differentiate between the two pressure scales by adding a suffix to the pressure units: bar(a) and bar(g) for example. This practice is frowned upon by the SI system, but it is unlikely that SI will ever be in a position to prevent it.

Pressure head

A silly, meaningless term used by people who aren't quite as technical as they think.

Density

The mass per unit volume, applicable to all matter. Water at 20°C and standard atmospheric pressure has a density of 998.323 kg/m^3. Note that this is slightly different to the saturated water conditions given in steam tables, 958.122 kg/m^3; however, cheap steam tables don't list pressurized water values! Also be aware that density values quoted by Americans might use 60°F or 65°F as the benchmark temperature rather than 68°F (ie 20°C). ■

Contact

Brian Nesbitt is an independent consultant specializing in positive displacement pumps. He has been involved with pumps and pumping systems since 1974. A member of the BSI MCE/6 committees, Brian represents the UK on CEN and ISO PD pump committees.

If you would like Brian to review or include a definition in future articles, he can be contacted at: briannesbitt@btinternet.com