7

Understanding Pump Curves

Pump performance curves

Pump performance curves are the least used, least consulted, least appreciated, and least understood aspect of the world of industrial pumps. The plant personnel who most need their pump curves, mechanics and operators, generally don't have the curves and accompanying information at their disposal. The people who control the performance curves store them in a file, in a drawer, in a cabinet that's almost never opened. They don't share the information contained in the curves with the people who need it. Maybe it's because they themselves don't understand the information to share it. In the next few paragraphs and pages, we're going to explain the pump performance curves. This might be the most important chapter of the book.

In reality, the performance curve is easy to understand. It isn't rocket science. The performance curve indicates that the pump will discharge a certain volume or flow (gpm) of a liquid, at a certain pressure or head (H), at an indicated velocity or speed, while consuming a specific quantity of horsepower (BHP). The performance curve is actually four curves relating with each other on a common graph. These four curves are:

1. The Head-Flow Curve. It is called the H-Q Curve.
2. The Efficiency Curve.
3. The Energy Curve. It records Brake Horsepower, BHP.
4. The Pump's Minimum Requirement Curve. Its called Net Positive Suction Head required, NPSHr.

Think of the pump curve like the dashboard or control panel of a car. No one would operate a car without the dash instrumentation panel.

The information on the dash panel is located right in front of the eyes of the operator of the car. It's a shame that most pump operators don't have their control panel (the curve) before their eyes, or even within reach, as they operate the pumps. This is the source of many problems with pumps.

History

Some three thousand years ago, the ancient Romans and Greeks understood the hydraulic laws that govern today's modern pumps. They had already calculated the physics and math required to bring water from the mountain streams, down through giant aqueducts and underground clay pipes, and spray a stream of water 12 ft up into the air in the fountain at the public square. They understood the laws of gravity and the concept of atmospheric pressure. They knew at what volume, and at what speed, the water had to fall through the troughs in the aqueducts, to arrive into the heart of the cities and supply the needs of the growing population.

About 2,200 years ago, a Grecian named Archimedes, developed the first practical pump. He took a hollow tree trunk, and carved an internal spiral corkscrew type groove from one end of the trunk to the other. By lowering one end of the tree trunk into a mountain lake and rotating the trunk (on its axial centerline), the water flowed upward through the spiral groove and dropped out of the upper end of the tree trunk. By positioning the upper end of the tree trunk over a trough of an aqueduct, the water began flowing down the aqueduct to irrigate crops, or to supply the city below with fresh water.

In those days, there were no oil refineries, nor bottlers of carbonated soda, nor sulfuric acid plants. There was only one liquid to consider, and move in large quantities ... fresh water from the mountains. With only one liquid under consideration, fresh water, and no sophisticated instrumentation, they measured the water's force, or pressure, in terms of elevation. It is for this reason that today all over the world, pump manufacturers use the term 'Head' measured in meters or feet of elevation to express pressure or force. The term 'flow' expresses volume over time, such as gallons per minute, or cubic meters per second.

Head versus pressure

There's a language barrier between the pump manufacturers and the pump users. They use different terminology. Pump users, the operators and mechanics, use pressure gauges that read in psi, pounds per square inch (or kilograms per square centimeter, in the metric system). The pump manufacturer denotes pressure in feet of head (or meters of head). The pump operator needs a pump that generates 20 psi. The manufacturer offers a model that generates 46 ft of head.

To understand pumps and analyze their problems, its necessary to dominate the formula that changes feet of head (H) into psi. This is explained in Chapter 2, but here is a brief review:

The formula is:

$$\textbf{Pressure in psi} = \frac{\textbf{H (Head in feet)} \times \textbf{sp. gr.}}{\textbf{2.31}}$$

And in the other direction:

$$\textbf{Head in Feet} = \frac{\textbf{psi} \times \textbf{2.31}}{\textbf{sp. gr.}}$$

If the liquid is water, the specific gravity is 1.00. We see that two factors separate 'psi' from 'head in feet'. First is the 2.31 conversion factor, and second, the specific gravity.

The pump companies develop their curves using head in feet (H), because when they make a new pump, they don't know the ultimate service of the pump (they don't know the liquid that the pump will be pumping), but they do know how many feet of elevation the pump can raise that liquid. This is why it's necessary to specify pumps in feet of head and not in psi. Let's begin by exploring the H-Q curve of the pump, using feet of head.

H-Q

The matrix of the pump curve graph is the same as the mathematical 'x-y' graph. On the horizontal line, the flow is shown normally in gallons per minute or cubic meters per second. The vertical line shows the head in feet or meters. See Figure 7–1.

By definition, the pump is a machine designed to add energy to a liquid with the purpose of elevating it or moving it through a pipe. The pump can elevate a liquid in a vertical tube up to a point where the weight of the liquid and gravity will permit no more elevation. The energy contained in the liquid's weight is the same as the energy produced by the pump. This point on the pump curve would be the 'shut-off head'. Shut-off head is the point of maximum elevation at zero flow. It's seen in Figure 7–2.

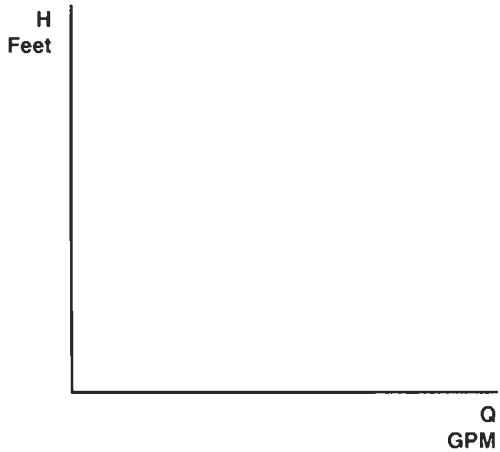

Figure 7-1

Once again, imagine starting a pump and raising the fluid in a vertical tube to the point of maximum elevation. On the curve this would be maximum head at zero flow. Now, rotate the running pump on its centerline 90°, until the vertical tube is now in a horizontal position. The very action of rotating the running pump on its centerline would trace the pump's curve. Any elevation in feet would coincide with a flow in gallons per minute. Consider the graph show in Figure 7–3.

On the graph, if point 'A' represents 10 ft of head at 0-gpm, and if point 'F' represents 10 gpm at 0 ft of head, then point 'C' on the curve represents 8 ft of head at 6-gpm. Here we see that the pump is always on its curve. The pump can operate at any point on this curve from point 'A' to point 'F'. At any specific head, this pump will pump a specific flow, or gpm corresponding to the head.

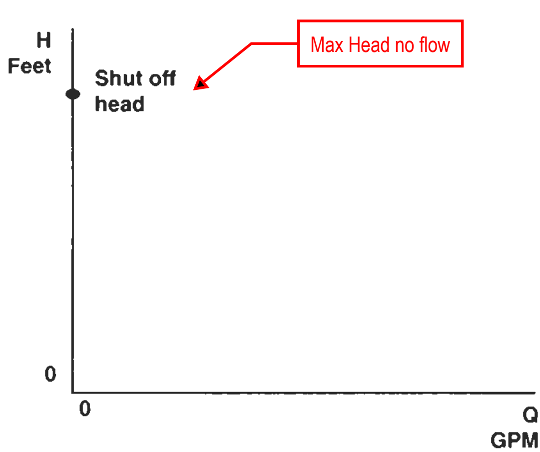

Figure 7-2

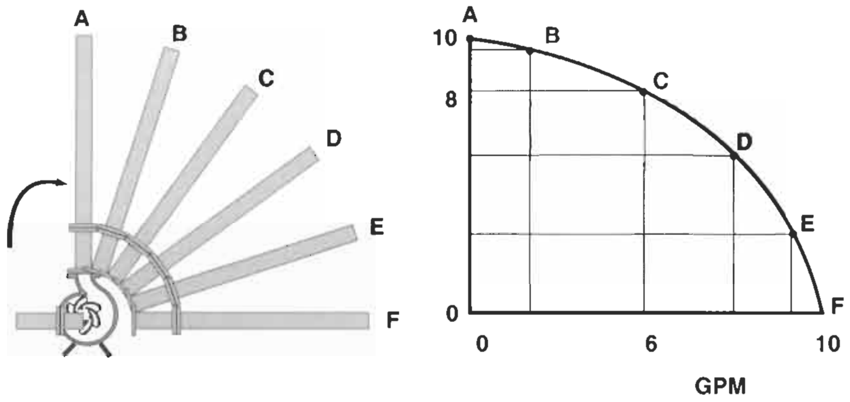

Figure 7-3

AUTHOR'S NOTE

Sometimes you hear people say that the pump is operating off its curve. If the velocity, the impeller diameter and design are correct, if the pump has all its parts installed and functioning correctly, including the mechanical seal and coupling, it is impossible to operate off the curve. The pump will be somewhere on its curve between shut-off head and maximum flow a zero elevation.

The pump can be too far to the right, or too far to the left of its best efficiency point (BEP) but it cannot be off the curve. Conceivably, the pump can be operating off the graph, and even off the page, but it cannot be off the curve. If the pump is off the curve, something else is out of control, like the velocity, or impeller diameter, assembled parts and tolerances. Now, the 'lack of control' is the real problem, and not the pump.

Pump efficiency

Let's talk about the pump efficiency. Imagine a small pump connected to a garden hose squirting a stream of water across the lawn. You could direct the flow from the hose up into the air at about a 45-degree angle, and the stream would arc upward and attain its best distance of reach from the nozzle or launch point. The stream of water would attain a specific height into the air and a specific distance. The efficiency curve of a pump is seen as the trajectory or arc of a stream of water. When squirted from a hose, the elevation that attains the best distance, when plotted onto the pump curve, is called the best efficiency point (BEP). On the pump curve, it is seen as in Figure 7–4.

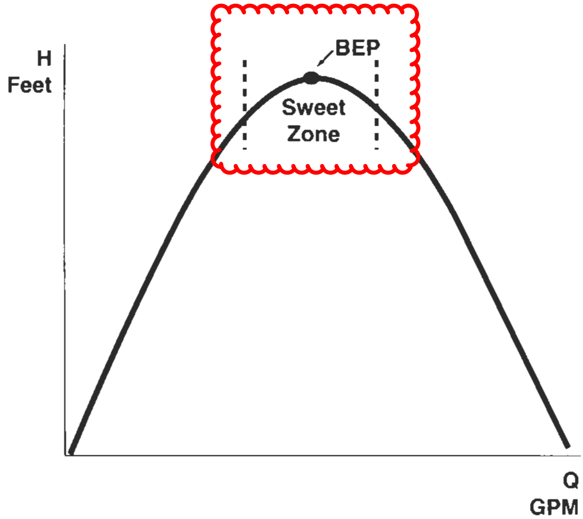

Figure 7-4

The energy (BHp) curve

Next, let's consider the energy curve, the brake horsepower (BHp), required by the pump. This curve is probably the easiest to interpret because it is practically a straight line. Consider the following: the pump consumes a certain quantity of energy just to maintain shut-off head. Then, as flow begins and increases, the horsepower consumption normally increases. (On certain specific duty pumps, the BHp may remain mostly flat or even fall with an increase in flow.) The BHp curve is normally seen this way (Figure 7–5).

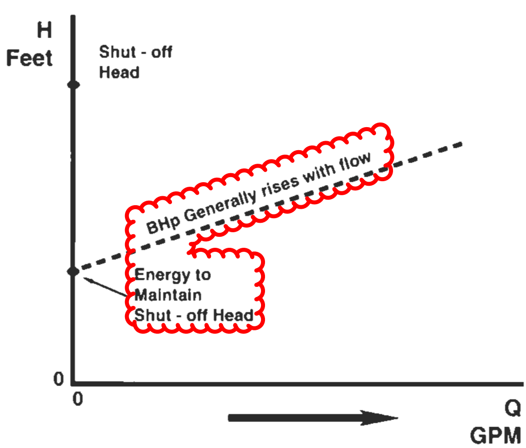

Figure 7-5

The pump's minimum requirements (NPSH)

The last component of the pump performance curve is the curve of the minimum requirements, or NPSH. Actually, the reading on the pump curve is the NPSHr, the Net Positive Suction Head required by the pump. There is a complete discussion on NPSHr and NPSHa, and the result of not respecting or understanding them in Chapters 3 and 4. Basically, the NPSHr curve, beginning at 0 flow, is mostly flat or modestly rising until it crosses through the BEP zone. As the NPSHr curve crosses through the BEP of the pump, the curve and values begin rising exponentially. Normally it is seen this way (Figure 7–6).

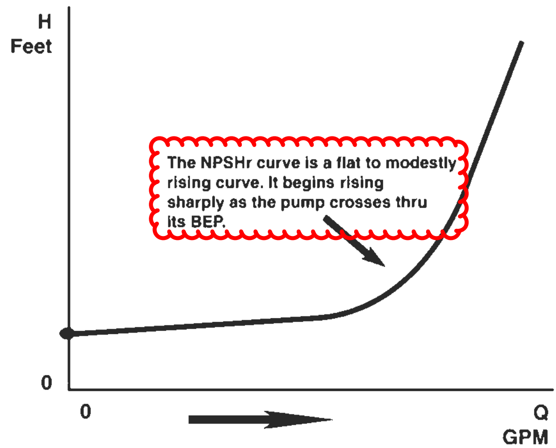

Figure 7-6

Review

See Figure 7–7 for the pump performance curve components.

As you can see in the four components of the pump curve:

- At point 'A' on the H-Q curve, the pump is pumping Q gpm (gallons per minute), at H feet of head. This point on the curve corresponds to the best efficiency, and it is also seen at approximately the middle of the energy curve, and also on the NPSHr curve where it begins its sharp rise.
- At point 'B', the flow is reduced and the head is elevated on the H-Q curve. The pump is being operated to the left of its best efficiency zone. Note that the pump has lost efficiency at this point. The minimum requirements of the pump, the NPSHr, and the horsepower consumption, BHP, have also been reduced, but with the efficiency drop and reduced flow, the pump is vibrating and heating the pumped liquid. The shaft is under deflection, causing stress to the bearings and mechanical seal (or shaft packing rings).

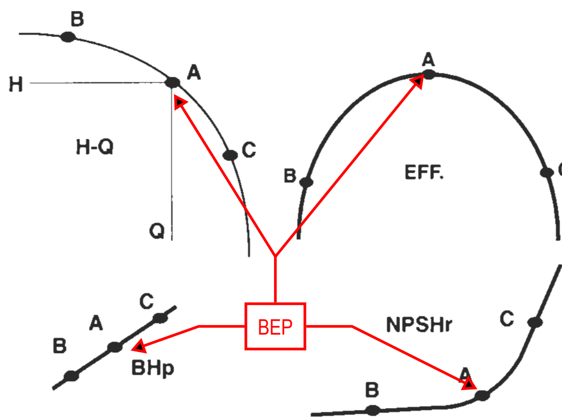

Figure 7-7

- At point 'C', the flow is high and the head (pressure) is low on the H-Q curve. This pump is operating with reduced efficiency, this time to the right of the optimum efficiency point. The BHP is rising and may overload the installed motor. The NPSHr has risen to the point that the pump is being strangled; the liquid is leaving the pump faster than it can come into the pump. The pumped liquid is prone to vaporize or boil. This is the zone where classic vaporization cavitation occurs. And, the shaft is under a deflection load, stressing the seal and bearings.

Let's see these four elements, as they appear on the same graph (Figure 7–8).

You can see in Figure 7–9 that the pump should run at or near zone 'A', its best efficiency point, the BEP. This is the preferred sweet or happy zone. The pump should be specified and operated in this zone.

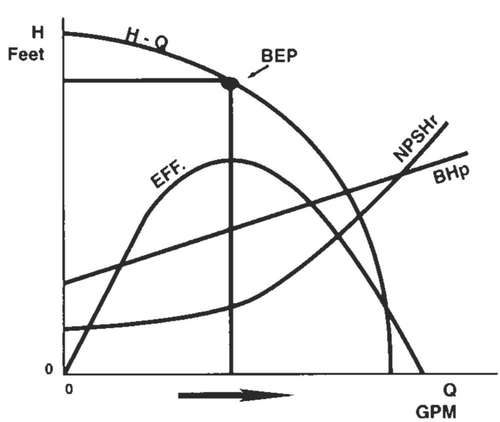

Figure 7-8

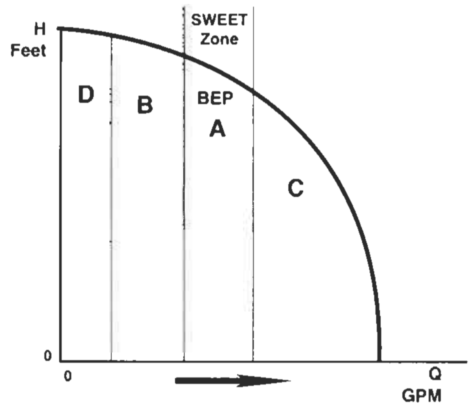

Figure 7-9

Avoid zones 'C' and 'D' at all times. The pump can be operated in zone 'B' only if it is necessary.

Zone 'B' is slightly to the left of the BEP. At this point the pump and impeller is slightly over-designed for the system. The pump will suffer a loss of efficiency. Radial loading is generated on the shaft that can stress the bearings and seal and may even break the shaft. If it is necessary to operate the pump in this part of its curve (to the left of the BEP), for more than a few hours, you should install an impeller with a reduced diameter. Remember that the back pullout pump exists for rapid and frequent impeller changes (see Chapter 6). By reducing the impeller diameter, you can maintain the head and pressure, but at a reduced flow. Figure 7–10 illustrates this point.

In zone 'C' the pump is operating to the right of the BEP and it is inadequately designed for the system in which it is running. To a point

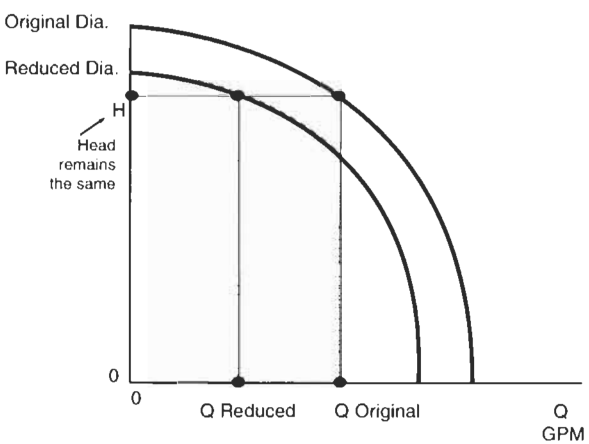

Figure 7–10

you could meet the requirements of flow, but not the requirements of head or pressure. The pump is prone to suffering cavitation, high flow, high BHp consumption, high vibrations, and radial loading (about 240° from the cutwater), resulting in shaft deflection. To counteract these results, the operator should restrict the control valve on the pump's discharge to reduce the flow.

Operating the pump in zone 'D' is very damaging to the pump. Now the pump is severely over-designed for the system, too far to the left of the BEP. The pump is very inefficient with excessive re-circulation of the fluid inside the pump. This low flow condition causes the fluid to overheat. The pump is suffering high head and pressure, and radial loading (about 60° from the cutwater), shaft deflection and high vibrations. To deal with or alleviate these results, you need to modify or change the system on the pump's discharge (ex. reduce friction and resistance losses on the discharge piping), or change the pump (look for a pump whose BEP coincides with the head and flow requirements of the system).

In the final analysis, pumps should be operated at or near their BEP. These pumps will run for years without giving problems. The pump curve is the pump's control panel, and it should be in the hands of the personnel who operate the pumps and understood by them.

Special design pumps

The majority of centrifugal pumps have performance curves with the aforementioned profiles. Of course, special design pumps have curves with variations. For example, positive displacement pumps, multi-stage pumps, regenerative turbine type pumps, and pumps with a high specific speed (Ns) fall outside the norm. But you'll find that the standard pump curve profiles are applicable to about 95% of all pumps in the majority of industrial plants. The important thing is to become familiar with pump curves and know how to interpret the information.

Family curves

At times you'll find that the information is the same, but the presentation of the curves is different. Almost all pump companies publish what are called the 'family of curves'. The pump family curves are probably the most useful for the maintenance engineer and mechanic, the design engineer and purchasing agent. The family curves present the entire performance picture of a pump.

- The family curve shows the range of different impeller diameters that can run inside the pump volute. They're normally presented as various parallel H-Q curves corresponding to smaller diameter impellers.
- Another difference in the family curves is the presentation of the energy requirements with the different impellers. Sometimes the BHp curves appear to be descending with an increase in flow instead of ascending. Sometimes, instead of showing the horsepower consumed, what we see is the standard rating on the motor to be used with this pump. For example, instead of showing 17 horsepower of energy consumed, the family curve may show a 20-horsepower motor, which is the motor you must buy with this pump. No one makes a standard 17 horsepower motor.
- By showing numerous impellers, motors and efficiencies for one pump, the family curve has a lot of information crushed onto one graph. So to simplify the curve, the efficiencies are sometimes shown as concentric circles or ellipses. The concentric ellipses demonstrate the primary, secondary and tertiary efficiency zones. They are most useful for comparing the pump curve with the system curve. (The system curve is presented in Chapter 8.)
- Normally the NPSHr curve doesn't change when shown on the family curve. This is because the NPSHr is based on the impeller eye, which is constant within a particular design, and doesn't normally change with the impeller's outside diameters. In all cases the impeller eye diameter must mate with the suction throat diameter of the pump, in order to receive the energy in the fluid as it comes into the pump through the suction piping.

Figure 7–11 is an example of a family curve for an industrial chemical process pump.

Next, let's consider the family curve for a small drum draining or sump pump. Note that this pump is not very efficient due to its special design. The purpose of this pump is to quickly empty a barrel or drum to the bottom through its bung hole on the top. A typical service would be to mix additives or add treatment chemicals to a tank or cooling tower. This pump can empty a 55 gallon barrel in less than a minute while elevating the liquid to a height of some 25 ft. Observe that the NPSHr doesn't appear on this curve. This is because the NPSHr is incorporated into the design of this specific duty pump. (Remember that it can reach into a drum through the top and drain it down to the bottom.) This is also the reason for the reduced efficiency. Also, notice that the BHp requirements are based on a specific gravity of 1.0 (water). When the liquid is not water, the BHp is adjusted by its

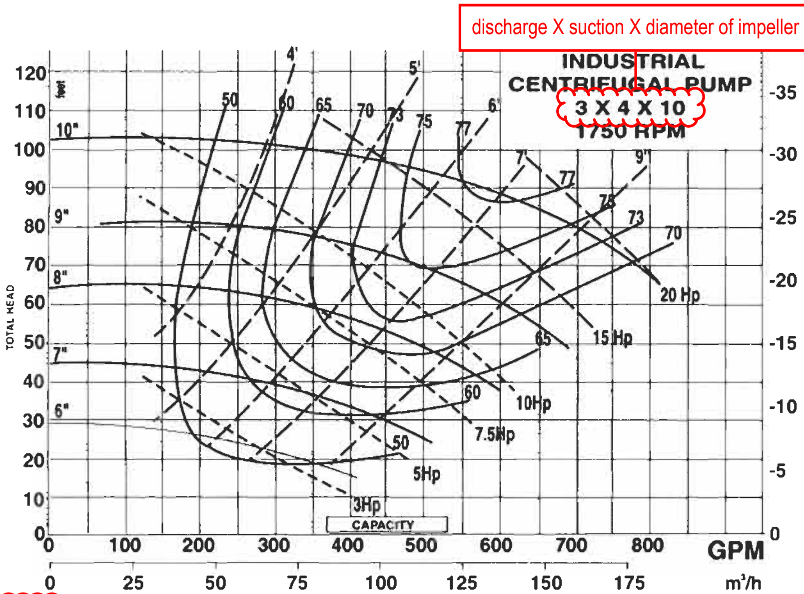

Figure 7-11

specific gravity. Observe that the profiles of this curve are similar to other centrifugal pumps.

See the following curve (Figure 7-12).

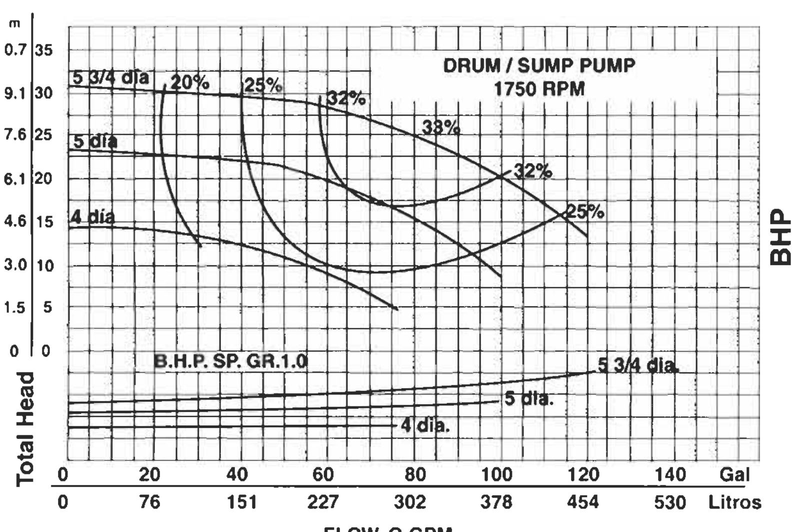

Figure 7-12

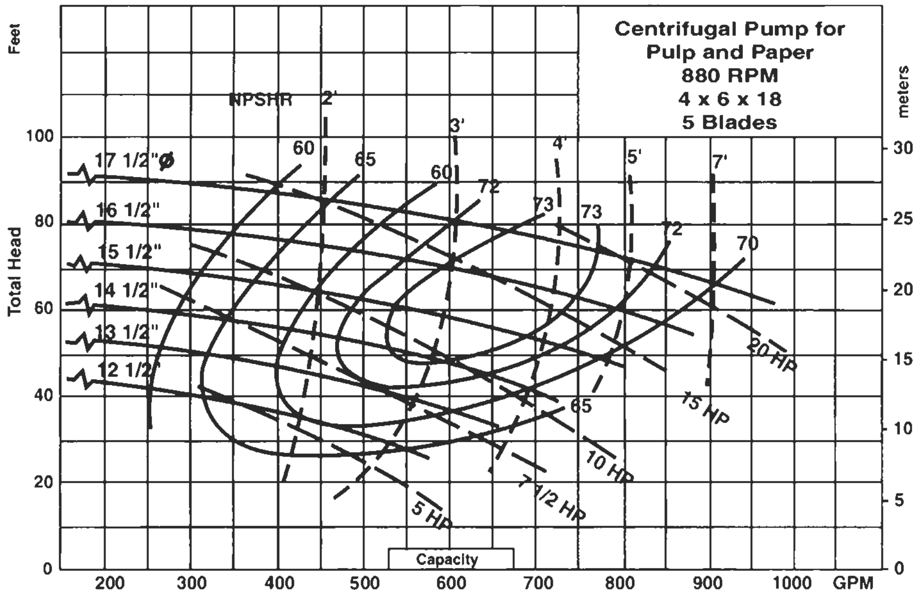

Figure 7-13

Next, consider this family curve for a centrifugal pump used in the pulp and papermaking industry (Figure 7–13).

The next graph is a typical family curve for a firewater pump (Figure 7–14):

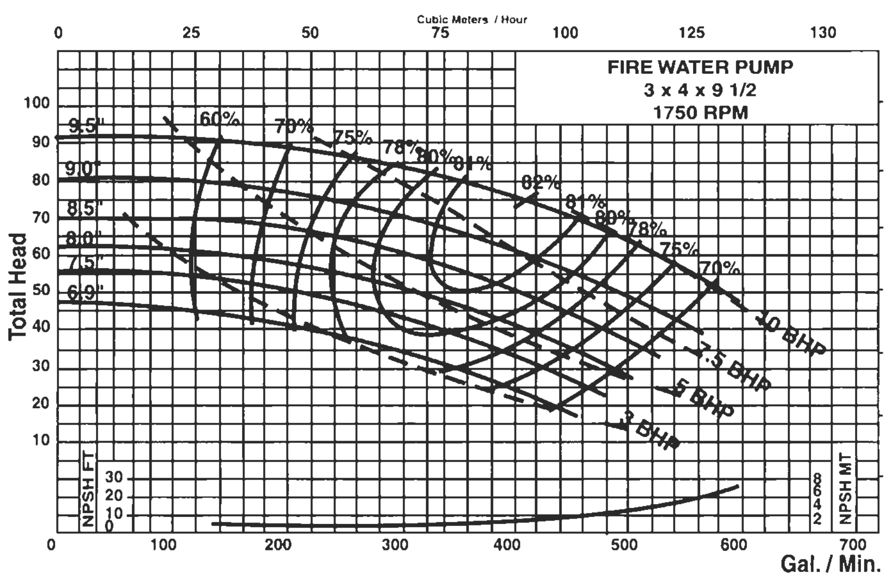

Figure 7-14

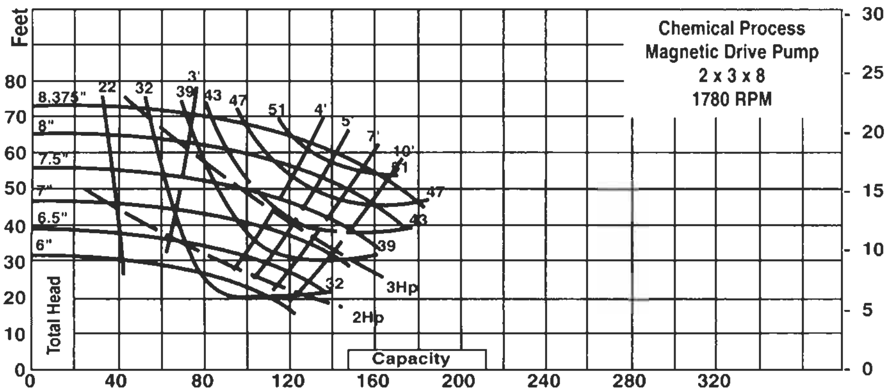

Figure 7-15

Observe this presentation of a family curve for a mag-drive pump used in the chemical process (Figure 7–15).

The graph below is a family curve for a petroleum-refining pump meeting API standards (Figure 7–16).

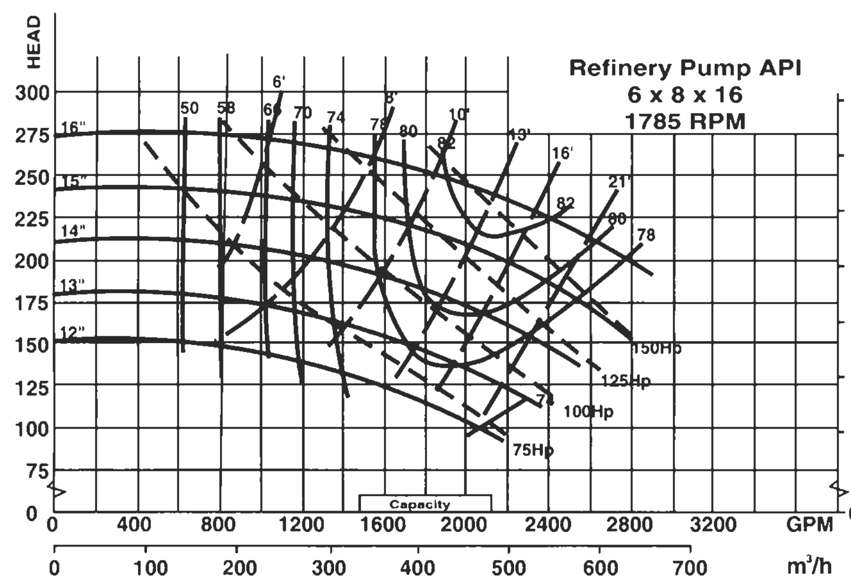

Figure 7-16

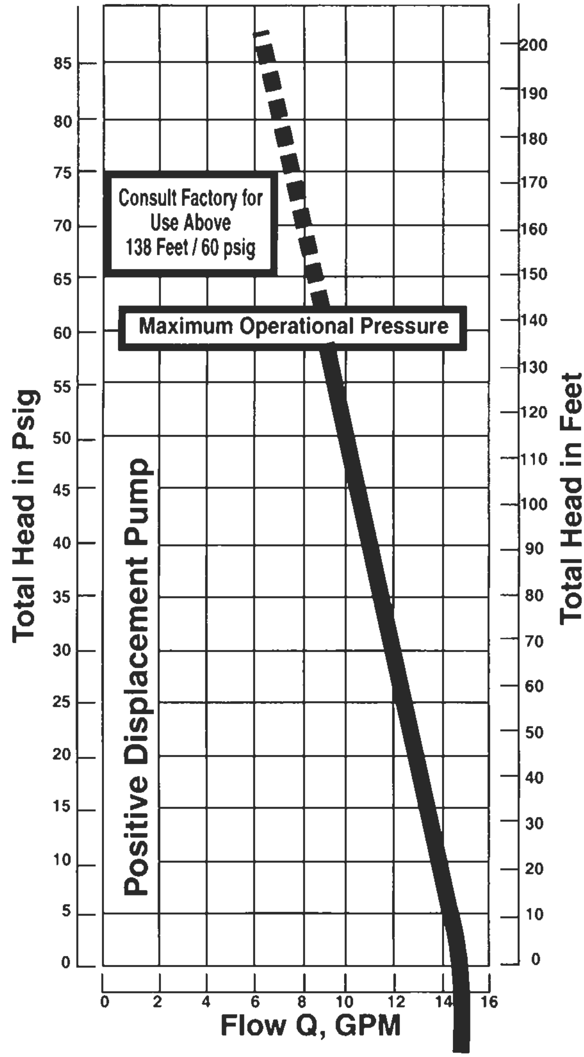

Figure 7-17

Although the pump is not part of this discussion, we present a curve of a positive displacement (PD) pump (Figure 7–17).

On seeing and examining these different pump curves, notice that all curves contrast head and flow. And, in every case the head is decreasing as the flow increases.

Except for the curve of the PD pump, the other pump curves show various diameter impellers that can be used within the pump volute. And, on all these family curves, the efficiencies are seen as concentric ellipses. There is very little variation in the presentation of the BHp and

NPSHr. Notice that the small drum pump doesn't show the NPSHr. This is because this pump, by design, can drain a barrel or sump down to the bottom without causing problems.

To end this discussion, the curve is the control panel of the pump. All operators, mechanics, engineers and anyone involved with the pump should understand the curve and it's elements, and how they relate. With the curve, we can take the differential pressure gauge readings on the pump and understand them. We can use the differential gauge readings to determine if the pump is operating at, or away (to the left or right) from its best efficiency zone and determine if the pump is functioning adequately. We can even visualize the maintenance required for the pump based on its curve location, and visualize the corrective procedures to resolve the maintenance.

Up to this point, you probably didn't understand the crucial importance of the pump curve. With the information provided in this chapter, and this book, we suggest that you immediately locate and begin using your pump curves with suction and discharge gauges on your pumps.

Get the model and serial number from your pumps, and communicate with the factory, or your local pump distributor. They can provide you with an original family curve, and the original specs, design and components from when you bought the pump. A copy of the original family curve is probably in the file pertaining to the purchase of the pump. Go to the purchasing agent's file cabinet.

Nowadays, some pump companies publish their family curves on the Internet. You can request a copy with an e-mail, phone call, fax, or letter. The curves and gauges are the difference between life and death of your pumps. The pump family curve goes hand in hand with the system curve, which we'll cover in the next chapter.