

## Understanding Pump Curves – TD09

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Often times someone will walk into a wholesaler and ask for a pump that:

1. Can produce flow of 10 gallons per minute  
or
2. Can lift the water in a system that's 20 feet tall (i.e. a 2 story house)  
or
3. Is the correct size to “match” a particular boiler

Although these are reasonable questions, none of them is sufficient to select a proper circulator for the situation. Proper circulator selection requires an understanding of circulator performance. This article describes one of the most basic indicators of circulator performance - the pump curve.

### CIRCULATOR CHARACTERISTICS

All circulators used in hydronic heating systems have an operating characteristic in which the flow they produce depends on the resistance they are working against. The resistance is generated by the friction of the fluid moving through the piping systems. The greater this resistance is, the slower a given circulator can move fluid through the piping system.

The term that in part describes the characteristic of a particular circulator is called “head”.

The most accurate way to describe head is **mechanical energy**. All operating circulators add head (or mechanical energy) to the fluid passing through them. This added mechanical energy does not increase the speed of the fluid (other than for a few seconds when the circulator first starts). It also does not increase the temperature of the fluid (as does thermal energy added to the fluid).

What the added head energy does do is increase the **pressure** of the fluid. The fact that the pressure on the outlet side of an operating circulator is higher than the pressure on the inlet side (differential pressure or  $\Delta P$ ) is the “evidence” that head energy has been added to the fluid.

### THE UNITS OF HEAD

The head added by the circulator is commonly measured in “feet.” This term has certainly confused many people over the years. After all, how can you measure energy using units of distance?

The explanation behind this unit is relatively simple. One of the units for measuring energy is called a “foot•pound”, which is abbreviated as ft•lb. A ft•lb is a very small amount of energy. It takes 778 ft•lb to equal one Btu (British Thermal Unit). It would take about 6480 ft•lb of energy to raise a gallon of water by just 1 °F.

Head is the number of ft•lb of energy that the circulator adds to each pound of fluid as it passes through. Thus, you could write down head as follows:

$$\text{head} = \frac{\text{ft}\cdot\text{lb}}{\text{lb}}$$

The units of lb in the top of this fraction cancels out the unit of lb in the bottom of the fraction. That leaves the remaining units as just plain feet. Again it helps to state this result as “feet of head” to distinguish it from feet of distance.

The amount of head energy a circulator adds to the fluid depends on the flow rate through the circulator. The faster the fluid passes through, the less head energy is added to each pound of fluid. This “trade off” between flow rate and added head energy is represented on a graph as a pump curve. An example is shown in Figure 1.

#### Taco Product Catalogs:

100-8.5 - “00” Series Cartridge Circulators

100-34 - 1400 Series High Capacity Circulators

#### Supporting Technical Documents:

TD10 - Selecting Circulators

Pump curves for hydronic circulators always show the head energy added along the vertical axis and the flow rate through the circulator on the horizontal axis. The pump curves start at a high point on the left side of the graph called the “shut off head.” This point represents a condition where the circulator is running but no flow is passing through it. This could occur, for example, if a valve in the piping loop were completely closed.

Under such conditions, the impeller of the circulator is simply churning the same volume of fluid inside the volute of the pump. Although most modern circulators can tolerate this condition for a short time, it is not a normal way to operate a pump. It’s like pushing down on the gas pedal of a car while holding down on the brake peddle at the same time.

When a circulator operates at the shut off head point it tends to heat up because there is not flow through it to cool it properly. All the head energy is converted into heat that’s absorbed by the same amount of fluid in the circulator’s volute. You might even say that the circulator is simply an electric-powered water heater for the small amount of water trapped in the circulator casing when operated this way. Again, there is no valid reason to operate a hydronic circulator at the shut off head point.

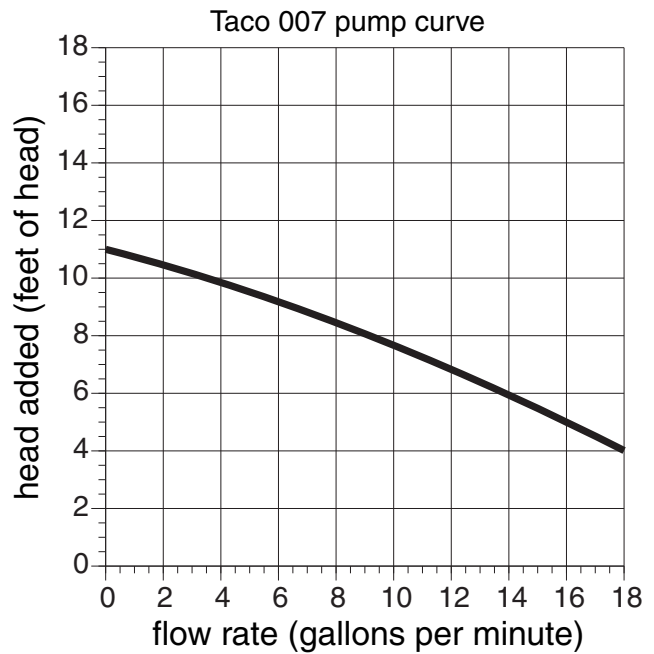


Figure 1

## SLIDING ALONG THE CURVE

As some flow is allowed to pass through the circulator, the amount of head energy added to each pound of fluid decreases. That’s why the pump curve slopes downward to the right. The greater the flow through the circulator the smaller the amount of head added.

It’s helpful to remember that a circulator always “operates on its pump curve.” This simply means that the tradeoff between added head energy and flow rate can always be shown by a point on the pump curve. Not surprisingly, this point is called the “operating point.”

Imagine the situation shown in Figure 2. Assume the valve in the piping circuit is completely closed and thus the circulator is operating at its shut off head. The operating point is thus at the very top of the curve.

Now imagine the valve is slowly opened allowing more and more flow through the circulator. As this occurs the operating point “slides down” the pump curve like a ball rolling along a grooved path. The more the valve is opened, the farther the operating point slides down the pump curve.

You might think that if you opened the valve all the way that the operating point would slide all the way to the other end of the pump curve. In reality this will never happen because the valve and piping in the loop always generates some friction as long as there is flow. This friction causes head loss from the fluid. To keep it flowing, the circulator must add the same amount of head energy back to the fluid.

Some pump curves are drawn all the way down to the horizontal axis of the graph. The point where the pump curve touches the horizontal axis is called the “run out point” of the circulator. This would be where the circulator produces its maximum flow rate, but in theory would add zero head to the fluid.

No real piping systems will allow a circulator to operate at the run out point of the pump curve. To do so would require a piping system with zero flow resistance and that just isn’t possible.

The pump curves of some circulators stop before they intersect the horizontal axis of the graph. In such cases, the circulator should not be operated at flow rates greater than that corresponding to the right end of the pump curve.

What determines how far the operating point can slide down the pump curve is the minimum flow resistance of the piping circuit. In the system shown in Figure 2 this would occur when the valve is fully open (all other things remaining unchanged).

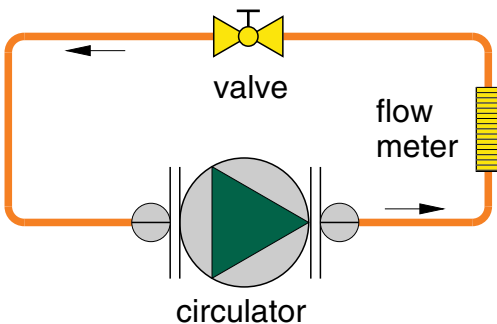


Figure 2

Every segment of pipe, every fitting, every valve or other component in a piping loop causes resistance to flow due to friction. Friction always causes energy to be dissipated. In this case, that energy is the head energy the circulator adds to the fluid. This is why it's appropriate to say that a piping component or loop creates "head loss."

The amount of head loss a given component or piping loop creates depends on several things. These include pipe size, pipe type (e.g. copper versus black iron), the density and viscosity of the fluid being pumped, and the shape of the flow passage through the component(s). The sum of the head losses of all components determines the total head loss of that loop.

## IT'S ALL ABOUT STAYING BALANCED

**Every piping loop will quickly seek out and find the flow rate where the total head loss of the loop exactly equals the head energy input from the circulator.** Only at this operating condition is there perfect balance between head energy input from the circulator and head loss from the piping system.

When the circulator is turned on, the flow rate in the piping loop increases until this balance point is reached, and remains at this flow rate. This usually only takes a few seconds.

If something happens that changes the head loss characteristic of the piping loop (such as a valve adjustment), the balance point slides up or down the pump curve to reestablish the balance between head energy input and head loss.

Likewise, if something happens that changes the pump curve of the circulator (such as a speed change of the motor), the balance point also slides up or down the pump curve until a new balanced condition is established.

To find the operating point at which a particular piping system and circulator will settle, you can plot a "system head loss curve" for the piping system on the same graph as the pump curve. Where these curves cross is the operating point (see Figure 3). The flow rate at this point is found by drawing a vertical line from the operating point down to the horizontal axis and reading the value of flow rate.

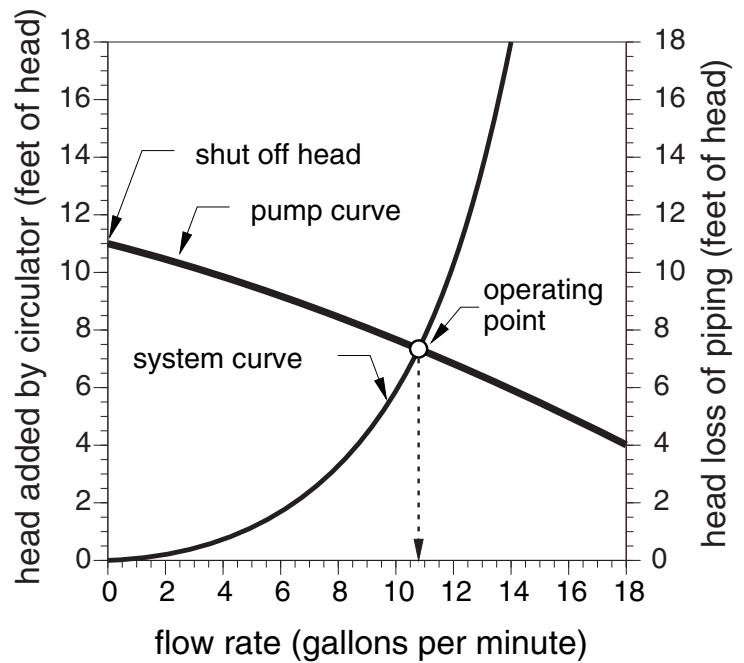


Figure 3

## THE SHAPE OF THE CURVE

Manufacturers design circulators to have specific types of pump curves. This is done to better match the operating characteristic of a circulator to a particular type of system. The Taco 00-family of circulators is an example of a set of pumps having significantly different pump curves so designers can select a circulator that's well matched to the application.

Some circulators are designed to produce relatively high heads at lower flow rates. Such circulators are said to have "steep" pump curves.

Circulators with steep pump curves are intended for systems having high head losses at modest flow rates. Examples include series piping circuits containing several components with high flow resistances, earth loop heat exchangers for geothermal heat pumps, or radiant floor heating systems using long circuits of small diameter tubing.

Other circulators are designed for lower, but relatively stable heads over a wide range of flow rates. Such circulators are said to have "flat" pump curves. Circulators having flat pump curves are desirable for systems using zone valves. The flat pump curve minimizes changes in flow through a given zone circuit as other zone valves open and close (see TD01, *When Zone Valves Close*, for additional information).

## READING FLOW WITHOUT FLOW METERS

The fact that a circulator always operates along its pump curve makes it possible to find the circuit's flow rate without using a flow meter.

What is required is an accurate measurement of the pressure increase across the circulator, and a copy of the circulator's pump curve.

The procedure requires the piping shown in Figure 4. A single 0-30 psi pressure gauge is installed on a tee between two ball valves. Only one of these ball valves is open at a given time.

Step 1: Open the ball valve on the inlet side of the pump and record the pressure gauge reading. Close this valve, then open the gauge on the discharge side and record the discharge pressure. Subtract the inlet pressure from the discharge pressure to get the pressure increase (  $P$  ) across the circulator.

Step 2: Convert the differential pressure obtained in Step 1 to head added using Formula 1.

$$\text{Formula 1: } H_{\text{added}} = P \times \left( \frac{144}{D} \right)$$

where:

$H_{\text{added}}$  = head added to fluid by circulator

$P$  = pressure increase measured across circulator (in psi)

$D$  = density of the fluid (in lb/cubic ft)

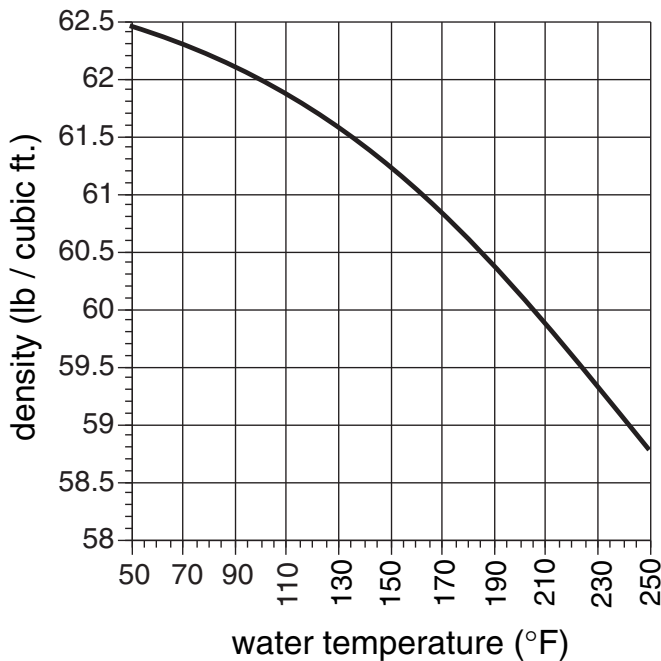


Figure 5

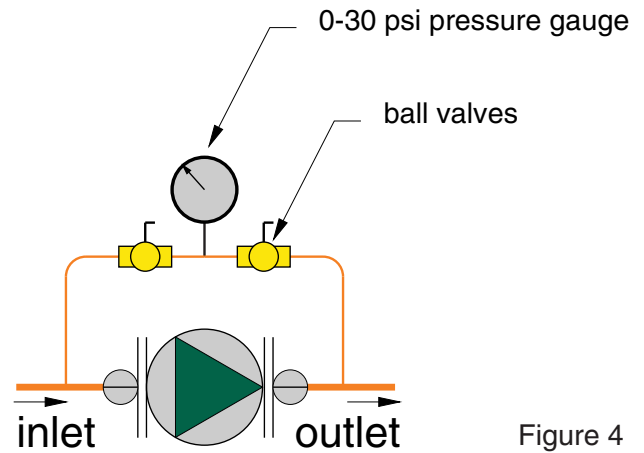


Figure 4

When using this formula the density should be based on the average temperature of the fluid in the circuit. The density of water at various temperatures can be read from the graph in Figure 5. If using an antifreeze solution, look up its density in the manufacturer's literature.

Example 1: Pressure reading on the inlet side of the pump reads 12 psi. Pressure on the discharge side reads 15 psi. Water temperature is 160°. What is the head added and corresponding flow rate using the pump curve in Figure 3?

Answer: Putting the numbers into Formula 1 yields:

$$H_{\text{added}} = (15-12) \times \left( \frac{144}{61} \right) = 3 \times 2.36 = 7.08 \text{ feet of head}$$

Step 3: Find the head calculated in Step 2 on the vertical axis of the pump curve graph, and draw a horizontal line from that value over to the pump curve. The intersection of this line and the pump curve is the operating point of the circulator.

Step 4: Draw a line straight down from the operating point and read the flow rate through the circulator on the horizontal axis.

Example 2: Using the pump curve in Figure 3, find 7.08 feet of head on the vertical axis. Draw a horizontal line across to the pump curve and then down to the horizontal axis to determine a flow rate of 10.75.

## SUMMARY

Pump curves are the “EKG” of circulators. They show the true trade-off between flow and head added. When used in combination with the head loss curve of the piping system, pump curves let the designer know what flow will develop long before the system is installed and turned on. This is much better than simply guessing if the circulator is properly sized, and having to change it out if that guess was wrong.

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