Selecting Circulators

TD10

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This article shows you how to select a Taco circulator that lets the hydronic system you're designing perform as expected. The process requires that you first define the flow performance of the piping system. After this, you will match the system's performance requirements with a circulator that can supply them. It's much like defining the performance requirements of a car and then selecting an engine capable of delivering that performance.

STEP 1: ESTABLISH THE TARGET FLOW RATE FOR THE SYSTEM

The word "target" means the flow rate you expect under design load conditions. This flow rate depends on **both** the rate of heat transfer needed and the temperature drop of the piping system as it delivers this heat transfer.

Keep in mind that the actual flow rate at which the system operates may not be exactly equal to the target flow. It should however be relatively close (within plus or minus 10 percent of the target flow rate).

For systems using water, the target flow rate can be calculated using the following formula.

Formula 1: $$f = \frac{Q}{500 \times (\Delta T)}$$

Where:

- f = flow rate (gpm)
- Q = rate of heat transfer (Btu/hr)
- ΔT = temperature drop of circuit (supply temperature – return temperature) (°F)

If the fluid is a 30% glycol solution, change the 500 in the formula to 479. If the fluid is a 50% glycol solution, change the 500 to 450.

Example 1: A hydronic distribution system is being designed to deliver 100,000 Btu/hr under design load conditions. The system fluid is water, and the expected temperature drop at design load is 20°F. What flow rate is required?

Answer: Putting the numbers into Formula 1 yields:

$$f = \frac{Q}{500 \times (\Delta T)} = \frac{100{,}000}{500 \times (20)} = 10 \text{ gpm}$$

Although it's customary to design hydronic circuits with target temperature drops of 20°F under design load conditions, there is nothing magical about the number 20. Many systems can be designed to operate with higher temperature drops. The greater the circuit temperature drop, the lower the flow rate needed for a given rate of heat transport. Lowered flow rates often lead to reduced tube sizes and smaller circulators.

STEP 2: SELECT THE TUBE SIZE

Once the target flow rate has been established, the tube size can be selected based on flow velocity limitations.

Select a tube size that keeps the flow velocity in the tube in the range of two to four feet/second. The lower end of this range provides sufficient velocity to entrain air bubbles and carry them along until the flow passes through an air separator. Flow velocities lower than two feet/second may not entrain larger air bubbles, especially in downward flow through a vertical pipe. The upper end of the velocity range keeps flow noise at acceptable levels for tubing passing through, above, or below occupied space.

Table 1 can be used to select sizes of type M copper tubing as well as PEX and PEX-AL-PEX tubing based on these limiting velocities.

Example 2: Assume the target flow rate of 10 gpm from example 1, and that copper tubing is used for the circuit. What is the proper tube size based on keeping the flow velocity between two and four feet per second?

Taco Product Catalogs:
- 100-8.5 – "00" Series Cartridge Circulators
- 100-34 – 1400 Series High Capacity Circulators

Supporting Technical Documents:
- TD09 – Understanding Pump Curves

Answer: Look at the copper tube sizes in Table 1. Find a size (or sizes) for which the target flow rate of 10 gpm falls within the values in the second and third column. In this case, a 1-inch copper tube meets this condition and so does a 1.25-inch copper tube. Either tube size is thus a possibility for the system based on the conditions stated. The 1.25-inch tube would generate less head loss than the 1-inch tube. This **might** mean that a smaller less expensive circulator could be used. On the other hand, the 1.25-inch tubing will increase initial cost. To make an informed decision as to which tube size is best the designer can follow the remainder of this procedure assuming 1-inch tube, repeat the procedure assuming 1.25-inch tubing, and then compare results. This is the only way to know if the larger tubing would allow a smaller circulator to be used. Based on the outcome the designer can then factor in cost estimates and make a final selection.

STEP 3: FIND THE EQUIVALENT LENGTH OF THE PIPING CIRCUIT

The total equivalent length of the piping circuit is the length of all straight tube segments plus the equivalent lengths of other components such as fittings and valves.

Table 2 lists the equivalent lengths of some common fittings and valves based on their tube size. To get the total equivalent length of the circuit add the equivalent lengths of all fittings and valves to the total length of straight tubing.

Example 3: A piping circuit consists of 150 feet of 1-inch type M copper tubing as well as 25, 90° copper elbows, three side port tees, and four ball valves. What is the total equivalent length of the circuit?

Answer: The equivalent length of the 1-inch fittings and valves is found in Table 2:

- 90° elbows – equivalent length for each elbow = 2.62 feet
- Side port tees – equivalent length for each tee = 5.25 feet
- Ball valves – equivalent length for each ball valve = 1.8 feet

The total equivalent length of the circuit is therefore:

(25x2.62) + (3x5.25) + (4x1.8) + 150 = 238.45 or about 239 feet.

TABLE 1

TUBING SIZE/TYPE	MINIMUM FLOW RATE [1] (gpm)	MAXIMUM FLOW RATE [2] (gpm)
3⁄8" copper	1.0	2.0
1⁄2" copper	1.6	3.2
3⁄4" copper	3.2	6.5
1" copper	5.5	10.9
1.25" copper	8.2	16.3
1.5" copper	11.4	22.9
2" copper	19.8	39.6
2.5" copper	30.5	61.1
3" copper	43.6	87.1
3⁄8" PEX	0.6	1.3
1⁄2" PEX	1.2	2.3
5⁄8" PEX	1.7	3.3
3⁄4" PEX	2.3	4.6
1" PEX	3.8	7.5
1.25" PEX	5.6	11.2
1.5" PEX	7.8	15.6
2" PEX	13.4	26.8
3⁄8" PEX-AL-PEX	0.6	1.2
1⁄2" PEX-AL-PEX	1.2	2.5
5⁄8" PEX-AL-PEX	2.0	4.0
3⁄4" PEX-AL-PEX	3.2	6.4
1" PEX-AL-PEX	5.2	10.4

(1) BASED ON 2 FT/SEC
(2) BASED ON 4 FT/SEC

TABLE 2

Copper Tube Sizes / Equivalent Length of Pipe *								
Fitting or Valve	**1⁄2"**	**3⁄4"**	**1"**	**1¼"**	**1½"**	**2"**	**2½"**	**3"**
90-degree elbow	1.55	2.06	2.62	3.45	4.03	5.17	6.17	7.67
45-degree elbow	0.83	1.10	1.40	1.84	2.15	2.76	3.29	4.09
Std. Tee (thru flow)	1.04	1.37	1.75	2.30	2.68	3.45	4.12	5.11
Std. Tee (branch flow)	3.11	4.12	5.25	6.90	8.05	10.3	12.3	15.3
Taco Venturi Tee	N/A	28.9	19.3	25.7	N/A	N/A	N/A	N/A
Gate Valve	0.41	0.55	0.70	0.92	1.07	1.38	1.65	2.04
Ball Valve	0.60	1.20	1.80	6.80	6.50	14.2	5.40	9.20
Swing Check	5.18	6.86	8.74	11.5	13.4	17.2	20.6	25.5
Taco Flow-Chek	N/A	143.0	83.7	47.8	57.9	61.8	N/A	N/A
Angle Valve	7.78	10.3	13.1	17.3	20.1	25.8	30.9	38.4
Globe Valve	17.6	23.3	29.7	39.1	45.6	58.6	70.0	86.9
Butterfly Valve	N/A	N/A	N/A	N/A	N/A	7.75	9.26	11.5
Taco 570 Series Valve	10.0	20.0	60.0	130.0	N/A	N/A	N/A	N/A
Taco ESP Zone Valve	9.50	8.40	47.4	N/A	N/A	N/A	N/A	N/A

* Calculated from data in Crane Co. Technical Paper 410 or testing.

STEP 4: ESTABLISH THE HEAD LOSS OF THE PIPING SYSTEM AT THE TARGET FLOW RATE

In a system with multiple zones, the head loss needs to be calculated for each parallel loop. The loop with the highest head loss will be used in figuring the total equivalent length in Example 4.

The formula for estimating the head loss for piping circuits constructed of smooth tubing such as copper, PEX, or PEX-AL-PEX is:

$H_L = k \times c \times L \times (f^{1.75})$

Where:

H_L = the head of the piping system (feet of head)
k = a number based on tubing type/size (found in Table 3)
c = correction factor for fluid type and temperature (found in Table 4)
L = total equivalent length of piping circuit (feet) (from Step 3)
$f^{1.75}$ = flow rate through piping (gpm) raised to 1.75 power (selected values found in Table 5)

Example 4: Find the head loss of the piping system having a total equivalent length of 239 feet of 1-inch type M copper and operating with water at an average temperature of 140 °F and at the target flow rate of 10 gpm.

Answer: The k value for 1-inch copper tubing (from Table 3) is k=0.000845. The value of the correction factor (from Table 4) is 1.000. The value of the flow rate to the 1.75 power (from Table 5) is 56.234. The total equivalent length is L=239 feet (from Step 3). Multiplying these values together yields:

$H_L = k \times c \times L \times (f^{1.75}) = 0.000845 \times 1.00 \times 239 \times 56.234 = 11.36$ feet

The target operating condition of our piping system is now defined as 10 gpm with a corresponding head loss of 11.36 feet. This flow / head loss condition is called the **target operating point** for this system.

TABLE 3

TUBING SIZE/TYPE	VALUE OF k (WATER IN SYSTEM)
⅜" copper	0.0484
½" copper	0.0159
¾" copper	0.00295
1" copper	0.000845
1.25" copper	0.000324
1.5" copper	0.000146
2" copper	0.0000397
2.5" copper	0.0000142
3" copper	0.0000061
⅜" PEX	0.140
½" PEX	0.0374
⅝" PEX	0.0140
¾" PEX	0.00731
1" PEX	0.00223
1.25" PEX	0.000794
1.5" PEX	0.00036
2" PEX	0.0001
⅜" PEX-AL-PEX	0.16
½" PEX-AL-PEX	0.0394
⅝" PEX-AL-PEX	0.0098
¾" PEX-AL-PEX	0.0034
1" PEX-AL-PEX	0.0012

TABLE 4

AVERAGE FLUID TEMPERATURE	100°F	140°F	180°F
Water	c = 1.095	c = 1.000	c = 0.933
30% Propylene Glycol	c = 1.353	c = 1.187	c = 1.088
50% Propylene Glycol	c = 1.582	c = 1.349	c = 1.225

TABLE 5

FLOW RATE (gpm)	FLOW RATE RAISED TO 1.75 POWER
0.5	0.297
1	1.000
1.5	2.033
2	3.364
2.5	4.970
3	6.839
3.5	8.956
4	11.314
4.5	13.903
5	16.719
6	23.002
7	30.125
8	38.055
9	46.765
10	56.234
12	77.369
14	101.327
16	128.000
18	157.229
20	189.148
25	279.508
30	384.558

STEP 5: SELECT A SUITABLE TACO CIRCULATOR

Plot the target operating point just established on a graph showing the pump curves of several "candidate" circulators as shown in Figure 1.

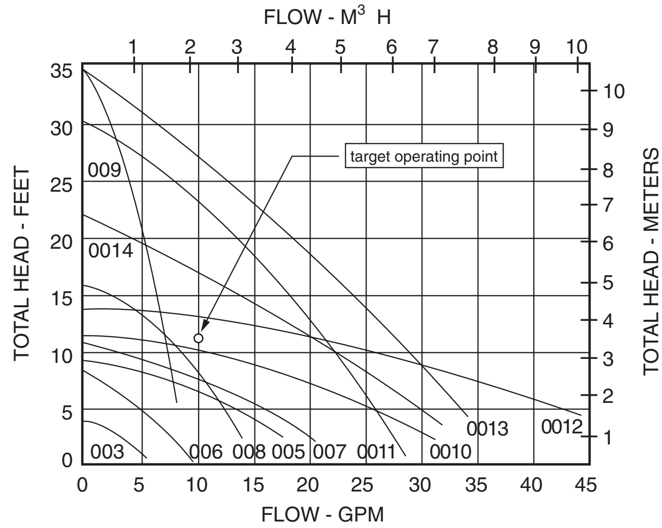

Figure 1

Look for a circulator with a pump curve passing through, or relatively close to, the target operating point. For our example system, a Taco 0012 meets this criteria. So does a Taco 0010.

Because the curve for the 0012 is slightly above the target operating point the flow rate in the system will be slightly **higher** than the target value. This is not necessarily a problem. It means that a slight safety factor would be present to cover for slightly greater installed piping lengths, or other unforeseen conditions that might increase system head loss. Think of it as analogous to selecting a boiler that has slightly more heat output than the design heating load of the building in which it will be used.

The pump curve for the 0010 circulator passes just under the target operating point. If this circulator were selected the flow rate in the system would be slightly less than the target flow rate. If the drop in flow was limited to no more than five percent the difference in the system's thermal performance would be negligible, and thus the smaller circulator might still be a suitable selection. However, it is generally considered poor practice to select a circulator that yields flow rates less than the calculated target flow rate for the system.

Another option the designer could investigate before making the final circulator selection is using 1.25 copper tubing rather than 1-inch tubing. Recall that the 1.25-inch tubing was a possibility based on flow velocities from Step 2. If 1.25-inch was used, the revised head loss is found by returning to Step 4 and using the appropriate k-value for 1.25-inch tubing:

$$H_L = k \times c \times L \times (f^{1.75}) = 0.000324 \times 1.00 \times 239 \times 56.234 = 4.35 \text{ feet}$$

Notice that head loss has decreased significantly based on the use of 1.25-inch rather than 1-inch tubing. The system's target operating point is now 10 gpm with an associated head loss of 4.35 feet. This is shown on the graph in Figure 2.

The new target operating point falls beneath the pump curves for several more circulators including the Taco 005 or Taco 007. These smaller circulators are less expensive and use less electrical energy than the larger Taco 0012 and Taco 0010 models. It's very likely that either of the smaller circulators (005 or 007) used in combination with the 1.25-inch tubing size would lower the overall life cycle cost of the piping system.

Hence, the designer has several possible circulator choices, all of which could satisfy the target flow rate requirement of 10 gpm. The final decision often depends on weighing the cost differences along with personal preferences. As is often the case, no one circulator must be used to achieve acceptable system performance. The situation is analogous to the fact that an automobile can be equipped with several different engine options and still yield acceptable performance.

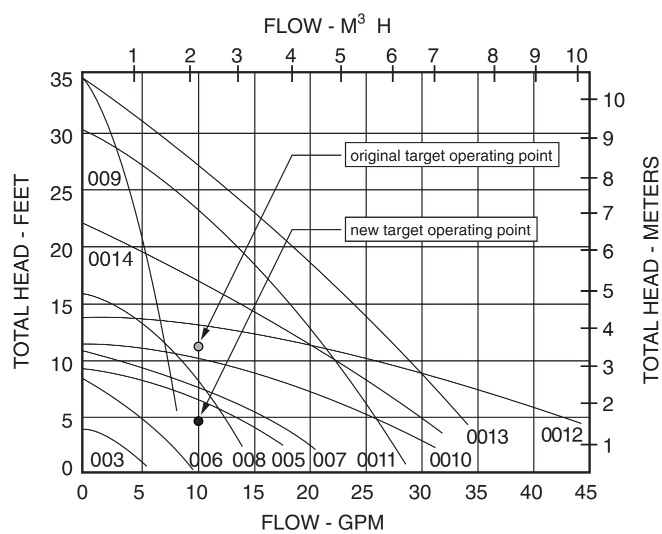

Figure 2

SOME FINAL POINTS

In addition to selecting a circulator that produces a flow equal to or slightly above the target value, other factors should be considered:

1. To achieve reasonable wire-to-water efficiency the target operating point should fall within the middle third of the flow rate range covered by pump curve for the selected circulator. It's not good practice to select a circulator where the target operating point falls near the outer ends of the pump curve, even if the pump curve is still above the target operating point. Doing so would force the circulator to operate at relatively low efficiencies that increase system operating cost.
2. In systems using zone valves (or manifold valve actuators) select a circulator with a relatively flat pump curve. This minimizes changes in differential pressure as the zone valves open and close. (See TD01, *When Zone Valves Close,* for additional information.)
3. In systems having a high flow rate and low head loss requirements consider using two smaller circulators in parallel rather than a single larger circulator. The "effective" pump curve for two identical circulators in parallel is found by doubling the flow rate at every value of head. In effect the pump curve of a single circulator is "stretched out" to twice its length along the horizontal axis as shown in Figure 3.

   If two or more circulators are used in parallel, be sure to include a check valve downstream of each circulator to prevent reverse flow should one circulator be inoperable.
4. Be very careful when selecting circulators with steep pump curves for use in high temperature systems. The potential for vaporous cavitation within the circulator is higher in such situations. Avoiding cavitation will require higher static pressures.

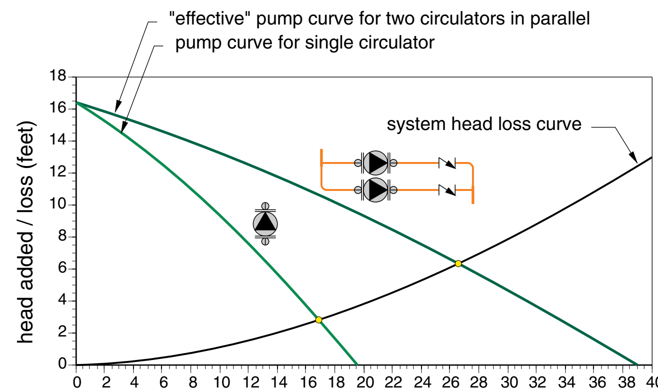

Figure 3

This article has outlined the steps that hydronic system designers can follow to select an appropriate circulator for a given piping system. In many cases, two or more circulator options can each yield acceptable performance based on tradeoffs in system piping. A good selection addresses the total owning and operating cost of the system (circulator and piping) over its design life rather than just first cost. Excessive oversizing of circulators increases initial as well as life cycle costs and should be avoided. The wide range of hydronic circulators available from Taco allows conscientious designers to properly match the circulator to the task.

5. When selecting components for a system, it is worth noting the effect that their imparted resistance has on pump performance. It may be one thing to see the final **number** that is calculated as part of establishing the head loss of the piping system, but how does that number actually effect the flow rate in the system? This becomes very clear when comparing a system where a conventional weighted flow check is installed versus a pump with an integral flow check (00-IFC), as illustrated in Figure 4.

   Shown is the 008 circulator, but this example holds true for any model. When a common Taco Model 219, ¾" Flo-Chek is installed along with the pump the imparted resistance shifts the pump curve down and to the left as illustrated. The hydraulics of the 00 Circulators with Integral Flow Checks (00-IFC) has been specifically engineered to minimize the total impact of the built-in flow check, hence the smaller pump curve shift. Just the difference of using a 008-IFC versus a standard 008 can be seen in the flow output of the circulator at a given head loss.

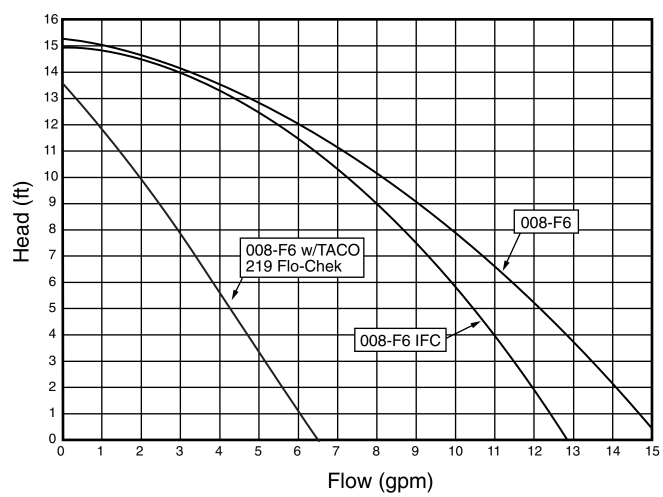

Figure 4

Example 5: If you had a system with 10 feet of head loss, you would expect to get 8 gpm of flow in the system. Say you forgot to add in a flow check to prevent gravity flow. If you were to add a 219, ¾" Flo-Chek, all of a sudden you would have a flow rate of 2 gpm through the same system. If you decided to install a 00-IFC instead of the in-line flow check, the flow would be just over 7 GPM. The selection of components, correct figuring of total system head loss, and matching the target operating point with the appropriate circulator can have a major impact on the performance of a system.

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