Calculating the Pump Head

Before we can discuss pump head, we must understand the difference between an open hydronic system and a closed hydronic system. It is important to know whether the pump serves an *open or a closed system, because the pump head calculation depends on the type of system that the pump serves.*

In a closed system, the fluid is not exposed to a break in the piping system that interrupts forced flow at any point. In an open system, it is. In a closed system, the fluid travels through a continuous closed piping system that starts and ends in the same place--- there is no break in the piping loop. The vast majority of hydronic piping systems are closed. The most common open system is the cooling tower portion of a chilled water system, as depicted below. A break in the piping system occurs where the water exits the spray nozzles, and is exposed to air in the fill section of the tower. The water collects in the cooling tower sump before being pumped around the loop again. Note that the chilled water side of this diagram (the right side) is closed. Because it is closed, an expansion tank absorbs any thermal expansion of the fluid. Open systems don't require expansion tanks, as the fluid is naturally free to undergo thermal expansion.

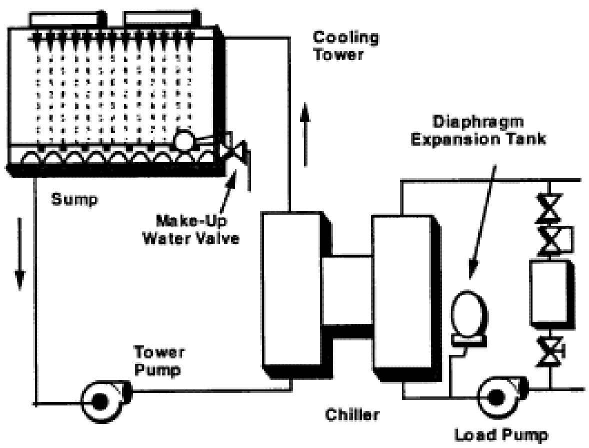

Figure 1: Closed and Open Hydronic Systems

What is Pump Head?

- **Units of Measure:** In the U.S. system, head is measured either in PSI or in "feet of head" (usually abbreviated to "feet").
- **Pump Head** is the total resistance that a pump must overcome. It consists of the following components:
  - **Static Head:** Static head represents the net change in height, in feet, that the pump must overcome. It applies only in open systems. Note that in a closed loop system, the static head is zero because the fluid on one side of the system pushes the fluid up the other side of the system, so the pump does not need to overcome any elevation.
  - **Friction Head:** This is also called *pressure drop.* When fluid flows through any system component, friction results. This causes a loss in pressure. Components causing friction include boilers, chillers, piping, heat exchangers, coils, valves, and fittings. The pump must overcome this friction. Friction head is usually expressed in units called "feet of head." *A foot of friction head is equal to lifting the fluid one foot of static height.*
  - **Pressure Head:** When liquid is pumped from a vessel at one pressure to a vessel at another pressure, pressure head exists. Common applications include condensate pumps and boiler feed pumps. Condensate pumps often deliver water from an atmospheric receiver to a deaerator operating at 5 PSIG, meaning that in addition to the other heads, the pump must overcome a

pressure head of 5 PSIG. One PSIG equals 2.31 feet, so the differential head in this application is 5 X 2.31 = 11.6.' Pressure head is a consideration only in some open systems.

- **Velocity Head:** Accelerating water from a standstill or low velocity at the starting point to a higher velocity at an ending point requires energy. In closed systems the starting point is the same as the ending point. Therefore the beginning velocity equals the final velocity, so velocity head is not a consideration. In an open system, the velocity head *is* theoretically a consideration, but the pipeline velocities used in hydronics are so low that *this head is negligible, and is ignored.* (Note that the velocity head is defined by the formula $V^2/2g$ where V is the fluid velocity in feet per second and g is the gravitational constant 32 feet/second ^{2}. Therefore at typical velocities of 2-6 fps, the velocity head is a fraction of a foot. Since head loss calculations are really estimates, this small figure becomes insignificant).

So, for hydronic applications, we can say that:

1. ***For closed systems: Pump head = the sum of all friction pressure drops***

   Where:

   Friction pressure drop = piping pressure drop + terminal unit pressure drop + source unit pressure drop* + valve pressure drop + accessories pressure drop.

2. ***For open systems: Pump head = the sum of all friction losses plus the static lift of the fluid plus the pressure head.***

   ** The "source unit" is defined as the boiler, chiller, or heat exchanger, which creates the hot or chilled water.*

Steps in Calculating the Pump Head
Basically, we need to plug values into the proper formula above.

Step 1: Lay out the piping system using logical routing as determined by the building requirements. Note each terminal unit and its GPM.

Step 2: Select pipe sizes for each segment, *based on proper velocity and pressure drop*.
The graphs below are from the ASHRAE Fundamentals Book. Recommended velocities are:

- ***Pipe Sizes of 2" and Under: 2 fps minimum to 4 fps maximum***
- ***Pipe Sizes of over 2": .75 ft. of P/100 equivalent feet minimum to 4 ft. of P/100 equivalent feet maximum***

Where P is the head loss (also called friction loss or pressure drop).

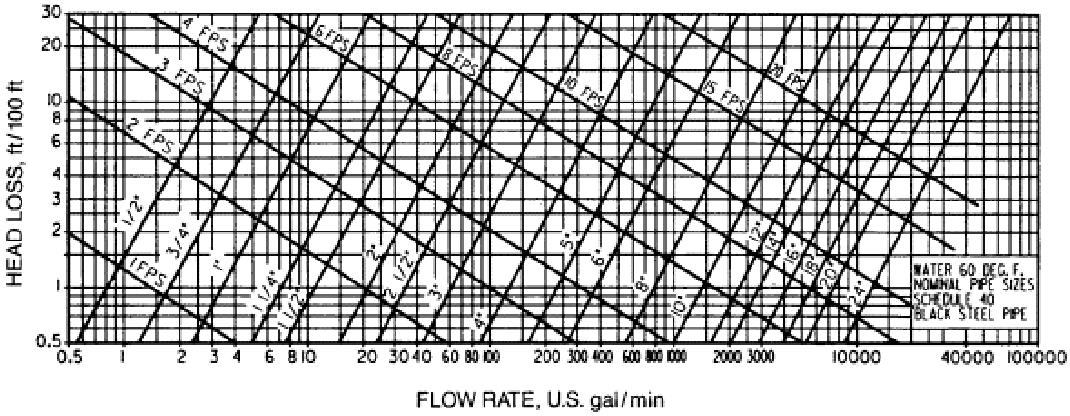

Fig. 1 Friction Loss for Water in Commercial Steel Pipe (Schedule 40)

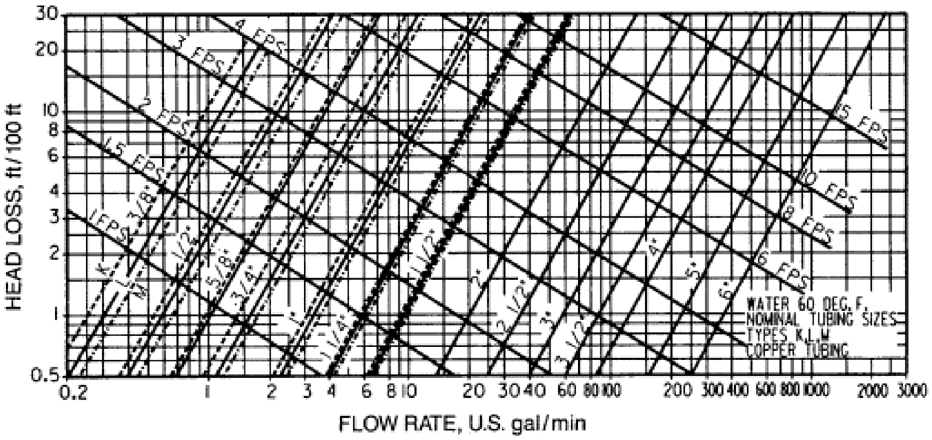

Fig. 2 Friction Loss for Water in Copper Tubing (Types K, L, M)

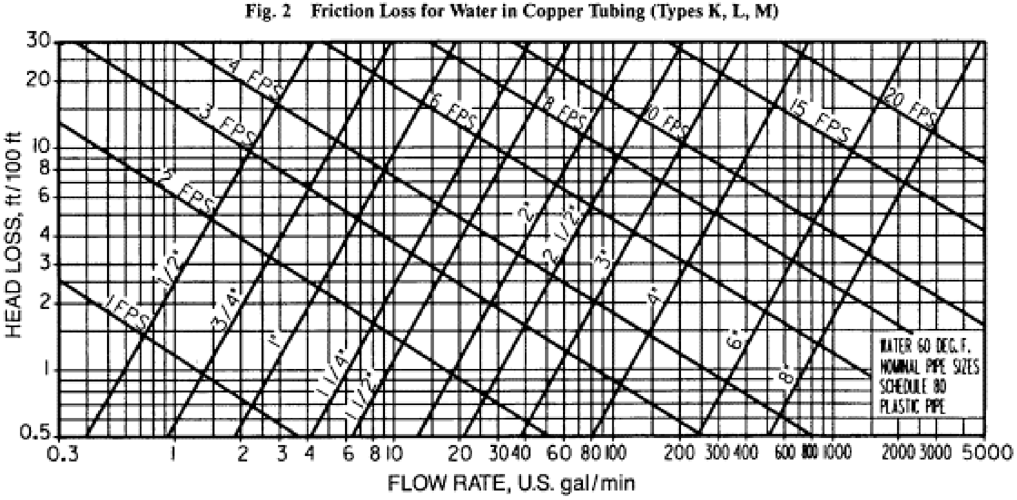

Fig. 3 Friction Loss for Water in Plastic Pipe (Schedule 80)

The recommended ranges ensure that the piping system will be quiet, consume reasonable pump horsepower, and be reasonably economical to install. Note that the minimum velocities are recommended based on the fact that lower velocities will allow air to collect at high points, with the possible result of air binding.

Once the layout and pipe size for each section has been determined follow these steps:

Step 3: Determine Friction Due to Source, Terminal and Accessory Equipment Including:

- Source and terminal Equipment: Consult manufacturer’s catalogs or computer selections.

- Accessory items include filters, strainers, check valves or multi purpose valves that could have a significant pressure drop that would not be covered under the equivalent feet of piping rule of thumb.

- To determine valve D P refer to curves or Cv ratings. A Cv is defined as the flow at which the valve will have a resistance of 1 PSIG (2.31 feet). Since the pressure drop is proportional to the square of the flow rate, use the following formula to calculate the pressure drop through the valve for any flow rate:

  PD In Feet = (Flow Rate/ Rated Cv)^2 X 2.31

Example: A valve has a Cv of 10. Flow through the valve is 21 GPM. What is the valve D P in feet of head?

PD in Feet = (21/10)^2 X 2.31= 10.2'

Special Consideration: Pressure Drops In PSI and Converting PSI to Head
Sometimes pressure drops will be given in PSI units instead of feet of head. To convert PSI units to feet of head:

PD in feet = PD in PSI X 2.31

Example: A plate and frame heat exchanger printout shows a pressure drop of 8.5 PSI. What P in feet must be added to the pump for this item?

Answer: Feet in Head = 8.5 PSI X 2.31ft./PSI = 19.64 ft.

Step 4: Determine the Static Head (Open Systems Only)
The static head is simply the total height that the pump must lift the fluid. It applies only in open systems. Remember that the static head is the *difference in height* that the pump will be required to provide.

In the drawing below, showing a cooling tower, the static height might appear to be 40'. However, the water level in the tower sump is 28' above the pump, so the pump must only provide a net lift of 12'. Therefore, the static head is 12'.

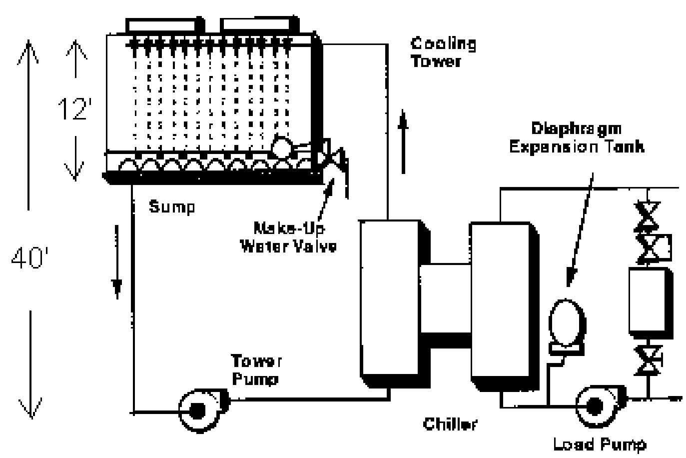

Figure 2, Static Height Example

Step 5: Determine the Pressure Head (Some Open Systems Only)
If the system is open, determine the pressure differential required, if any. Don't forget to multiply pressure differentials in PSI X 2.31'/PSI.

Step 6: Determine the "Worst Pressure Drop Loop" and Estimate the Friction Loss for that Loop by Using 'Equivalent Feet"
Because fittings result in more pressure drop than plain pipe, we account for them by using "equivalent length." The equivalent length of a piping circuit is the actual measured length plus an allowance for all the fittings (elbows, tees, valves, etc.).

- **Long method for determining equivalent length:**

The table below lists the number of equivalent feet of piping for various fittings and accessories:

Friction loss of water in pipe fittings in terms of equivalent length—(L)—feet of straight pipe

Nominal pipe size	Actual inside diameter inches d	Friction factor f	Gate valve — full open	90° elbow	Long radius 90° or 45° std elbow	Std tee — thru flow	Std tee — branch flow	Close return bend	Swing check valve — full open	Angle valve — full open	Globe valve — full open	Butter-fly valve	90° Welding elbow r/d = 1	90° Welding elbow r/d = 2	Mitre bend 45°	Mitre bend 90°
½	.622	.027	.41	1.55	.83	1.04	3.11	2.59	5.18	7.78	17.6					
¾	.824	.025	.55	2.06	1.10	1.37	4.12	3.43	6.86	10.3	23.3					
1	1.049	.023	.70	2.62	1.40	1.75	5.25	4.37	8.74	13.1	29.7					
1¼	1.380	.022	.92	3.45	1.84	2.30	6.90	5.75	11.5	17.3	39.1					
1½	1.610	.021	1.07	4.03	2.15	2.68	8.05	6.71	13.4	20.1	45.6					
2	2.067	.019	1.38	5.17	2.76	3.45	10.3	8.61	17.2	25.8	58.6	7.75	3.45	2.07	2.58	10.3
2½	2.469	.018	1.65	6.17	3.29	4.12	12.3	10.3	20.6	30.9	70.0	9.26	4.12	2.47	3.08	12.3
3	3.068	.018	2.04	7.67	4.09	5.11	15.3	12.8	25.5	38.4	86.9	11.5	5.11	3.07	3.84	15.3
4	4.026	.017	2.68	10.1	5.37	6.71	20.1	16.8	33.6	50.3	114	15.1	6.71	4.03	5.03	20.1
5	5.047	.016	3.36	12.6	6.73	8.41	25.2	21.0	42.1	63.1	143	18.9	8.41	5.05	6.31	25.2
6	6.065	.015	4.04	15.2	8.09	10.1	30.3	25.3	50.5	75.8	172	22.7	10.1	6.07	7.58	30.3
8	7.981	.014	5.32	20.0	10.6	13.3	39.9	33.3	33.3	99.8	226	29.9	13.3	7.98	9.98	39.9
10	10.02	.014	6.68	25.1	13.4	16.7	50.1	41.8	41.8	125	284	29.2	16.7	10.0	12.5	50.1
12	11.938	.013	7.96	29.8	15.9	19.9	59.7	49.7	49.7	149	338	34.8	19.9	11.9	14.9	59.7
14	13.124	.013	8.75	32.8	17.5	21.8	65.6	54.7	54.7	164	372	38.3	21.8	13.1	16.4	65.6
16	15.00	.013	10.0	37.5	20.0	25.0	75.0	62.5	62.5	188	425	31.3	25.0	15.0	18.8	75.0
18	16.876	.012	16.9	42.2	22.5	28.1	84.4	70.3	70.3	210	478	35.2	28.1	16.9	21.1	84.4
20	18.814	.012	12.5	47.0	25.1	31.4	94.1	78.4	78.4	235	533	39.2	31.4	18.8	23.5	94.1
24	22.628	.012	15.1	56.6	30.2	37.7	113	94.3	94.3	283	641	47.1	37.7	22.6	28.3	113
30	28	.011	18.7	70	37.3	46.7	140	117					46.7	28	35	140
36	34	.011	22.7	85	45.3	56.7	170	142					56.7	34	43	170
42	40	.010	26.7	100	53.3	66.7	200	167					66.7	40	50	200
48	46	.010	30.7	115	61.3	76.7	230	192					76.7	46	58	230
L/D			8	30	16	20	60	50	½ to 6 = 100; 8 to 24 = 50	150	340		20	12	15	60

Calculated from data in Crane Co.—Technical Paper 410. $K = f\frac{L}{D}$; $f = \frac{KD}{L}$; $L = \frac{KD}{f}$ where D = inside pipe diameter in feet.

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To use this method, add the *equivalent length of each item* in the fluid's path to *the actual length* of piping to get the *total equivalent feet of piping*.

- **Shortcut method for determining equivalent length:**

Designers often skip the above method and simply *multiply the actual piping length times 1.5 to 1.75 to get the equivalent length.* This provides speed and a reasonably accurate estimation for "typical" hydronic piping systems. As with any rule of thumb, however, watch out for oddball situations (the boiler room is 2 blocks away from the building, a piping system with an extreme number of fittings, etc). In such situations, the long method provides better accuracy.

Now multiply the friction loss per 100' of piping from the ASHRAE charts times the equivalent length in the "worst" loop to get the total piping friction loss. Select the worst loop by inspection, if possible. Calculate several branches if there is a doubt. ***The friction in the worst loop is used as the friction head.***

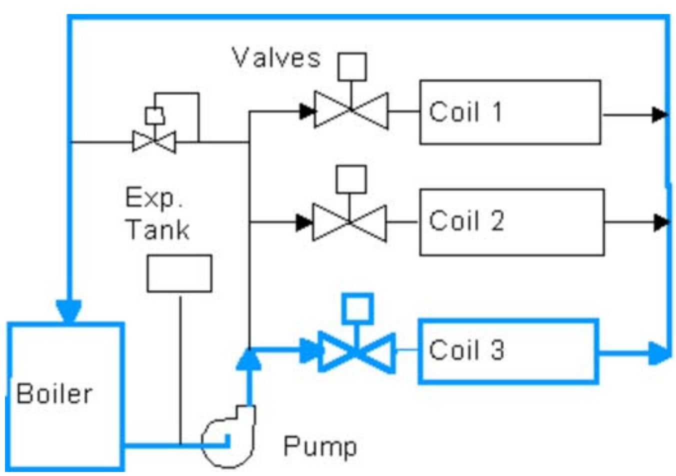

Figure 3, Worst Pressure Drop Circuit

Note that the worst loop is simply that the loop that results in the largest total pressure drop. *Do not add pressure drops from other parallel loops.* In the drawing above, assume that the pressure drop through Coil 3 and its valve are higher than the pressure drop through Coils 1 and 2. Assuming that the branch piping for all three circuits is similar, the "worst case" total friction loss loop is shown in light blue. It would be erroneous to add the pressure drops of the piping shown in black.

Notes

1. Those circuits with less pressure drop than the "worst" circuit will be balanced in the field by partially closing balancing valves (not shown above).
2. If there are different pipe sizes on the circuit, the circuit may have to be analyzed in sections, because the pressure drop/foot may vary by section. This is one good reason for selecting all piping at the same pressure drop per 100.' It simplifies the calculations considerably.

Safety factors
You may wish to add a safety factor to the calculated head for two reasons:

- Jobsite conditions may not allow direct routing of piping as shown on the plan. Extra length and extra elbows result in added friction.
- The interior pipe walls become rough over time due to corrosion, especially in open systems, where fresh water makeup brings in a steady supply of corrosion-causing oxygen. This increases friction. Various sources recommend total safety allowances of 15-25% for friction calculations. Note that the friction tables assume cold water, which results in more friction than hot water. ***Therefore, if you are designing a hot water system, you already have a safety margin of around 12%***. Be careful of excessive safety factors. They result in oversized pump impellers that cause wasted energy!

Pressure Drop Corrections for Glycol.
Some systems utilize either ethylene or propylene glycol mixtures in lieu of water. These fluids result in higher pump heads than does water. For discussions of the effects of glycol, see the Newsletter section of this WEB site. The **Summer 2000** newsletter discusses the correction required to calculate the amount of glycol to be circulated to meet a given heat transfer load. The **Winter 2001** newsletter provides correction factors for pump applications, including factors for correcting head calculations.

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