Ion Exchange:

HYDRAULICS—

Taking the Pressure Off Your Softeners

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Summary: *There is considerable debate today regarding what constitutes a properly sized filtration system. The plumbing codes would have us believe that a single family home requires flow rates of 20 gpm or more because of the number of fixtures rather than the actual water demand. Many filter providers think all they have to do is match the in/out of the filter to the pipe size. The truth is somewhere in between.*

This article will review the relationship between flow rates and pressure drop as well as the impact of pipe, valve and vessel size.

Working pressure

To provide adequate water service to a home or business, the design engineer looks at only one primary thing—the flow rate requirements at the point of use. Assuming a minimum working pressure of 25 pounds per square inch (psi) at the end of the line, the difference between the inlet feed pressure and the needed working pressure defines how much pressure loss can be tolerated in the piping and filtration design.

Water flowing through a pipe travels faster through the center than it does along the walls. This produces drag or friction that results in pressure loss. This drop in pressure is related to the flow rate and the pipe size. At high flow rates, the flow inside the pipe may be turbulent, resulting in higher losses. At lower flow rates, referred to as laminar flow, the losses are minimal. The trick is to design for minimal pressure losses by keeping the flow within the pipe laminar.

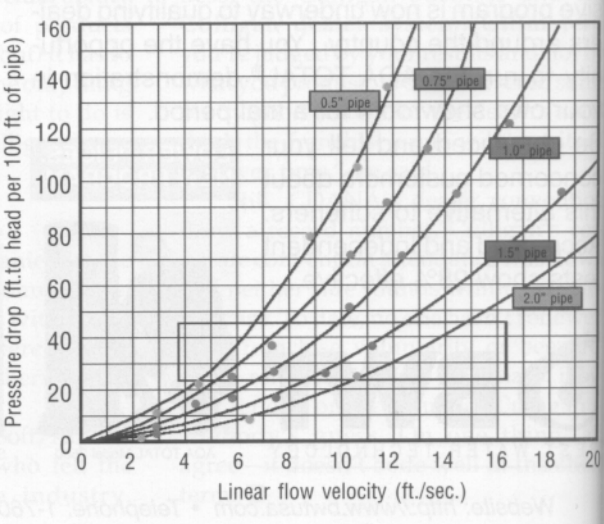
If we compare the cross sectional area of the pipe to the volumetric flow rate, we can calculate the linear flow rate. For example, 1 US gallon = 231 cubic inches. Therefore, 1 gallon per minute (gpm) equals 231 cubic inches per minute (in^3/min). A nominal 0.5-inch ID (interior diameter) pipe has a cross sectional area of 0.2 square inches (in^2). The linear velocity—in minutes (min) and seconds (sec)—is therefore: $231 \div 0.2 = 1{,}177$ in/min or 19.6 in/sec (1.63 ft/sec). Since the cross section of a pipe is proportional to the square of the pipe diameter, a 2-inch pipe can handle four times the flow of a 1-inch pipe and a 4-inch pipe can handle 16 times the flow of a 1-inch pipe. A useful memory jogger is that a 4-inch pipe can handle 400 gpm. As we cut the pipe size in half, we cut the flow by four times. Therefore, a 2-inch pipe will handle 100 gpm and a 1-inch pipe will handle 25 gpm. Being larger, a 1.5-inch pipe ($1.5 \times 1.5 = 2.25$) will therefore handle 56 gpm (2.25×25 gpm). A ¾-inch pipe is half the size of 1.5 and will therefore handle 1/4 the flow, or 14 gpm.

If we examine the DP—pressure differential or delta P (ΔP)—for an increasing flow rate through various pipe sizes, we see a similar shape to the curves (see *Figure 1*). We note with all curves that the DP seems to increase at a rapid rate as the flow goes up. In Figure 1, there is a box outlining the area of the graph where the pressure drops lie between 10 and 20 psi per 100 feet of pipe.

Note that the values for pressure drop are expressed in feet of head. To determine psi, divide the head by 2.31. This should be your target design flow. To determine the pressure drop through any section of pipe, ratio the length in question to the values from Figure 1. For example, what is the DP through 50 feet of 1-inch pipe at 35 gpm? Thirty-five gpm is 8,085 cubic inches (in^3) of flow per minute or 134.75 in^3/sec. A 1-inch pipe has a cross section of 0.785 square inches (in^2). The linear velocity is then: $134.75 \div 0.785 = 172$ in/sec, or 14.3 feet per second (ft/sec).

From Figure 1, we note that the DP is approximately 93 feet of head or 40.25 psi/100 ft of pipe. The drop through 50 feet is then $50 \div 100 \times 40.25$ psi, or 20 psi. Please note that this is for straight pipe. Each elbow or "T" is the equivalent of three to five additional feet of pipe. Now,

Figure 1. Pressure differential of various pipe sizes



you know why there is very little pressure in the upstairs bath of a large house plumbed in ¾-inch pipe. Then again, there isn't a 35 gpm flow demand in normal sized homes.

Matter of gravity

In addition to the head loss from friction, we also have to consider the head loss due to gravity. The second or third floor of a house will lose an extra 10 to 20 feet of head pressure just climbing the stairs. Older homes may even neck down to ½-inch pipe for the last six to eight feet of pipe. Ten feet of ½-inch pipe will drop line pressure to a shower head (2½ gpm) by about 1 psi over that of a ¾-inch pipe.

Note from Figure 1 that the larger the pipe, the less the DP penalty at any given linear flow rate. Although design engineers generally accept 10 ft/sec as a practical limit for linear flow, we can see that for 23.1 ft of head loss (10 psi), the flow through ½-inch pipe is only 4.5 ft/sec; whereas through 2-inch pipe, it's 10.5 ft/sec. Using 10 and 20 psi as limit ranges for DP, Table 1 shows the flow range in gpm for each size pipe.

Table 1. Maximum recommended flow rates through pipe

Pipe size inches	10 psi gpm	20 psi gpm
0.5	3.1	4.5
0.75	7.5	11.3
1.0	16.5	45
1.5	47	68
2.0	98	145

DP is per 100 ft. of pipe.
For valves, use 80% of these values.

This brings up an interesting question. Is it OK to use smaller diameter pipe for short runs? Sure. But it may cost you 1 to 2 psi. For example, a 24-inch piece of 1-inch pipe in a 1.5-inch system at 40 gpm will increase the DP by approximately 1.0 psi. Keep this in mind if you have to take a smaller pipe off a header for multiple systems in parallel.

Valves

Valves are often given a C_v value (see *Equation 1*), which represents a ΔP of one psi in flow rate. The C_v of any valve is the flow rate at which the DP is 1 psi.

Equation 1:
$$C_v = Q \div \sqrt{\Delta P}$$
Where: Q is gpm or flow rate and √ is square root.

If the C_v is 4.8, the DP (for valve only) will be 1 psi at 4.8 gpm. At 9.6 gpm, the DP will be 4 psi and at 15 gpm it will be 9.8 psi. This valve may be rated at a maximum flow rate of 18.6 gpm because at that flow rate, the DP will be 15 psi. Most certifications, however, rate the maximum flow of a system at 15 psi. This includes not only the valve but the in/out pipe, tank, resin bed and riser.

Using a 13/16 riser in place of a 1.050-inch pipe, a 10×54-inch resin tank will increase the DP by approximately 0.6 psi at 10 gpm, 1.4 psi at 15 gpm and 2.4 psi at 20 gpm. The bottom and top strainers in most small tank softening and filtration units actually has an open surface area of a 1-inch pipe. They aren't significant sources of pressure drop. On larger systems, the lateral distribution system is generally designed to provide 1 psi DP for good fluid distribution.

Pressure vessels

The linear flow through tanks is measured in in/min rather than ft/sec. We would not expect the tank itself to contribute measurable DP; however, there are prudent design factors in fitting the right size tank to the job due to the DP considerations

Table 2. Recommended flow rates through pressure vessels

Tank diameter inches	X-sec area sq. ft.	Min. flow gpm	Max. flow gpm	Peak flow gpm
6	0.196	0.8	2.9	3.9
7	0.267	1.0	4.0	5.3
8	0.349	1.4	5.2	7.0
9	0.442	1.8	6.6	8.8
10	0.545	2.2	8.2	10.9
12	0.785	3.1	11.8	15.7
13	0.921	3.7	13.8	18.4
14	1.07	4.3	16.1	21.4
16	1.40	5.6	21.0	28.0

Min. flow is 4 gpm/sq.ft. for proper distribution to avoid channeling.
Max. flow is based on 15 gpm/sq.ft.
Peak flow is based on 20 gpm/sq.ft. and should only be short term.

from the media bed. Table 2 shows minimum (important for proper flow distribution), maximum (upper limits of steady flow) and peak (spike flow for a few minutes at a time).

The DP through a regular sized resin will be dependent on the flow per square foot (sq ft) of the cross section of the tank. A general rule of thumb is 1.0 psi of DP per foot of bed depth at 10 gpm/sq ft of area. Therefore, a 24-inch diameter tank (surface area = 3.14 sq ft) with a flow of 30 gpm (about 10 gpm/sq ft) and containing 10 cubic feet (cu ft) of resin (10 ÷ 3.14 = about a 3 ft bed depth) will exhibit 3 psi of DP. At 5 gpm/sq ft, the DP is only ¾ psi (cutting the flow in half cuts the pressure by four times).

Elbows and fittings

It takes energy to move water and changing direction causes energy losses that reflect as added DP. The convention is to report these losses of pressure in terms of an equivalent length of pipe. Table 3 shows the approximate pipe equivalents for various fittings. Note that even changing from a small pipe to a larger one in a line (sudden enlargement) has a pressure penalty.

To figure the DP for an entire system, one has to calculate the DP contribution of all components: the pipe, fittings, valve, resin bed and distribution system. For example, figure the DP of a system using a 9-inch softener tank with a 30-inch bed depth (1 cu ft), plumbed through ¾-inch copper pipe. The run from the street is 40 feet, and 40 feet to the upstairs bath. Assume two other fixtures are open with a draw of 5 gpm and the upstairs shower draws 2.5 gpm. With a 60 psi regulator from the street, what's the available pressure to the shower? There are 20 fittings (L's and T's) in the line. The total pipe run is 80 feet (40 + 40) plus 20 fittings with a 1-½ ft equivalent (30 ft). Total pipe is equivalent to 110 feet. Flow rate is 7.5 gpm. The linear velocity through the pipe is 5.5 ft/sec and DP is 27 feet of head or 11.7 psi.

The softener has a cross sectional area of 0.44 sq. ft. so the surface flow is 17.1 gpm/sq ft (7.5 ÷ 0.44). Since our rule of thumb was for 10 gpm, we divide the 17.1 by 10 (1.71) and square the result (1.71 × 1.71) to arrive at 2.92. Our DP through the resin is 2.92 times the bed depth (30 ÷ 12 = 2.5 ft). The DP is therefore 7.3 psi. Since the valve has a C_v of 5.2, the DP through the valve will be 2.1 psi (assuming no bypass). Add another 2 psi for risers, strainers, bypass and the like and we have a total DP of 23 psi from the equipment and piping. There is also DP from the elevation change (from the street level to the shower).

Table 3. Pressure losses in fittings (equivalent pipe length)

Fitting	0.5	0.75	1.0	1.5	2.0
Square 90	3	4	6	9	12
Short 90	1	2	2.5	4	6
Med 90	1	1.5	2.5	3.5	5
Sweep 90	0.7	1.4	1.8	3	4
Tee (T)	2.5	5	7	10	14
45° El (L)	0.6	1	1.1	2	2.5
Reducer down	0.4	0.8	1	1.5	1.8
Bushing up	0.7	1.4	1.8	2.9	3.8

Use in conjunction with Figure 1 for total DP in pipe.

Shower heads are about 6 feet above the floor, which is 9 feet above the downstairs floor. Let's assume that the house is 6 feet above the street and that the water pipe is 4 feet down. There is a total elevation change of 25 feet (of pressure head), which costs another 10.8 psi. Total DP to the shower head becomes almost 34 psi. This means a working pressure of 26 psi at the shower. If we increased the flow demand to 10 gpm by flushing the toilet, we would increase the DP to 52 psi and experience a big drop in the cold water flow. The working pressure at the shower would only be 8 psi. I'm sure we have all stayed in hotels with this problem.

Multiple filtration systems

Using the reasoning outlined above, one can quickly see the potential problems of stringing an oxidizing filter, media filter, granular activated carbon (GAC) filter and softener in series. Even by reducing the flow to only 3 gpm, we still experience a total DP of 14.5 psi. Add another 2 psi per extra vessel. Series filtration poses serious pressure restrictions as flows increase.

Conclusion

Usually, the largest contributor to DP installation will be the plumbing itself. It will always be less expensive to use the proper pipe size than increase the horsepower of the delivery pump. Use wide sweeping L's rather than short L's for changing the direction of water flow to reduce the DP. Plan your work to use as few fittings as possible. Never exceed 15 gpm/sq ft of cross section in sizing residential systems, 10 gpm for commercial (hotels, small plants, car washes, etc.) and 8 gpm for industrial softeners and deionizers. Each story of elevation in a building will generally cost you 5 psi in head losses. Use larger filter tanks when installing multiple units in series. Also consider using valves one size larger. ❑

References

1. *Cameron Hydraulic Data*, 14th Ed., Ingersoll-Rand Co, New York, 1965.

2. *Purolite Technical Manual-C100*, Purolite Co., Bala Cynwyd, Pa., 1996.

About the author

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