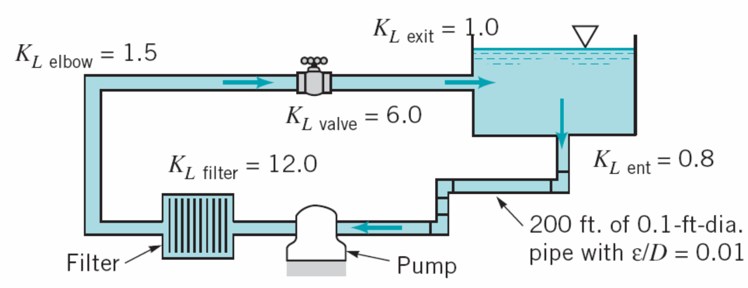
8.93.



The energy equation can be written around the complete loop, which can be thought of as following a streamline from one point on the surface of the reservoir (point 1), around the pipe loop, and to a different point on the surface of the reservoir (point 2). The two endpoints for the analysis have the same elevation, and they both have zero velocity and zero pressure, so the energy equation simply states that the energy added to the fluid by the pump is all lost to friction as the water makes a complete loop. Thus:

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1+h_{pump}=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_{L,pipe}+h_{L,minor}$$

$$h_{pump}=h_{L,pipe}+h_{L,minor}=\left(f\frac{l}{D}+\sum K_L\right)\frac{V^2}{2g}$$

The head provided by the pump can be related to the velocity through the pipe via the given information about the power input:

$$P=Q\gamma h_{pump}=VA\gamma h_{pump}$$

$$h_{pump}=\frac{P}{VA\gamma}=\frac{200\text{ ft-lb/s}}{V\left(\frac{\pi}{4}[0.1\text{ ft}]^2\right)\left(62.4\frac{\text{lb}}{\text{ft}^3}\right)}=\frac{408\text{ ft}^2\text{/s}}{V}$$

The contributions to the K_L summation include 0.8 for the entrance to the pipes, 1.5 from each of five 90° elbows, 12.0 from the filter and 1.0 from the exit of the pipe back into the reservoir. Thus, ΣK_L equals 27.3, and the equation becomes:

$$h_{pump}=\left(f\frac{l}{D}+\sum K_L\right)\frac{V^2}{2g}$$

$$\frac{408\text{ ft}^2\text{/s}}{V}=\left(f\frac{200\text{ ft}}{0.1\text{ ft}}+27.3\right)\frac{V^2}{2\left(32.2\text{ ft/s}^2\right)}$$

$$V^3 = \frac{2\left(32.2\ \text{ft/s}^2\right)\left(408\ \text{ft}^2/\text{s}\right)}{f\,\dfrac{200\ \text{ft}}{0.1\ \text{ft}} + 27.3} = \frac{26112\ \text{ft}^3/\text{s}^3}{2000\,f + 27.3}$$

$$V = \left(\frac{26112\ \text{ft}^3/\text{s}^3}{2000\,f + 27.3}\right)^{1/3}$$

This equation provides one relationship between f and V. The definition of the Reynolds number provides a relationship between V and Re, and the Colebrook equation (or, equivalently, the Moody diagram) provides a relationship between f and Re (since ε is given). These latter relationships are shown below:

$$\text{Re} = \frac{VD\rho}{\mu} = \frac{V\left(0.1\ \text{ft}\right)\left(1.94\ \text{slug/ft}^3\right)}{2.34\text{x}10^{-5}\ \text{lb-s/ft}}\left(1\frac{\text{lb}}{\text{slug-ft/s}^2}\right) = \left(8290\frac{\text{s}}{\text{ft}}\right)V$$

$$\frac{1}{\sqrt{f}} = -2.0\ \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right) = -2.0\ \log\left(\frac{0.01}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right)$$

Thus, we have three equations in three unknowns. We can solve for the three unknowns simultaneously by a trial and error approach. There are many acceptable ways to do this, one of which is described here. The approach involves setting up a spreadsheet in which we make a wild guess for f in one cell. In the adjacent cell, we use the f-V relationship to compute the corresponding value of V. We then use that value of V to compute Re. Finally, we use the values of Re and f to evaluate the right-hand side of the Colebrook equation, and take the square of the inverse of that value to get a new value of f.

If our original guess of f matches this new, computed value of f, then our original guess was correct. However, chances are that the original guess was not correct, so the two values of f will differ. In that case, we can use the computed value of f as the new guess and repeat the procedure. Very quickly, the value of f converges so that the guessed and computed values are equal; at that point, all the equations are solved simultaneously, the current values of f, V, and Re are the correct ones. The results of the calculations for three iterations, starting with a guess that $f = 0.001$, are shown below.

f	*V*	Re	Colebrook RHS	Colebrook new *f*
0.0010	9.60	79597	4.864	0.0423
0.0423	6.15	50950	5.063	0.0390
0.0390	6.27	51981	5.061	0.0390

The result is that $V = 6.27$ ft/s, from which Q can be computed:

$$Q = VA = \left(6.27\frac{\text{ft}}{\text{s}}\right)\left(\frac{\pi}{4}\left[0.1\ \text{ft}\right]^2\right) = 0.049\frac{\text{ft}^3}{\text{s}}$$