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Piping Systems

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Whether you are pumping water to fill a pond or to aerate, it pays to do it as economically as possible. A key to economical operation is to minimize the work you have to do and to match your pump to the requirements. Both depend upon the piping system you move your water through. A suitable piping system for your operation can be determined by considering the three components that make up the total resistance to water movement in the pipe. This resistance, called the total dynamic head, determines the amount of work required to move each gallon of water. The total dynamic head is the sum of the lift, the velocity head and the friction head.

Lift

Lift is the vertical distance between the level of supply water's surface and point of discharge at the end of the pipe while the pump is running. It is the only component of the total dynamic head which is not directly affected by the piping system.

Velocity Head

The energy contained in a stream of water due to its velocity. This energy is lost when the water is discharged. The amount of work required to produce this velocity is equivalent to picking up the water high enough so that it would obtain the required velocity in falling. This height is called a "head" and is commonly measured in feet of water (the height the water has to be picked up). Numerically, it is equal to the square of the velocity (in feet per second) divided by 64.

$$\text{Velocity Head} = V^2/64 \quad (V \text{ in feet per second})$$

Most losses, and the work required to move the water in the pipe, vary with the velocity head. For a given flow rate, the velocity head is very sensitive to the size of the pipe. The velocity head depends upon the fourth power of the pipe diameter. For example, if the pipe diameter is halved, the velocity head is 16 times greater. Mathematically this relationship can be expressed as:

$$\frac{\text{new velocity head}}{\text{old velocity head}} = \left(\frac{\text{old diameter}}{\text{new diameter}}\right)^4$$

Example: Determine the velocity and velocity head for 1,200 gallons per minute (gpm) of water flowing in a 1-inch diameter pipe.

The velocity is calculated by dividing the flow rate by the cross-sectional area of the pipe. Since there are 7.48 gallons in 1 cubic foot and 60 seconds in a minute, the flow rate in cubic feet per second (CFS) is obtained by dividing 1,200 gpm by 60 seconds per minute and 7.48 gallons per cubic foot. The flowrate is:

$$\frac{1200 \text{ gpm}}{(60 \text{ sec/min})(7.48 \text{ gallons/ft}^3)} = 2.67 \text{ CFS}$$

The cross-sectional area, A, is equal to pi times the diameter squared divided by 4. Realizing that there are 144 square inches in 1 square foot, the area is calculated as:

$$\frac{3.14 \times 6 \text{ inches} \times 6 \text{ inches}}{4 \times 144 \text{ square inches per square foot}} = 0.20 \text{ square feet}$$

The velocity, V, is:

$$V = \frac{\text{Flowrate}}{\text{Area}} = \frac{2.67 \text{ CFS}}{0.2 \text{ square feet}} = 13.35 \text{ft/sec}$$

And the velocity head is:

$$\frac{V^2}{64} = \frac{13.35 \times 13.35}{64} = 2.78 \text{ feet}$$

As a rule of thumb, the velocity head should be less than 0.4 foot. The velocity head in feet for various diameter pipes and flow rates is given in Table 1.

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Table 1. Velocity head in feet.

Flow gpm → Dia. (inches)	100	200	400	600	800	1,000	1,500
4	0.10	0.41	1.62	3.65	6.48	10.13	22.80
6	0.02	0.08	0.32	0.72	1.28	2.00	4.50
8	0.01	0.03	0.10	0.23	0.41	0.63	1.42
10	0.00	0.01	0.04	0.09	0.17	0.26	0.58
12	0.00	0.01	0.02	0.05	0.08	0.13	0.28
14	0.00	0.00	0.01	0.02	0.04	0.07	0.15
16	0.00	0.00	0.01	0.01	0.03	0.04	0.09
18	0.00	0.00	0.00	0.01	0.02	0.02	0.06
20	0.00	0.00	0.00	0.01	0.01	0.02	0.04
24	0.00	0.00	0.00	0.00	0.01	0.012	0.02

Flow gpm → Dia. (inches)	2,000	2,500	3,000	4,000	5,000	7,500	10,000
4	40.53	63.32	91.19	162.11	253.29	569.91	1,013.17
6	8.01	12.51	18.01	32.02	50.03	112.57	200.13
8	2.53	3.96	5.70	10.13	15.83	35.62	63.32
10	1.04	1.62	2.33	4.15	6.48	14.59	25.94
12	0.50	0.78	1.13	2.00	3.13	7.04	12.51
14	0.27	0.42	0.61	1.08	1.69	3.80	6.75
16	0.16	0.25	0.36	0.63	0.99	2.23	3.96
18	0.10	0.15	0.22	0.40	0.62	1.39	2.47
20	0.06	0.10	0.15	0.26	0.41	0.91	1.62
24	0.03	0.05	0.07	0.13	0.20	0.44	0.78

Friction Head

The friction head is the pressure loss (in feet of water) caused by friction resistance when water flows through pipe, fittings, valves, etc. This loss is directly dependent on the length of the pipe and the number of fittings. A pipe twice as long as another pipe of the same diameter with the same water flow would have twice the friction loss and require twice the power to overcome the loss. The friction losses vary approximately as the velocity squared. Thus, like the velocity head they are very dependent on pipe diameter – the smaller the pipe the more losses (pressure drop) and the more pumping power required to move the same amount of water. Friction losses for pipe are quite often given as the loss in feet of water at a given flow rate for a 100 foot length of pipe. The following tables list head loss at various flow rates of water for 100 feet of several diameters of pipes.

Table 2. Friction loss in feet for 100 feet of steel pipe.

Flow gpm → Dia. (inches)	100	200	400	600	800	1,000	1,500
4	0.88	3.18	11.48	24.31	41.39	62.55	132.43
6	0.12	0.44	1.60	3.39	5.77	8.72	18.46
8	0.13	0.11	0.40	0.84	1.43	2.15	4.56
10	0.01	0.04	0.13	0.28	0.48	0.73	1.54
12	0.00	0.02	0.06	0.12	0.20	0.30	0.64
14	0.00	0.01	0.03	0.06	0.09	0.14	0.30
16	0.00	0.00	0.01	0.03	0.05	0.07	0.16
18	0.00	0.00	0.01	0.02	0.03	0.04	0.09
20	0.00	0.00	0.00	0.01	0.02	0.03	0.05
24	0.00	0.00	0.00	0.00	0.01	0.01	0.02

Flow gpm → Dia. (inches)	2,000	2,500	3,000	4,000	5,000	7,500	10,000
4	225.48	340.72	477.40	812.86	1,228.28	2,600.56	4,427.96
6	31.43	47.49	66.54	113.30	171.20	362.46	617.16
8	7.76	11.73	16.44	27.99	42.30	89.55	152.47
10	2.62	3.97	5.56	9.46	14.30	30.27	51.55
12	1.08	1.64	2.29	3.90	5.90	12.48	21.25
14	0.51	0.77	1.08	1.84	2.79	5.90	10.05
16	0.27	0.40	0.57	0.96	1.46	3.08	5.25
18	0.15	0.23	0.32	0.54	0.82	1.74	2.96
20	0.09	0.14	0.19	0.33	0.49	1.04	1.78
24	0.04	0.06	0.08	0.13	0.20	0.43	0.73

Table 3. Friction loss in feet for 100 feet of plastic pipe.

Flow gpm → Dia. (inches)	100	200	400	600	800	1,000	1,500
4	0.66	2.39	8.63	18.28	31.12	47.03	99.57
6	0.09	0.33	1.20	2.55	4.34	6.55	13.88
8	0.02	0.08	0.30	0.63	1.07	1.62	3.43
10	0.01	0.03	0.10	0.21	0.36	0.55	1.16
12	0.00	0.01	0.04	0.09	0.15	0.23	0.48
14	0.00	0.01	0.02	0.04	0.07	0.11	0.23
16	0.00	0.00	0.01	0.02	0.04	0.06	0.12
18	0.00	0.00	0.01	0.01	0.02	0.03	0.07
20	0.00	0.00	0.00	0.01	0.01	0.02	0.04
24	0.00	0.00	0.00	0.00	0.01	0.01	0.02

Flow gpm → Dia. (inches)	2,000	2,500	3,000	4,000	5,000	7,500	10,000
4	169.53	256.18	358.94	611.17	932.52	1,955.31	3,329.29
6	23.63	35.71	50.03	85.18	128.72	272.53	464.03
8	5.84	8.82	12.36	21.05	31.80	67.33	114.64
10	1.97	2.98	4.18	7.11	10.75	22.76	38.76
12	0.81	1.23	1.72	2.93	4.43	9.38	15.98
14	0.38	0.58	0.81	1.39	2.10	4.44	7.55
16	0.20	0.30	0.43	0.72	1.10	2.32	3.95
18	0.11	0.17	0.24	0.41	0.62	1.31	2.23
20	0.07	0.10	0.14	0.25	0.37	0.78	1.33
24	0.03	0.04	0.06	0.10	0.15	0.32	0.55

Fittings such as elbows and couplings are often rated in terms of friction loss as equivalent lengths of pipe. That is, if a fitting has an equivalent length of 20 feet, it would have about the same friction loss as 20 feet of the same diameter pipe. The following table lists representative equivalent lengths of some common fittings in the form of equivalent length (L) divided by the diameter(D).

Table 4. Equivalent lengths.

Entrances

Rounded	Sharp Edged	Reentrant
L/D = 2.2	L/D = 22	L/D = 45

Fittings

	Standard ELL	Coupling	Gate Valve Wide Open	Swing Check Valve (Open)
L/D	30	1.5	6.7	80

Sudden Enlargement

Diameter Ratio	1.25	1.33	1.5	2	3	4
Equivalent Length of Smaller Pipe L/D	5.8	8.6	13.9	25.3	35.6	39.6

Sudden Contraction

Diameter Ratio	1.25	1.33	1.5	2	3	4
Equivalent Length of Smaller Pipe L/D	8	11	12.5	16.2	18.9	20.3

A piping system or segments of a piping system may be arranged in series or parallel. Series pipe means that all the water will have to flow through each section of pipe, one after the other. A parallel arrangement means that the water may flow in two or more paths. In a parallel arrangement, the water will divide the total flow so that the total pressure drop in each path will be the same. The total pressure drop in a series is found by adding the pressure drop in each section. The total pressure drop in a parallel arrangement is found by following one path and adding up all the pressure drops in that path.

Finding the pressure drop in a parallel path may require a trial and error approach. A flow rate in each path is assumed so that the total flow in all paths equals the total flow rate. The pressure drop in each path is then determined. If the pressure drop in each path is not the same, a new guess for the flow in each path is made and the pressure drops determined. This procedure is continued until agreement is reached.

Usually, in aquaculture systems, series analysis can be used since all the water is likely to be directed to one exit at some time during the operation and this will result in pipe sizing that is satisfactory under other flow conditions.

The following procedure should be used to analyze your piping system or a piping system you are considering:

1. Determine the required flow rate in gallons per minute (gpm). You may want to add a safety factor, say 10 percent, to take care of pump wear and pipe aging.
2. Determine the lift in feet.
3. Choose the diameter of the pipe.
4. Determine the total equivalent length of the pipe. This is equal to the length of the pipe plus the equivalent length of all fittings.
5. Use the velocity head table and diameter of the pipe at the discharge to determine the velocity head. (It will not help much to suddenly enlarge the pipe here because of the losses the enlargement will cause.)
6. Use the friction loss tables to determine the friction loss.
7. If the diameter of the pipe changes, treat each section of pipe of different diameters separately and then add the total friction losses.
8. Add up the lift, the friction losses and the velocity head. The result is the total head in feet that the pump will have to supply. The pressure in psi the pump must supply is equal to the total head divided by 2.3.
9. The power a perfect pump (100 percent efficient) would require is called the water horsepower and is:

$$\text{water horsepower} = \frac{\text{gpm x total head in ft.}}{3960}$$

10. Examine the pressure and power requirements of the piping system. If the performance is not suitable, try a different design and repeat the steps.
11. Determine the suction required of the pump. The suction required is the sum of the lift to the pump, the friction head loss from the water source to the pump and the velocity head. Choose a suitable pump. If no suitable pump can be found, redesign the piping system.

Example:

It is required to pump 2,000 gpm of water from a source 5 feet below and 400 feet from the discharge. Three ells and 20 couplings are required in the pipe run. Choose the size of pipe to use. There is a quantity of 6-inch plastic pipe available.

Solution:

Since plastic pipe is available, the first trial will use 6-inch plastic. Following the procedure:

1. Required flow rate 2,000 gpm, no safety factor was used.
2. Lift is 5 feet.
3. Choose a pipe diameter of 6 inches on the first try since 6-inch pipe is available.
4. Determine equivalent length: There are 400 feet of horizontal run of pipe and 5 feet of vertical pipe for 405 feet of pipe; there are three ells, from Table 4, L/D for a standard ell is 30, since the pipe diameter is 6 inches, the equivalent length of the three ells = 3*30*6/12 = 45 feet; there are 20 couplings, from Table 4 the L/D per couplings = 1.5, the pipe diameter is 6 inches, thus the equivalent length of the couplings is 20*1.5*6/12 = 15 feet. The total equivalent length is the sum, 405 + 45 + 15 = 465 feet, the equivalent length of pipe.
5. Determine the velocity head: From Table 1 at a flow rate of 2,000 gpm in a 6-inch pipe the velocity head = 8.01 feet.
6. Determine the friction loss: From Table 3, the friction loss for 100 feet of 6-inch plastic pipe with a flow rate of 2,000 gpm is 23.63 feet. The total friction loss for 465 equivalent feet of pipe is 23.63 * 465/100 = 109.9 feet.
7. Skip step 7 since there is no change in the diameter of the pipe.
8. Determine the total head the pump must supply: The total head is the sum of the lift (5 feet), the velocity head (8.01 feet), and the friction loss (109.9) feet. Total head = 5 + 8.01 + 109.9 = 122.91 feet
9. Determine the water horsepower. Water horsepower = 2,000 * 122.91 /3,960 = 62.1 hp.

10. Examine the pressure and power requirements of the piping system. Pressure requirement = 122.91 / 2.3 = 53.4 psi; minimum power required is 62.1 horsepower.

If this seems to be too large, choose again.

1. No change, the flow rate is still 2,000 gpm.
2. No change, the lift is still 5 feet.
3. Choose a pipe diameter: Since 12-inch pipe nearly satisfies the rule of thumb that the velocity head be less than 0.4 feet (Table 1), and the pipe run is not extremely long, try 12 inches.
4. Determine the total equivalent length of pipe. Total length of pipe is still 405 feet, and the L/D for the fittings does not change. The L/D for the three ells is 3*30 or 90, and for the 20 couplings 20 * 1.5 or 30 for a total L/D of 120. With an L/D of 120 for fittings and a diameter of 1 foot, the equivalent fitting length = 120 feet. The total equivalent length is 405 + 120 or 525 feet.
5. From Table 1, the velocity head = 0.5.
6. From Table 3 the fiction loss for 100 feet of plastic pipe with a flow rate of 2,000 gpm is 0.81 feet. The total friction loss for the piping system is 0.81 * 525/100 = 4.25 feet.
7. Skip step 7 since pipe diameter does not change.
8. Determine the total head the pump must supply: Total head = 5 + 0.5 + 4.25 = 9.75 feet
9. Determine the water horsepower. Water horsepower = 2,000 * 9.75/3,960 = 4.9
10. Examine the pressure and power requirements of the piping system. Pressure requirement = 9.75/2.3 = 4.2 psi, minimum power required is 4.9 horsepower.

This seems to be a reasonable value, although you may want to try a few more sizes of pipe and compare the results. Step 11 depends upon the location of the pump, and will not be considered until a candidate pump is chosen.

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