Some Basic Concepts 2

There are some basic concepts relating to water and moving water through pipes that are particularly important to us as we start thinking about designing an irrigation system. First of all, water has weight, about 62.4 pounds per cubic foot (lb/ft^3) {1000 kg/m^3}. This weight exerts a force on its surroundings, for example, a pipe. We usually don't talk about force specifically, but the force per unit area or pressure (pounds per square inch, lb/in.^{2} or psi) {kPa, bars} is an important parameter in any irrigation design. When we turn on a faucet, water flows out because of pressure inside the pipe. This pressure is usually generated from a pump but could be generated just as easily from a reservoir located on a nearby mountain. Most municipal water supplies have pumps that supply water to an elevated tank for storage (fig. 2.1). Thus, our first concept:

A column of water causes pressure.

We can compute the relationship between the height of a column of water and the resulting pressure. We find that 2.31 ft of water provides 1 lb/in.^{2} and that 23.1 ft of water provides 10 lb/in.^{2}, thus, the relationship:

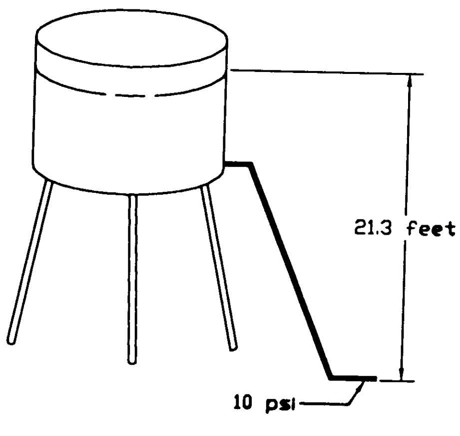

Figure 2.1. Water tank used for storage and pressure.

$$E = p\left(\frac{2.31 \text{ ft}}{1 \text{ lb/in.}^2}\right) \qquad 2.1$$

where
E = elevation in ft
p = pressure in lb/in.^{2}

{In metric, 1 m of water provides 9.81 kPa pressure. To convert pressure in kilopascals (kPa) to elevation in meters (m), divide pressure in kPa by 9.81 kPa/m.}

Actually, the column doesn't have to be vertical and it usually isn't; if we want to compute the pressure at a point or the change in pressure between two points caused by elevation changes, all we need to know is the difference in elevation between the two points. Later in this chapter (see pg. 17) we will discuss other factors that will also affect water pressure such as friction caused by water moving through a pipe.

When we turn on a faucet, or an irrigation system, water begins to move through our piping system. We refer to the speed at which the water moves as velocity and its units are feet per second (ft/s) {m/s}. If we measured water velocity in a pipe, it would be greatest in the middle of the pipe, and least near the pipe walls. (However, that's not particularly important to our discussion.) So when we say velocity, we are really talking about the average velocity of water in the pipe. Related to velocity is another term "flow" sometimes called flow rate. Flow is a measure of the amount of water moved during a period of time and can be reported as gallons per minute (gal/min) {m^3/s or L/s}. A unique relationship exists between the components in our second concept:

There is a relationship between velocity, flow, and pipe cross-sectional area.

$$q = va \qquad 2.2$$

where
q = flow
v = velocity
a = cross-sectional area

Perhaps now is a good time to talk about units in equations. The above equation doesn't have any constants to correct for units; its up to you to be sure everything is correct. For example, if you enter the pipe cross-sectional area in square feet (ft^2) and the velocity in feet per second (ft/s), the flow is the product of the two or cubic feet per second (ft^3/s). This is a perfectly good measure of flow but not the one we usually want (i.e., gal/min). To get gallons per minute we convert, knowing that there are 7.48 gal in 1 ft^3 and 60 s/min. (Appendix B provides this and other useful conversion factors.) An easier, but sometimes riskier way to obtain the units that we want is to introduce a constant into the equation so that we can enter and compute directly with the most convenient units. We could develop an equation where we enter the inside diameter (d) of the pipe in inches, the velocity (v) in ft/s, and compute the flow (q) in gal/min. Such an equation would be:

$$q = 2.45\, v d^2 \qquad 2.3$$

An even easier and surer way to determine flow and velocity is to look up the values in the friction-loss tables for the particular pipe that you are planning to use (see appendix C).

At any point in a piping system, water has energy associated with it. The energy can be in many forms including pressure, elevation, and velocity. The amount of energy associated with velocity is usually small compared to elevation and pressure, and will be ignored in our irrigation designs. If there isn't a pump in the piping system (which adds energy), energy remains the same at all points in the system when water isn't flowing (static conditions) and decreases in the down-stream direction when water is flowing (dynamic conditions). If consistent units are used, pressure and elevation can be added together to describe the amount of energy at a point:

$$H = p\left(\frac{2.31\ \text{ft}}{1\ \text{lb/in.}^2}\right) + E \qquad 2.4$$

where
- H = energy head (ft)
- p = pressure (lb/in.^{2})
- E = elevation (ft)

{In metric units, energy head can be expressed in meters. Pressure (kPa) is converted to energy head in meters by dividing the pressure by 9.81 kPa/m.}

The elevation can be the height above or below any convenient point in the area so long as you use the same point (datum) for all your computations. Equation 2.4 again demonstrates that the units of pressure can be lb/in.^{2} {kPa},

$$E = p\left(\frac{2.31\ \text{ft}}{1\ \text{lb/in.}^2}\right) \qquad 2.1$$

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{In metric, 1 m of water provides 9.81 kPa pressure. To convert pressure in kilopascals (kPa) to elevation in meters (m), divide pressure in kPa by 9.81 kPa/m.}

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$$H = p\left(\frac{2.31\ \text{ft}}{1\ \text{lb/in.}^2}\right) + E \qquad 2.4$$

where
H = energy head (ft)
p = pressure (lb/in.^{2})
E = elevation (ft)

{In metric units, energy head can be expressed in meters. Pressure (kPa) is converted to energy head in meters by dividing the pressure by 9.81 kPa/m.}

The elevation can be the height above or below any convenient point in the area so long as you use the same point (datum) for all your computations. Equation 2.4 again demonstrates that the units of pressure can be lb/in.^{2} {kPa}, but can also be described in feet {m} of water. Equation 2.4 can also be used to compute the pressure at any point in a static piping system.

Example 2.1

For example (fig. 2.2), the pressure at the point of connection (POC) to an irrigation system is 50 lb/in.^{2}. A sprinkler head is located at another location which is 25 ft lower than the POC. What is the static water pressure at the sprinkler head?

For convenience, let's use the POC as the elevation datum. The total energy at the POC is then:

$$50 \text{ lb/in.}^2\left(\frac{2.31 \text{ ft}}{1 \text{ lb/in.}^2}\right) + 0 = 115.5 \text{ ft}$$

In this example, there is no water flowing, therefore, the energy at all points of the system is the same, and pressure at the sprinkler head is found by solving equation 2.4 for p and substituting a negative value for elevation since it is below the datum:

$$\begin{aligned} p &= (H - E)\left(\frac{1 \text{ lb/in.}^2}{2.31 \text{ ft}}\right) \\ &= (115.5 \text{ ft} + 25 \text{ ft})\left(\frac{1 \text{ lb/in.}^2}{2.31 \text{ ft}}\right) \\ &= 60.8 \text{ lb/in.}^2 \end{aligned}$$

You should get the same answer if you assume the sprinkler is the datum. Surprisingly, perhaps, you have more pressure at the sprinkler than you have at the POC. You can see that the increased pressure was obtained by decreasing elevation.

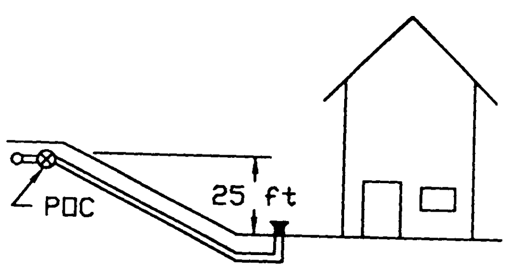

Figure 2.2. Pressure change caused by elevation.

Water flowing in a pipe loses energy because of friction between the water and the pipe and because of turbulence. In the above example, when the sprinkler head is operating, sprinkler pressure would be less than the 60.8 $lb/in.^2$ due to friction loss in the pipe. We must be able to determine the amount of energy loss in pipes so that we can properly size them. The quick way is to look up losses due to friction in a table (appendix C), but beware, tables are developed from equations, and, unfortunately, some equations are more accurate than others. Many friction-loss tables are based on the Hazen-Williams equation, which provides usable results for most pipe sizes and water temperatures encountered in spray and sprinkler irrigation. A more accurate equation, Darcy-Weisbach, may be needed in trickle irrigation or when heated water is used. For most cases we can use the Hazen-Williams equation:

$$h_f = 0.2083\left[\frac{100}{C}\right]^{1.852}\frac{q^{1.852}}{d^{4.866}} \qquad 2.5$$

where
h_f = loss due to friction (ft/100 ft)
q = flow (gal/min)
C = Hazen-Williams coefficient
d = pipe inside diameter (in.)

Notice that friction loss is a function of three factors: flow, q, pipe diameter, d, and pipe roughness, C. Actually, C is a measure of pipe smoothness with higher values assigned to smoother pipe. Plastic pipe, which is smoother than steel pipe, has a higher C value (150) compared to the C value (120) for steel. Copper has a C value of 140. Thus, increasing flow, or choosing a rougher pipe, will increase energy losses, causing decreased pressures downstream; while increasing inside diameter of the pipe, d, decreases losses and provides greater pressure downstream. The Hazen-Williams equation is used throughout this text.

Units in Irrigation Design

Most people in the United States are more familiar with English units, but much of the world uses metric units, and the U.S. is in the process of converting to metric. Metric units are simpler to use since divisions are in multiples of 10 rather than 12 as in 12 inches per foot compared to 100 centimeters per meter. But, there is variation in some units even among countries that use metric. Pressure is one variable that can be a problem. Depending upon the country, pressure may be reported in bars, kilopascals (kPa), or kilograms per square centimeter (kg/cm^2). Manufacturers in the United States are now providing metric tables, some are using bars for pressure, while others are using kPa.

Time is measured in seconds, minutes, and hours (not a convenient convention) worldwide. To simplify time, seconds are sometimes used as the basic unit and larger units of time are reported in kiloseconds (ks) or megaseconds (Ms) rather than hours or days. Most irrigation documents and texts, however, use hours or days for long time periods.

Distances are usually measured in meters (m), millimeters (mm) for small distances, or kilometers (km) for large distances. In metric, the prefixes are the key to size. A kilometer is 1,000 times larger than a meter, for example. Appendix B provides a review of prefixes as well as some useful conversions.

Some large dimensions have special names such as the measurement of larger areas in hectares. A hectare is 10 000 m^2. Large volumes are measured in cubic meters (m^3), but smaller volumes may be reported in liters (L). There are 1000 L in 1 m^3.

Chapter 2 Problems

2.1 A pressure of 33 lb/in.^{2} is displayed on a pressure gage. Find the maximum height above the pressure gage that water would rise in a pipe.

2.2 The Grand Canyon is approximately 5,000 ft deep. Drinking and irrigation water are obtained from a stream located 2,000 ft below the rim of the canyon. What would be the water pressure at the canyon floor if the pressure is obtained by change in elevation only?

2.3 What would be the maximum flow in a pipe with a 1 in. inside diameter, if the maximum allowable velocity is 5 ft/s?

2.4 Find the difference in pressure caused by elevation for two sprinklers that are located at elevations 100 ft and 175 ft.

2.5 Use the tables in the appendices to find the pressure loss due to friction in a 2-in. schedule 40 PVC (plastic) pipe line that is 1,000 ft long if the flow is 55 gal/min. What is the total friction loss and average water velocity?

2.6 A 3-in. PVC pipe is conveying 110 gal/min over a distance of 750 ft. Determine the class or schedule pipe if the pressure loss is 6.4 lb/in.^{2}.

2.7 A 2-in. type M copper tube has a flow of 2 L/s. Find the pressure loss in kilopascals for a 10-m length. Also determine the velocity in meters per second.

2.8 Repeat problem 2.5 using the Hazen-Williams equation and the flow-velocity equation. Use the inside pipe diameter that is reported in the appendix tables.