Pump and piping sizing

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Jacques Chaurette

There is no reason why anyone should not be able to go out and buy a pump, do the installation, and be satisfied with the results. There are 3 things to establish: the flow rate which can be easily determined, this is your basic requirement, the height to which you need to deliver the liquid (typically water), the friction loss associated with a moving liquid through pipes which can be determined by consulting Charts 2 and 3 in this document.

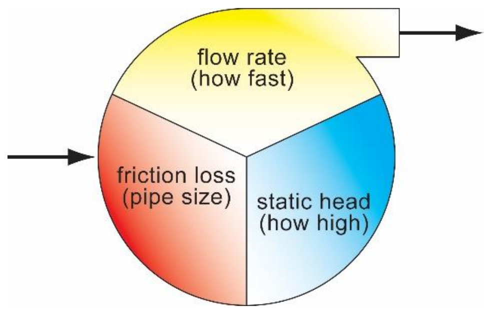

Figure 1 Three important characteristics

Imagine rolling an object downhill, a slight push starts it on its way. Since we are high up, we have elevation energy (or kinetic energy) on our side driving the object downwards and gradually being converted to velocity energy (kinetic energy) as we approach the bottom. You can put that same object in a tube producing the same result. Now if you make those same objects very tiny and slippery then pack them tightly together (in other words a liquid) we get the same result but now we have to hold them together in a container at the top (Figure 2a & 2b).

Now suppose the reverse has to be done, we need to get an object from a low to a high elevation. For solid objects we need to provide them with a substantial push or force and velocity to get them to the top. In the case of the liquid, we need to provide pressure because a liquid will not respond to a force it will just slip around anything trying to push it. Therefore, we need to provide pressure and flow which is what a pump does.

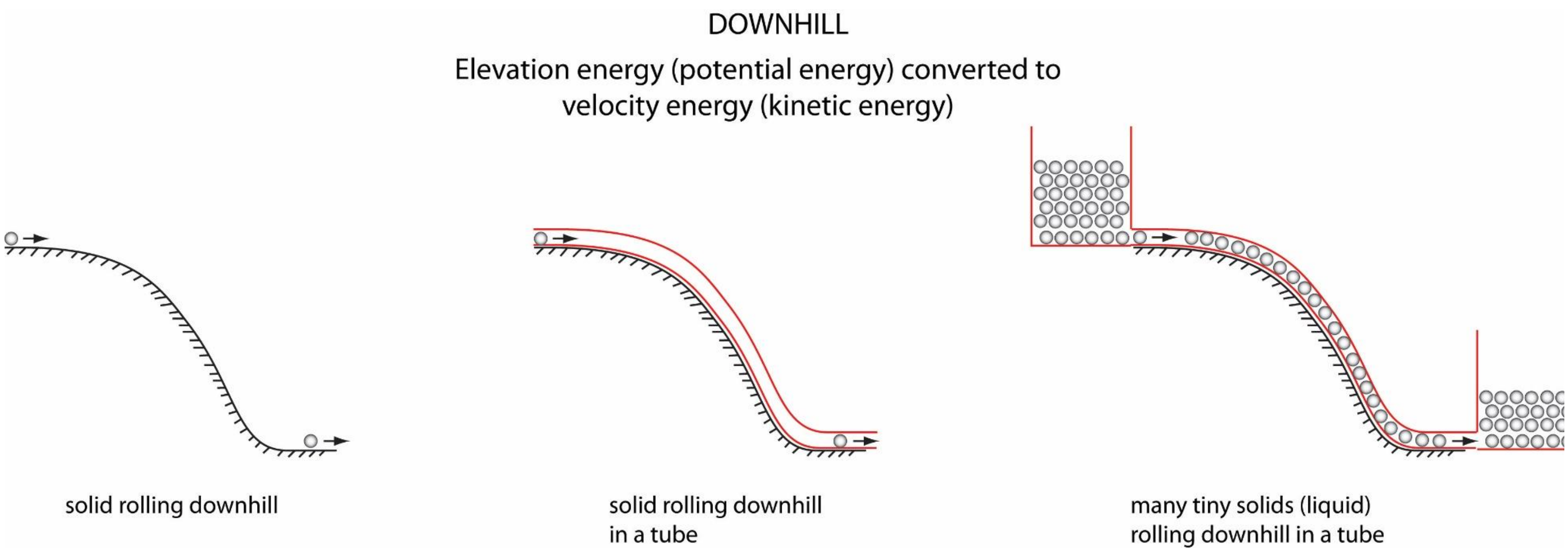

Figure 2a Solids and liquids moving down.

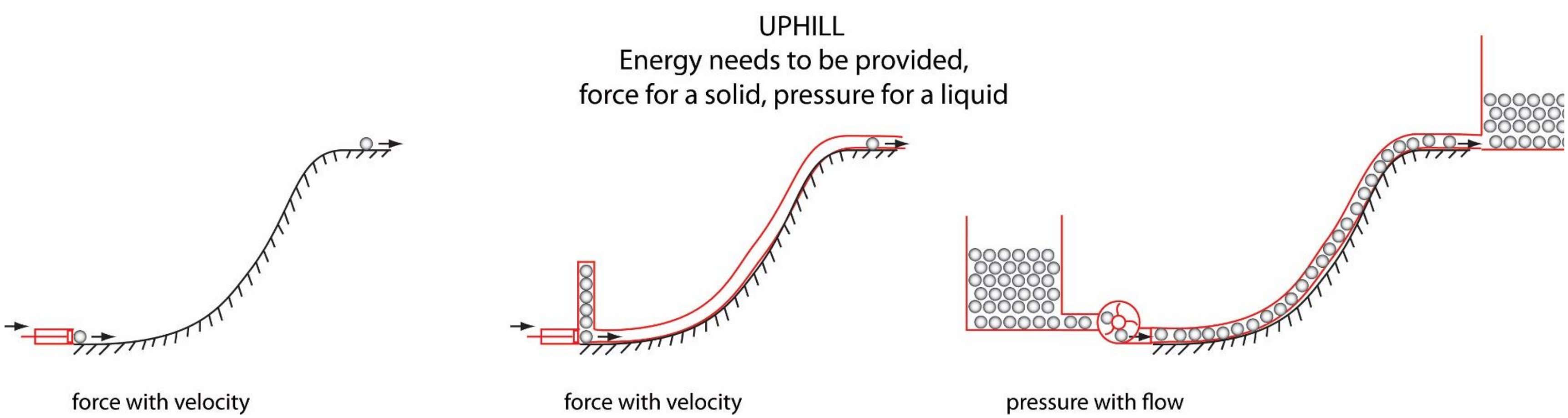

Figure 2b Solids and liquids moving up.

A pump produces pressure, but the term head is used instead, fortunately there is very simple and direct relationship between head and pressure. Head is directly proportional to pressure and you can see some typical values for water in Table 1. In Figure 3, we see how pressure and head are related. Pressure will be produced due to the weight of water at the bottom of a tank and the same is true of a piping system. The head or in this case static head is the height of water above the location of interest.

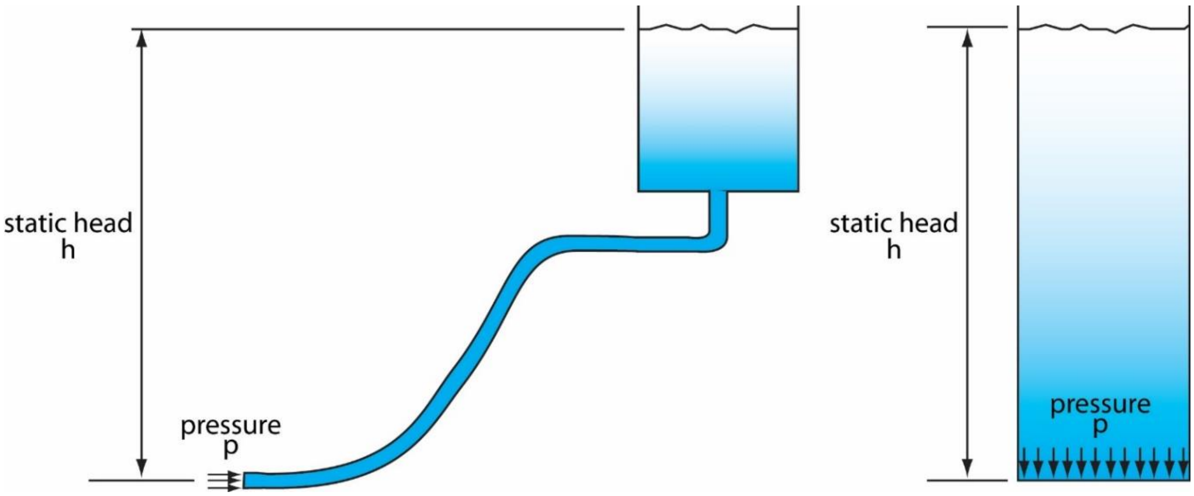

Figure 3 Pressure in a tube vs. pressure at the bottom of a tank.

Pressure vs head for water			
Pressure (psi)	Head (ft)	Head (ft)	Pressure (psi)
0	0	0	0
1	2.31	1	0.43
2	4.62	2	0.87
3	6.93	3	1.3
4	9.24	4	1.73
5	11.55	5	2.16
7.5	17.32	7.5	3.25
10	23.1	10	4.33
15	34.65	15	6.49
20	46.2	20	8.66

Table 1 Pressure to head values for water.

A typical pump system user is faced with a bewildering set of conditions and terminology when it comes to selecting a pump and associated parts. I will answer some basic questions without using any complex formulas or calculations using a few charts and basic concepts that we are all familiar with. In particular:

- What is a pump system?
- What is the role of height (i.e. head) in a pump system?
- How is velocity defined for a liquid and how does it help us determine the optimal diameter of a pipe or tube?
- What is the role of friction and why is it called friction head?
- What are the important characteristics of a pump?
- How do you select a pump for a given application?
- Why are we using head instead of pressure?

A pump system consists of a pump, usually some sort of tank for storing or supplying liquid, and pipes or tubes to transfer the liquid from one place to another. The start of the system is at the free surface of the suction tank and the end is at the outlet of a pipe or the free surface of a discharge or storage tank. Here are two typical systems.

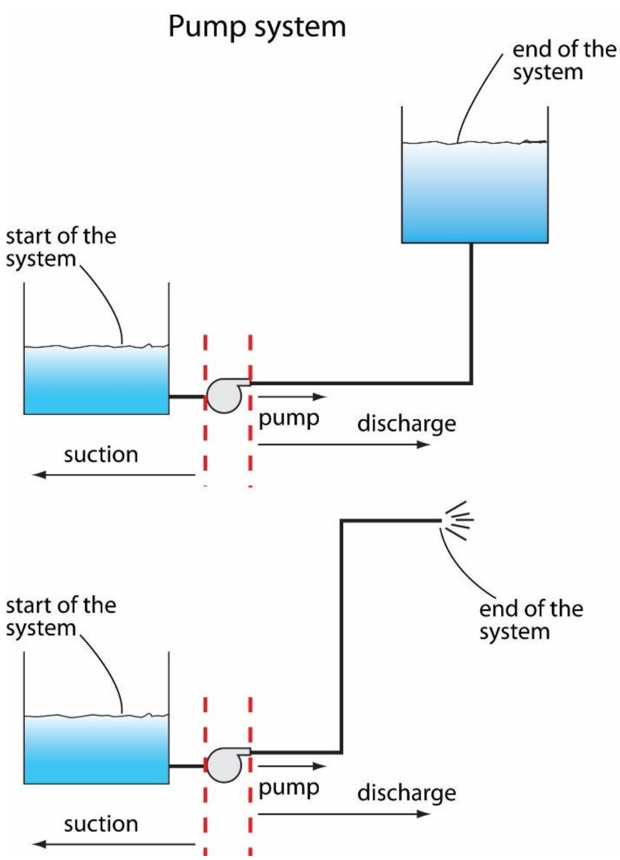

Figure 4 Two typical pump systems.

How high do you need to deliver the liquid?

From the perspective of finding the correct pump size or capacity, it is the difference in height between the high point and the low point that needs to be considered. This is no different from lifting a set of weights in the gym, you start from the floor which you can set at zero height and you lift it as high as your arms can go vertically, that height minus the floor height is the height you will have to lift the weight, for example 6' – 0' = 6'; we can always set the lower height to zero and measure from there.

Since there are a multitude of systems for different applications here are a few of them with their high and low points.

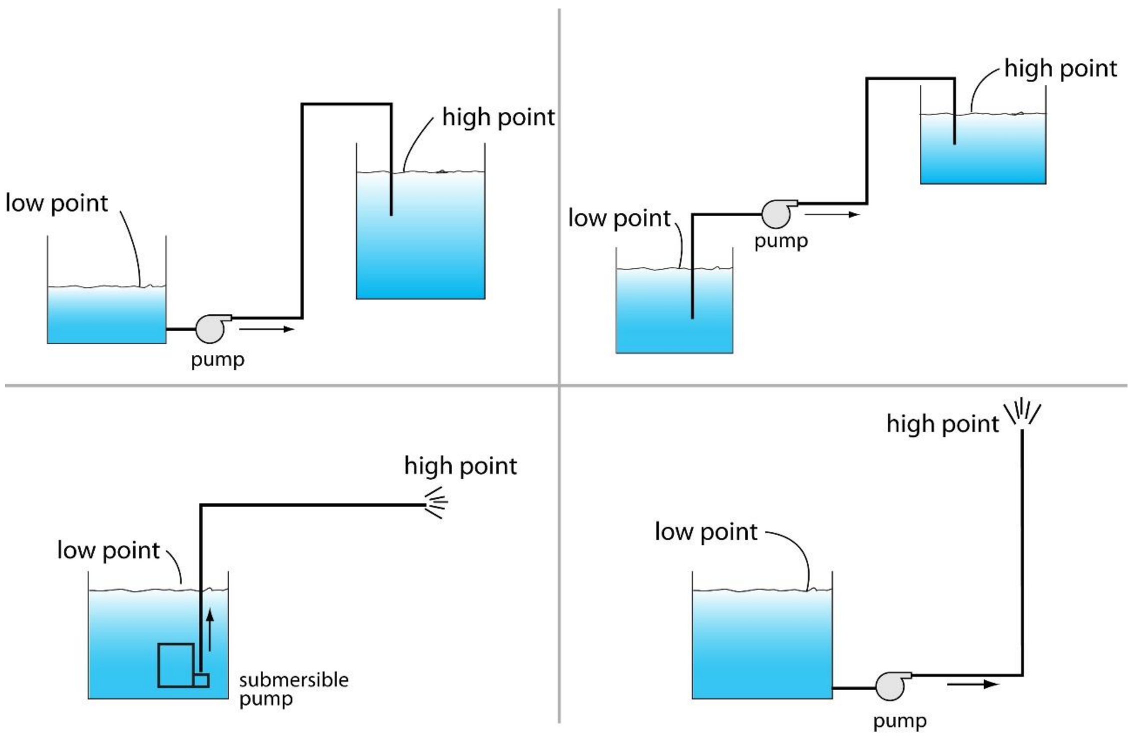

Figure 5 Locations of the system low point and high point.

As you may have noticed the low point and high point correspond respectively to the start and end of the system.

What are some of the errors we can make when choosing the high point or low point?

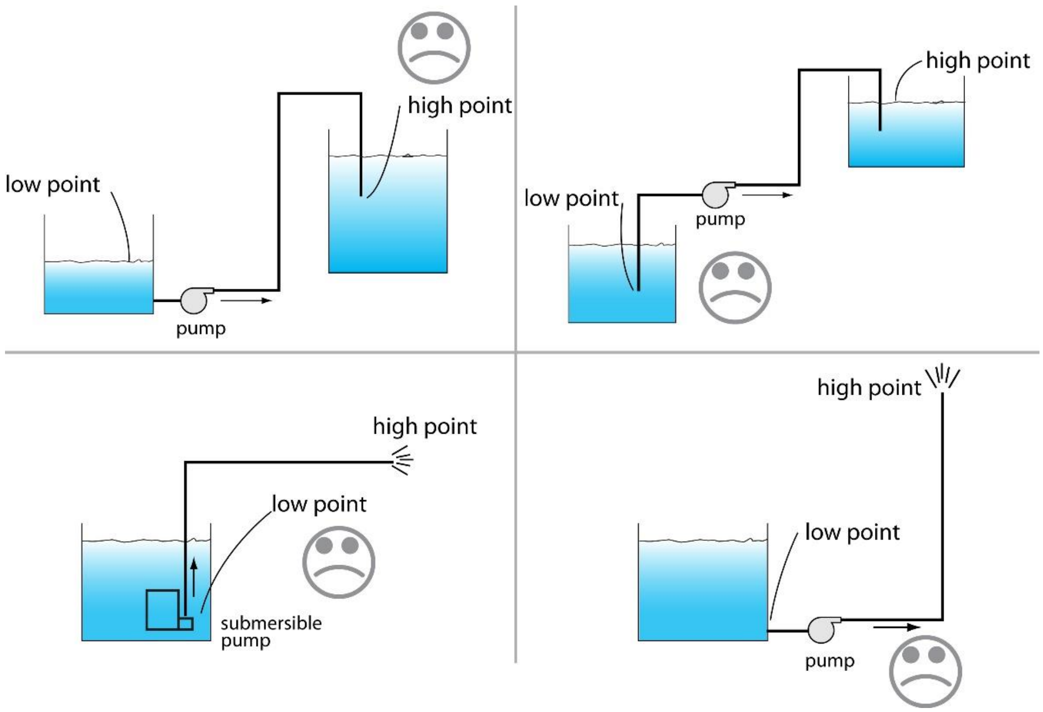

Figure 6 Errors in locating the system low point and high point.

How fast do you want to transfer the liquid, or how many gallons do you want to transfer per minute?

Do you want to fill a 5 gallon bucket in 1 minute or 10 minutes. The flow rate in the first case is 5/1 = 5 gals./minute and in the second case 5/10= 0.5 gals./minute or gpm.

How does it get there?

The pump is the engine and the pipes or tubes are the pathway or road. If you have to get up a steep hill in your car, you won't be able to go as fast as on a flat road, because it will require more energy, perhaps more than you have available. The same applies to a pump, if you want to transfer a liquid quickly to a high point it will be harder to get it there.

What if you need to transfer a liquid horizontally or to a destination at the same level as the starting point? If the tube is long, it will take more energy to transfer a liquid at a high rate vs. a slower one. Like a car, it takes allot of energy to drive fast on a flat road, consider a Porsche vs. a Subaru. The faster you go the more energy is required.

The pump and the tube size or diameter are the 2 elements that typically can be changed. The bigger the pipe the easier it is to increase the flow rate within reason. It will not help you to go from a ½ in dia. tube to a 3 in pipe. Or maybe it would if you have completely mis-estimated the size of tube required. To avoid this problem, we need to look at velocity and friction which we will deal with further down. To increase the flow rate, you could also put in a bigger pump, often it is easier to change the pipe or tube than to change the pump. In practice, to get the optimal system you have to select the pump capacity (i.e. flow rate) and head in conjunction with the right pipe or tube size to get the flow rate you intend at the destination.

How do you know if changing the pipe will make a significant difference? Calculating the amount of friction that the water encounters in the pipe will determine whether it is worth it or not.

In many typical home projects, this is all you need to know about how to size your system. However, if you are looking to avoid extra cost on your materials, for example, selecting and paying for 1” dia. tubing when you only need ½ in tubing, then we need to look at *why friction matters*.

What haven’t we talked about?

Static head and pressure.

Velocity, friction, and viscosity.

Static head

Static head is the height of water above a given reference point. The suction static head is the height of water above the pump suction or intake. Discharge static head is the height of water above the pump discharge. Total static head is the difference between these two, this is the head that the pump will have to produce to at least get the water up to the high point.

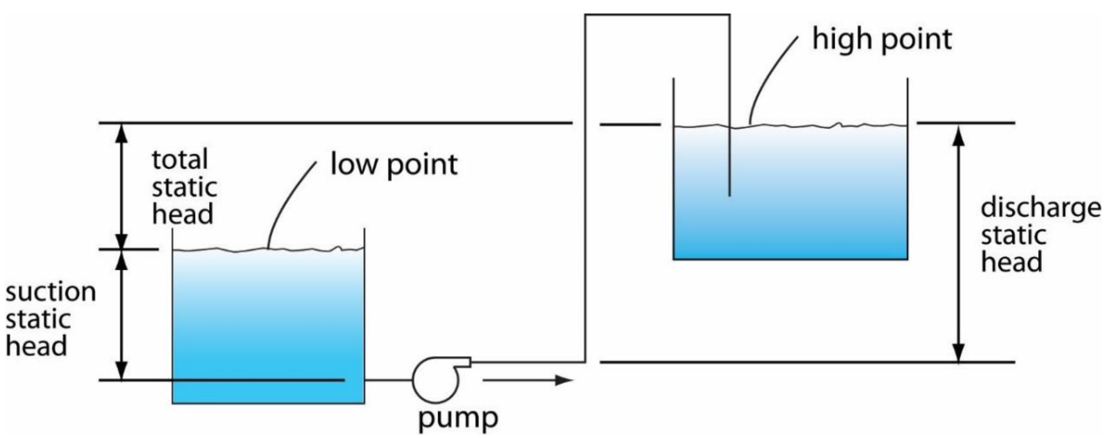

Figure 7 Suction, discharge and total static head.

The total static head is what we determined in the first part. It’s the difference between the levels of the free surfaces of both tanks. The selected pump should have more head than just the total static head since you need to account for friction. Remember that even a pipe that runs horizontally will produce friction in the liquid and more head is required to account for this.

Whether the pipe is running horizontally or vertically, it's the length that counts when we calculate friction.

Pressure is a little trickier to visualize; a balloon is a good example; when you blow it up you need to produce pressure to get it to inflate. Pressure is produced by the pump; it is the driving force that moves the liquid. It is not possible to push a liquid because of its low viscosity that's why we need pressure.

Imagine that you have an object that you cannot hold, pick-up, push or affect in any way. *How do you get it from one place to another?* <u>This is a fluid</u>. Fluids are always in containers because they cannot hold themselves. You can move them around by moving the container. But what if you need to move allot of it? What if you don't want to go to the well several times a day to get the water that you need. Then you need a device that can pressurize water within a container, or a pump.

A force is required to move solid objects, pressure is required to move liquids.

The terms low and high point for static head are perhaps not the best qualifiers because it is quite possible that the high point is actually lower than the low point. Better terms are <u>inlet</u> and <u>outlet</u> of the system.

Velocity, viscosity and friction

Velocity is the key to friction. To calculate the velocity, we take the flow rate and divide by the cross-sectional area of the tube. The area is $\pi\ d^2 / 4$ and the flow rate is whatever we require.

The following table shows the tube diameter vs. the velocity for different flow rates. Velocity does not tell us much on its own. However, it is essential for calculating friction along with its viscosity.

Velocity vs. tube inside diameter		
0.5 gpm - 10 mins to fill a 5 gallon bucket		
Tube dia. (in)	Area (in)	Velocity (ft/s)
0.25	0.05	3.27
0.5	0.2	0.82
0.75	0.44	0.36
1	0.79	0.2
1.25	1.23	0.13
1.5	1.77	0.09
1 gpm - 5 mins to fill a 5 gallon bucket		
Tube dia. (in)	Area (in)	Velocity (ft/s)
0.25	0.05	6.54
0.5	0.2	1.63
0.75	0.44	0.73
1	0.79	0.41
1.25	1.23	0.26
1.5	1.77	0.18
2 gpm - 2.5 mins to fill a 5 gallon bucket		
Tube dia. (in)	Area (in)	Velocity (ft/s)
0.25	0.05	13.07
0.5	0.2	3.27
0.75	0.44	1.45
1	0.79	0.82
1.25	1.23	0.52
1.5	1.77	0.36

Table 2 Velocity, flow rate and tube diameters.

Chart 1 shows the flow rate vs. the velocity for a 0.5” diameter pipe and the friction loss as marks along the curve. For example, a flow of 5 gpm for an 0.5 in pipe diameter has a velocity of 8 ft/s and produces a friction loss of 77 feet per 100 feet of pipe. That friction loss is high and would be a strong indication that a bigger tube is required; a diameter of 0.75” is more suitable and would produce a friction loss of 10 ft/100 ft of pipe. You can verify this with chart 2 and later we will discuss why friction has this curious unit of feet per 100 feet of pipe.

As a guideline, any velocity above 12 ft/s is considered high and will create a high level of friction loss.

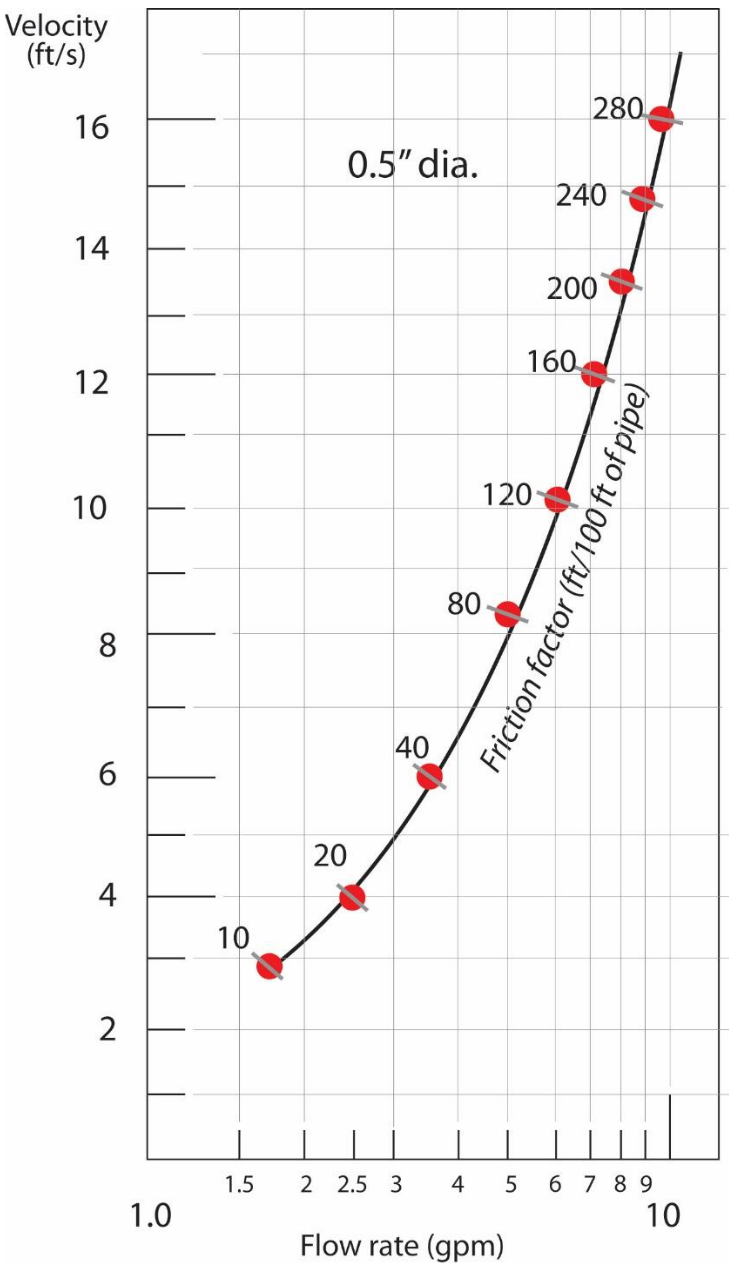

Chart 1. Friction values for a 0.5” diameter tube.

Chart 2 provides the friction value for several pipe sizes. If the friction is high then we may want to consider a bigger pipe. Let's do an example, say we have a flow rate of 6 gpm and we are using a 0.75" diameter pipe or tube. Then the velocity will be 4.5 ft/s and the friction 18 ft per 100 ft of pipe. The reason friction is given in ft per 100 ft of pipe is that the pipe length will be different in each application. Let's say your pipe is 20 ft long, then the friction is 18 x 20/100 = 3.6 feet.

It sounds a bit strange to have friction in units of feet. The reason is it can be added to the total static head which will then provide you with the total head of the pump.

Here's a way to visualize this - see Figure 8. Take the end of the tube that is connected to the discharge side of the pump and raise it up vertically, at some point the flow will stop and this will correspond to the maximum static head you can achieve with that pump, however there is no flow. To get flow you have to lower the end of the tube. *How much do you have to lower it?* To get to your required flow, for example to 6 gpm you will have to lower by 3.6 feet.

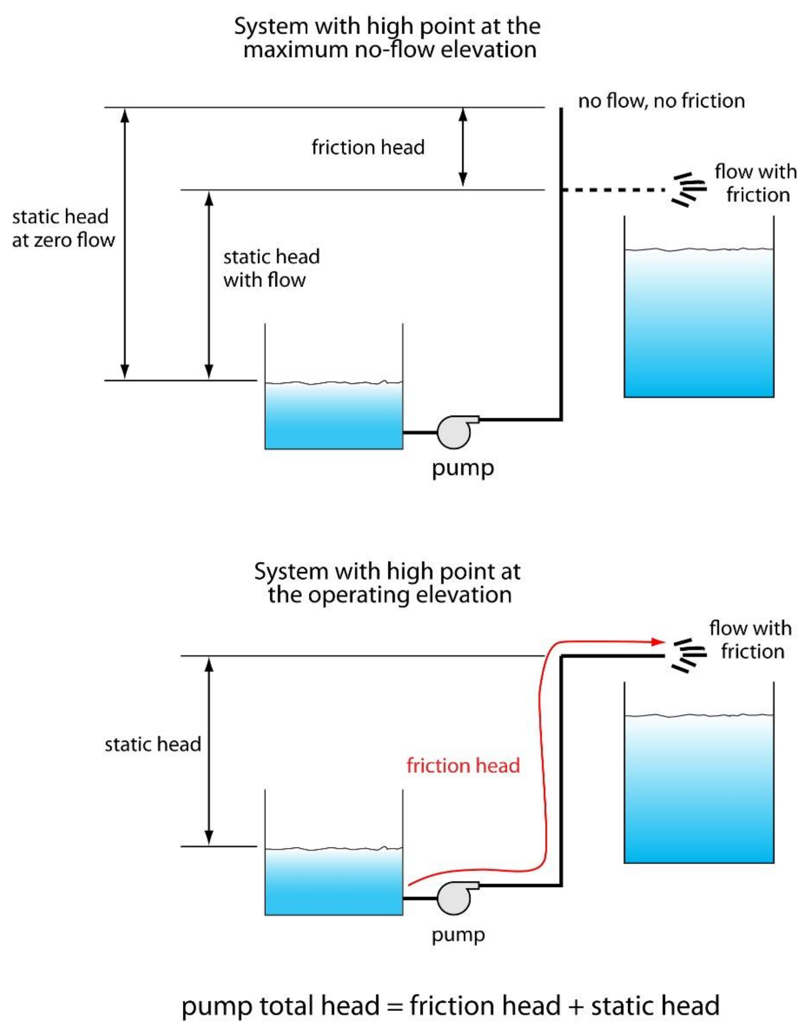

Figure 8 Friction head.

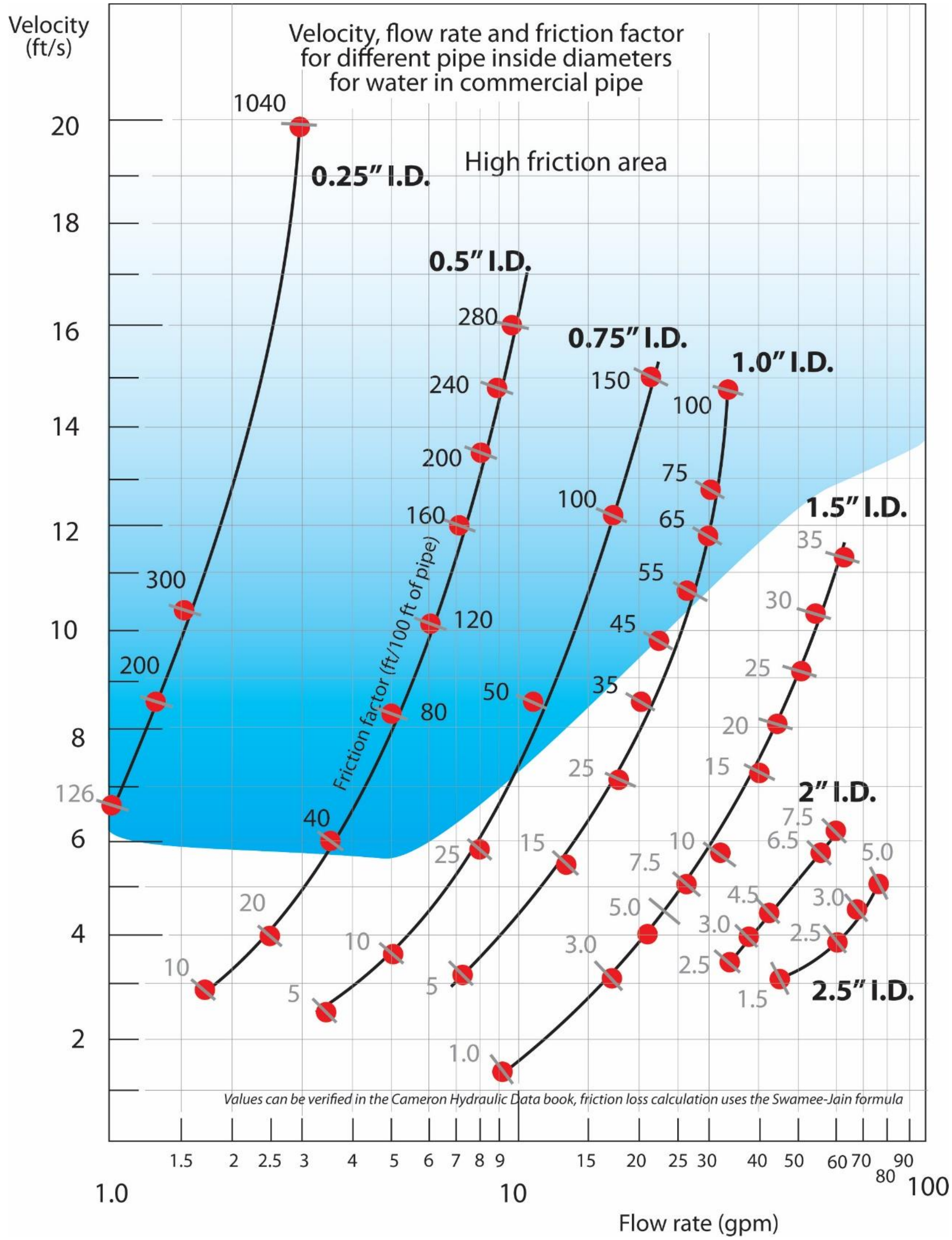

Chart 2 Friction values for different flow rates, pipe diameters and velocities.

The typical home project often involves small diameter tubing. Chart 3 provides friction loss values for small tubing. When the flow rate is small, the flow rate is often given in gallons per hour (gph).

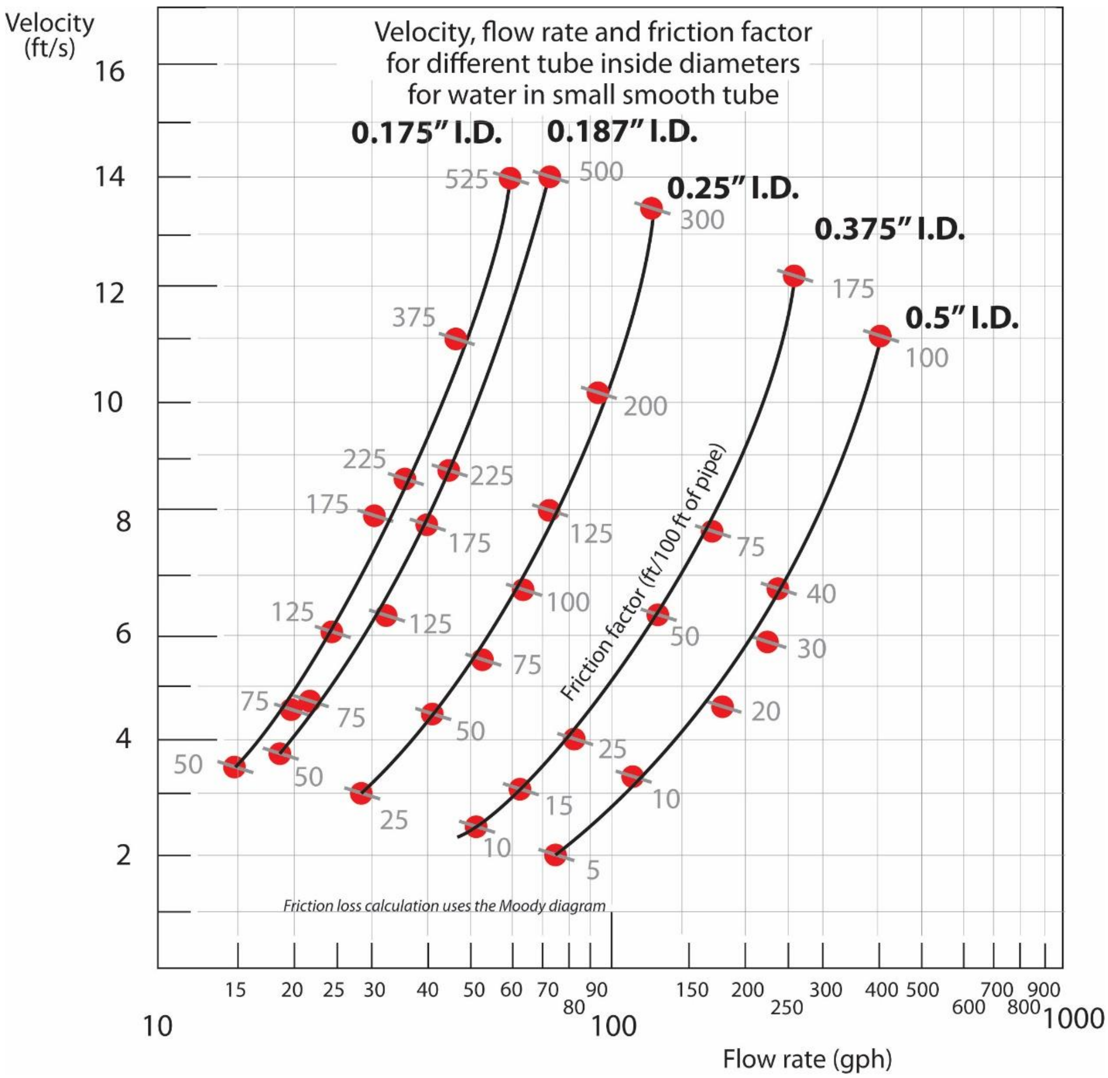

Chart 3 Friction values for different flow rates for small pipe diameters.

The last question to be asked is how do you select the right pump? We know how to calculate friction head and we can easily measure the static head. Let's say the static head is 16.4 ft and the friction head is 3.6 feet, then the total head of the pump will be 20 feet. *How do we find a pump that will gives us 20 feet of head at 6 gpm?*

All centrifugal pumps operate on what is called a performance curve or a pump curve. The curve shows that there is a relationship between the head produced by the pump and the flow rate.

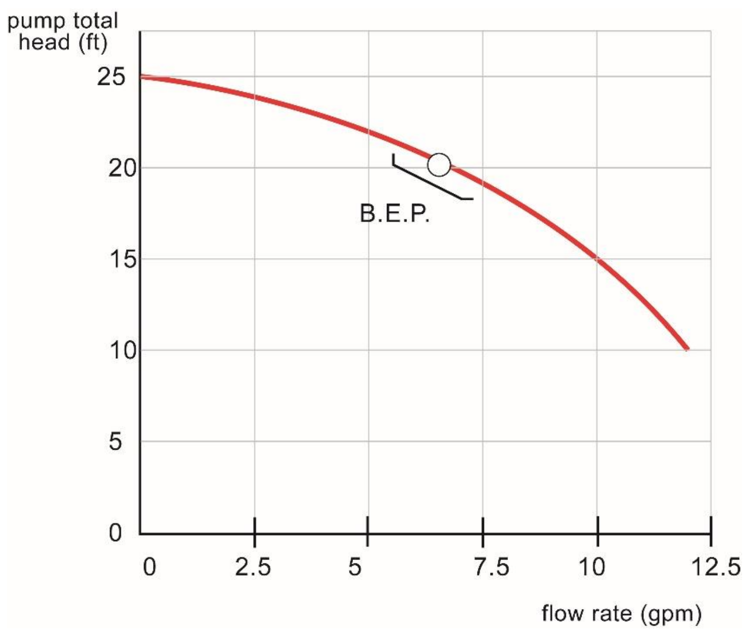

Figure 9 Typical pump performance curve.

The two most important characteristics of a centrifugal pump are its flow rate and head. The manufacturer will provide the head and flow rate at the best efficiency point of the pump or the B.E.P and they often call this the rated flow and head. If the pump is moderately large, with a discharge diameter bigger than 0.5" for example, they may also provide a performance curve. The goal is to find a pump whose rated flow and head matches your operating conditions the closest. Typically, it will be difficult to find a pump that exactly matches your conditions. It will most likely have a higher head than you require at a higher flow rate. The higher flow rate is easy to control, all we need is a valve on the discharge pipe that we can close to get to the flow we require.

How does the pump establish its position on the performance curve? The pump starts up quickly attaining its running speed in a few seconds. Because the pump is of a certain size it is pushing fluid forward at a rate that is characteristic of its size. As the system fills up the liquid gets to its top level establishing the static head and since the liquid is moving the friction head also builds up. The sum of these two determines the position on the performance curve.

If you had the ability to instantly increase the pipe size then the friction head would drop, the flow would increase and the pump would be operating on a lower part of its curve. The reverse would happen if you could decrease the pipe size, the pump would operate higher on its curve and the flow would diminish.

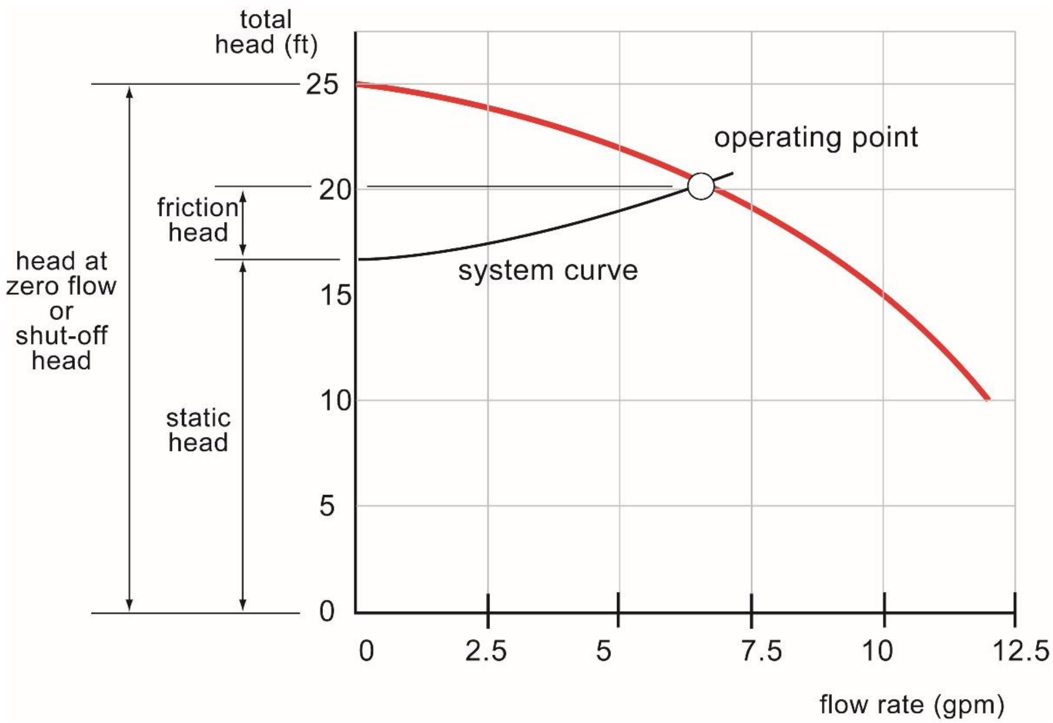

Figure 10 The interaction of the system curve and pump curve.

The pump is built to a certain size, for example it might have a 2” diameter discharge connection, an 8” diameter impeller and appropriate size casing to go around this. It is intended to provide a flow range within 30-60 gpm and not 1-3 gpm. Therefore, it will naturally tend to operate somewhere around the mid-point of its curve, around 45 gpm, if the operating conditions are also in that area. If the operating conditions are different there will be an adjustment upwards or downwards on the curve depending on the physical constraints (i.e. pipe size and static head). Just like driving a car, if you decide to go up a hill you are going to naturally slow down.

One last word about head, the pump doesn’t actually produce head, it produces pressure. Head is merely a convenient term that we use because it corresponds to height and pumps are often used to move a liquid to a higher elevation. If we have to get a liquid to a height of 10 feet for example, we need a pump that has a head of at least 10 feet of head to move the liquid to that height (the static head) plus some extra to account for friction and get the flow required.

We will use pressure if we are trouble-shooting a problem with the pump, for example whether it is providing the right flow for a given head as its performance curve states. Pressure is easily measured by installing a pressure gauge on the discharge of the pump. And then pressure (p) is converted to head (H) with the following formula.

$$H(ft) = 2.31 \times \frac{p(psi)}{SG}$$

where SG is the specific gravity of the liquid, in the case of water SG=1.