Understanding small typical pump systems

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Purpose

The purpose of this discussion is to familiarize ourselves with common pumping situations. How to size a pump, size pipes and establish the flow demand. Something like a statuary fountain, pond water circulation or a small cottage water supply from an artesian well or lake. The pumps for these systems are mostly available at your local hardware store if the flow demand is not too high. Since fluid behavior is so fascinating, we will also look at the unusual behaviour of liquids as compared to solids.

This document is intended to provide background on how pump systems work and calculations are performed. It is not a guide on how to use the software.

Understanding fluid systems

The movement of fluids is difficult to understand because it's not part of our everyday experience, at least not in a way that is obvious to us. In the modern world we have water available at the turn of a tap but it wasn't always so. You can argue that our modern infra-structure of water supply and waste management allowed the development of great civilizations.

The Romans starting in 312 BC, were early innovators in massive water supply projects. They realized that fresh water was a prerequisite for building a massive city with a large population. They had mastered the building of arches and used that technology of building structures to support aqueducts that could span valleys. The aqueduct needed to slope downward at a very small slope over long distances therefore no variations from a straight line were allowed.

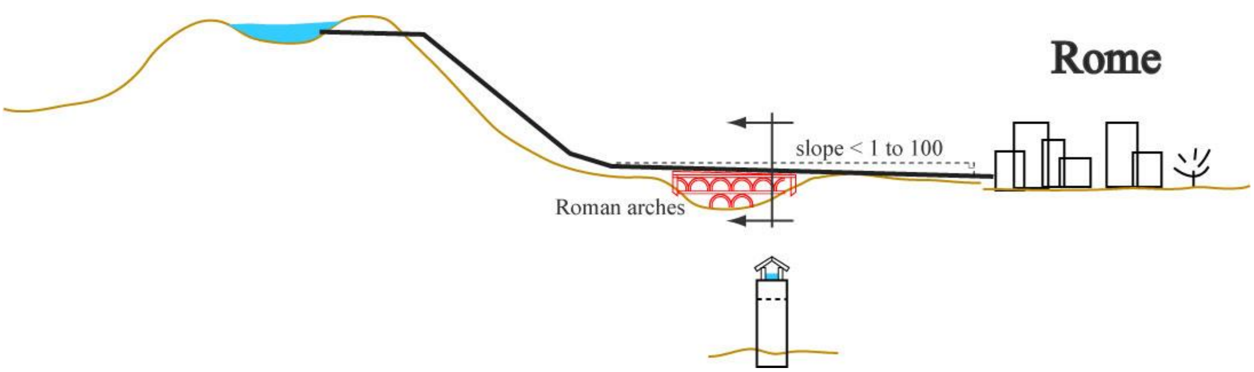
Here is a beautiful section of aqueduct in Pont de Garde, France

The picture is from the web site https://en.wikipedia.org/wiki/Roman_aqueduct; "*The multiple arches of the Pont du Gard in Roman Gaul (modern-day southern France). The upper tier encloses an aqueduct that carried water to Nimes in Roman times; its lower tier was expanded in the 1740s to carry a wide road across the river.*"

The building material was a type of concrete, more exactly cement with some hard aggregate such as broken pieces of clay pottery. This cement was very strong and versatile.

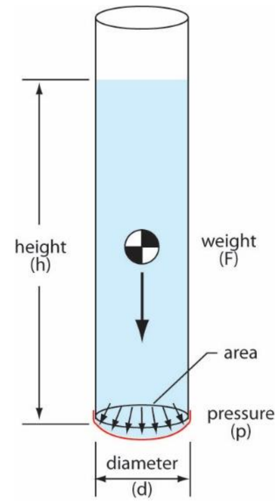
The top tier is where an open channel is located and slopes downward very gradually, less than1%; this channel holds the water that moves by gravity over long distances. In fact, the above aqueduct had a slope of 10 m over a distance of 16.4 km. In some cases, the gradient was a modest 3 ft in 1000 ft (ref. Roman Empire by Nigel Rogers, Metro Books 2013). The channel was covered to prevent evaporation and regularly maintained as the surface could be worn down over the years gradually impeding flow.

The 30,00 feet view looks like this:



The arches are required to span the valleys and ensure that the water channel can maintain a constant slope.

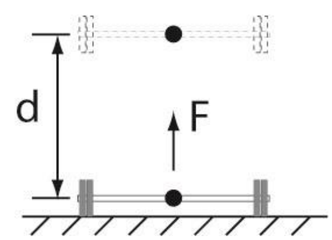
The Romans but impressive sewage lines that were mainly used to drain low lying areas in the city. Citizens in private homes were reluctant to connect their toilets to the main sewer as there were no traps or impediments for small creatures crawling up the drain pipe. And also the pipes used were made of clay and were very susceptible to leakage over time causing bad odour.



See this web site: https://phys.org/news/2015-11-toilets-sewers-ancient-roman-sanitation.html

Or this file if the above site has disappeared: http://www.pumpfundamentals.com/What toilets and sewers tell us about ancient Roman sanitation.pdf

We move objects and things around everyday and never think twice about it. We know approximately how heavy the object is. How do we measure weight, we can use a scale, or perhaps the weight is conveniently written on the packaging of the object. If we have to raise it to a certain height, we know that it takes energy and we have an intuitive idea of what that means. It's work! The higher we have to lift, the more work it takes and a heavier object requires more work. We can measure weight directly with a scale and also distance with a tape measure. But work or energy is a calculation or combination of force (i.e. effort) and distance. By the way, work and energy mean the same thing, traditionally work has been used to express the amount of force required to execute some task. Energy is used in a more general fashion for example stroking a pump to inflate a bicycle tire is the amount of work or energy needed to pressurize the tire. Once the tire is pressurized, you can use it as a source of energy to drive something else such as blowing up a balloon or driving a pneumatic drill, it is then referred to as energy.



The definition of work is force x distance (F x d). The units of force in the Imperial system are pounds, abbreviated as lbf for pound force; in the metric system the force unit is a Newton. Distance is measured in inches or feet, abbreviated respectively in and ft; and in the metric system millimeter (mm) or meters (m). I'm going to use Imperial units mostly. If we want to know how much work is required to lift a 50 lbfs weight vertically up 6 ft, we simply multiply them and get 6 ft x 50 lbf = 300 ft-lbf of work. Sounds like allot, and it is for the human body, we all know that from working out in the gym.

In the metric system the work unit is watt-h, or watt-hours. If you have ever been to a science museum, they sometimes have a bicycle hooked up to a generator that produces electricity to power a 60-watt lightbulb, it's hard work to keep that bulb glowing.

You move an object by applying a force, but what about moving liquids? Can you apply a force to a liquid such as water? No. Water will just slip through your fingers; but you can apply pressure.

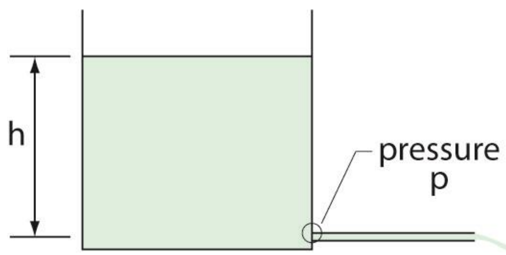
In the world of liquids pressure is the equivalent of force. *What is pressure?* We have an intuitive understanding, we feel pressure on our ear drums when we dive to the bottom of a pool; we feel the same thing in an airplane when we get up to altitude and the air pressure drops inside the plane.

What does pressure look like? Say we have a tube filed with water and a thin membrane such as Saran wrap sealing the low end. It's easy to imagine that the wrap will bulge out due to the force exerted by the weight of the water. This weight is distributed across the surface of the membrane, and this is what we call pressure.

There is a wonderful and simple relationship between the pressure at the bottom of a container and the height of the liquid column

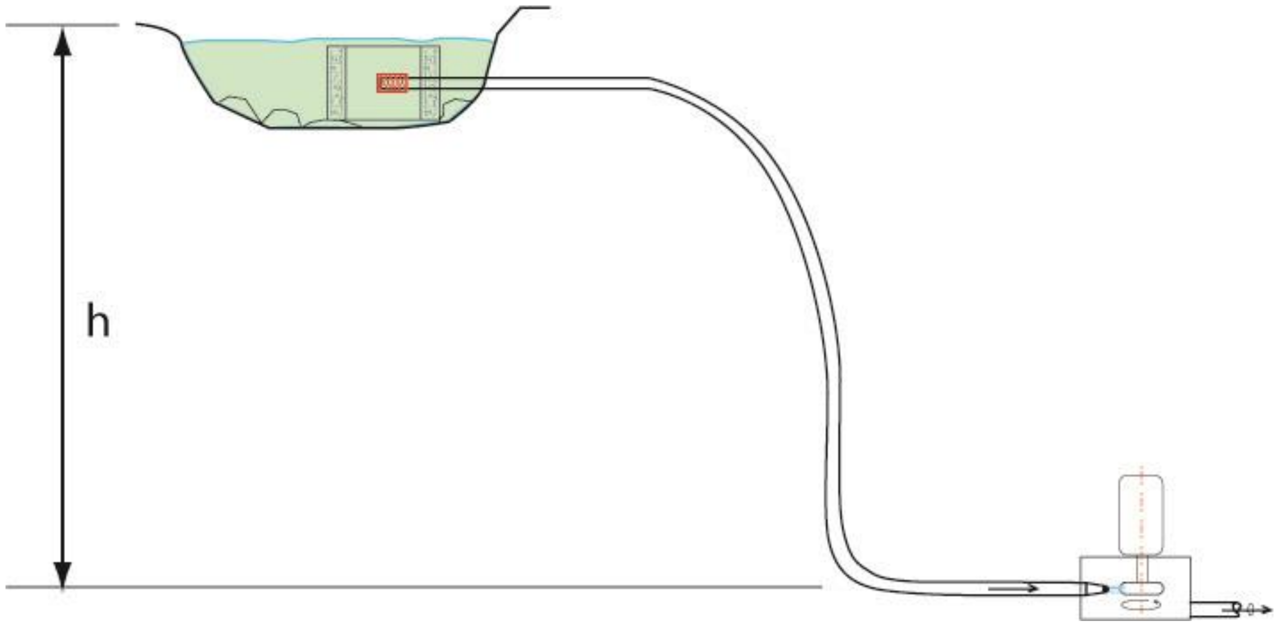
$$p(psi) = h(ft) / 2.31$$

The simplest fluid system we can imagine is a tube connected to a tank full of water. We can determine the pressure by using the height to pressure formula: p(psi) = h(ft)/2.31. If the height is 10 feet then the pressure is 4.3 psi.



The pressure at the inlet of the pipe is what drives the liquid; this pressure is produced by the height of water above the pipe connection. The higher the water level the more pressure will be produced and the faster the water will exit from the pipe. In this system there is no pump, we don't need one, all the work is done by having the liquid available at a height and that height is known as head, a term that is used a lot in pump systems.

We started by saying that fluids cannot be moved by a force but can be moved by pressure. In this system we see that pressure can be produced by a body of water at a height. The work produced to create pressure comes from the elevation of the liquid. This is how a damn works; an elevated reservoir provides water to a turbine located far below the water level.



This work or energy that the body of water produces is called potential energy, and in the pump system world it is referred to as static head. Head is a term that is frequently used in describing pump systems as opposed to pressure which is seldom used. The reason is that head, because it is a form of work or energy can be added and subtracted whereas pressure cannot.

This is what is meant by head is a form of energy; the precise term for head is specific energy. Because head is a form of energy it can be added or subtracted from another head term within the system. For example:

In a typical pump system, we have a suction and a discharge tank. The suction static head is the amount of head supplied to the pump. The discharge static head is the amount of head required at the discharge of the pump. The pump has to supply the difference between these two. Therefore, the pump head is the discharge head minus the suction head, and this is known as the total static head. This is how easy it is to calculate the pump head.

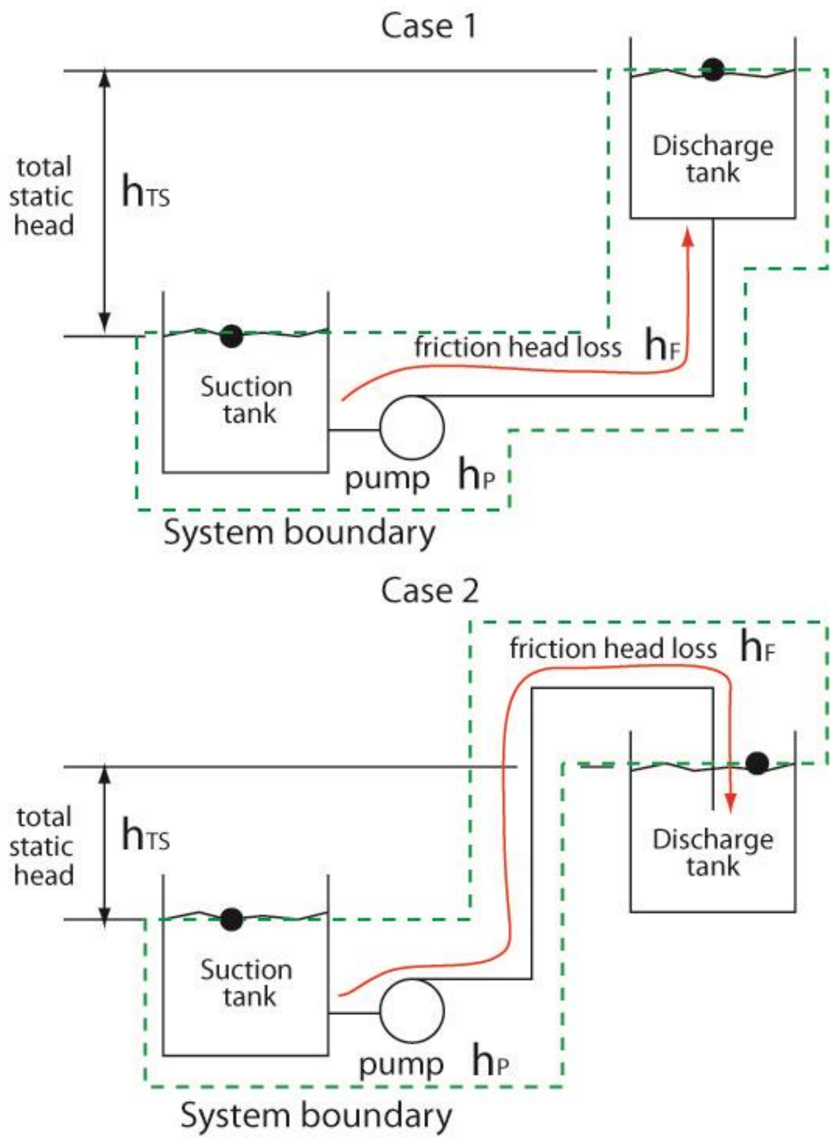
Of course, in the real world we have friction to contend with so the only thing missing is the friction head. Once we have calculated the friction head which will depend on fluid velocity, pipe size and length then we add this to the total static head and we get the pump total head.

The next couple of figures will show how we can determine the static head of various systems. Each system is surrounded by a boundary which helps locate the various levels of tanks or pipes.

pump total head — total static head

$$h_P = h_F + h_{TS}$$

friction head

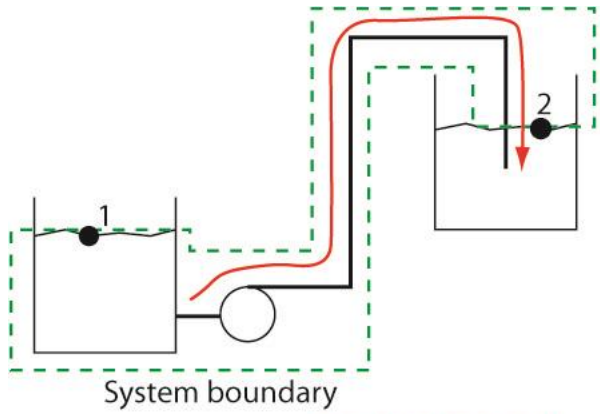


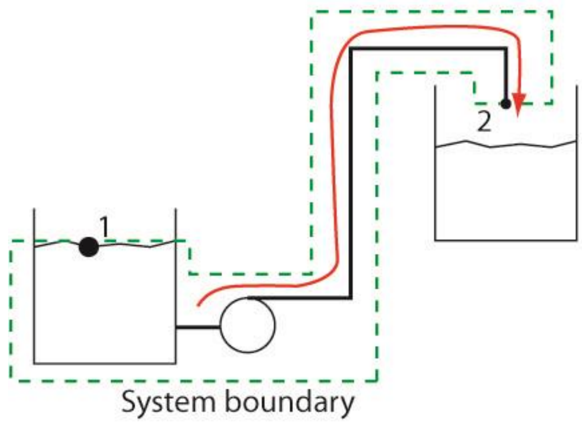
The dashed line is the boundary of the system, it serves as a reminder of what to consider in our calculations. The basic principle is you need to include all fluid particles from the inlet of the system to the outlet. For example, in case 1, we start at the level of the suction tank, we follow the liquid through the pipe and into the pump up to the discharge tank and further up to the elevation of the liquid in the discharge tank.

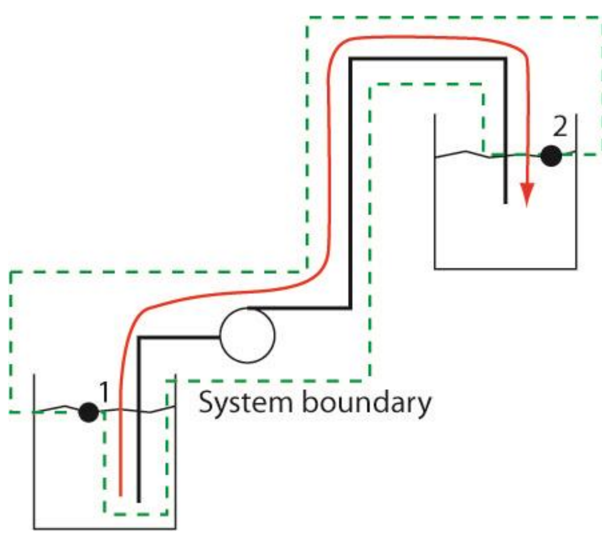
In case 2 which is more typical, we start at the level of the suction tank, we follow the liquid through the pipe and into the pump up to the discharge tank and into the discharge tank to the end of the pipe and further up to the elevation of the liquid in the discharge tank.

System boundary

Points 1 and 2 identify the respectively the inlet and the outlet of the system. Different systems will have different boundaries, here are a few examples:

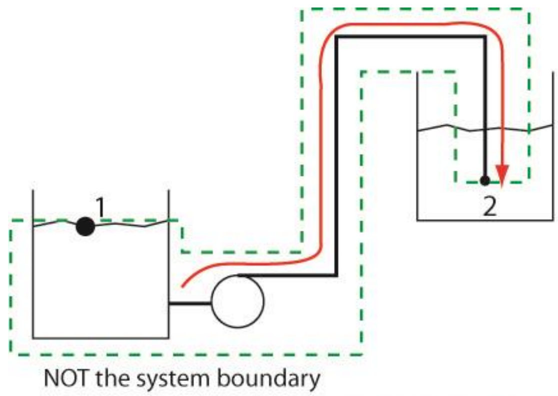


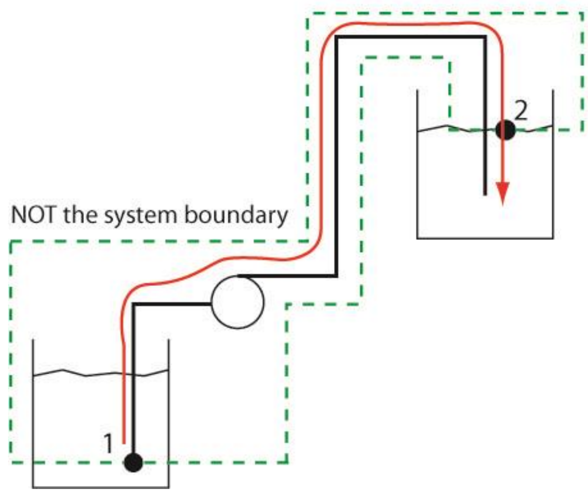




Point 1 is where the system begins and point 2 where it ends, with these two locations correctly identified we can establish the static and friction head from which we derive the pump total head.

These two systems are examples of incorrectly positioning the boundaries:

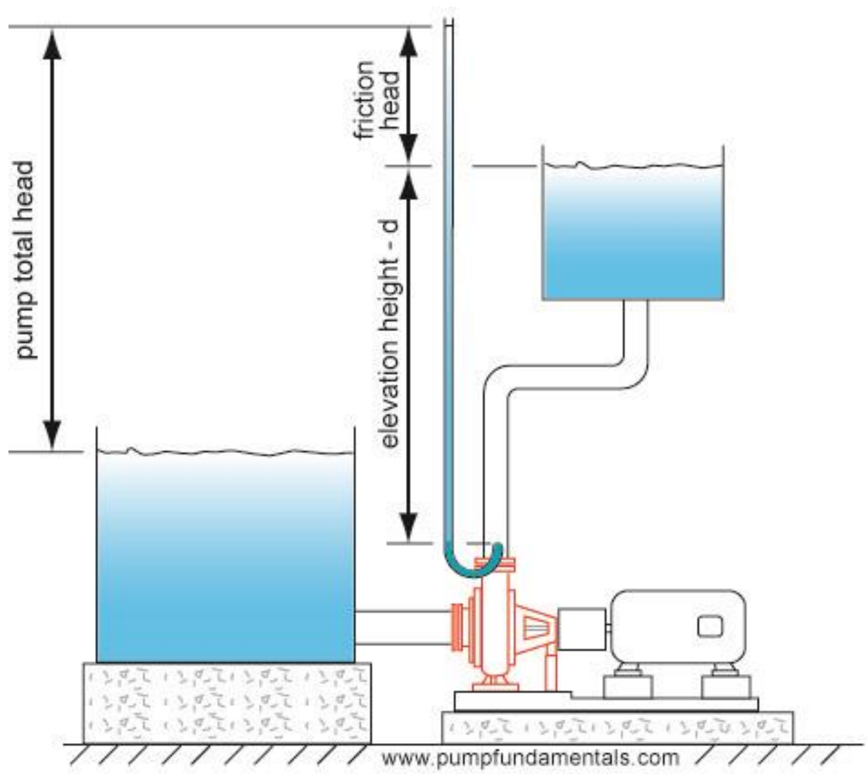




This doesn't cover all the different conditions or output requirements that can occur, only the most common ones. What happens when you have a pressurize suction tank, or a system where you need a high velocity jet at the outlet such as a fireman's hose. I think it best to discuss these in the appendix, not that they are so complicated to explain but they do require more math and physics to explain properly. For our current purpose this will be sufficient.

The term head is a very useful to describe the capacity of a pump to raise a liquid to a height which is often the main purpose of a pump. There are situations where we need to move a liquid over long distances with little change in height but and these are much less frequent; and there are many situations in between.

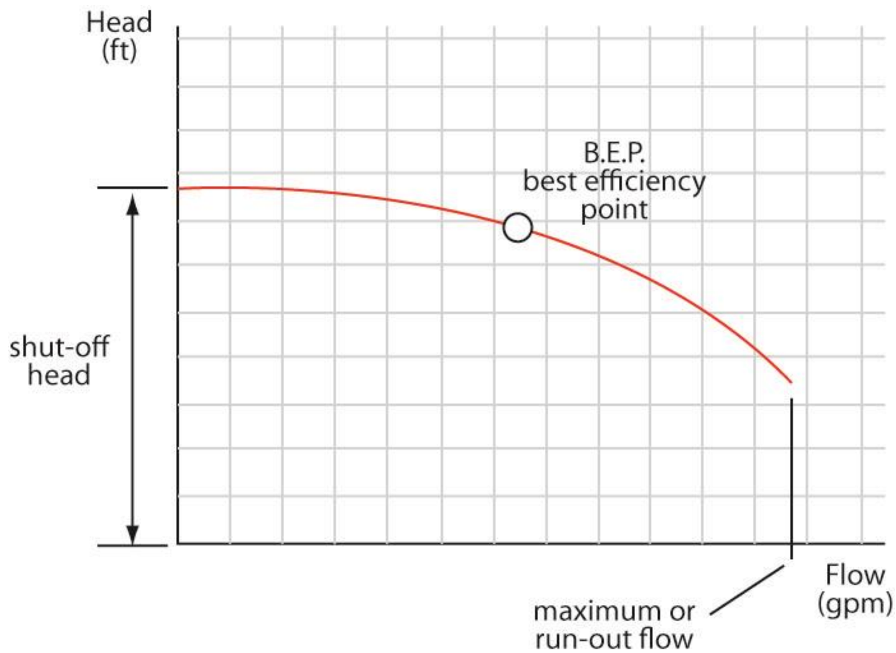
If you attach a tube to the discharge side of the pump and run the pump, the height that is achieved in the tube is the pump's discharge head.



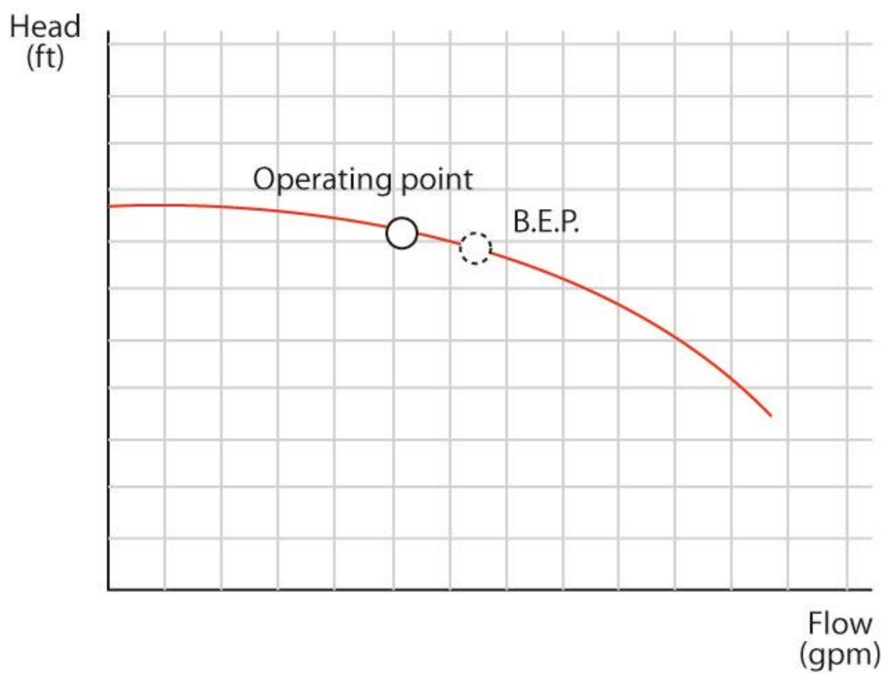
Therefore, if you know the head of a pump you know immediately how high the liquid can be moved upwards based on the level of the suction tank. If a pump has 10 feet of head at 30 gpm then you know that you can get the liquid up 10 ft or somewhat less because there is friction to consider.

The head of the pump will vary with the flow rate. The maximum head will be when there is no flow called the shut-off head. As flow increases, we get to a region in the curve where the efficiency of the pump is at its maximum and this is the area in which you would like your pump to operate. When you select the pump you want to find one where the required flow rate is matched by the head you require at the best efficiency point or B.E.P. And that is very often possible because there is a large selection pumps and sizes.

It is not good to have the pump run at it run-out flow rate since at that point excessive vibration will occur and cavitation as well may occur.



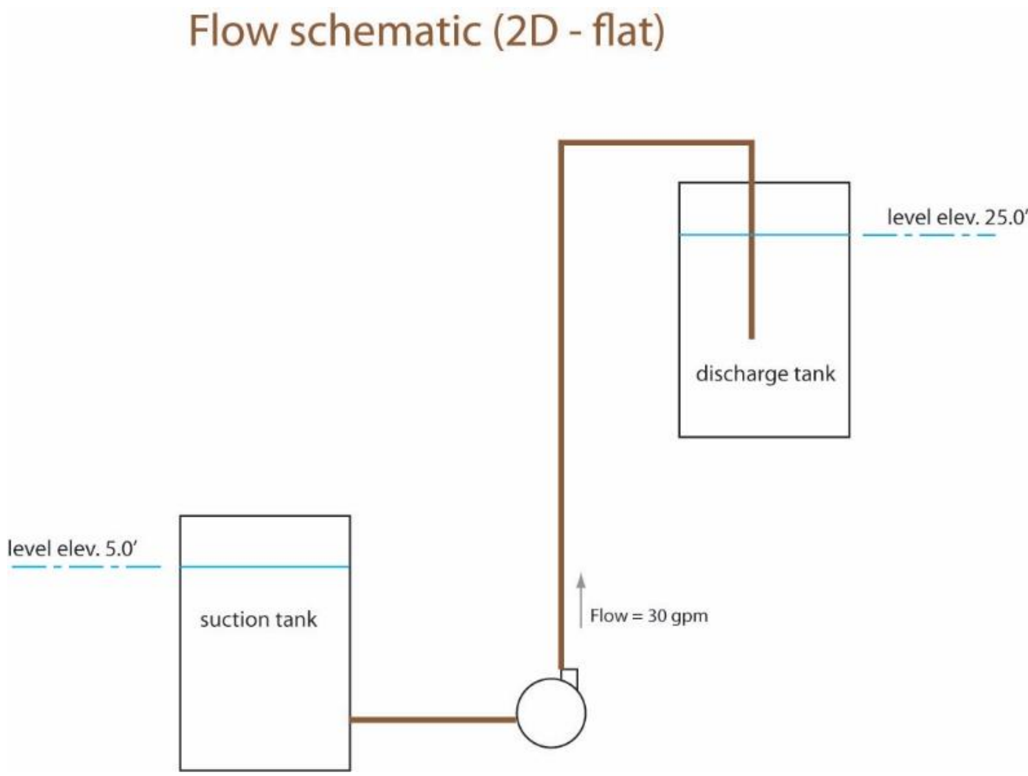
Naturally it is not always possible to select a pump to match exactly our requirements.



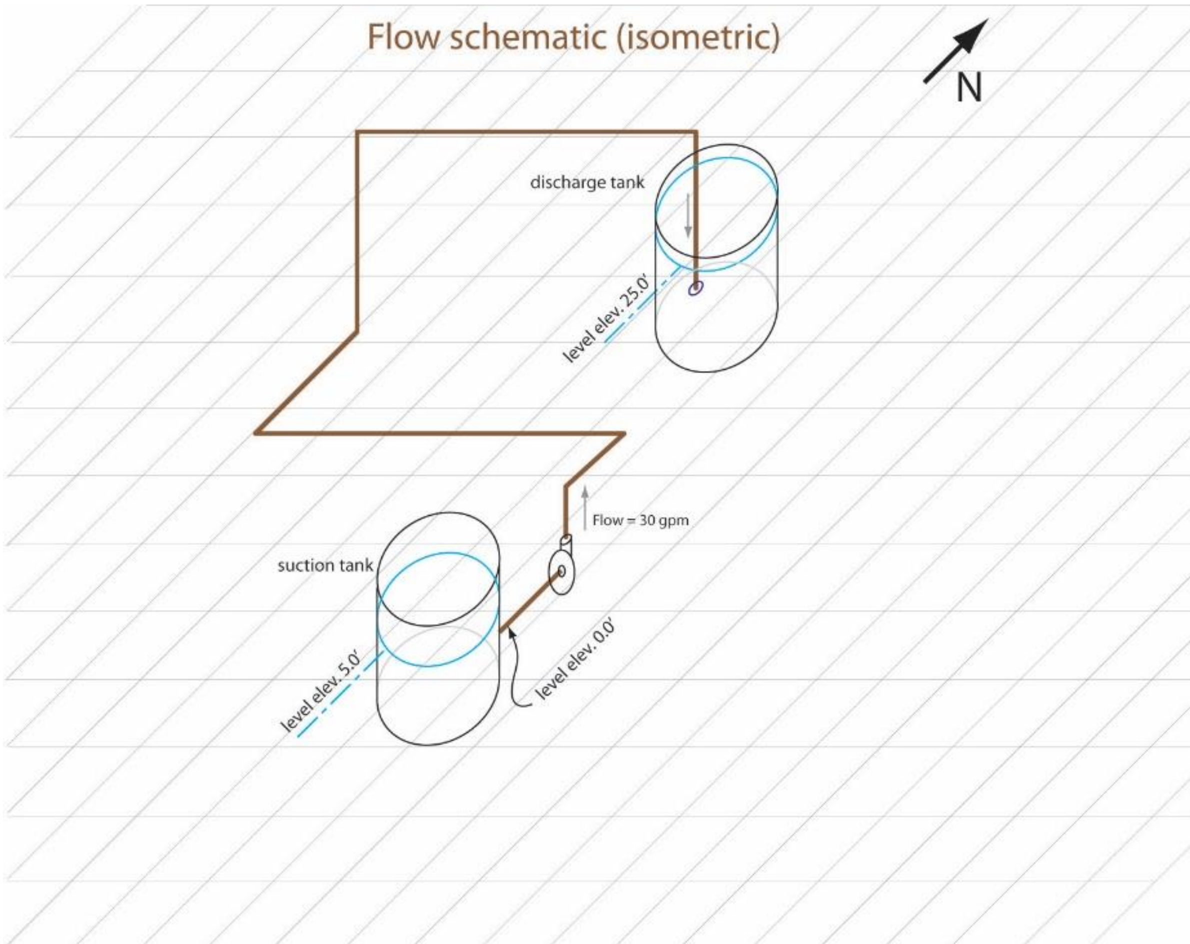
Flow schematic

A flow schematic is a single line diagram that shows the pipes and equipment within the system. It is often disregarded but no project should be without it. The schematic should tell you everything you need to know about your system, the tank levels, the pipe sizes and length, the flow, etc. There are two ways to do a schematic: a flat 2D image which is often sufficient for a simple system or an isometric view which allows you to see your system in a simulated 3D perspective.

This is a 2D flat view with basic information, it's just the start of your thinking process or description of the system.

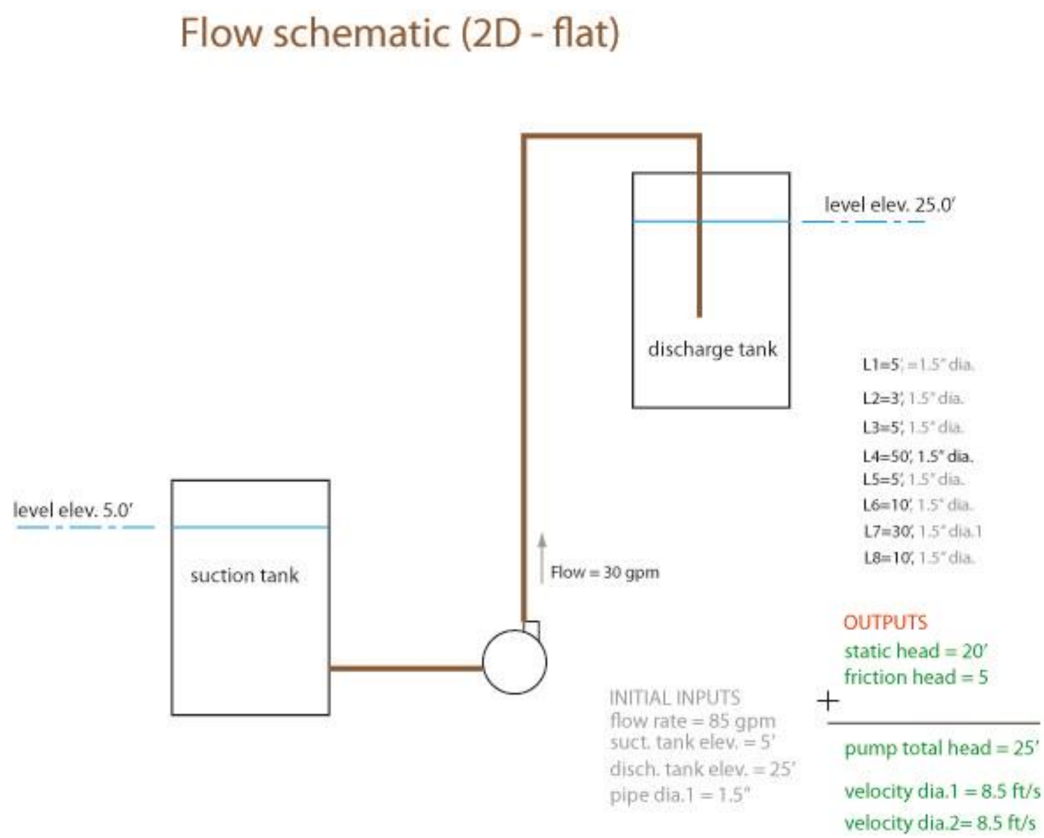


The 2D isometric looks like this:

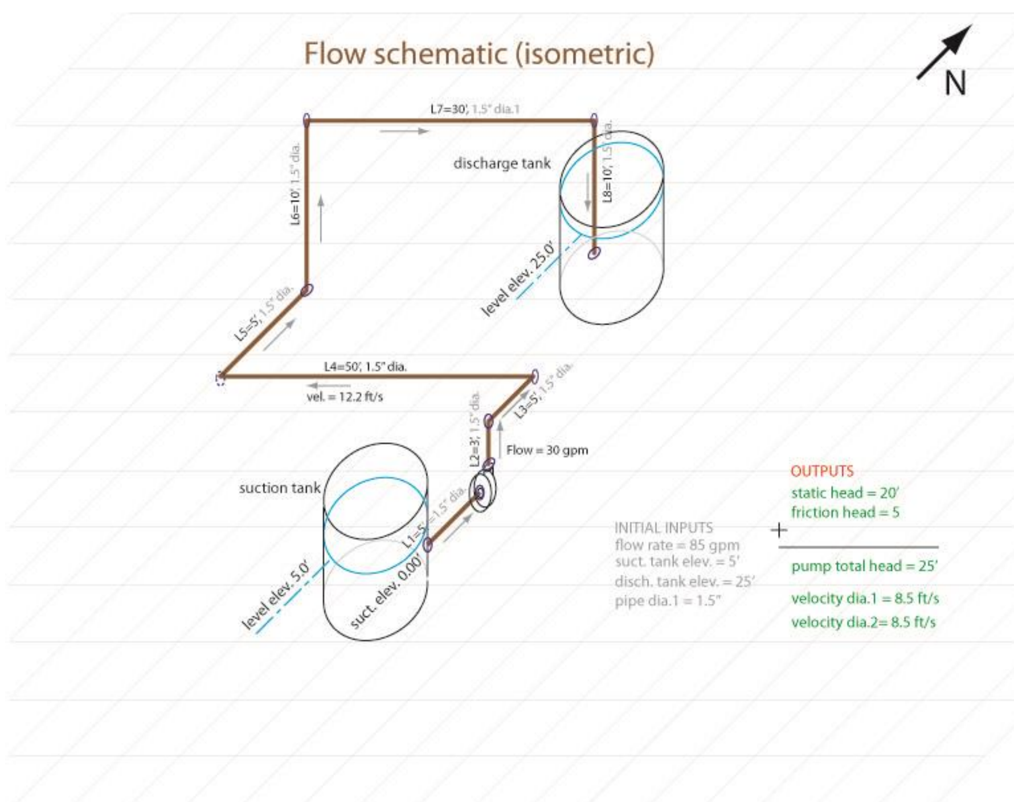


As you can see this is the same system as above but many more twists and turns in the piping can be shown in the isometric view. The slanted lines in the background are guides for the isometric perspective. If you follow those lines you will be going either North or South or anything in between. If you go vertically up you are changing elevation going up or down. Notice that we don't need to identify the exact position of where the suction line connects to the tank because that's not relevant to our goal. The same applies to the position of the end of the discharge line unless the end discharges to atmosphere then we need to know the elevation of that point. Here we are mainly interested in the lengths of the various pipe segments, their diameter and their routing.

Here is the 2D flat schematic as we put more data and the results of our calculations:



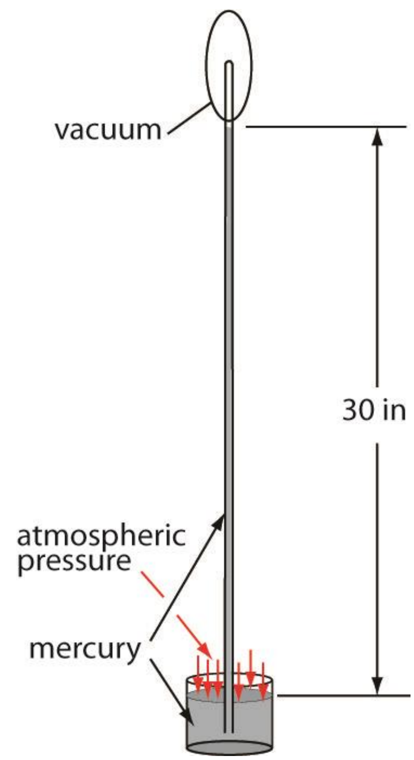
And the 2D isometric schematic:



All we need to show in the isometric view is where we go up, down, left or right. It gets a little bit more complicated if you have to go at an angle but remember that piping fittings only come in certain standard shapes, such a 45 deg. or 22.5. Use the approach that you are most comfortable with, however, it's well worth while putting some effort into an isometric view when the routing gets complicated. The key is to put all the information in one place.

Pressure

As I mentioned pressure is usually not mentioned when talking about pump systems because we are mostly interested in getting flow through the system at the correct rate. However, we need to understand pressure and its manifestation if we want to describe how our pump system is operating; also pressure has many fascinating aspects.

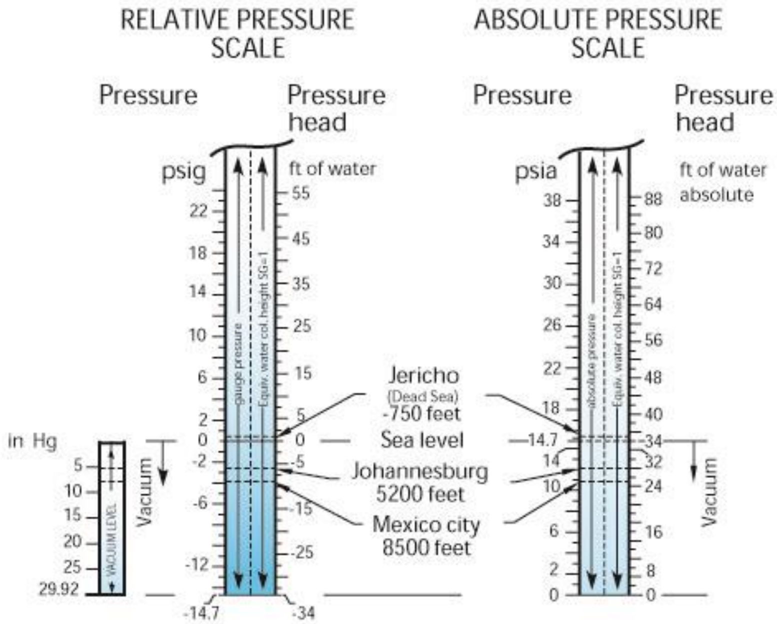


Blaise Pascal was the first to recognize that a vacuum could exist and how to measure it. He was ridiculed for this idea by none other than Rene Descartes in the mid 1600's. By vacuum I mean a region of space where the pressure is less than the atmospheric pressure. The consensus of the time was that a vacuum could not exist and that "nature abhors a vacuum".

He realized that you could measure the atmospheric pressure by using a glass tube filled with mercury sealed at one end, turned upside down with the open end inserted into a jar of mercury. In this way the atmospheric pressure could act on the surface of the mercury and balance out the weight of the volume of mercury in the tube. The height of mercury represents the atmospheric pressure. The device is known as a mercury barometer and is still used today in weather prediction. 30 inches of mercury corresponds to the normal atmospheric pressure at sea level of 14.7 psia. Anything less indicates low pressure in the atmosphere which correlates with wind and rain. As you can see as the level of mercury in the tube varies due to change in the atmospheric pressure a vacuum or low-pressure area is formed at the top since there is nothing to fill that void.

The unit for pressure in the Imperial system is psi or pounds per square inch and the Pascal (Pa) or kilopascal (kPa) in the metric system. The values for pressure can vary from zero such as the pressure in outer space up to any value, and this scale is the psia scale. As a reference 14.7 psia is the value for air pressure at sea level. Most often the psig scale is used because in everyday pump systems we don't encounter vacuum or low pressure conditions. In this scale 0 psig is the same as 14.7 psia. The psig scale is known as a relative pressure scale and the psia scale is the absolute pressure scale. We sometimes say that pressure has a negative value such as - 4 psig down to -14.7 psig which is the same as 0 psia. Of course, negative pressure does not exist and this is merely a way to keep using the psig scale even though the pressure is lower than atmospheric.

This next image shows the various pressure units along side of the elevation of water that would produce this pressure.



Atmospheric pressure varies with elevation, the higher your location the lower the atmospheric pressure.

Atmospheric pressure at different altitudes

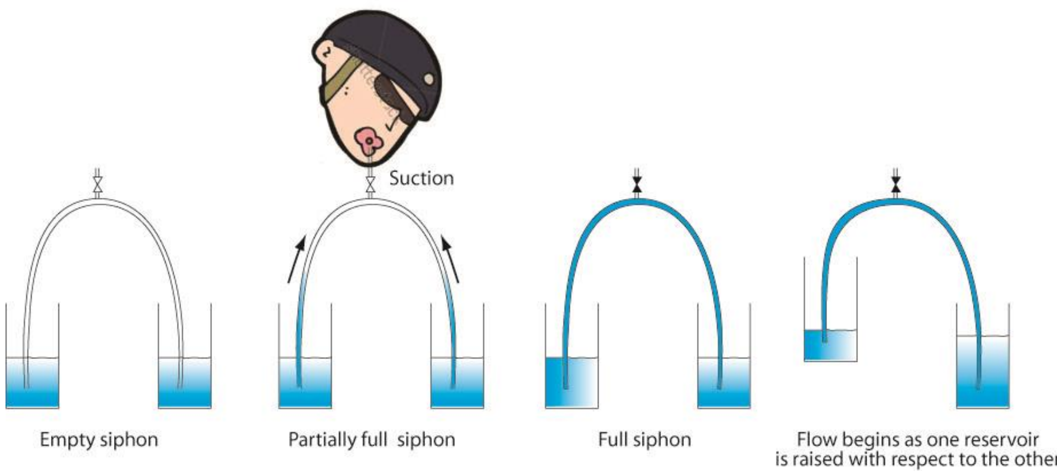
Altitude Above Sea Level			Temperature		Barometric Pressure		Atmospheric Pressure		
Feet	Miles	Meters	F	C	In. Hg. Abs.	mm Hg. Abs.	PSIA	Kg / sq. cm	kPa A
0		0	59	15	29.92	760.0	14.696	1.0333	101.33
500		153	57	14	29.38	746.3	14.43	1.015	99.49
1000		305	55	13	28.86	733.0	14.16	0.956	97.63
1500		458	54	12	28.33	719.6	13.91	0.978	95.91
2000		610	52	11	27.82	706.6	13.66	0.960	94.19
2500		763	50	10	27.32	693.9	13.41	0.943	92.46
3000		915	48	9	26.82	681.2	13.17	0.926	90.81
3500		1068	47	8	26.33	668.8	12.93	0.909	89.15
4000		1220	45	7	25.84	656.3	12.69	0.892	87.49
4500		1373	43	6	25.37	644.4	12.46	0.876	85.91
5000	0.95	1526	41	5	24.90	632.5	12.23	0.86	84.33
6000	1.1	1831	38	3	23.99	609.3	11.78	0.828	81.22
7000	1.3	2136	34	1	23.10	586.7	11.34	0.797	78.19
8000	1.5	2441	31	-1	22.23	564.6	10.91	0.767	75.22
9000	1.7	2746	27	-3	21.39	543.3	10.5	0.738	72.40
10,000	1.9	3050	23	-5	20.58	522.7	10.1	0.71	69.64
15,000	2.8	4577	6	-14	16.89	429.0	8.29	0.583	57.16
20,000	3.8	6102	-12	-24	13.76	349.5	6.76	0.475	46.61
25,000	4.7	7628	-30	-34	11.12	282.4	5.46	0.384	37.65
30,000	5.7	9153	-48	-44	8.903	226.1	4.37	0.307	30.13
35,000	6.6	10,679	-66	-54	7.06	179.3	3.47	0.244	23.93
40,000	7.6	12,204	-70	-57	5.558	141.2	2.73	0.192	18.82
45,000	8.5	13,730	-70	-57	4.375	111.1	2.15	0.151	14.82
50,000	9.5	15,255	-70	-57	3.444	87.5	1.69	0.119	11.65
55,000	10.4	16,781	-70	-57	2.712	68.9	1.33	0.0935	9.17
60,000	11.4	18,306	-70	-57	2.135	54.2	1.05	0.0738	7.24
70,000	13.3	21,357	-67	-55	1.325	33.7	0.651	0.651	4.49
80,000	15.2	24,408	-62	-52	0.8273	21.0	0.406	0.406	2.80
90,000	17.1	27,459	-57	-59	0.520	13.2	0.255	0.255	1.76
100,000	18.9	30,510	-51	-46	0.329	8.36	0.162	0.162	1.12
150,000	28.4	45720				1.10	$2.1x10^{-3}$	$1.4x10^{-3}$	0.146
200,000	37.9	60960				0.17	$3.27x10^{-3}$	$2.0x10^{-4}$	$2.2x10^{-2}$
300,000	56.8	91440				$8x10^{-4}$	$1.47x10^{-5}$	$1.06x10^{-4}$	$1.09x10^{-6}$
500,000	94.7	152400				$3.73x10^{-6}$	$7.22x10^{-8}$	$5.07x10^{-9}$	$4.98x10^{-7}$
2,000,000	378.8	609600				$3.6x10^{-9}$	$7.0x10^{-11}$	$4.9x10^{-12}$	$4.8x10^{10}$

The previous figure is from the web site: https://www.avs.org/AVS/files/c7/c7edaedb-95b2-438f-adfb-36de54f87b9e.pdf

If the atmospheric pressure is lower than normal at your location this means that there will be less pressure at the pump suction. In most everyday cases this is not an issue. In some critical cases it might be a factor and this effect should be checked to see if the pump will handle this lower pressure. The atmospheric pressure value is incorporated into a term called the Net Positive Suction Head Available or N.P.S.H.A. It is compared to the N.P.S.H.R. or the Net Positive Suction Head Required and the N.P.S.H.A. must be greater than the N.P.S.H.R.. I won't get into this now since this is rarely an issue with typical everyday systems.

The siphon

Fluids in movement can behave very curiously, and this can only be understood by considering how pressure varies within the system. It is possible for a fluid to go upwards without any source of energy such as a pump using pressure only. This is what happens with a syphon. You can't do that with solid objects.

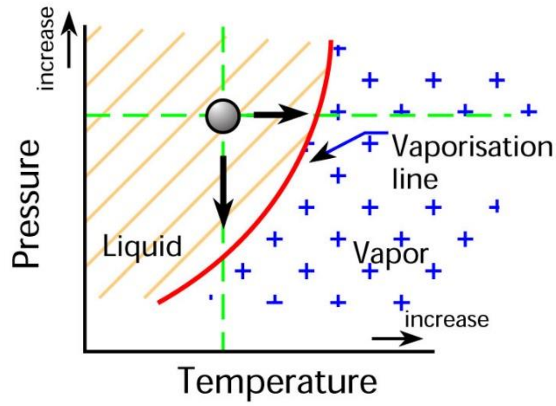


The reason the liquid is suspended is because of low pressure at the top of the tube. Suction provides the initial lift and filling of the tube; this low pressure suspends the liquid in the tube and allows it to flow freely. It's almost like anti-gravity.

Water boiling way below it's normal boiling temperature

We know that we can boil water at 212 °F using an open pot on a stove. But can you boil water at a much lower temperature? A liquid such as water under low pressure will boil or vaporize even when the temperature is relatively low. For example, water will boil at 120 °F when it is at a pressure of 2 psia or -12.7 psig.

The following chart shows what happens when you vary the temperature and the pressure of in a sealed volume containing a liquid. As you maintain the pressure - such as the normal case of boiling water in an open pot – and increase the temperature, when the temperature gets to 212 °F the water will boil. In terms of the chart you are moving horizontally across until you hit the vaporization line. If you maintain the temperature and vary the pressure by lowering it in a sealed container you will boil or vaporize the liquid when you reach the vapor pressure of that liquid. In this case we are moving vertically downward on the chart.



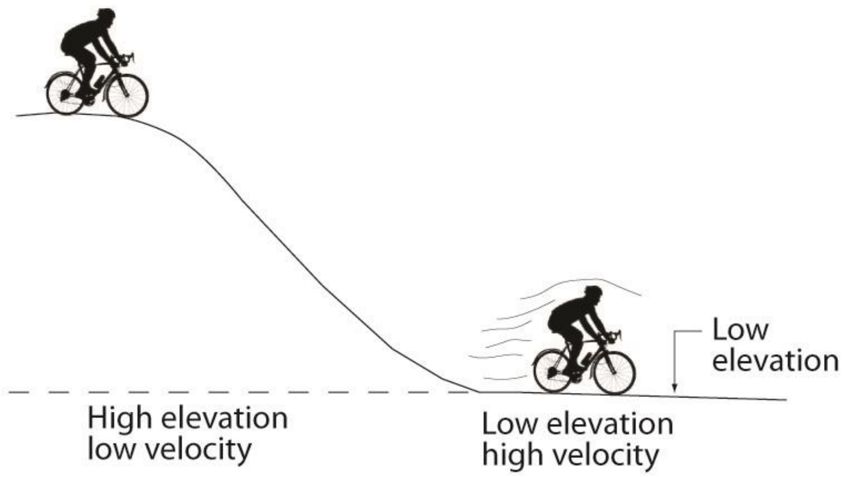
This phenomenon is related to cavitation which is a problem that occurs in pumps under certain conditions at the suction. This is not a common occurrence.

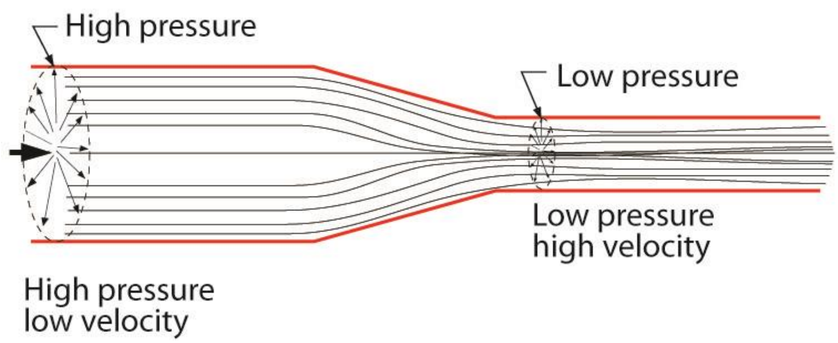
Control valve inlet pressure

As we encounter problems or when we need to understand better how our pump system is functioning, we need to know what the pressure at any given point in the system. You probably realize by now that the pressure in the system will vary from point to point since the liquid is moving up and down and there is more or less accumulated friction. Some systems have a control valve to control the flow. To select the proper valve, it is critical to know the pressure at the entrance of the valve. This requires an in depth look at the system taking into account static, friction and pump total head to determine the pressure at any given point.

The venturi

When a moving liquid enters a constriction, the pressure goes down. This is very counter intuitive, one would expect the pressure to go up because we are impeding the flow. There is a relationship between pressure and velocity. Elevation is a form of head since an elevated fluid has potential energy, pressure is also a form of head and so is velocity. As you probably know energy can neither be created or destroyed but one form of energy can be converted into another. An example is a cyclist at the top of a hill. Even standing still she has potential energy because of the height she has with respect to the bottom of the hill. As she begins to move downward her potential energy is converted to velocity energy or kinetic energy.



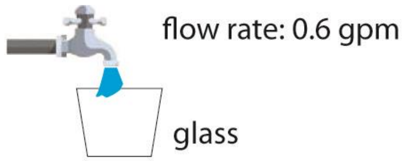


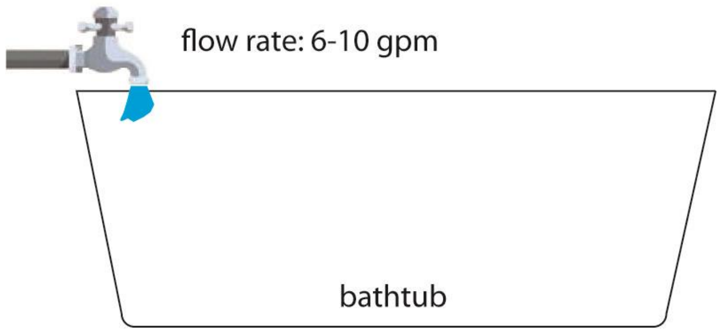
A similar situation happens when a fluid is approaching a constriction. At this point the pressure is relatively high providing high pressure energy or pressure head. As the fluid enters the constriction the velocity goes up, the same amount of fluid must go through since there is nowhere else for it to go. If it must go through a smaller opening at the same rate then the velocity must increase. If the velocity goes up, the velocity energy goes up and by the principle of conservation of energy the pressure energy must decrease, therefore the pressure drops. In the same fashion that the cyclist's elevation energy or potential energy is converted to velocity or kinetic energy; in this case the pressure energy is converted to velocity energy.

In fact, you can create a significant amount of low pressure down to 1-2 psia (atmospheric pressure is 14.7 psia) with a very simple cheap plastic device that you can install on your sink tap called a Nalgene vacuum pump that you can purchase at Fisher Scientific. If you have a sealed container you can use this pump to demonstrate that water can boil at a low temperature. Such containers are readily found in laboratory supplies such as a flask with a necked down top where a cork or rubber stopper and a hole for a tube, but any glass bottle with a neck will do.

Flow rate

The other important characteristic of a pump system is flow rate. Flow rate is expressed in gallons per minute (gpm) in the Imperial system and in liters per minute (l/min) or meters cubed per hour (m^3/h) in the metric system. Let's see if we can develop an intuitive sense for flow rate by looking at the requirements of some daily tasks.





Filling a drinking glass requires about 0.6 gpm if you want to keep the water in the glass. A bathtub requires around 6-10 gpm to fill it in a reasonable amount of time. If you have a remote cottage and you have your own water pump then you will want to size the pump for 20-30 gpm to accommodate more than one bathroom and other services.

These are typical situations. In industry you will encounter much greater flow rates where 1000 gpm is typical and 20,000 gpm is at the high end.

Pipe size, flow rate and friction

Pipe size and flow rate are linked. You can imagine that it will be difficult or take a long time to fill a bathtub with a ¼" diameter tube. The link between these two is the velocity of the liquid in the pipe and the friction it produces. The velocity will be equal to the flow rate divided by the cross-sectional area of the tube or pipe.

Vel = flow rate / area

In the Imperial system we use the unit of ft/s for velocity and using typical units for flow rate and diameter we get

$$v\left(\frac{ft}{s}\right) = 0.4085 \times \frac{q(gpm)}{(d(in))^2}$$

where q is the flow rate, v the velocity and d the tube internal diameter.

A typical rule of thumb for sizing a pipe is to stay within a velocity range of 9-12 ft/s. This will keep the friction head at a reasonable value and help you size a pipe, at least initially.

Friction is very common in everything that we do, try sliding something across the floor and you will see that it is not easy to keep the movement going, it takes energy. Throw a ball and it won't go as far as if there were no air friction; the same applies to riding a bike, air friction is a major component of the resistance moving forward.

It's the same with liquids moving in a pipe, friction between the liquid and the pipe wall as well as between the fluid particles themselves (turbulence) tends to slow down the movement and to keep the liquid going you have to continue applying energy.

The following chart shows the value for friction for different pipe sizes at a velocity of 10 ft/s and the corresponding flow rate. The friction is shown in terms of friction head and this is no different than height being understood as static head. Since for every application the pipe length will be different, friction head is shown as friction head per 100 ft of pipe. This is typical in all pipe friction tables.

Pipe friction at 10 ft/s velocity for water at various pipe diameters

Pipe int. dia. (in)	Flow (gpm)	Friction in feet per 100 ft of pipe
0.25	1.5	272
0.5	6.1	115
0.75	13.8	67
1	24.5	47
1.5	55	29
2	98	19
3	220	12
4	392	8.4
6	881	5
8	1567	3.5

For example, the friction head loss for a 1" diameter pipe, 50 feet long and a velocity of 10 ft/s is

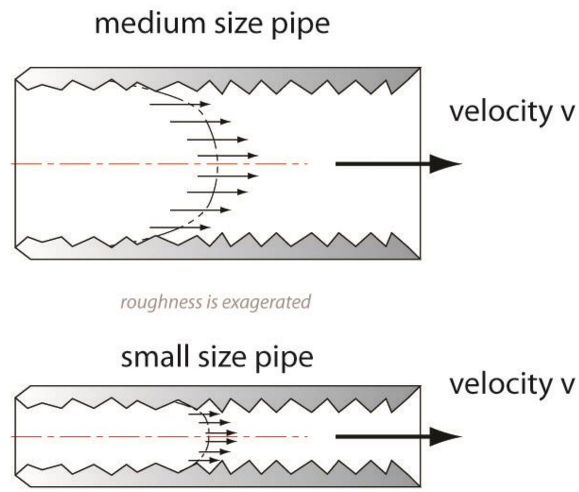
47 x 50 /100 = 23 ft.

The above chart shows that for the same velocity small pipes produce much more friction than larger pipes. Therefore, one has to be more careful when selecting small pipes as the friction is likely to be higher than expected or desirable. The next figure shows what happens when we reduce the velocity by half or 5 ft/s.

Pipe friction at 5 ft/s velocity for water
at various pipe diameters

Pipe int. dia. (in)	Flow (gpm)	Friction in feet per 100 ft of pipe
0.25	0.8	84
0.5	3.1	32
0.75	6.9	18
1	12.2	13
1.5	27.5	7
2	49	5.3
3	110	3.1
4	196	2.2
6	440	1.4
8	783	0.9

Why does a small pipe have so much more friction than a large pipe for the same velocity? Friction is due to two factors, the turbulence in the liquid and the contact of the liquid with the internal pipe wall surface. This surface has roughness and certain pipe materials are rougher than others (see the next figure). When the pipe is small the rough peaks and valleys through which the liquid must flow occupy more of the space comparatively to a larger pipe causing the portion of friction due to liquid contact with the wall to increase.


medium size pipe
velocity v
roughness is exagerated
small size pipe
velocity v

Appendix

The calculations for friction loss due to flow resistance through pipes are not complicated and they are listed here so that you may do your own calculations.

Pipe friction calculations
Imperial units

use these formulas to verify for yourself the results

velocity

$$\mathbf{v}\,(\text{ft/s}) = \frac{\mathbf{0.4085 \times q}\,(\text{gpm})}{(\mathbf{d}\,(\text{in}))^2}$$

v - velocity
q - flow rate
d - internal pipe diameter

Reynolds number

$$\mathbf{Re} = \frac{\mathbf{7745.8 \times v}(\text{ft/s})\,\mathbf{\times d}(\text{in})}{\nu\,(\text{cSt})}$$

Re - Reynolds number
ν **- viscosity, 1.0 for water**

Friction parameter (Swamee-Jain)

$$\mathbf{f} = \frac{\mathbf{0.25}}{\left[\mathbf{log}_{10}\left(\frac{\varepsilon\,(\text{in})}{\mathbf{3.7 \times d}(\text{in})} + \frac{\mathbf{5.74}}{\mathbf{Re}^{0.9}}\right)\right]^2}$$

f - friction parameter
ε **- absolute roughness, steel = 0.00015/12** (in)

Friction factor - friction per 100 ft of pipe

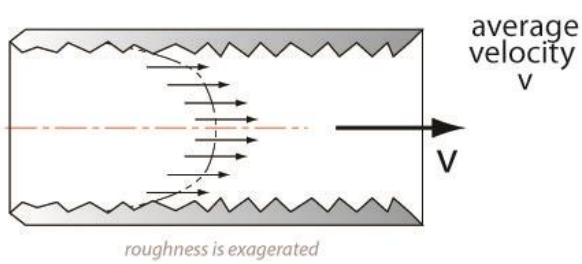
$$\mathbf{Fr}\left(\frac{\text{ft}}{100\text{ ft}}\right) = \frac{\mathbf{1200 \times f \times v}^2(\text{ft/s})^2}{\mathbf{d}(\text{in})\,\mathbf{\times 2 \times g}\,(\text{ft/s}^2)}$$

Fr - friction factor
g = 32.17 (ft/s^2)

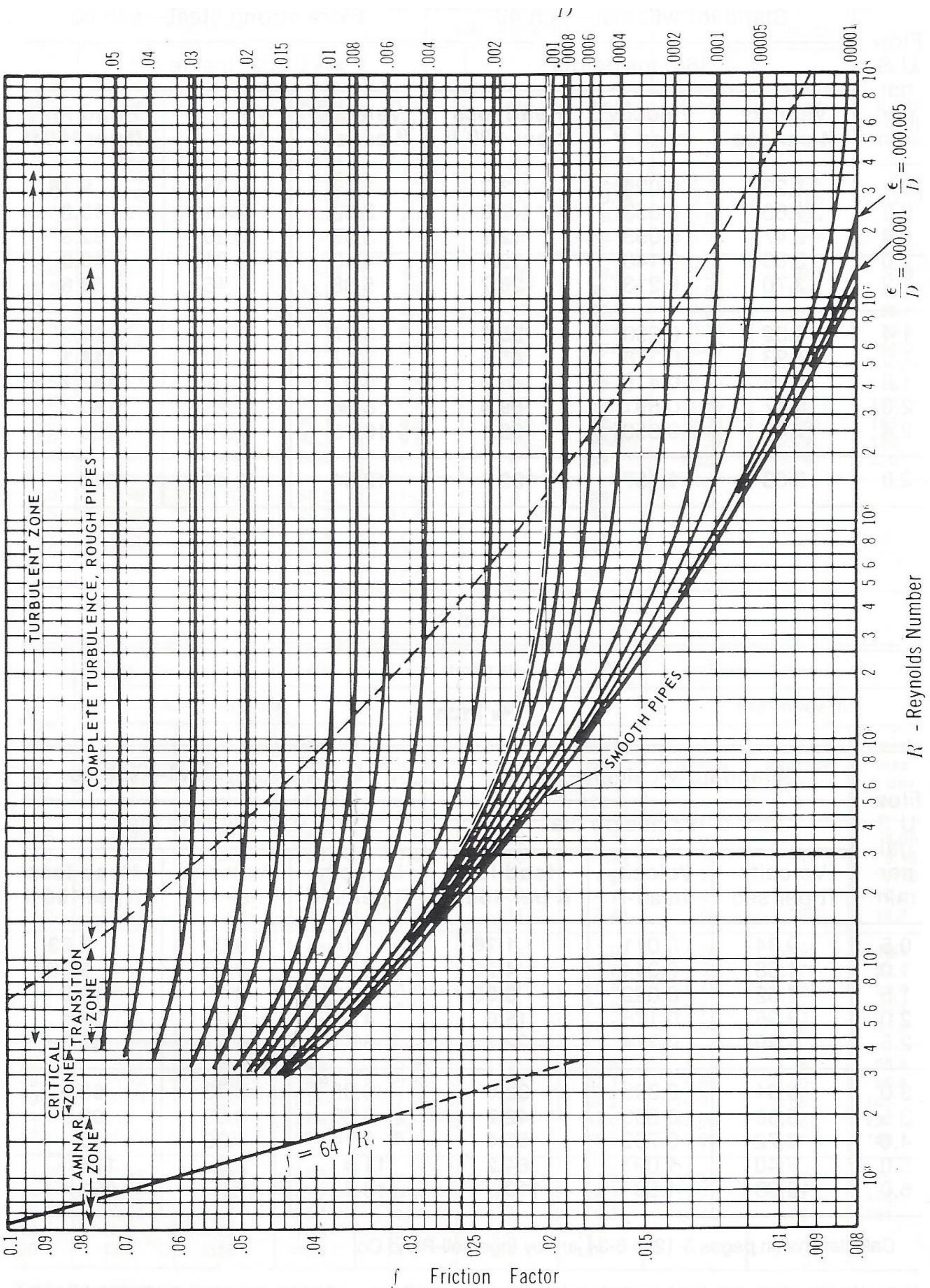
Total pipe friction

$$\mathbf{h_F}\,(\text{ft}) = \frac{\mathbf{Fr \times L\,(ft)}}{\mathbf{100}}$$

hF - Total pipe friction
L - pipe length



roughness is exagerated



Moody diagram. (V. L. Streeter, "Fluid Mechanics," 5th ed. Copyright 1971 by McGraw-Hill Book Company, New York)

Note: Chart shows relation of relative roughnesss — ϵ/D where ϵ is absolute roughness in feet and D is diameter in feet.

Type of pipe (new, clean, condition)	Absolute roughness* ϵ (in feet)
Drawn tubing—glass, brass, plastic	0.000005
Commercial steel or wrought iron	0.00015
Cast iron—asphalt dipped	0.0004
Galvanized iron	0.0005
Cast iron—uncoated	0.00085
Wood stave	0.0006–0.0003
Concrete	0.001–0.01
Riveted steel	0.003–0.03

* Basis data from Hydraulic Institute Engineering Data Book.

PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE WITH FLOW IN ZONE OF COMPLETE TRUBULENCE

Nominal Size	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2", 3"	4"	5"	6"	8-10"	12-16"	18-24"
Friction Factor (f_T)	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

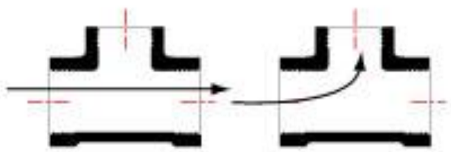
from The Crane Technical Paper no. 410

STANDARD ELBOWS

90° 45°

$K = 30\ f_T$ $K = 10\ f_T$

STANDARD TEES

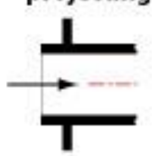


Flow through run $K = 20\ f_T$

Flow through branch $K = 60\ f_T$

PIPE ENTRANCE

Inward projecting

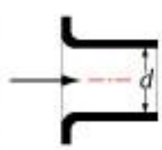


$K = 0.78$

r/d	K
0.00*	0.5
0.02	0.28
0.04	0.24
0.06	0.15
0.10	0.09
0.15 & up	0.09

* sharp edge

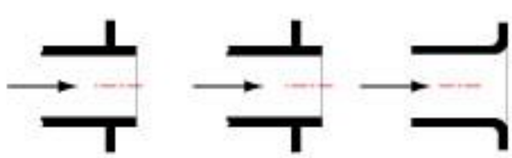
Flush



for K see table

PIPE EXIT

Projecting **Sharp -edged** **Rounded**



$K = 1.0$ $K = 1.0$ $K = 1.0$

Friction loss

$$h_f\ (ft) = K\ \frac{(v(ft/s))^2}{2\ g\ (ft/s^2)}$$

$$g = 32.17\ (ft/s^2)$$

90° PIPE BENDS AND FLANGED OR BUTT-WELDED 90° ELBOWS

r/d	K	r/d	K
1	20 F_t	10	30 F_t
2	12 F_t	12	34 F_t
3	12 F_t	14	38 F_t
4	14 F_t	16	42 F_t
6	17 F_t	18	46 F_t
8	24 F_t	20	50 f_t

The resistance coefficient, K , for pipe bends other than 90° may be determined as follows:

$$K_\beta = (n - 1)\ \left(0.25\ \pi\ f_T \frac{r}{d} + 0.5\,K\right) + K$$

n = number of 90° bends

K = resitance coefficient for one 90° bend (per table)

PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE WITH FLOW IN ZONE OF COMPLETE TURBULENCE

Nominal Size	½″	¾″	1″	1¼″	1½″	2″	2½, 3″	4″	5″	6″	8-10″	12-16″	18-24″
Friction Factor (f_T)	.027	.025	.023	.022	.021	.019	.018	.017	.016	.015	.014	.013	.012

FORMULAS FOR CALCULATING "K" FACTORS FOR VALVES AND FITTINGS WITH REDUCED PORT

- **Formula 1**

$$K_2 = \frac{0.8 \sin\frac{\theta}{2}(1-\beta^2)}{\beta^4}$$

- **Formula 2**

$$K_2 = \frac{0.5\,(1-\beta^2)\sqrt{\sin\frac{\theta}{2}}}{\beta^4}$$

- **Formula 3**

$$K_2 = \frac{2.6 \sin\frac{\theta}{2}(1-\beta^2)^2}{\beta^4}$$

- **Formula 4**

$$K_2 = \frac{(1-\beta^2)^2}{\beta^4}$$

- **Formula 5**

$$K_2 = \frac{K_1}{\beta^4} + \text{Formula 1} + \text{Formula 3}$$

$$K_2 = \frac{K_1 + \sin\frac{\theta}{2}\left[0.8\,(1-\beta^2) + 2.6\,(1-\beta^2)^2\right]}{\beta^4}$$

- **Formula 6**

$$K_2 = \frac{K_1}{\beta^4} + \text{Formula 2} + \text{Formula 4}$$

$$K_2 = \frac{K_1 + 0.5\sqrt{\sin\frac{\theta}{2}}\,(1-\beta^2) + (1-\beta^2)^2}{\beta^4}$$

- **Formula 7**

$$K_2 = \frac{K_1}{\beta^4} + \beta\,(\text{Formula 2} + \text{Formula 4}) \text{ when } \theta = 180°$$

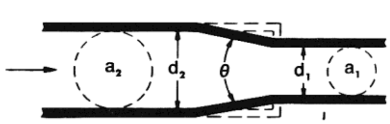
$$K_2 = \frac{K_1 + \beta\left[0.5\,(1-\beta^2) + (1-\beta^2)^2\right]}{\beta^4}$$

$$\beta = \frac{d_1}{d_2}$$

$$\beta^2 = \left(\frac{d_1}{d_2}\right)^2 = \frac{a_1}{a_2}$$

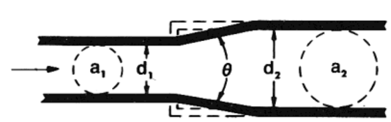
Subscript 1 defines dimensions and coefficients with reference to the smaller diameter.
Subscript 2 refers to the larger diameter.

SUDDEN AND GRADUAL CONTRACTION



If: $\theta \leq 45°$ ....K_2 = Formula 1
$45° < \theta \leq 180°$ ...K_2 = Formula 2

SUDDEN AND GRADUAL ENLARGEMENT



If: $\theta \leq 45°$ ....K_2 = Formula 3
$45° < \theta \leq 180°$ ...K_2 = Formula 4

From the Crane Technical manual 410

Seamless Wrought Steel Pipe

Size	Schedule no	Diameter External (inches)	Diameter Internal (inches)	Thickness (inches)	Circumference External (inches)	Circumference Internal (inches)	Transverse area External (sq in)	Transverse area Internal (sq in)	Length of pipe per sq ft of surface area: External surface (feet)	Length of pipe per sq ft of surface area: Internal surface (feet)	Weight per ft of length (lbs)	Allowable working pressure to 650° F (lb/sq in)	Water hammer factor
⅛	40 S	0.405	0.269	0.068	1.272	0.845	0.129	0.057	9.431	14.199	0.24	1382	338
	80 X		0.215	0.095	1.272	0.675	0.129	0.036	9.431	17.766	0.31	3658	535
¼	40 S	0.540	0.364	0.088	1.696	1.144	0.229	0.104	7.073	10.493	0.42	2237	185
	80 X		0.302	0.119	1.696	0.949	0.229	0.072	7.073	12.468	0.54	4270	268
⅜	40 S	0.675	0.493	0.091	2.121	1.549	0.358	1.191	5.658	7.748	0.57	1915	101
	80 X		0.423	1.126	2.121	1.329	0.358	0.141	5.658	9.030	0.74	3712	137
½	40 S	0.840	0.622	0.108	2.639	1.954	0.554	0.304	4.547	6.141	0.85	2233	63.4
	80 X		0.546	0.147	2.639	1.715	0.554	0.234	4.547	6.99	1.09	3817	82.3
	160		0.464	0.188	2.639	1.458	0.554	0.169	4.547	8.23	1.31	5674	114
	XX		0.252	0.294	2.639	0.792	0.554	0.050	4.547	15.15	1.71	11,352	385
¾	40 S	1.050	0.824	0.113	3.299	2.589	0.866	0.533	3.637	4.635	4.13	1891	36.1
	80 X		0.742	0.154	3.299	2.331	0.866	0.433	3.637	5.15	1.47	3227	44.5
	160		0.612	0.219	3.299	1.923	0.866	0.294	3.637	6.24	1.94	5542	65.2
	XX		0.434	0.308	3.299	1.363	0.866	0.148	3.637	8.80	2.44	9175	130
1	40 S	1.315	1.049	0.133	4.131	3.296	1.358	0.864	2.904	3.641	1.68	1994	22.3
	80 X		0.957	0.179	4.131	3.007	1.358	0.719	2.904	3.99	2.17	3194	26.8
	160 0		0.815	0.250	4.131	2.560	1.358	0.522	2.904	4.69	2.84	5195	36.9
	XX		0.599	0.358	4.131	1.882	1.358	0.282	2.904	6.38	3.66	8647	68.3
1¼	40 S	1.660	1.380	0.140	5.215	4.335	2.164	1.495	2.301	2.768	2.27	1406	12.9
	80 X		1.278	0.191	5.215	4.015	2.164	1.283	2.301	2.99	3.00	2424	15.0
	160		1.160	0.250	5.215	3.645	2.164	1.057	2.301	3.29	3.76	3671	18.2
	XX		0.896	0.382	5.215	2.815	2.164	0.631	2.301	4.26	5.21	6762	30.5
1½	40 S	1.900	1.610	0.145	5.969	5.058	2.835	2.036	2.010	2.372	2.72	1307	9.46
	80 X		1.500	0.200	5.969	4.712	2.835	1.767	2.010	2.55	3.63	2260	10.9
	160		1.338	0.281	5.969	4.205	2.835	1.406	2.010	2.86	4.86	3752	13.7
	XX		1.100	0.400	5.969	3.456	2.835	0.950	2.010	3.47	6.41	6158	20.3
2	40 S	2.375	2.067	0.154	7.461	6.494	4.430	3.555	1.608	1.847	3.65	1159	5.74
	80 X		1.939	0.218	7.461	6.092	4.430	2.953	1.608	1.97	5.02	2038	6.52
	160		1.687	0.344	7.461	5.300	4.430	2.235	1.608	2.26	7.46	3890	8.60
	XX		1.503	0.436	7.461	5.300	4.430	1.774	1.608	2.54	9.03	5356	10.9
2½	40 S	2.875	2.469	0.203	9.032	7.757	6.492	4.788	1.328	1.547	5.79	1498	4.02
	80 X		2.323	0.276	9.032	7.298	6.492	4.238	1.328	1.64	7.66	2339	4.54
	160		1.125	0.375	9.032	6.676	6.492	3.545	1.328	1.80	10.01	3540	5.43
	XX		1.771	0.552	9.032	5.564	6.492	1.391	1.328	2.16	13.69	5878	7.82

Selected from ANSI/ASME B36.10M – 1985 and B31.1 – 1992 "Power Piping". S = Standard, X = Extra strong, XX = Double extra strong.
Allowable working pressures based on Grade B pipe, tensile strength 60,000 psi minimum. Allowable working pressures are from -20°F to 650°F.
Allowable working pressures for Grade A pipe from -20°F to 650°F are 80% of Grade B pipe.
Water hammer factors should be used to reduce allowable working pressure by the amount of flow in gpm times water hammer factor.
Additional thickness allowance for threading, mechanical strength and/or corrosion is included: 0.05 inch for pipe sizes 1 inch and smaller and 0.065 inch for pipe sizes over 1 inch.

Seamless Wrought Steel Pipe

Size	Schedule no	Diameter External (inches)	Diameter Internal (inches)	Thickness (inches)	Circumference External (inches)	Circumference Internal (inches)	Transverse area External (sq in)	Transverse area Internal (sq in)	Length of pipe per sq ft of surface area: External surface (feet)	Length of pipe per sq ft of surface area: Internal surface (feet)	Weight per ft of length (lbs)	Allowable working pressure to 650° F (lb/sq in)	Water hammer factor
0	40 -S	3.500	3.068	0.216	10.996	9.638	9.621	7.393	1.091	1.245	7.58	1341	2.60
	80 -X		2.900	0.300	10.996	9.111	9.621	6.605	1.091	1.32	10.25	2129	2.92
	160		2.624	0.438	10.996	8.244	9.621	5.408	1.091	1.46	14.32	3495	3.56
	XX		2.300	0.600	10.996	7.226	9.621	4.155	1.091	1.66	18.58	52.25	4.64
31/2	40 -S	4.000	3.548	0.226	12.566	11.146	12.566	9.886	0.954	1.076	9.11	1248	1.94
	80 -X		3.364	0.318	12.566	10.57	12.566	8.888	0.954	1.14	12.50	1999	2.17
	XX		2.728	0.636	12.566	8.57	12.566	5.845	0.954	1.40		4835	3.29
4	40 -S	4.500	4.026	0.237	14.137	12.648	15.904	12.703	0.848	0.948	10.79	1193	1.51
	80 -X		3.826	0.337	14.137	12.020	15.904	11.497	0.848	0.998	14.98	1905	1.67
	120		3.624	0.438	14.137	11.39	15.904	10.315	0.848	1.05	19.00	2663	1.87
	160		3.438	0.531	14.137	10.80	15.904	9.282	0.848	1.11	22.51	3387	2.08
	XX		3.152	0.674	14.137	9.90	15.904	7.803	0.848	1.21	27.54	4553	2.47
5	40 -S	5.563	5.047	0.258	17.477	15.856	24.306	20.006	0.686	0.756	14.62	1071	0.960
	80 X		4.813	0.375	17.477	15.120	24.306	18.19	0.686	0.793	20.78	1950	1.06
	120		4.563	0.500	17.477	14.34	24.036	16.35	0.686	0.837	27.04	2502	1.18
	160		4.313	0.625	17.477	13.55	24.036	14.61	0.686	0.897	32.96	3284	1.32
	XX		4.063	0.750	17.477	12.76	24.306	12.97	0.686	0.897	38.56	4098	1.49
6	40 -S	6.625	6.065	0.280	20.813	19.054	34.472	28.891	0.756	0.629	18.97	1000	0.666
	80 -X		5.761	0.432	20.813	18.099	34.472	26.07	0.756	0.663	28.57	1739	0.738
	120		5.501	0.562	20.813	17.29	34.472	23.77	0.756	0.695	36.39	2394	0.810
	160		5.187	0.719	20.813	16.30	34.472	21.13	0.756	0.736	45.35	3215	0.912
	XX		4.897	0.864	20.813	15.38	34.472	18.83	0.756	0.780	53.16	4004	1.02
8	20	8.625	8.125	0.250	27.096	25.53	58.43	51.87	0.443	0.470	22.36	655	0.371
	30		8.071	0.277	27.096	25.39	58.43	51.30	0.443	0.473	24.70	752	0.375
	40 S		7.981	0.322	27.096	25.07	58.43	50.03	0.443	0.473	28.55	916	0.385
	60		7.813	0.406	27.096	24.54	58.43	47.94	0.443	0.489	36.64	1225	0.402
	80 X		7.625	0.500	27.096	23.955	58.43	45.66	0.443	0.500	43.39	1577	0.422
	100		7.437	0.594	27.096	23.36	58.43	43.44	0.443	0.514	50.95	1935	0.443
	120		7.187	0.719	27.096	22.58	58.43	40.56	0.443	0.532	60.71	2422	0.475
	140		7.001	0.812	27.096	21.99	58.43	38.50	0.443	0.546	67.76	2792	0.500
	XX		6.875	0.875	27.096	21.60	58.43	37.12	0.443	0.556	72.42	3046	0.519
	160		6.813	0.906	27.096	21.40	58.43	36.44	0.443	0.561	74.69	3173	0.529

Selected from ANSI/ASME B36.10M – 1985 and B31.1 – 1992.
See notes page 7-8.

Seamless Wrought Steel Pipe

Size	Schedule no	Diameter External (inches)	Diameter Internal (inches)	Thickness (inches)	Circumference External (inches)	Circumference Internal (inches)	Transverse area External (sq in)	Transverse area Internal (sq in)	Length of pipe per sq ft of surface area: External surface (feet)	Length of pipe per sq ft of surface area: Internal surface (feet)	Weight per ft of length (lbs)	Allowable working pressure to 650° F (lb/sq in)	Water hammer factor
10	20	10.750	10.250	0.250	33.77	32.20	90.76	82.52	0.355	0.373	28.04	523	.233
	30		10.136	0.307	33.77	31.84	90.76	80.69	0.355	0.377	34.24	688	.239
	40 S		10.020	0.365	33.77	31.48	90.76	78.85	0.355	0.381	40.48	856	.244
	60 X		9.750	0.500	33.77	30.63	90.76	74.66	0.355	0.392	54.74	1255	.258
	80		9.562	0.594	33.77	30.04	90.76	71.81	0.355	0.399	64.43	1537	.268
	100		9.312	0.719	33.77	29.25	90.76	68.10	0.355	0.410	77.03	1918	.283
	120		9.062	0.844	33.77	28.48	90.76	64.50	0.355	0.421	89.29	2308	.299
	140 XX		8.750	1.000	33.77	27.49	90.76	60.13	0.355	0.437	104.13	2804	.320
	160		8.500	1.125	33.77	26.70	90.76	56.75	0.355	0.449	115.64	3211	.340
12	20	12.750	12.250	0.250	40.06	38.46	127.68	117.86	0.299	0.312	33.38	440	.163
	30		12.090	0.330	40.06	37.98	127.68	114.80	0.299	0.316	43.77	634	.168
	S		12.000	0.375	40.06	37.70	127.68	113.10	0.299	0.318	49.56	744	.170
	40		11.938	0.406	40.06	37.50	127.68	111.93	0.299	0.320	53.52	820	.172
	X		11.750	0.500	40.06	36.91	127.68	108.43	0.299	0.325	65.42	1052	.178
	60		11.626	0.562	40.06	36.52	127.68	106.16	0.299	0.329	73.15	1207	.181
	80		11.374	0.688	40.06	35.73	127.68	106.61	0.299	0.336	88.63	1526	.190
	100		11.062	0.844	40.06	34.75	127.68	96.11	0.299	0.345	107.32	1927	.200
	120 XX		10.750	1.000	40.06	33.77	127.68	90.76	0.299	0.355	125.49	2337	.212
	140		10.500	1.125	40.06	32.99	127.68	86.59	0.299	0.364	139.67	2672	.222
	160		10.126	1.312	40.06	31.81	127.68	80.53	0.299	0.377	160.27	3183	.239
14	10	14.000	13.500	0.250	43.98	42.41	153.94	143.14	0.272	0.283	36.71	401	.134
	20		13.376	0.312	43.98	42.02	153.94	140.52	0.272	0.286	45.61	537	.137
	30 S		13.250	0.375	43.98	41.63	153.94	137.89	0.272	0.288	54.57	676	.138
	40		13.124	0.438	43.98	41.23	153.94	135.28	0.272	0.291	63.44	817	.142
	X		13.000	0.500	43.98	40.84	153.94	132.73	0.272	0.294	72.09	956	.145
	60		12.812	0.594	43.98	40.25	153.94	128.92	0.272	0.298	85.05	1169	.149
	80		12.500	0.750	43.98	39.26	153.94	122.72	0.272	0.306	106.13	1528	.157
	100		12.124	0.938	43.98	38.09	153.94	115.45	0.272	0.315	130.85	1969	.167
	120		11.876	1.062	43.98	37.31	153.94	110.77	0.272	0.322	150.79	2265	.174
	140		11.500	1.250	43.98	36.13	153.94	103.87	0.727	0.332	170.21	2724	.185
	160		11.188	1.406	43.98	35.15	153.94	93.31	0.272	0.341	189.11	3112	.206

Selected from ANSI/ASME B36.10M – 1985 and B31.1 – 1992.
See notes page 7-8.

Seamless Wrought Steel Pipe

Size	Schedule no	Diameter External (inches)	Diameter Internal (inches)	Thickness (inches)	Circumference External (inches)	Circumference Internal (inches)	Transverse area External (sq in)	Transverse area Internal (sq in)	Length of pipe per sq ft of surface area: External surface (feet)	Length of pipe per sq ft of surface area: Internal surface (feet)	Weight per ft of length (lbs)	Allowable working pressure to 650° F (lb/sq in)	Water hammer factor
16	10	16.000	15.500	0.250	50.27	48.69	201.06	188.69	.239	.246	42.05	350	.102
	20	16.000	15.376	0.312	50.27	48.31	201.06	185.68	.239	.248	52.27	469	.104
	30 S	16.000	15.250	0.375	50.27	47.91	201.06	182.65	.239	.250	62.58	590	.105
	40 X	16.000	15.000	0.500	50.27	47.12	201.06	176.71	.239	.255	82.77	834	.109
	60	16.000	14.688	0.656	50.27	46.14	201.06	168.44	.239	.260	107.50	1142	.114
	80	16.000	14.312	0.844	50.27	44.96	201.06	160.88	.239	.267	136.61	1520	.120
	100	16.000	13.938	1.031	50.27	43.79	201.06	152.58	.239	.274	164.82	1903	.126
	120	16.000	13.562	1.219	50.27	42.61	201.06	144.64	.239	.282	192.43	2296	.133
	140	16.000	13.124	1.438	50.27	41.23	201.06	135.28	.239	.291	223.64	2764	.142
	160	16.000	12.812	1.594	50.27	40.25	201.06	128.92	.239	.298	245.25	3104	.149
18	10	18.000	17.500	0.250	56.55	54.98	254.47	240.53	.212	.218	42.39	312	.080
	20	18.000	17.376	0.312	56.55	54.98	254.47	237.13	.212	.220	58.94	416	.081
	S	18.000	17.250	0.375	56.55	54.19	254.17	233.71	.212	.221	70.59	524	.082
	30	18.000	17.124	0.438	56.55	53.80	254.47	230.30	.212	.223	82.15	632	.084
	X	18.000	17.000	0.500	56.55	53.41	254.47	226.98	.212	.225	93.45	739	.085
	40	18.000	16.876	0.562	56.55	53.02	254.47	223.68	.212	.226	104.67	847	.086
	60	18.000	16.500	0.750	56.55	51.84	254.47	213.82	.212	.231	138.17	1178	.090
	80	18.000	16.124	0.938	56.55	50.66	254.47	204.19	.212	.237	207.96	1514	.094
	100	18.000	15.688	1.156	56.55	49.29	254.47	193.30	.212	.243	244.14	1911	.100
	120	18.000	15.255	1.375	56.55	47.92	254.47	182.77	.212	.250	274.22	2318	.105
	140	18.000	14.876	1.562	56.55	46.73	254.47	173.80	.212	.257	308.50	2673	.111
	160	18.000	14.438	1.781	56.55	45.36	254.47	163.72	.212	.265		3096	.118
20	10	20.000	19.500	0.250	62.83	61.26	314.16	298.65	.191	.196	46.27	280	.064
	20 S	20.000	19.250	0.375	62.83	60.48	314.16	291.04	.191	.198	78.60	471	.066
	30 X	20.000	19.000	0.500	62.83	59.69	314.16	283.53	.191	.201	104.13	664	.068
	40	20.000	18.812	0.594	92.83	59.10	314.16	277.95	.191	.203	123.11	811	.069
	60	20.000	18.376	0.812	62.83	57.73	314.16	265.21	.191	.208	166.40	1155	.073
	80	20.000	17.938	1.031	62.83	56.35	314.16	252.72	.191	.213	208.87	1507	.076
	100	20.000	17.438	1.281	62.83	54.78	314.16	252.72	.191	.219	256.10	1917	.081
	120	20.000	17.000	1.500	62.83	53.41	314.16	226.98	.191	.225	296.37	2284	.085
	140	20.000	16.500	1.750	62.83	51.84	314.16	213.82	.191	.231	341.09	2710	.090
	160	20.000	16.062	1.969	62.83	50.46	314.16	202.62	.191	.238	379.17	3091	.095

Selected from ANSI/ASME B36.10M – 1985 and B31.1 – 1992.
See notes page 7-8.

Seamless Wrought Steel Pipe *(Continued)*

Size	Schedule no	Diameter External (inches)	Diameter Internal (inches)	Thickness (inches)	Circumference External (inches)	Circumference Internal (inches)	Transverse area External (sq in)	Transverse area Internal (sq in)	Length of pipe per sq ft of surface area External surface (feet)	Length of pipe per sq ft of surface area Internal surface (feet)	Weight per ft of length (lbs)	Allowable working pressure to 650° F (lb/sq in)	Water hammer factor
24	10	24.000	23.500	0.250	75.40	73.83	452.4	433.7	.159	.163	63.41	233	.044
	10	24.000	23.438	0.281	75.40	73.63	452.4	431.5	.159	.163	71.18	272	.045
	20 S	24.000	23.250	0.375	75.40	73.04	452.4	424.6	.159	.164	94.62	392	.045
	X	24.000	23.000	0.500	75.40	72.26	452.4	415.5	.159	.166	125.49	552	.046
	30	24.000	22.876	0.562	75.40	71.87	452.4	411.0	.159	.167	140.68	635	.047
	40	24.000	22.624	0.688	75.40	71.08	452.4	402.0	.159	.169	171.29	795	.048
	60	24.000	22.062	0.969	75.40	69.31	452.4	382.3	.159	.173	238.45	1165	.050
	80	24.000	21.562	1.219	75.40	67.74	452.4	365.1	.159	.177	296.58	1500	.053
	100	24.000	20.938	1.513	75.40	65.78	452.4	344.3	.159	.182	367.39	1927	.056
	120	24.000	20.376	1.812	75.40	64.01	452.4	326.1	.159	.187	429.39	2319	.059
	140	24.000	19.876	2.062	75.40	62.44	452.4	310.3	.159	.192	483.12	2674	.062
	160	24.000	19.312	2.344	75.40	60.67	452.4	292.9	.159	.197	542.13	3083	.066
30	10	30.000	29.376	0.312	94.25	92.29	706.9	677.8	.127	.130	98.93	254	.028
	S	30.000	29.250	0.375	94.25	91.89	706.9	672.0	.127	.131	118.65	313	.029
	20 X	30.000	29.000	0.500	94.25	91.11	706.9	660.5	.127	.132	157.33	440	.029
	30	30.000	28.750	0.625	94.25	90.32	706.9	649.2	.127	.133	196.08	568	.030
36	10	36.000	35.376	0.312	113.10	111.14	1017.9	982.9	.106	.108	118.92	207	.020
	S	36.000	35.250	0.375	113.10	110.74	1017.9	975.9	.106	.108	142.68	260	.020
	20 X	36.000	35.000	0.500	113.10	109.96	1017.9	962.1	.106	.109	189.57	366	.020
	30	36.000	34.750	0.625	113.10	109.17	1017.9	948.4	.106	.110	263.13	473	.020
	40	36.000	34.500	0.750	113.10	108.38	1017.9	934.8	.106	.111	282.35	580	.021
42	S	42.000	41.250	0.375	131.95	129.59	1385.4	1336.4	.091	.093	166.71	223	.014
	X	42.000	41.000	0.500	131.95	128.81	1385.4	1322.3	.091	.093	221.61	313	.015
48	S	48.000	47.250	0.375	150.80	148.44	1809.6	1753.5	.080	.081	190.74	195	.011
	X	48.000	47.000	0.500	150.80	147.65	1809.6	1734.9	.080	.081	253.65	274	.011

Selected from ANSI/ASME B36.10M – 1985 and B31.1 – 1992.
See notes page 7-8.

Steel Pipe Flanges — American National Standard

Nominal pipe size	Flange rating psi	Outside flange dia in	Flange thickness (min) in	Diameter bolt circle	Length thru hub in: Threaded slip-on socket welding	Length thru hub in: Lapped	Length thru hub in: Welding neck
½	150	3.50	0.44	2.375	0.62	0.62	1.88
	300	3.75	0.56	2.625	0.88	0.88	2.06
	400	3.75	0.56	2.625	0.88	0.88	2.06
	600	3.75	0.56	2.625	0.88	0.88	2.06
	900	4.75	0.88	3.25	1.25	1.25	2.38
	1500	4.75	0.88	3.25	1.25	1.25	2.38
	2500	5.25	1.19	3.5	1.56	1.56	2.88
¾	150	3.88	0.50	2.75	0.62	0.62	2.06
	300	4.62	0.62	3.25	1.00	1.00	2.25
	400	4.62	0.62	3.25	1.00	1.00	2.25
	600	4.62	0.62	3.25	1.00	1.00	2.25
	900	5.12	1.00	3.5	1.38	1.38	2.75
	1500	5.12	1.00	3.5	1.38	1.38	2.75
	2500	5.50	1.25	3.75	1.69	1.69	3.12
1	150	4.25	0.56	3.125	0.69	0.69	2.19
	300	4.88	0.69	3.5	1.06	1.06	2.44
	400	4.88	0.69	3.5	1.06	1.06	2.44
	600	4.88	0.69	3.5	1.06	1.06	2.44
	900	5.88	1.12	4.0	1.62	1.62	2.88
	1500	5.88	1.12	4.0	1.62	1.62	2.88
	2500	6.25	1.38	4.25	1.88	1.88	3.50
1¼	150	4.62	0.62	3.5	0.81	0.81	2.25
	300	5.25	0.75	3.875	1.06	1.06	2.56
	400	5.25	0.81	3.875	1.12	1.12	2.62
	600	5.25	0.81	3.875	1.12	1.12	2.62
	900	6.25	1.12	4.375	1.62	1.62	2.88
	1500	6.25	1.12	4.375	1.62	1.62	2.88
	2500	7.25	1.50	5.125	2.06	2.06	3.75
1½	150	5.00	0.69	3.875	0.88	0.88	2.44
	300	6.12	0.81	4.5	1.19	1.19	2.69
	400	6.12	0.88	4.5	1.25	1.25	2.75
	600	6.12	0.88	4.5	1.25	1.25	2.75
	900	7.00	1.25	4.875	1.75	1.75	3.25
	1500	7.00	1.25	4.875	1.75	1.75	3.25
	2500	8.00	1.75	5.75	2.38	2.38	4.38
2	150	6.00	0.75	4.75	1.00	1.00	2.50
	300	6.50	0.88	5.0	1.31	1.31	2.75
	400	6.50	1.00	5.0	1.44	1.44	2.88
	600	6.50	1.00	5.0	1.44	1.44	2.88
	900	8.50	1.50	6.5	2.25	2.25	4.00
	1500	8.50	1.50	6.5	2.25	2.25	4.00
	2500	9.25	2.00	6.75	2.75	2.75	5.00
2½	150	7.00	0.88	5.5	1.12	1.12	2.75
	300	7.50	1.00	5.875	1.50	1.50	3.00
	400	7.50	1.12	5.875	1.62	1.62	3.12
	600	7.50	1.12	5.875	1.62	1.62	3.12
	900	9.62	1.62	7.5	2.50	2.50	4.12
	1500	9.62	1.62	7.5	2.50	2.50	4.12
	2500	10.50	2.25	7.75	3.12	3.12	5.62

From ANSI B 16.5.
Slip-on welding not in 2500 lb rating, and only in 1½ to 2½ sizes for 1500 lb rating and 1½ to 3 in sizes for 150 lb rating.
Socket welding not in 400, 900 and 2500 lb ratings and only in ½ to 2½ sizes for 1500 lb rating and ½ to 3" sizes in 300 lb rating.
Threaded in 1500 lb rating from ½ to 12 in sizes only.

Schedule 40 PVC Pipe Dimensions

Nom. Pipe Size (in)	O.D.	Average I.D.	Min. Wall	Nominal Wt./Ft.	Maximum W.P. PSI*
1/8	0.405	0.249	0.068	0.051	810
1/4	0.540	0.344	0.088	0.086	780
3/8	0.675	0.473	0.091	0.115	620
1/2	0.840	0.602	0.109	0.170	600
3/4	1.050	0.804	0.113	0.226	480
1	1.315	1.029	0.133	0.333	450
1-1/4	1.660	1.360	0.140	0.450	370
1-1/2	1.900	1.590	0.145	0.537	330
2	2.375	2.047	0.154	0.720	280
2-1/2	2.875	2.445	0.203	1.136	300
3	3.500	3.042	0.216	1.488	260
3-1/2	4.000	3.521	0.226	1.789	240
4	4.500	3.998	0.237	2.118	220
5	5.563	5.016	0.258	2.874	190
6	6.625	6.031	0.280	3.733	180
8	8.625	7.942	0.322	5.619	160
10	10.750	9.976	0.365	7.966	140
12	12.750	11.889	0.406	10.534	130
14	14.000	13.073	0.437	12.462	130
16	16.000	14.940	0.500	16.286	130
18	18.000	16.809	0.562	20.587	130
20	20.000	18.743	0.593	24.183	120
24	24.000	22.544	0.687	33.652	120

Schedule 80 PVC Pipe Dimensions

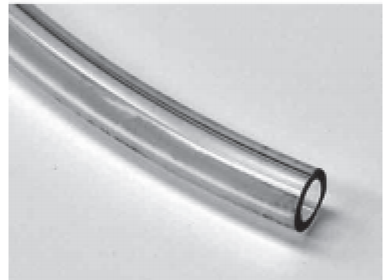
Nominal Pipe Size (in)	O.D.	Average I.D.	Min. Wall	Nominal Wt./ft.	Maximum W.P. PSI*
1/8	0.405	0.195	0.095	0.068	1230
1/4	0.540	0.282	0.119	0.115	1130
3/8	0.675	0.403	0.126	0.158	920
1/2	0.840	0.526	0.147	0.232	850
3/4	1.050	0.722	0.154	0.314	690
1	1.315	0.936	0.179	0.461	630
1-1/4	1.660	1.255	0.191	0.638	520
1-1/2	1.900	1.476	0.200	0.773	470
2	2.375	1.913	0.218	1.070	400
2-1/2	2.875	2.29	0.276	1.632	420
3	3.500	2.864	0.300	2.186	370
4	4.500	3.786	0.337	3.196	320
6	6.625	5.709	0.432	6.102	280
8	8.625	7.565	0.500	9.269	250
10	10.750	9.493	0.593	13.744	230
12	12.750	11.294	0.687	18.909	230
14	14.000	12.41	0.750	22.681	220
16	16.000	14.213	0.843	29.162	220
18	18.000	16.014	0.937	36.487	220
20	20.000	17.814	1.031	44.648	220
24	24.000	21.418	1.218	63.341	210

From this web site: https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensions/

From this web site http://media.wattswater.com/ES-ClearVinyltubing.pdf

LEAD FREE*

Clear Vinyl Tubing



Our Clear Vinyl Tubing is manufactured from Polyvinyl Chloride

Attributes

- Clarity of glass
- Smooth dense bore maximizes flow and reduces sediment buildup

Applications

- Beverage dispensing
- Potable water
- Drainage lines
- Aquarium tubing
- Laboratory tubing
- Protective insulation

DO NOT USE AS ICE MAKER SUPPLY LINE.

Resistant to

Acids, alkalis, variety of chemical, gases and liquids (see PL-Tubing for listing of chemicals)

Pressure Range	19 to 55psi (131 – 379 kPa)
Maximum Operating Temperature	175°F (79°C)
Brittle Point	-40°F (-40°C)
Material	Polyvinyl Chlorine
Color	Clear
Hardness	Durometer 83+/-3 Shore A
Toxicity	Non-toxic FDA Listed Material

Packaging

Coils, dispenser boxes, dispenser spools

***The wetted surface of this product contacted by consumable water contains less than one quarter of one percent (0.25%) of lead by weight.**

Pressure Range

O.D. INCH	I.D. INCH	WALL	WORKING PRESSURE (PSI @ 70°F)
1/8	1/16	1/32	55
3/16	1/8	1/32	55
1/4	1/8	1/16	55
5/16	3/16	1/16	55
1/4	3/16	1/32	55
7/16	3/16	1/8	55
3/8	1/4	1/16	55
7/16	1/4	3/32	55
1/2	1/4	1/8	55
7/16	5/16	1/16	50
1/2	5/16	3/32	55
9/16	5/16	1/8	55
1/2	3/8	1/16	45
9/16	3/8	3/32	55
5/8	3/8	1/8	55
9/16	7/16	1/16	45
5/8	7/16	3/32	50
11/16	7/16	1/8	55
5/8	1/2	1/16	45
11/16	1/2	3/32	50
3/4	1/2	1/8	55
7/8	11/16	3/32	35
13/16	9/16	1/8	45
3/4	9/16	3/32	50
3/4	5/8	1/16	30
13/16	5/8	3/32	45
7/8	5/8	1/8	40
7/8	3/4	1/16	30
15/16	3/4	3/32	35
1	3/4	1/8	35
1-1/8	7/8	1/8	30
1-1/4	1	1/8	25
1-3/16	1	3/32	25
1-3/4	1-1/4	1/4	25
1-5/8	1-1/4	3/16	25
1-1/2	1-1/4	1/8	25
2	1-1/2	1/4	25
1-7/8	1-1/2	3/16	25

ISO 9001-2008 CERTIFIED

WATTS®
A Watts Water Technologies Company

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Canada: Burlington, ON • Tel: (905) 332-4090 • Fax: (905) 332-7068 • www.wattscanada.ca

ES-ClearVinyltubing 1151

Size	Actual outer diameter, inches	Type		
		K	L	M
		Actual inner diameter, inches		
3/8	1/2	0.402	0.430	0.450
1/2	5/8	0.528	0.545	0.569
5/8	3/4	0.652	0.668	0.690
3/4	7/8	0.745	0.785	0.811
1	1 1/8	0.995	1.025	1.055
1¼	1 3/8	1.245	1.265	1.291
1½	1 5/8	1.481	1.505	1.527
2	2 1/8	1.959	1.985	2.009

Type L is the most commonly used tube. This data comes from:
https://www.sizes.com/materials/pipeCopper.htm