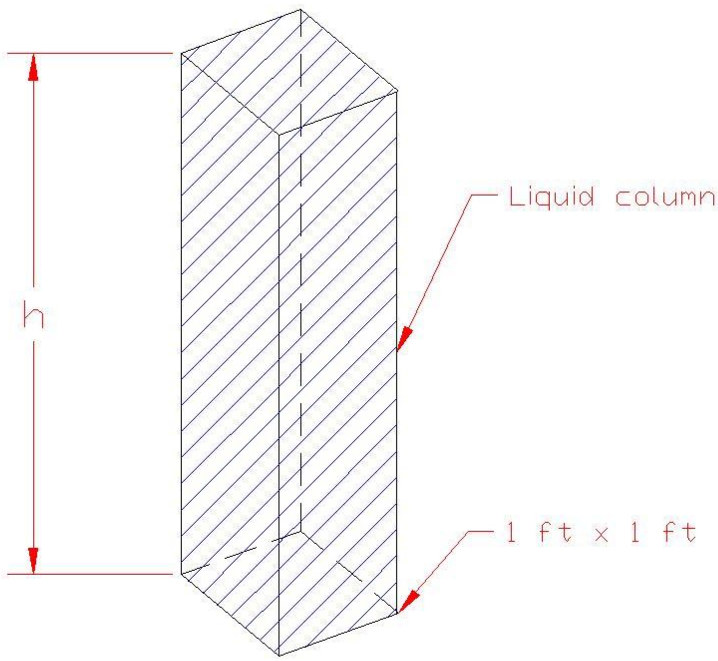
Pressure and Flow rate

Pressure Definition

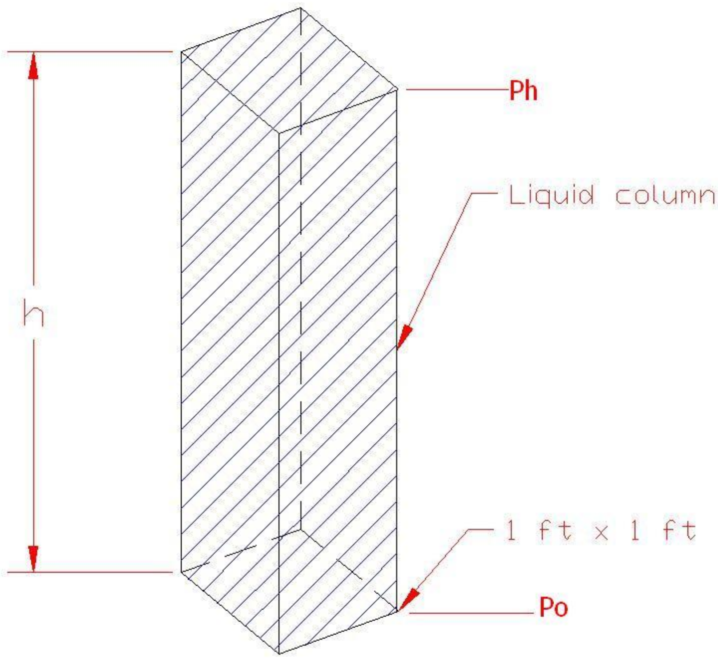
Absolute Pressure: Absolute pressure is the force per unit area applied to anything, whether that anything is a solid, liquid or gas. Imagine a column of liquid above an area 1 ft by 1 ft.



The force exerted on the 1ft x 1 ft area is the weight of that column of liquid. If the liquid is water and h = 5 ft then the total volume of the column is 5 ft^3. Water weighs 62.4 Lb/ft^3 so the weight of the column above would be 312Lb .Since this weight is spread over 1 ft^2 the pressure exerted by that column of water would be 312 Lb/ft^2 or 2.2 Lb/in^2 (2.2 psi). Since this is the total pressure on that 1ft x 1 ft area we say that this is an absolute pressure and write 2.2 psi**a**. The "a" refers to absolute.

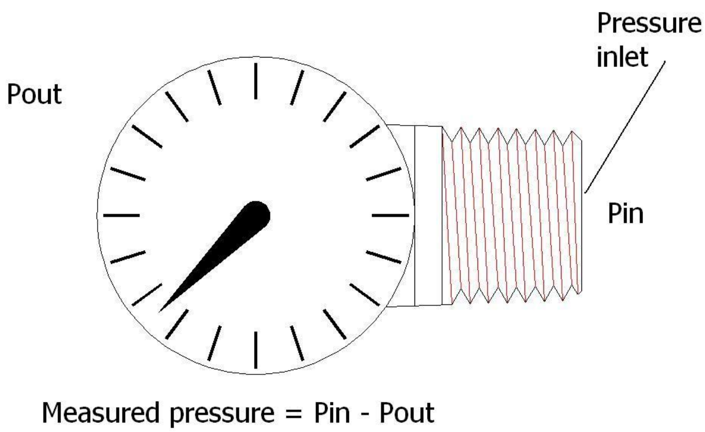
Atmospheric Pressure: Atmospheric pressure is the pressure exerted on a solid, liquid or gas by the atmosphere. Imagine the 1ft x 1ft area above without the column of liquid above it. Instead the 1ft x 1ft area is at sea level and there is a column of gases above it reaching to the top of the atmosphere. That column of gas has some weight. On a typical day at sea level that column will weigh around 2117 Lbs. So the atmospheric pressure on that 1ft x 1ft area will be approximately 2117 Lb/ft^2 or 14.7 Lb/in^2. Since this is an absolute pressure we write 14.7 psia. This is a **typical** atmospheric pressure (barometric pressure). It varies from day to day.

Now imagine the 1ft x 1ft area at the bottom of a pool 5 ft deep. What is the absolute pressure at the bottom of the pool? There are two columns of fluid above the 1 ft x 1 ft area. One is a 5 foot column of water. The other is the column of gases reaching to the top of the atmosphere. The column of water weighs 312 Lb and the column of gases weighs 2117 Lbs. The total weight above the 1ft x 1ft area is 2429 Lbs. So the pressure on the 1ft x 1ft area is 2429 Lbs/ft^2 or 16.9 psia.



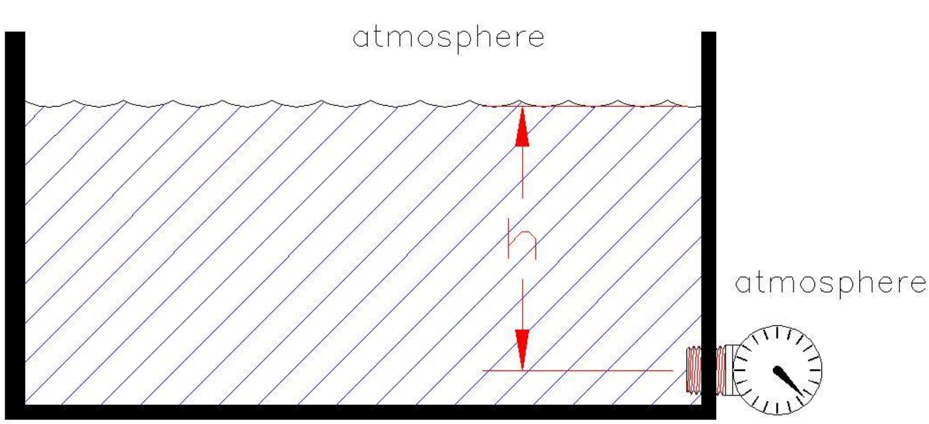
Another way to look at it is the pressure at the bottom of the pool (Po) is simply the atmospheric pressure (14.7 psia) plus the pressure exerted by the water column (2.2 psi). So Po = 14.7 + 2.2 = 16.9 psia. Note that Ph is the pressure at the top of the water column where the water meets the atmosphere. So Ph is the atmospheric pressure in this case.

<u>Gauge Pressure:</u> Gauge pressure is the pressure as measured by a pressure gauge. A pressure gauge does not measure absolute pressure. It measures the difference between the pressure applied at the pressure inlet (P in) and the pressure outside the rest of the gauge (P out).



So if you have a pressure gauge sitting on a table what will it read? Well the pressure at the pressure inlet (Pin) is atmospheric pressure. The pressure surrounding the rest of the gauge is also atmospheric pressure. So Pin – Pout = 0. The gauge will read 0 psig. Notice I wrote psi**g**. The “g” refers to gauge. This is important. Atmospheric pressure is almost always 0 psig.

What pressure will you read if you stick a pressure gauge into the bottom of an above ground pool? If h = 5 feet in the diagram below then the absolute pressure at gauge depth is 16.9 psia as calculated previously. That is Pin. Pout is atmospheric pressure, 14.7 psia.



So the gauge reads Pin – Pout = 16.9 psia – 14.7 psia = 2.2 psig. Notice that 2.2 psi is the pressure exerted by the column of water above the pressure gauge. Notice also that I wrote 2.2 psi**g** because this the pressure measured by a gauge. It is not the true (absolute) pressure.

In general, pressure gauges will be measuring the pressure inside a pipe or a vessel and the rest of the gauge will be in the atmosphere. So the gauge will read the difference between the absolute pressure inside the pipe/vessel and the atmospheric pressure. This is an important point which we will re-visit when we look at pressure and flow rate. Another important point is that 95% of the time (or more) absolute pressure is gauge pressure plus atmospheric pressure. Psia = 14.7 psia + psig.

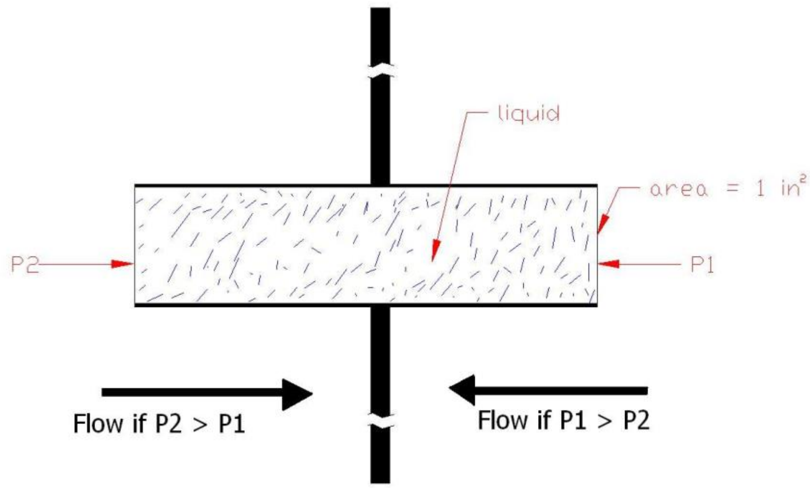
We often talk about pressure differences in the nozzle business. A pressure difference is neither psia nor psig. We can write psi**d** to identify a pressure difference.

Flow rate and Pressure

Flow rate: In the nozzle business we are concerned with flow rate through a nozzle or sometimes flow rate through a pipe. What causes a liquid or gas (a fluid) to flow? With nozzle applications it's almost always a pressure difference that causes flow. A fluid will try to flow from high pressure to low pressure. But there are other things that can cause flow, such as a height difference or even a temperature difference. The basic relationship between flow and pressure for a nozzle is:

Flow1/Flow2 = square root(ΔP1/ΔP2). ΔP = pressure difference across the nozzle

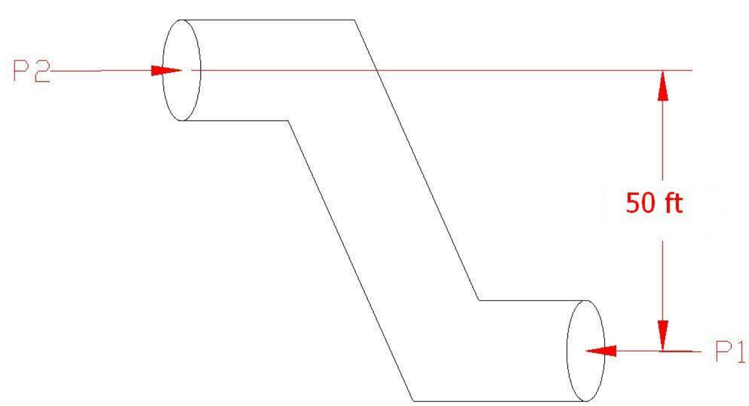
Imagine a short length of horizontal pipe with a cross sectional area of 1in^2. There is pressure against the right face of the pipe (P1) and also pressure against the left face of the pipe (P2).



Let’s say P1 is 15psia and P2 is 10psia. Since the cross sectional area of the pipe is

1 in^2 - that means the force on the right face of the pipe is 15Lbs and the force on the left face is 10Lbs. As such, there will be an overall force of 5Lbs forcing the liquid to the left and that will be the direction of the flow. If P2 is more than P1, then the liquid will flow in the opposite direction. If P1 and P2 are the same there will be no flow or liquid will dribble out of both ends equally. The point here is that a pressure difference is required to create flow.

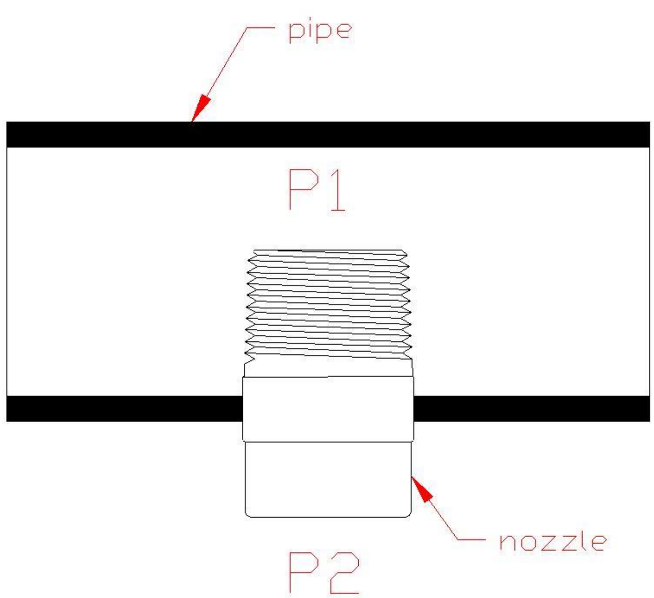
Liquid will not always flow in the direction of lower pressure. Consider the example



where the pipe is not horizontal, but rises 50ft over its length. For water if P1 is 30 psia and P2 is 20 psia flow in the pipe will still be downhill, from left to right, even though the pressure difference suggests flow should be right to left. In fact P1 must be greater than P2 by more than 22 psi before water will flow uphill in this pipe. Remember 2.2 psi was the pressure exerted by a column of water 5 ft high. A column of water 50 ft high would exert 22 psi. As such a 50 ft rise in the pipe exerts a resistive pressure of 22 psi on the lower entrance to the pipe that must be overcome by the pressure difference (P1-P2) before the water will flow uphill.

It takes 2.31 feet of water column to equal 1 psi. So if you are piping water 15 ft up to nozzles in the roof it will take 15 feet ÷ 2.31 = 6.5psid just to lift the water those 15 feet. If you want 20 psig at the nozzle entrance then you want at least 20psig + 6.5psid = 26.5 psig in the pipe before the 15 foot rise. In fact, you will want more because you also have to overcome friction and flow resistance in the pipe. So you will probably want something like 28-30 psig in the pipe before the 15ft rise.

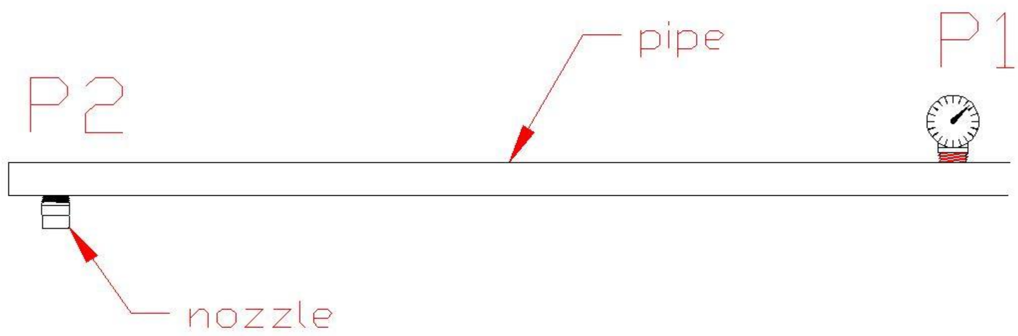
In the BEX catalogue, flow rates are listed at various pressures for each nozzle. Sometimes customers ask if the pressures listed in these charts are gauge pressure or absolute pressure. In truth they are neither. They are pressure **differences** across the nozzle. To calculate pressure differences across a nozzle you simply subtract the exit pressure from the entrance pressure.



In the diagram above the pressure difference across the nozzle would be P1 - P2. One very important point here is that if P1 is in psig then P2 must also be in psig if you want to get the correct pressure difference. It doesn't matter if you use gauge pressure (psig) or absolute pressure (psia) for your calculation as long as you don't mix them. Another important point is that P2 is almost always atmospheric pressure (0 psig). Remember if you stick a gauge in that pipe the gauge will measure the difference between the pressure in the pipe and the pressure outside the gauge. The pressure outside the gauge is almost always atmospheric pressure. So the gauge measures the pressure difference from inside the pipe to atmosphere. This is the same as the pressure difference across the nozzle in almost all nozzle applications.

It is best to stick to psig for nozzle applications as you are almost always getting your pressure from a gauge. Remember atmospheric pressure is 0 psig.

Sometimes the actual pressure drop across a nozzle will be miscalculated due to a misplaced gauge. This can lead to a conclusion that the nozzle is plugged or defective when the nozzle is fine. Consider the situation as shown in the diagram below. The pressure does not remain the same along the length of the pipe when some fluid is flowing in the pipe.



If there is flow in the pipe, there will be some energy required to move the water (or other fluid) from P1 to P2. This energy loss will show up as a pressure difference between P1 and P2. This pressure difference can be enough that the expected performance of the nozzle (at P1) is very different from the performance at P2.

Increase in flow rate = increase in pressure drop
Increase in pipe length = increase in pressure drop
Decrease in inside pipe diameter = increase in pressure drop

The chart below shows calculated pressure drops for various flow rates for a typical 1-1/4 sched 40 pipe.

(http://www.engineeringtoolbox.com/pressure-loss-steel-pipes-d_307.html

Nominal Pipe Size: *1 1/4"*

- Inside Diameter: *0.032 m (1.28 inches)*

Flow			Velocity		Pressure Drop			
(US gpm)	*(liter/s)*		*(m/s)*	*(ft/s)*	*(Pa/100m)*	*(mmH$_2$O/100m)*	*(psi/100ft)*	*(ftH$_2$O/100ft)*
1.59	0.1		0.124	0.41	1037	106	0.046	0.106
1.74	0.11		0.137	0.45	1226	125	0.054	0.125
1.9	0.12		0.149	0.49	1424	145	0.063	0.145
2.1	0.13		0.162	0.53	1630	166	0.072	0.166
2.2	0.14		0.174	0.57	1843	188	0.081	0.188
2.4	0.15		0.187	0.61	2116	216	0.094	0.22
2.5	0.16		0.199	0.65	2346	239	0.104	0.24
2.7	0.17		0.21	0.69	2648	270	0.117	0.27
2.9	0.18		0.22	0.73	2891	295	0.128	0.3
3.0	0.19		0.24	0.78	3221	328	0.142	0.33

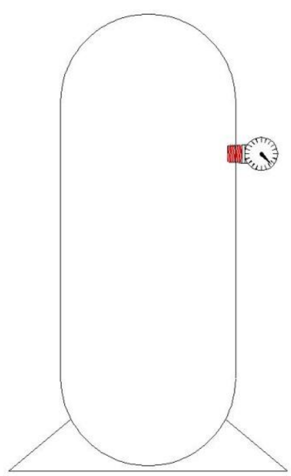
Flow			Velocity		Pressure Drop			
(US gpm)	(liter/s)		(m/s)	(ft/s)	(Pa/100m)	(mmH$_2$O/100m)	(psi/100ft)	(ftH$_2$O/100ft)
3.2	0.2		0.25	0.82	3473	354	0.153	0.35
4.8	0.3		0.37	1.22	7162	730	0.32	0.73
6.3	0.4		0.5	1.63	11961	1220	0.53	1.22
7.9	0.5		0.62	2.0	18087	1844	0.8	1.85
9.5	0.6		0.75	2.4	25177	2567	1.11	2.6
11.1	0.7		0.87	2.9	34269	3494	1.51	3.5
12.7	0.8		0.99	3.3	43215	4407	1.91	4.4
14.3	0.9		1.12	3.7	54695	5577	2.4	5.6
15.9	1.0		1.24	4.1	65113	6640	2.9	6.6
17.4	1.1		1.37	4.5	78786	8034	3.5	8.0
19.0	1.2		1.49	4.9	93762	9561	4.1	9.6
21	1.3		1.62	5.3	105965	10805	4.7	10.8
22	1.4		1.74	5.7	122894	12532	5.4	12.5
24	1.5		1.87	6.1	141077	14386	6.2	14.4
25	1.6		1.99	6.5	160515	16368	7.1	16.4

Flow			Velocity		Pressure Drop			
(US gpm)	*(liter/s)*		*(m/s)*	*(ft/s)*	*(Pa/100m)*	*(mmH_2O/100m)*	*(psi/100ft)*	*(ftH_2O/100ft)*
27	1.7		2.1	6.9	181206	18478	8.0	18.5

Some Problem Examples

The pipe in the diagram below is 1-1/4" pipe. There is 50ft of pipe between the gauge and the nozzle. The nozzle is flowing at 22 USgpm. What is the pressure drop between the gauge and the nozzle? At 22 USgpm, as per the chart above, the pressure drop is 5.4 psi/100 ft. Since there are only 50ft in the pipe above, the pressure drop would be half that or 2.7 psi.

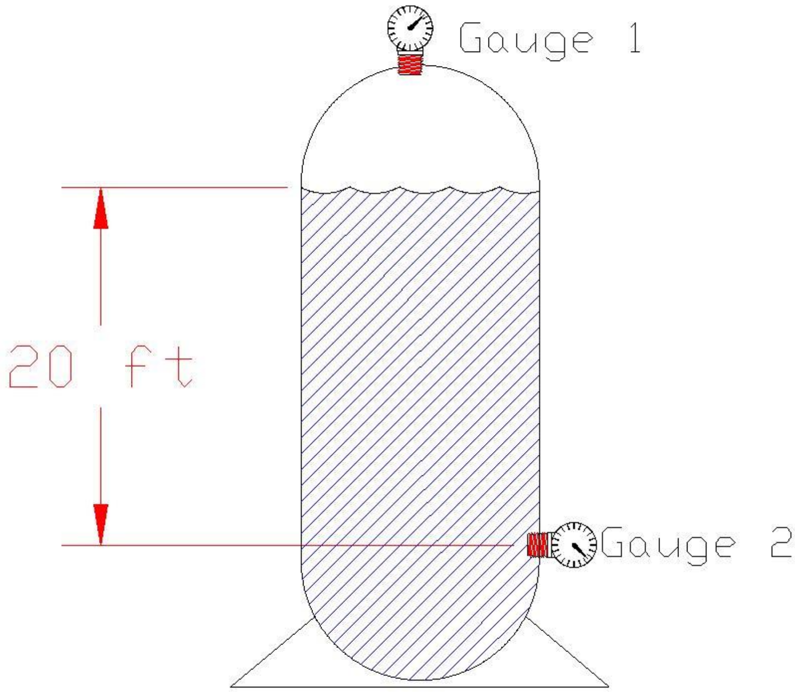
Problem 1:



The gauge in the diagram above is reading 25 psi.

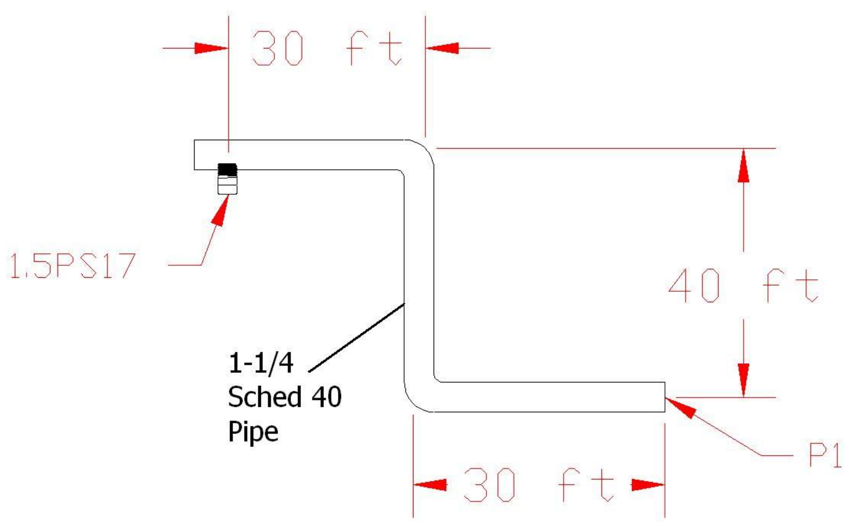
1) What is this gauge pressure inside the tank ?
2) What is the absolute pressure inside the tank ?

Problem 2:



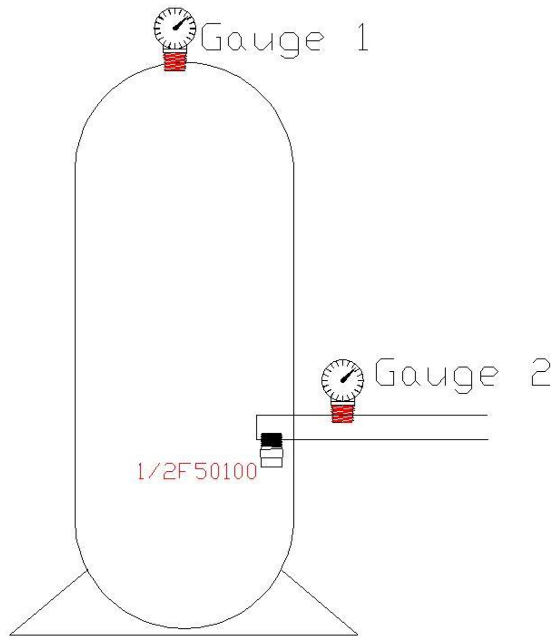
Gauge 1 is reading 15 psig. The liquid in the tank is water. What pressure is gauge 2 showing?

Problem 3:



If the 1.5PS17 nozzle above is to flow at 24 USgpm what should the pressure be at P1?

Problem 4:



If the 1/2F50100 nozzle is flowing at 11 US gpm and gauge 1 is reading 15 psig, what is gauge 2 reading? What would be the reading on gauge 2 if gauge 2 was inside the tank?

Solutions to Problems

Problem 1:

1) **<u>25 psig</u>**
2) 39.7 psia. Atmospheric pressure is typically 14.7 psia. So the absolute pressure inside the tank would be 25 psig + 14.7 psia = **<u>39.7 psia</u>**.

Problem 2:

There is 20 feet of water above gauge 2. At the top of the water the pressure is 15 psig. At the gauge the pressure is 15 psig + 20 ft water = 15 psig + 20/2.31 psi = 15 + 8.7 = 23.7 psig. The gauge shows the pressure difference between the pressure at the inlet (23.7 psig) and the pressure outside the gauge (0 psig). So the gauge would read **<u>23.7 psig</u>**.

Problem 3:

The chart in the catalogue tells us that a 1.5PS17 requires 20 psid to flow at 24 USgpm. So the difference between the pressure in the pipe at the nozzle entrance and the pressure outside the pipe is 20 psid. Since the nozzle is spraying in to atmosphere the pressure outside the pipe is 0 psig. Therefore the pressure inside at the nozzle entrance is 20 psig.

To get the pressure at P1 you have to add up the pressure drops in the pipe and add them to 20 psig.

Pressure drop due to 40 ft rise = 40 ft ÷ 2.31 = 17.3 psid

Pressure drop due to pipe friction: length of pipe = 30 ft + 40 ft + 30 ft = 100 ft. From chart above the pressure drop for 1-1/4 pipe at 24 gpm = 6.2 psid

Therefore P1 = 20 psig + 17.3 psid + 6.2 psid = **43.5 psig**

Actually the pressure drop due to friction would be a bit more than 6.2 psid as each elbow adds a small pressure drop.

Problem 4:

From the chart in the catalogue we know that the 1/2F50100 will flow at 10 gpm at 40 psid. So using the nozzle equation for 11 gpm:

(10 gpm/11 gpm) = square root (40 psi/ΔP1) => ΔP1 = 48.4 psid

So the pressure drop across the nozzle is 48.4 psid. The pressure inside the tank is 15 psig as per gauge 1 so the pressure in the pipe must be 15 psig + 48.4 psid = 63.4 psig. Gauge 2 is very close to the nozzle so we can assume the pressure drop from the gauge to the nozzle is negligible. As such gauge 2 reads **63.4 psig**.