Head or pressure, what's the deal

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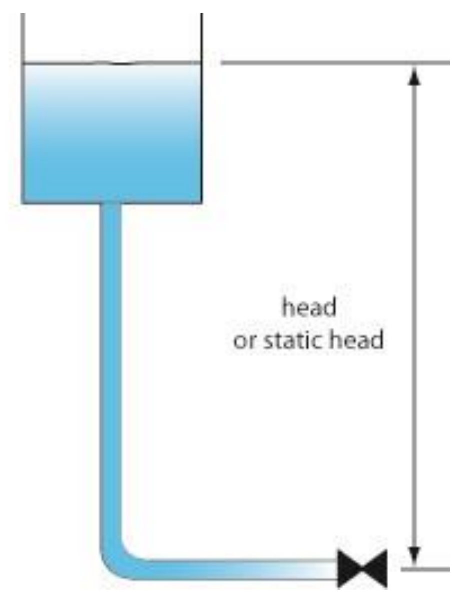
Why do we use head as a measurement of a pump's capacity and not pressure? The short answer is that it is more convenient. Convenient for who? The pump manufacturer and also the user. The main reason is that head is an easy measurement to make; in the case of static head it is a vertical measurement from one level to another.

Head is a term that has a chameleon like qualities, it has a secret identity. It can be interpreted as the height of a body of water which is its normal day to day appearance or it can reveal itself as a form of energy. Let's take a look at its units. If it is equivalent to a height then its unit must be in feet or meters.

For example

static head = height (ft)



We can see that a body of water held at a given height contains energy. If we release the water we convert the liquids potential energy to kinetic energy and we could accomplish useful work such as driving a turbine to generate power.

Let's take a look at another way to express those units. If head is really a form of energy there must be an energy term associated with it.

We know that *ft-lbfs* is an energy term.

Static head = energy / unit weight = ft-lbf / lbf = ft

The secret identity of head is that it is really energy per unit weight which happens to be the same unit as feet which is why we can turn it into a measurement with a tape.

This is significant because we can add and subtract energies just as we do with linear measurements.

What is energy? It's all around us in our day to day activities. If you're a linebacker running down the field for a touchdown you are a moving mass with velocity, if the defense hits you head on it has to come up with the same amount of energy to halt you in your tracks. Everyone has thrown a ball; if you get hit by a ball at 40 mph you feel the energy. A pump's energy is its head or the pressure it can develop, the more pressure it develops the faster it can propel the liquid down a pipe.

We use energy terms in our pump system such as head because we need to know how much energy will be required to do the job (that's the energy the pump requires) such as transferring liquid to a higher level and overcoming friction.

Let's show how this works with a familiar example of a cyclist at the top of a hill. The rider has potential energy at the top of a hill even though she is not moving; as she rolls down the hill she exchanges her potential energy for kinetic energy or velocity energy. As she reaches the bottom of the hill all her potential energy has been converted to kinetic energy neglecting friction for the moment. That's the principle of conservation of energy, if one increases the other must decrease, there is no free lunch.

Potential energy - kinetic energy = 0

The formula for potential energy is:

potential energy = mg x h

m is the mass, g the acceleration due to gravity, the product of these two is weight or W and h is the height above a reference plane. Why a reference plane? Usually when you measure heights on large structures you refer to a reference plane such as sea level, you then subtract your elevation above sea level of the start point from the elevation of the lowest point to establish the height difference.

Let's put some numbers on this, if the rider weighs 150 lbfs and the bike weighs 20 lbfs and the hill is 50 feet high then the potential energy is (150 + 20) x 50 = 8500 lbf-ft, according to the formula above the kinetic energy will also be 8500 ft-lbf.

The formula for kinetic energy is:

$$\text{Kinetic energy} = \frac{1}{2} m v^2$$

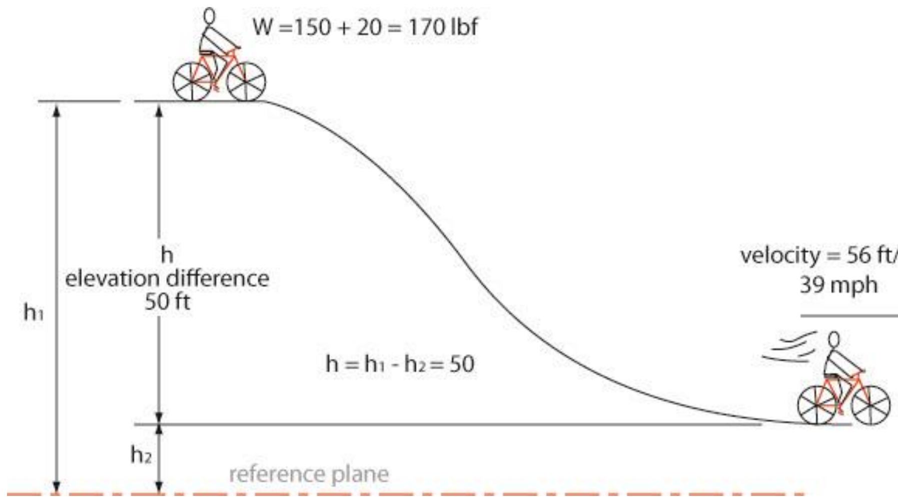
In the Imperial system (yes, I know sorry) we need a conversion constant g_c to make the units work.

$$gc = \frac{32.17\ lbm - ft}{lbf - s^2}$$

Therefore kinetic energy using consistent units is:

$$Kinetic\ energy = \frac{1}{2} \times \frac{m}{g_c} \times \left(v(\frac{ft}{s})\right)^2 = \frac{1}{2} \times \frac{170}{32.17} \times v^2 = 8500\ ft - lbf$$

Solving for v we get v = 57 ft/s or 39 miles per hour, not bad. Of course it would be a bit slower if friction was considered.



How does this compare to a pump system. We can do a balance of energy in the same way that we did for the cyclist, the energy that we have available to the system i.e. the suction head (the height of water above the suction of the pump) plus the pump differential head must be equal to the energy required i.e. the discharge static head (how high we transfer the water) plus the friction head. In other words

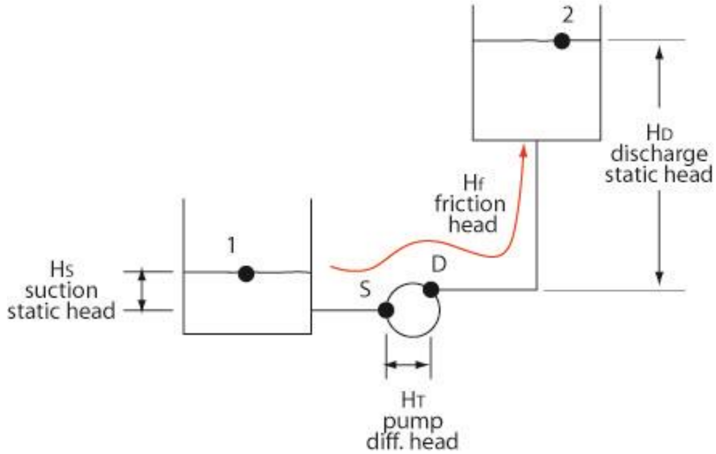
suction static head + pump diff. head = discharge static head + friction head

Usually we isolate the pump differential head on one side

pump diff. head = discharge static head - suction static head + friction head

and let's call these terms H_T for pump differential head, h_f for friction head, H_S for suction static head and H_D for discharge static head.

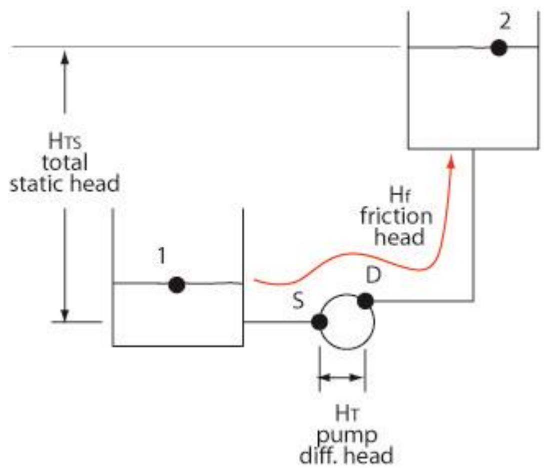
$$H_T = H_D – H_S - H_f$$



Because we like things to be simple and efficient we don't normally separate the suction and discharge static heads. Since these are energy terms we can combine these two into one called total static head H_{TS}.

Total static head = discharge static head – suction static head

$$H_{TS} = H_D - H_S$$



Therefore the pump total head is:

$$H_T = H_{TS} - H_f$$

Pretty simple result eh?

Using head allows us to calculate how much energy is required to make our system operate as expected. We haven't talked about flow rate, it's the other fundamental characteristic that will describe our system. This is a number that we need to fix prior to selecting a pump and prior to finishing our calculation of pump head required. The number is arbitrary and depends on the needs of the user. We use the flow rate to calculate friction. If you require 50 gallons per minute of flow, this means that the liquid will have to flow at a certain velocity through the pipes and if you select small pipes the velocity will be high making the friction head high and for larger pipes the friction head will be lower, so a balance needs to be struck, also the longer the pipe the more friction. A typical number that is used for design is 9-12 ft/s of velocity for the discharge piping, this is the starting point and from there you can calculate the pipe diameter based on the flow rate required.

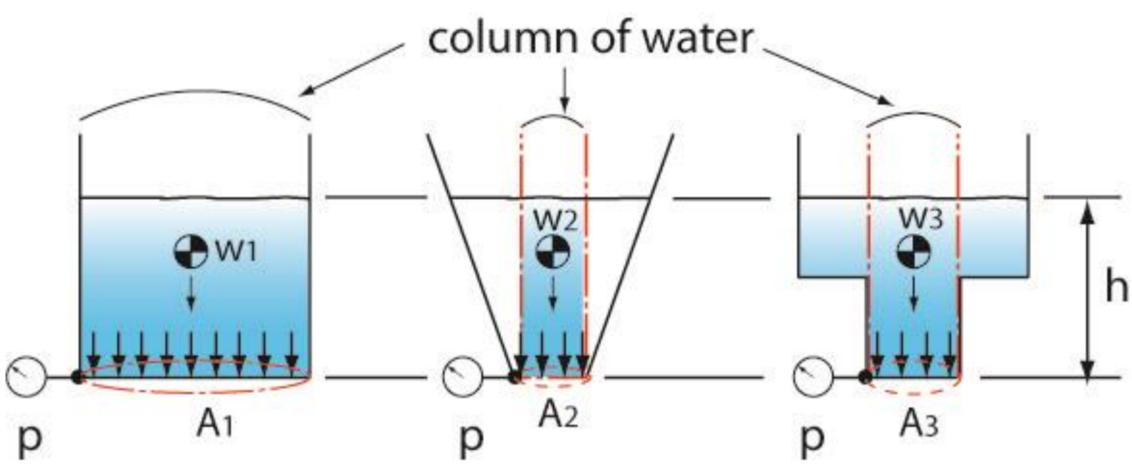
Could we have done these calculations using pressure units? The answer is yes because pressure is also a form of energy. In reality pressure is the bottom line, static head produces pressure, a pump produces pressure, and pressure is the driving force for liquid systems.

There is a relationship between head and pressure. It is based on the weight of water in a tank and the pressure that is created at the bottom.

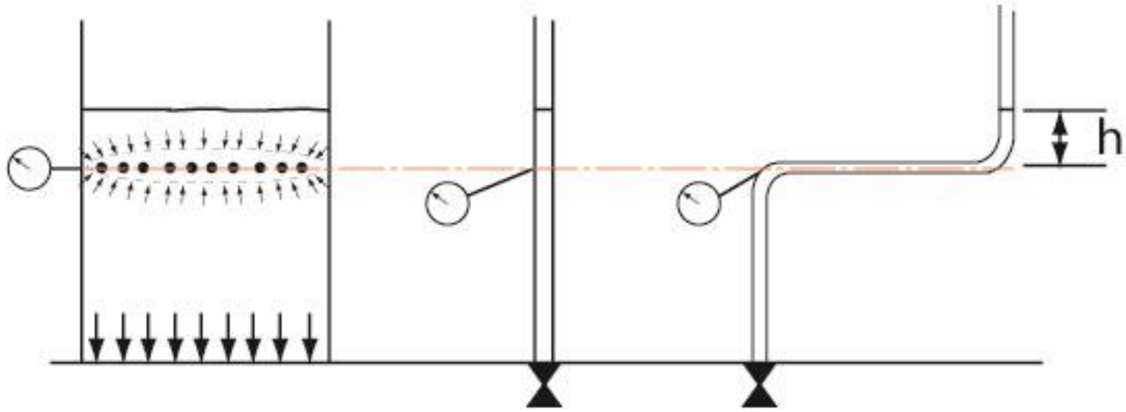
$$p\ (psi) = SG \times h\ (feet) / 2.31$$

2.31 is a conversion factor that allows h to be expressed in feet and p in psi, SG is the specific gravity of the liquid, for water SG = 1.

No matter the tank shape you will get the same pressure for the same height of water above the surface where pressure is measured, seems counter-intuitive since the bigger tank having the larger volume should produce more pressure. The column of water above each bottom surface is a different size, therefore a different weight, when the surface is smaller the weight is smaller and the reverse is true for the bigger surface but the pressure will be the same since p = w/A. If you are interested in the proof see this article www.pumpfundamentals.com/pressure_or_head.htm, it's not complicated but I just don't want to clutter up this discussion.

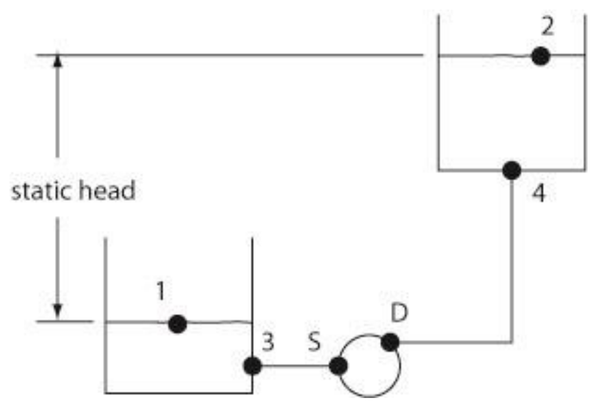


What this tells us is no matter what size reservoirs we have in our system we can always find the pressure if we know the liquid level height. It also works for pipes no matter what pipe size we have we can always find the pressure at a given point if we know the height of water above it assuming a static system or no flow.



In a tank it seems obvious that all liquid particles on the same level will be under the same pressure. The same is true in a pipe and there can be long horizontal distances before going vertical. This means that in a piping system from a static head point of view we can ignore horizontal distances. That's not true when we introduce flow and friction, we will need extra pressure to counteract friction.

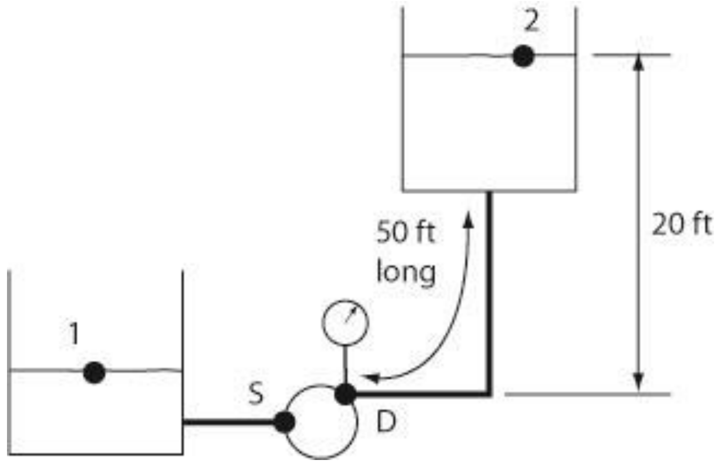
Many pump applications involve transferring liquid from one level to another. By looking at the rating of the pump we can quickly compare it to the requirements of the intended application. If the pump has a rating of 10 gpm at 70 ft assuming that's the flow rate we require the pump will produce 70 feet of head. This means that the static head must be less because a portion of the pump head is required to overcome friction. Therefore if the static head is close to the rated head we know immediately that that the system will not work as intended.



That's quite useful and the pump manufacturers have been using this for a long time but it appears to be a curious practice when you first encounter it. Why not use pressure as the main criteria? After all, pressure is easy to measure; all you have to do is install a pressure gauge at the location of interest. Also pressure is really the fundamental characteristic we are interested in, a pump is a device that produces pressure, no pressure no flow.

Let's take a look at a simple system. We might be interested in the pressure at many points. The pressure at point 3 will help calculate the pressure at point S the pump suction, the pressure at point 4 helps get the pressure at point D the pump discharge.

Let's concentrate on calculating the pressure at points S and D within our system.



The pressure at point D will depend on 2 things, the weight of water above point D and the friction due to flow between points D and 2. We don't need to calculate the weight of water above point D since we have just said that the pressure will depend on the height of water above D.

$$p_w = 20 / 2.31 = 8.6 \ psig$$

$$P_D = p_w + P_f$$

where P_D is the pressure to be calculated, p_W is the pressure due to the weight of water known as the static pressure and p_f is the pressure required to overcome friction. The static pressure at D is the pressure we would measure if the pump were stopped and if we had a closed valve on the suction to keep the system from draining.

The pressure required to overcome friction p_f will depend on the velocity in the pipe which depends on the diameter and the flow rate, the viscosity of the liquid and length of pipe horizontal or vertical. There are tables available that provide this value depending on the diameter and velocity in the pipe most often using water since it is so common. Here is a typical table.

Ingersoll-Dresser Pumps Cameron Hydraulic Data

Friction of Water New Steel Pipe *(Continued)*

(Based on Darcy's Formula)

1 Inch

Flow U S gal per min	Standard wt steel—sch 40			Extra strong steel—sch 80			Schedule 160 steel		
	1.049" inside dia			.957" inside dia			.815" inside dia		
	Velocity ft per sec	Velocity head ft	**Head loss ft per 100 ft**	Velocity ft per sec	Velocity head ft	**Head loss ft per 100 ft**	Velocity ft per sec	Velocity head ft	**Head loss ft per 100 ft**
2	0.74	.009	**.385**	.89	.01	**.599**	1.23	.023	**1.26**
3	1.11	.019	**.787**	1.34	.03	**1.19**	1.85	.053	**2.60**
4	1.48	.034	**1.270**	1.79	.05	**1.99**	2.46	.094	**4.40**
5	1.86	.054	**1.90**	2.23	.08	**2.99**	3.08	.147	**6.63**
6	2.23	.077	**2.65**	2.68	.11	**4.17**	3.69	.211	**9.30**
8	2.97	.137	**4.50**	3.57	.20	**7.11**	4.92	.376	**15.9**
10	3.71	.214	**6.81**	4.46	.31	**10.8**	6.15	.587	**24.3**
12	4.45	.308	**9.58**	5.36	.45	**15.2**	7.38	.845	**34.4**
14	5.20	.420	**12.8**	6.25	.61	**20.4**	8.61	1.15	**46.2**
16	5.94	.548	**16.5**	7.14	.79	**26.3**	9.84	1.50	**59.7**
18	6.68	.694	**20.6**	8.03	1.00	**32.9**	11.07	1.90	**74.9**
20	7.42	.857	**25.2**	8.92	1.24	**40.3**	12.30	2.35	**91.8**
22	8.17	1.036	**30.3**	9.82	1.50	**48.4**	13.53	2.84	**110**
24	8.91	1.23	**35.8**	10.7	1.8	**57.2**	14.76	3.38	**131**
26	9.65	1.45	**41.7**	11.6	2.1	**66.8**	15.99	3.97	**153**
28	10.39	1.68	**48.1**	12.5	2.4	**77.1**			
30	11.1	1.93	**55.0**	13.4	2.8	**88.2**			
35	13.0	2.62	**74.1**	15.6	3.8	**119**			
40	14.8	3.43	**96.1**	17.9	5.0	**154**			
45	16.7	4.33	**121**	20.1	6.3	**194**			

There are other methods to determine friction which you will find on this web site www.pumpfundamentals.com.

According to the table above for a flow of 10 gpm in a 1 in diameter pipe the friction head is 6.81 ft per 100 ft of pipe, for a pipe length of 50 feet the friction will be 6.81 x 50 / 100 = 3.4 feet of head. We convert head to pressure: 3.4 / 2.31 = 1.5 psig

The pressure at D is then

$$p = 8.6 + 1.5 = 10.1 \text{ psi}$$

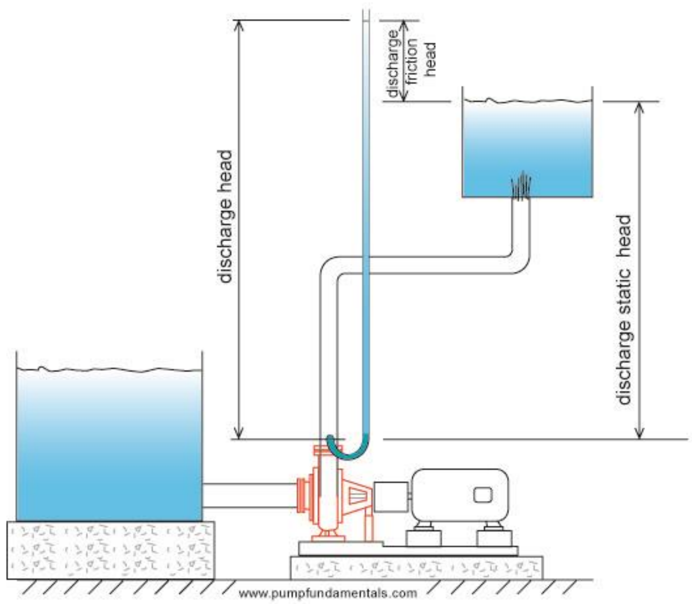
We use the same approach to calculate the pressure at point S using the static head for the suction side and the friction loss for the pump suction pipe.

We now subtract the pressure at S from D and this provides the differential pressure that the pump must supply at the flow rate that we require. We convert this differential pressure to head because the pump manufacturer uses head as a characteristic unit so this is the differential head of the pump, often called total head or total dynamic head.

If we do it the other way, only using head units, we have no conversions to do and we arrive at the result quicker.

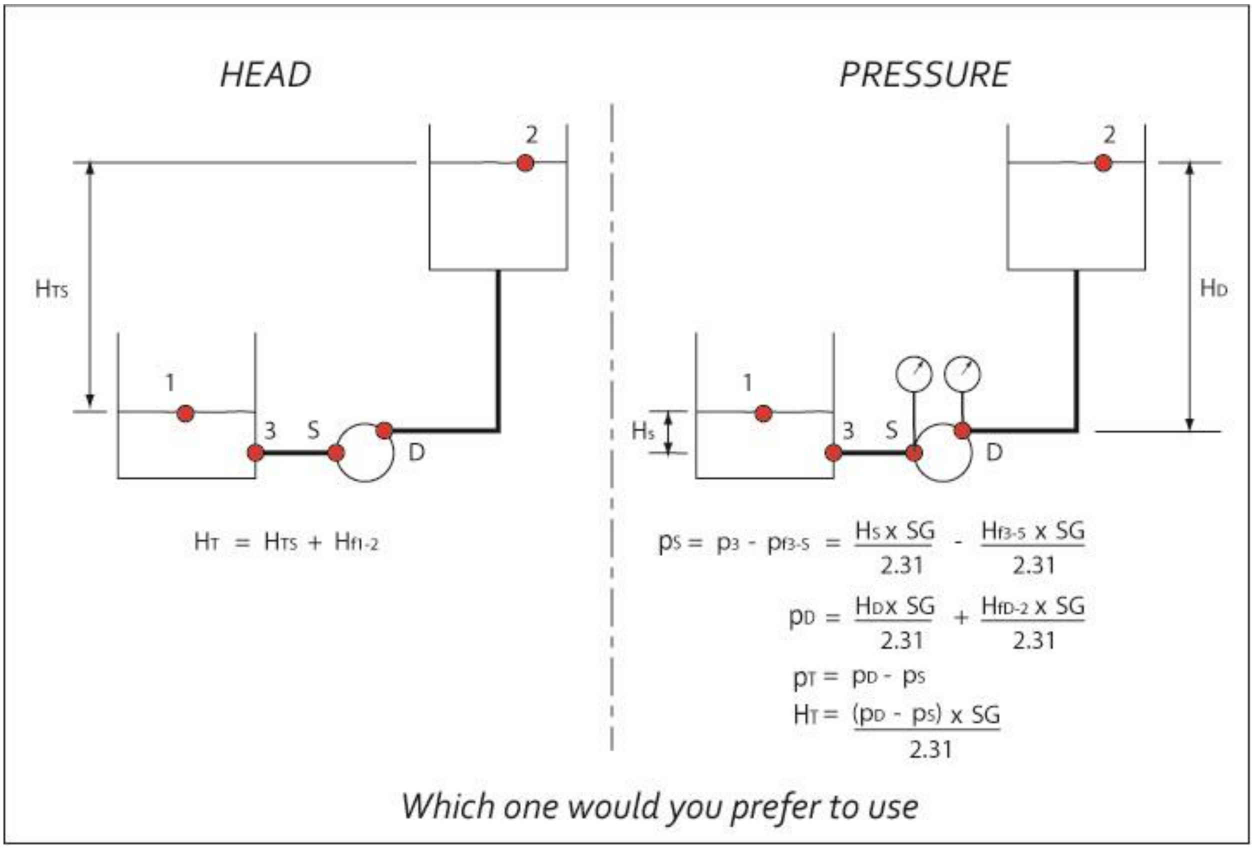
In what situation is a pressure measurement or calculation essential? When the system is running. We can measure static head and convert it to pressure any time we want either measurement is sufficient, but when the system is running the component of friction loss can only be measured by a pressure gauge. Well, that not strictly true but it is the easiest way to do it.

Consider this approach:



If we install a vertical tube on the discharge side of the pump, the water column that we will measure will correspond to the static discharge head plus the friction head. But as you can see it would be easier to install a pressure gauge.

Now we can reveal what lies behind the curtain, pressure is the true hero of this story; it is the physical force that moves liquids through a system. Head is its partner providing a valuable shortcut.


HEAD
PRESSURE
2
HTS
1
3
S
D
HT = HTS + Hf1-2
2
HD
1
HS
3
S
D
pS = p3 - pf3-S = HS x SG / 2.31 - Hf3-S x SG / 2.31
pD = HD x SG / 2.31 + HfD-2 x SG / 2.31
pT = pD - pS
HT = (pD - pS) x SG / 2.31
Which one would you prefer to use