Basic Principles and Calculations in Chemical Engineering
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Module – 2: Process Variables and Rate
Lecture – 2.2
Pressure and Temperature
of Flow Process

Welcome to massive open online course on Basic Principles and Calculations in Chemical Engineering. So, we are discussing about process variables and rate under module 2. So under this module 2, today we will discuss more about the process variables like pressure and temperature of flow processes.

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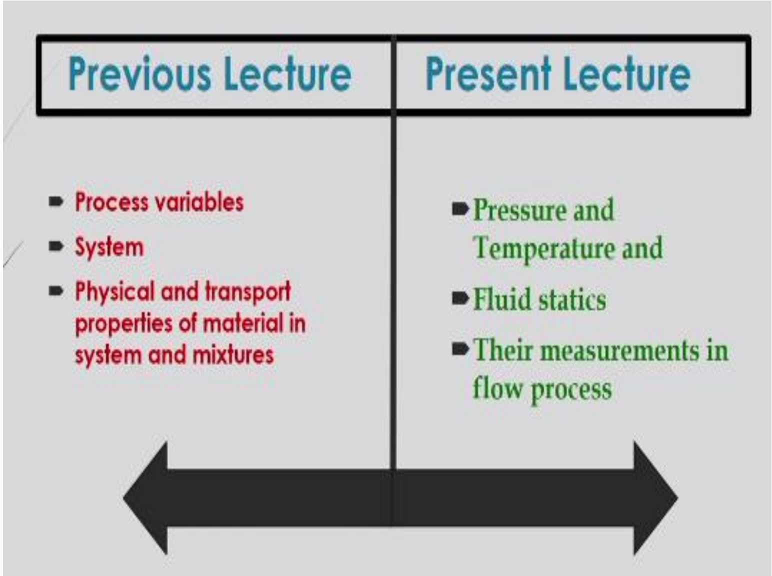

We have discussed in the previous lectures some process variables and their principles about a system, even physical and transport properties of material in system and mixtures. So, in this lecture, extension of that part will something more about that process variables like pressure and temperature, fluid statics and their measurement in flow processes, we will try to learn something about this.

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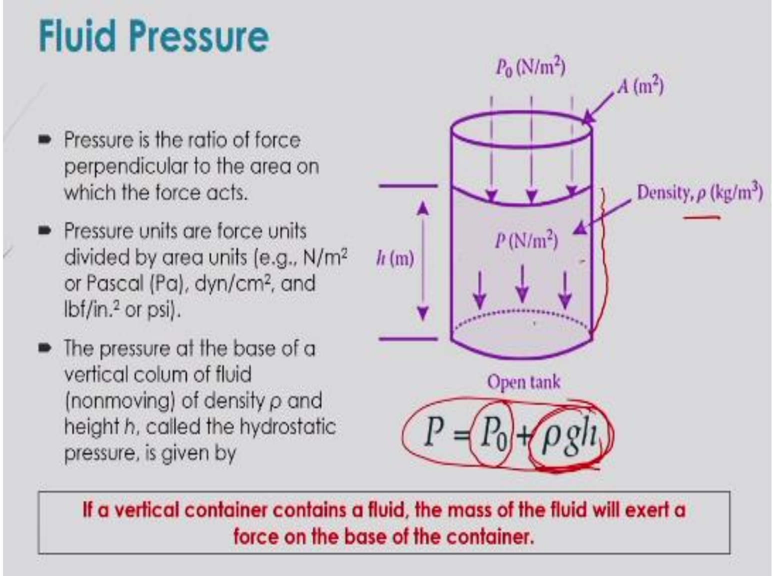

Now, the pressure at the base of a vertical column of fluid that is not moving and whose density will have a certain value and if it is denoted by rho and the fluid height is h, then this pressure exerted by this particular height of this liquid in the container of that particular density, it will be regarded as hydrostatic pressure and it can be defined as this rho gh. So, here see in this figure in the slide to see that in a container some amount of fluid whose density is rho is kept there.

Here you will see that this amount of fluid will exert pressure at the bottom of this container even at its wall of this container at a certain value. Now, this pressure you will see that will be equal to rho gh, it is called hydrostatic pressure. That means, what will be the length of this or height of this fluid that shows by this fluid or liquid in the container and also what would be the density of the fluid if you know that, then you can easily calculate what should be the hydrostatic pressure, but this total pressure will be what you will see at the surface of this container.

Some atmospheric pressure will be acting on this container and this atmospheric pressure if you add on this hydrostatic pressure, it will be total pressure that is acting on this bottom of this container there. So, it will be regarded as total pressure here. So, this total pressure is here this atmospheric pressure and the hydrostatic pressure. So, this atmospheric pressure is represented by P0 as shown here and hydrostatic pressure will be equal to rho gh, though the summation of this atmospheric pressure and hydrostatic pressure will be total pressure that is exerted by the fluid and atmosphere on this bottom of this container.

So, we can say that if a vertical container contains a fluid, the mass of the fluid will exert a force on the base of the container. So, this is the basic of this hydrostatic pressure whenever fluid will be kept in a certain container and what will be the pressure exerted by the total mass of this fluid that you can get by this hydrostatic pressure.

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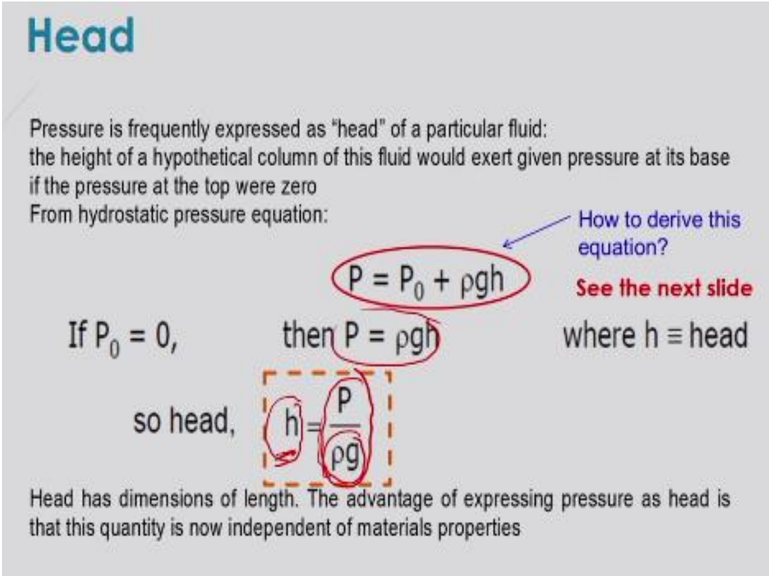

Now, interesting is that sometimes this pressure will be represented by head because it will be sometimes regarded as what is that length of the fluid there and by which the hydrostatic pressure will be sometimes will be represented. Now, in this case the height of a hypothetical column of this fluid if it exert certain pressure at its base and if the pressure at the top will be 0, then from that hydrostatic pressure equation you can say that it will be simply P is equal to rho gh. So, here this rho gh from this equation we can say that here h will be equal to P by rho g. So, this h will be called as head.

So, pressure is sometimes regarded by this head and its unit will be equal to unit of the length because this is simply height, but this height you can get it from this equation because P is, what is that unit for P is Newton per meter square whereas you will get that this rho gh unit will be equal to what? So, accordingly after banishing that equation and also unit, so finally you will get that unit of this head will be h or length or you can say that meter there. So, the advantage of expressing this pressure as a head is that this quantity is now independent of the material property.

So, that is why sometimes the pressure is represented by head and now important thing is that what we told that there will be some hydrostatic pressure on the fluid element. Now, what should be the pressure if you have the certain distance or certain height of that liquid, you can easily calculate this hydrostatic pressure, but sometimes you see that you need to express this hydrostatic pressure in more general format.

How to derive this hydrostatic pressure that you can have from consideration of certain fluid element that is kept in a container or if it is flowing through the conduit, then from that fluid element, we can easily derive some expression of this pressure within a static fluid element.

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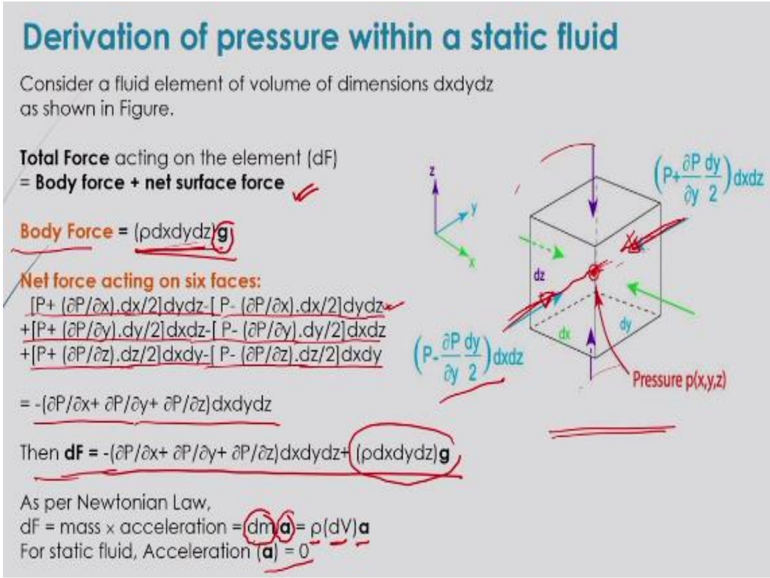

So, in this case if we consider that a fluid element of volume of dimensions like here x, y and z and its volume will be as you know dx into dy into dz. So, in this case here if you consider this fluid development here as shown in the figure in this slide, you will see that the pressure P will be acting at the center of this fluid element and it will have 6 faces and on all these 6 faces, the pressure will be acting from all its directions.

So, you will see that if we consider that x, y and z direction, now if you consider this the element of this volume of dimensions like dx, dy and dz in x, y and z direction, then we will get or we can consider that there will be 6 faces, now on each face what should be the pressure that is exerted from surrounding fluid. So, in that case, we can express this total force that is acting on the element will be actually as dF, then this dF means here a a small amount of portion will be acting over this small volume of fluid element that we consider here.

So, total force acting on the element will be dF. Now, this dF actually will be sum of the body force and what will be the net surface force acting over this small fluid element. So, this small fluid element will have some body force that will be regarded as gravity force. So, this body force and what will be the total force acting over the surface of this fluid element that will be as net surface force because here 2 forces will be subjected to the pressure from the opposite direction here in this fluid element like in the x direction.

If you consider that, in this direction the force will be acting and from this direction also force will be acting. Now, since this force will be acting in the opposite direction, then there will be some net force will be acting on this let us say x direction. So, what should be the net surface force that you have to calculate. So, what should be the first you have to calculate the body force. The body force will be equal to what, we know that gravity force that will be called to m into z. So, what is m here, since we are considering the fluid element volume dx, dy and dz, this is volume.

So, if you know the density of the fluid, what should be the mass. So, volume into density that will be your mass. So, you know the density is rho and volume is dx, dy and dz. So, we can write rho into dx, dy and dz here. So, this will be your mass and if you multiply this mass with this gravitational acceleration, then you can say it will be your body force. Then you have to calculate what should be the net surface force acting on 6 faces. Now, first you considered in x direction. So, what will be the force acting on this face here as shown in the figure.

So, that will be your what is that P plus dou P dou x into dx by 2 into dydz. Why it is coming like this, you know that forces acting at the center as P whereas you will see that since this face here this what face we can say here, this is simply that here dy and dz, dydz. So, this face will be at a distance of dx, so what will be the pressure gradient there at this face here. So, it will be dou P by dou x. Now, since this pressure gradient will be at a length of dx by 2, why dx by 2 because from this face to this face, total distance is x.

So here since from the center to this face is dx by 2 distance, then we can have this distance as dx by 2. Now, if you multiply this pressure gradient over this dx by 2 distance, then we can have pressure difference over this dx by 2. So, this pressure difference will give you that what would be the pressure at the surface there. So, this at the surface in the positive x direction, we can easily say that at this point what is the pressure and at the surface what would be the pressure there. So, it will be P + dou P dou y into dou y by 2 into dxdz.

So, in this way, we can calculate what should be the net force here, only that you have to calculate first in this positive direction what would be the pressure and in the negative direction in the same way what should be the pressure there. So, if you subtract these positive two here this side of pressure then you can easily express by this equation here. So, this will be your in the x direction. Similarly, you know that dxdz front or face, you can express the pressure like this here.

Similarly, in this dxdy plane or face, you can express what would be the net force over there. So, if you add all those net force acting on these 6 faces, then you can get here this equation minus dou P dou x + dou P dou y + dou P dou z into dxdydz. So, in this way, you can calculate what should be the net force acting on 6 faces. Now, substitution of this net force and the body force in this equation here of total force acting on the element that can be expressed then by this equation here. So, dF will be equal to minus dou P dou x + dou P by dou y and + dou P dou z into dxdydz + what is that, you know body forces there.

As per Newtonian law, we can see that this small amount of force that will be equal to mass into acceleration. So, if we consider that small amount of masses, you know that dm and its acceleration is a, this acceleration will be you know that in x direction, in y direction, and in z direction also. So, we can write here what will be the dm here, rho dV into a, rho is the density and dV is the small volume that is dxdydz and then rho into dV will be mass, then into a it will be acceleration.

So, it will be called as force as per Newton, then Newtonian law or you can see that as far Newton's law of force. They are so it will be mass into acceleration and for static fluid we can say that there will be no acceleration, so a will be is equal to 0. So, in this case, we can have this dF will be equal to 0.

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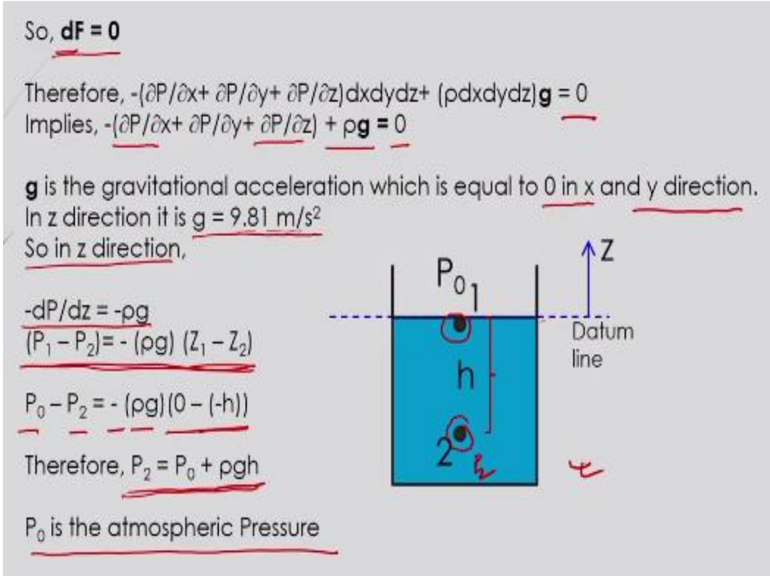

Therefore, if we substitute this dF here, this left hand side and that will be close to 0 by this equation. Then you can say that minus of here dou P dou x + dou P doy y + dou P dou z + rho g that will be equal to 0. In this case, g is gravitational acceleration. This acceleration will be acting you know that it is in general that g can be regarded a general here, but if it is working in vertical direction, then you have to consider it as gravitational acceleration. Otherwise, in either direction you have to consider a certain value of acceleration there other than gravitational acceleration.

Now, this g if we consider here, which is equal to 0 in x and y direction, that means in the x and y direction, there will be no acceleration since the fluid element is in static condition. So, in the z direction, we can say that that g will be equal to gravitational acceleration and this gravitational acceleration will be equal to 9.81 meter per second square. So, finally after substitution of this g in the z direction, we can easily say that minus dp dz that will be equal to minus rho g.

So, from these, we can say that here P1 minus P2 that will be equal to minus rho g into Z1 minus Z2. This Z1 minus Z1 is the distance between two points and P1 minus P2 will be is equal to pressure between two points. So, in this case as far figure shown here in the slides, if we consider the two points here on this fluid element at the surface, you will see that if we represent here or denote here as point 1 and at a depth h the point here 2, then you can say that at the point one you will get the pressure only atmospheric pressure or as at point two you will get the pressure here at a certain height of h.

That h will be equal to hydrostatic head, and based on these, you can express by this equation as P0 minus P2 because here at this point one pressure is P0 atmospheric pressure and at this point two pressure is here P2. So we can write here P0 minus P2 that will be equal to minus rho g into what is that, what is Z minus Z, Z1 minus Z2 here at this point one since we are considering datum line is at point one, so here distance is 0 and what is that, here h Z2, Z2 is basically since it is in that negative Z direction, it will be minus h.

So, 0 minus of minus h because Z2 here to be equal to minus h. So, ultimately we can say that this P2 minus P0 will be equal to rho gh. So this P2 will be equal to then P0 + rho gh. Now this P0 is the atmospheric pressure. So, in this way, we can derive these hydrostatic pressure based on the consideration of the small fluid element at its static condition in x, y and z directions and considering their forced acting on that fluid element from all the directions at a certain amount.

So, based on which we can derive like this what should be the hydrostatic pressure there and so we have got this very interesting equation here, this will be equal to P1 minus P2 that will be equal to minus rho g Z1 minus Z2. This you have to remember because this equation will be useful to estimate the pressure of the fluid flow whenever it will be flowing through the pipe or any other conduit or any other system or any other unit where you need to calculate, you have to estimate, you have to obtain the pressure between two points and this equation will be helpful to calculate.

So, we will give some example also there, how to calculate, how to use this equation to calculate the pressure there.

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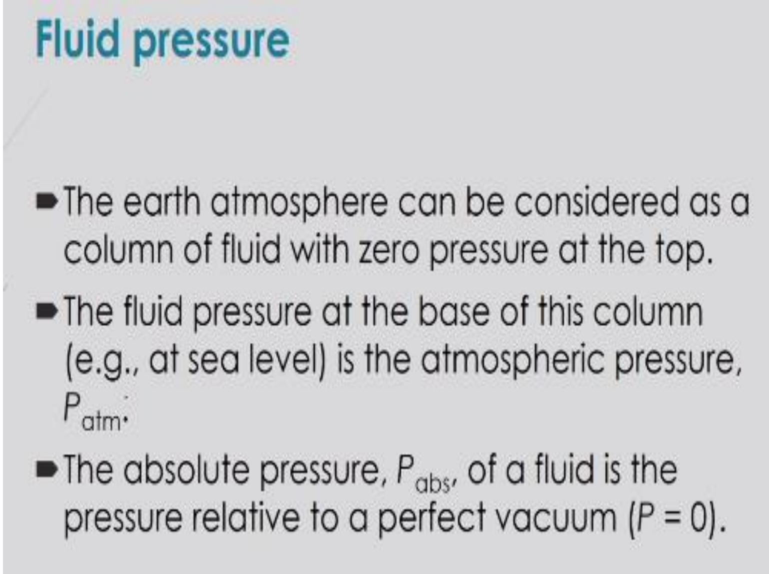

Now, the earth atmosphere can be considered as a column of fluid with 0 pressure at the top and the fluid pressure at the base of this column like at sea level is the atmospheric pressure that you have to consider and the absolute pressure of a f.uid is the pressure that is related to a perfect vacuum there that will be P is equal to 0.

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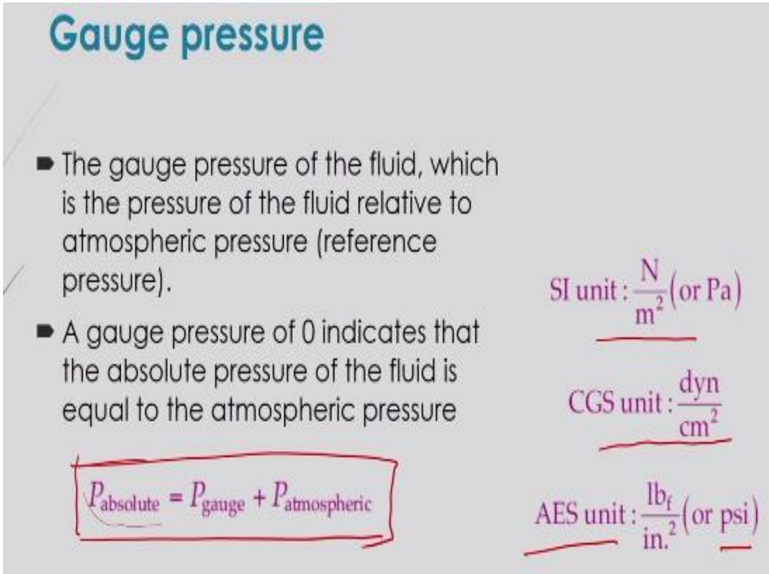

gauge pressure is basically that is pressure of the fluid, which is the pressure of the fluid relative to the atmospheric pressure, that is reference pressure. A gauge pressure of 0 indicates that the absolute pressure of the fluid is equal to the atmospheric pressure. So, you have to use this equation or remember this equation to calculate the absolute pressure. Basically whenever fluid will be flowing in a system and the pressure whatever it will be exerted without consideration of atmospheric pressure, it will be regarded as gauge pressure.

So, absolute pressure will be basically the gauge pressure plus atmospheric pressure. So, in this way you have to remember whereas gauge pressure will be what is your absolute pressure? If you subtract that what is that atmospheric pressure you will get the gauge pressure there. So, you have to remember this equation what will be the atmospheric pressure, atmospheric pressure will be equal to gauge pressure plus, sorry absolute pressure will be equal to gauge pressure plus atmospheric pressure.

What is the unit for pressure that we told Newton per meter square, in CCS unit it is dyne per centimeter square whereas in American engineering system, this unit will be psi, that means pound-force per inch square.

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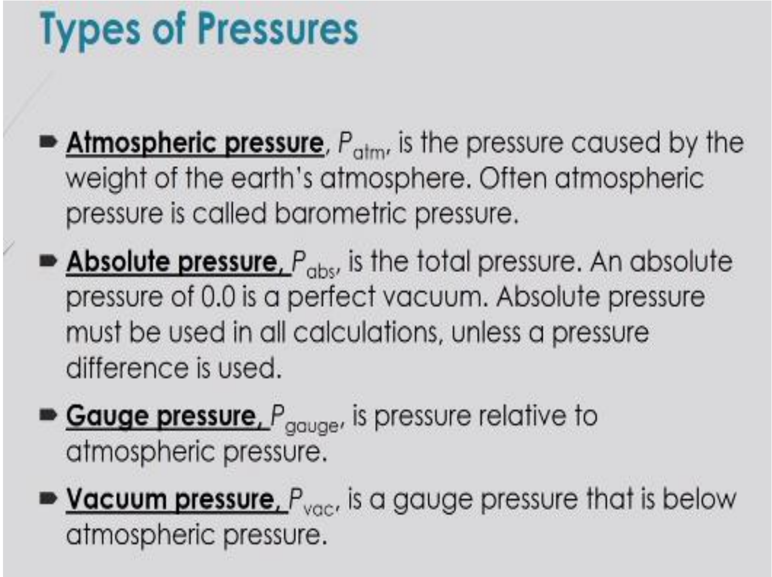

What are the different types of pressures atmospheric pressure, absolute pressure, gauge pressure, and vacuum pressure. Vacuum pressure is a gauge pressure that is below atmospheric pressure. Even other than these pressures, you will have different types of pressure whenever fluid will be moving through a pipe or any other system, like you will see that whenever fluid will be flowing, the measurable pressure.

Total pressure will be actually summation of this hydrostatic pressure and frictional pressure and also if is there any pressure because of change of crosssectional area or any heat energy supply to the pipe or any other you know that force acting on this conduit or not, like magnetic force, electrical force, or some other force or if any change of momentum is there inside the pipe or any system there.

So, in that case, the total pressure will be equal to able to pressure due to friction, pressure due to hydrostatic pressure, and pressure due to the change of momentum or pressure because of other exerting force on the system. So, these are the various types of pressure that you have to remember.

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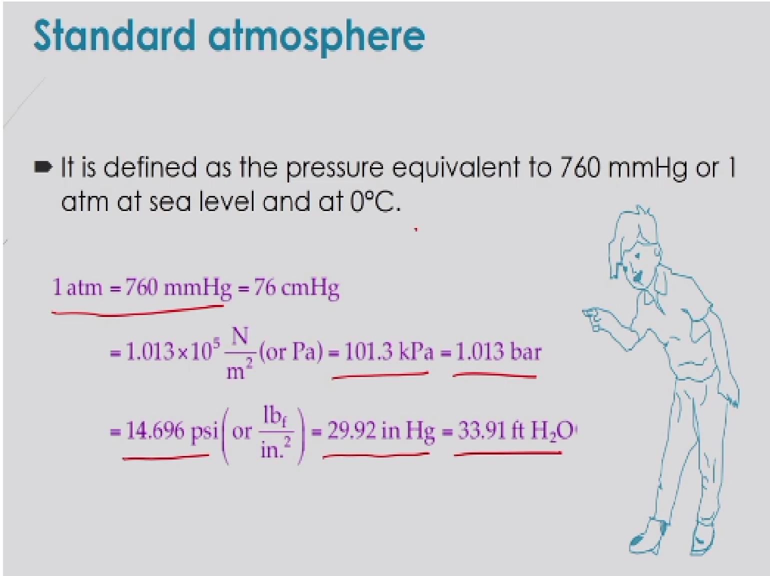

You have to know also what is the standard atmospheric pressure. It is defined as the pressure that is equivalent to 760 millimeter mercury or 1 atmosphere at sea level and at 0 degrees centigrade. So, this you have to remember. So, in this case 1 atmosphere will be is equal to what is the 760 millimeter mercury. That means, in a column if you take mercury and you will see what will be the pressure if you take that mercury of length of 760 millimeter length.

So, in that case, what will be the two amount of hydrostatic pressure because of that mercury, it will be actually equivalent to the atmospheric pressure. So, it is actually after calculation because here you know that it will be again that rho g into h, rho of mercury, density of mercury will be 13,600 kg per meter cube, g is 9.81 and you know that h is here, it is 766 millimeter, you have to convert it to meter, that means what is that seven pint six zero 7.60.

In that case, you will see that centimeter sometimes it will be represented as 76 centimeter mercury and you have to convert it to meter like 0.760 meter. Then if you multiply that you know density like 13,600 into 9.81 into 0.760, then you will get that atmospheric pressure as like this 1.013 into 10 to the power 5 that will be equal to Newton per meter square. So, it is regarded as what is that Pascal's also. So, it will be 101.3 kilopascal just divided by 1000, then you will get.

Even this will be regarded as also bar like 1 into 10 to 1.013 into 10 to the power 5 Pascal it will be called as 1.013 bar. Similarly, this standard pressure can be represented by AE system it will be equivalent to 14.696 psi or you can say that is 14.7 psi. So, it also will be equivalent to 29.92 inch of mercury and also you can say that it is 33.91 feet of water column pressure there. So, in this way, we can represent that standard atmospheric pressure at different or by different units.

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Pressure Equivalent

mm Hg	in. Hg	bar	atm	kPa	psia
1	3.937×10^{-2}	1.333×10^{-3}	1.316×10^{-3}	0.1333	1.934×10^{-2}
25.40	1	3.386×10^{1}	3.342×10^{-2}	3.386	0.4912
750.06	29.53	1	0.9869	100.0	1.415×10^{-3}
760.0	29.92	1.013	1	101.3	14.696
75.02	0.2954	1.000×10^{-2}	9.872×10^{-3}	1	0.1451
51.71	2.036	6.893×10^{-2}	6.805×10^{-2}	6.893	1

Now, there are some conversions of pressure from one system to another system. It is given in this stable in the slide, you can go through this conversion. This conversion table may be useful for your further calculation.

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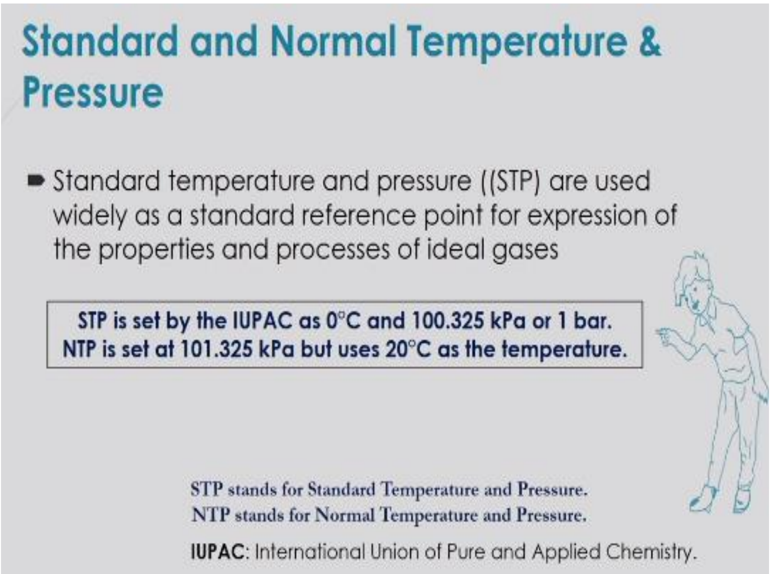

Now, standard normal temperature and pressure, what is that also you also have to know that standard temperature and pressure are used widely as a standard reference point for expression of the properties and processes of ideal gases. So, in that case, STP set by IUPAC at 0 degrees centigrade and 100.325 kilopascal or 1 bar. This is STP means standard temperature and pressure, whereas NTP is another condition it is called normal temperature and pressure.

It is set at generally 101.325 kilopascal, but the temperature will not be 0 degree centigrade, whereas it will be 20 degrees centigrade there. So, there is a difference of this STP and NTP is that pressure will be same but temperature will be different. In case of STP, the temperature will be 0 degree centigrade whereas in case of NTP, the temperature will be 0 to 20 degree centigrade.

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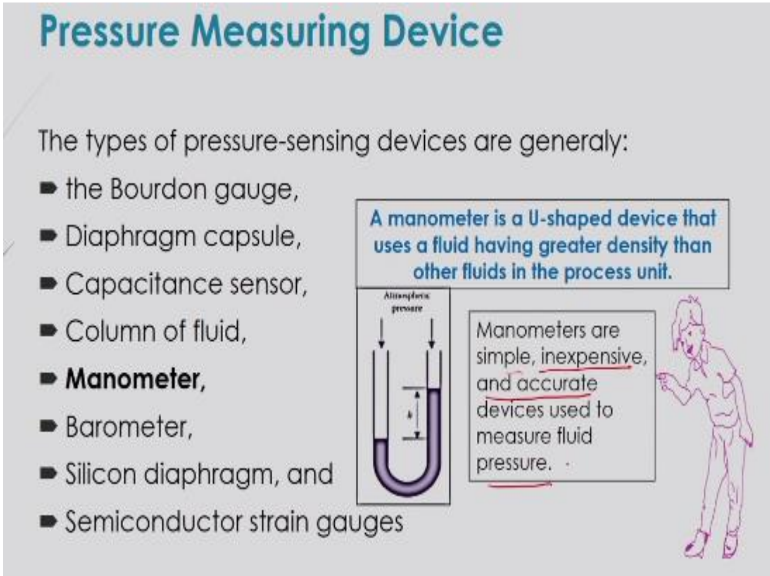

and Also you can say that this pressure whatever we are getting that standard pressure or pressure in a particular system how to measure that pressure. There are various types of pressure sensing devices are available to estimate the pressure or measure the pressure whenever fluid will be flowing through the pipe or through the other systems there. Like here the Bourdon gauge, diaphragm capsule, capacitance sensor, column of fluid, manometer, barometer, silicon diaphragm and semiconductor strain gauges are used to measure the pressure.

In laboratory scale even most of the manometer is a U shaped device that are are used to measure fluid pressure there in the system.

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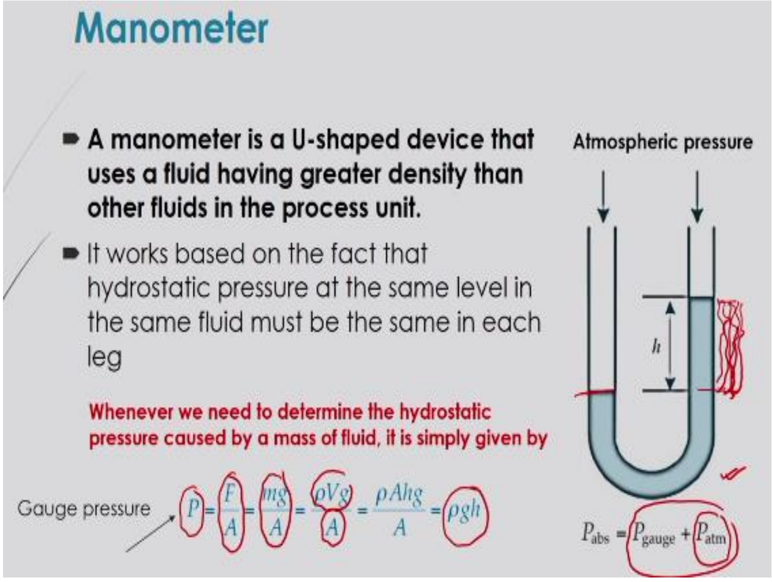

So, this manometer is a U-shaped device that uses a fluid having greater density than other fluids in the process unit. So, this is very useful and these manometers are actually inexpensive and simple and also it will give you that accurate measurement. These are basically used to measure the fluid pressure in the system and also we can say that there will be certain principle of the manometer by which you can calculate the pressure. So, there how it works that manometer there in the fluid system to get the pressure from this manometer that you have to know.

So, a manometer is a U-shaped device that I told that is being used for measuring that fluid pressure and in this case whatever fluid is being used generally it will higher density relative to the fluid that is flowing through the system and it works based on the fact that hydrostatic pressure at the same level in the same fluid must be same in each leg of this U-tube manometer. So, the schematic of the U-tube manometer is shown here in the slides.

It will have two legs, the left leg and right leg, you will see the U-tube manometer some fluid that will be higher in dense relative to other fluid that is flowing through the system and in this case this higher density fluid whenever pressure will be subjected on this manometer leg, you will see that the fluid will be moving up little bit and there will be a difference of this fluid level or you can say that liquid level inside that manometer and based on which you can calculate what should be the hydrostatic pressure exerted by that fluid in the system.

So, whenever we need to determine the hydrostatic pressure that is caused by a mass of fluid, it is simply given by gauge pressure that will be as P that is F by A that mg by A, that is mg means rho Vg by A, rho is the density, V is the volume, and g is the gravitational acceleration, A is the crosssectional area and then you can say that rho into A into h here as shown in figure here. Suppose this right leg of this fluid will be above this level of initial left leg level.

So, what should be that force exerted by that liquid that is shown in within this length of h there. So, here in this case, we can say that it will be rho into A into h into g by A. So, it will be simply rho into g into h. So, here absolute pressure will be equal to this gauge pressure plus atmospheric pressure. So, whatever hydrostatic pressure will be based on this small h of this fluid element it will be regarded as gauge pressure, whereas on this gauge pressure there will be extra pressure that is atmospheric pressure will be acting on that on the surface then to be that atmospheric pressure. Now, sum of this gauge pressure and atmospheric pressure will be equal to absolute pressure.

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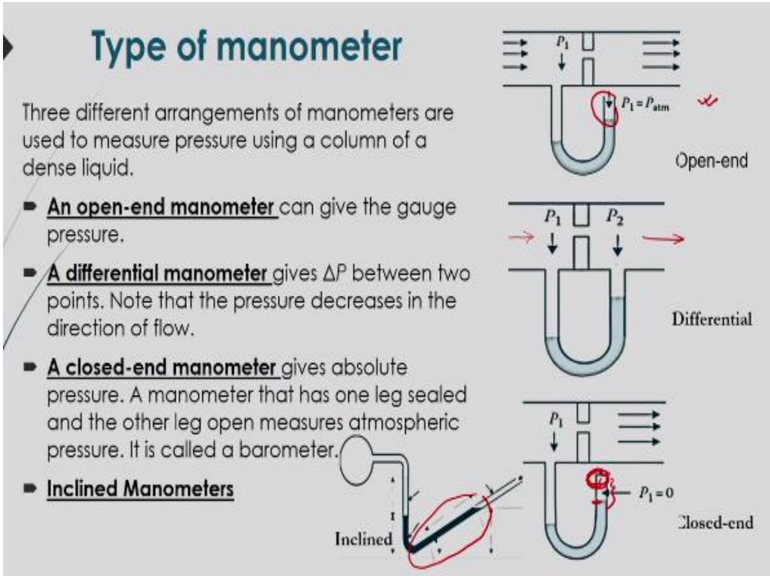

There are various types of manometers are generally used to estimate the pressure. Basically 3 different arrangements of the manometers are actually, used to measure this pressure using a column of a dense liquid. One is open-end manometer as shown here. In this case, the one end of the leg, that is you can see this is manometer, so one end of this manometer will be open, that is why it is called open-end manometer and another is differential manometer. In this case, both the leg will be connected to the process system or like if there is a fluid is flowing through the pipe.

Then at the two point 1 and 2, this manometer leg will be connected. So, it will give you that pressure difference, that is why it is called the differential manometer. In this case, you have to remember that the pressure decreases in the direction of the flow. So, that is why if pressure is given like this at P1 and P2 at this point 1 and 2, you will see that at point 2,pressure will be lower whereas at point 1, pressure will be higher. So, that is why the pressure will decrease in the direction of the flow.

So, the pressure difference will be equal to P1 minus P2 or if you are considering that P2 minus P1, it will be as negative delta P or negative pressure difference. A closed-end manometer also used to actually calculate the absolute pressure. In this case, a manometer that has one leg sealed and the other leg open measures the atmospheric pressure So, in this case, very interesting that one leg sealed here like this and another leg that will be connected to the process system and it is called the barometer or something.

There in this case whenever there will be any seal of that, right leg there, so in between that denser liquid and that sealed end there will be an open space, not open space, it will be a space there, but there will be certain amount of gas may be present or may not be present. So, if there is no gas is present, the pressure will be 0, whereas if some gas will be there, there may be some pressure will be exerted by that space there that you have to consider. So, in this way, this closed-end manometer is also used to calculate the pressure difference.

Sometimes inclined manometers are also used to generally conventional installment of pressure measuring instrument as per condition of that process where have to be installed there. So, sometimes the inclined manometer are also used to calculate the pressure difference there. So, in this case also here, the same principles is being followed like hydrostatic pressure, but here the manometric height that will be actually be shown in here, in this case it will be inclined, but for the calculation you have to calculate what should be the vertical height of that just because of what is that inclined angle it will come.

Based on which that inclined angle, what will be the vertical height for that you have to calculate based on that angle, and based on this vertical height from its inclined leg, you have to calculate what should be the hydrostatic pressure and that pressure will be actually gauge pressure of your that system.

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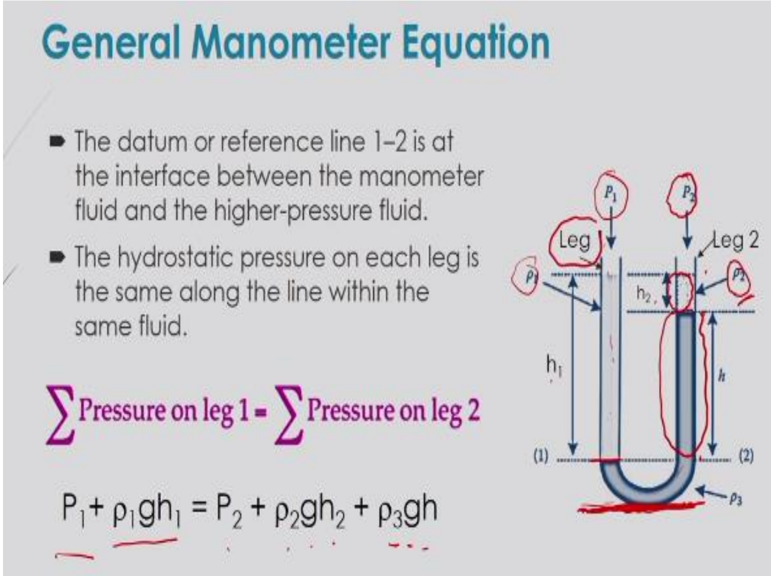

General manometer equation if we consider that what we have to remember for the balancing of that pressure on its both sides, you will see that one leg will be connected to the process system, another leg may not be there. So, in one leg whenever system will give you some pressure on that particular leg, so, there some force will be acting on that and because of which what will be the manometer fluid will be used that manometer fluid will be rise on that right leg of the manometer, and on that right leg if it is kept to open its end, then atmospheric pressure also will be acting on that open end surface of the manometric fluid.

So, in that case on the leg, there will be a force acting, but at a certain condition, this manometric fluid will remain static there because of that force balance. Now, from that static condition of that manometric fluid rise, from there are you can calculate what should be the pressure just by balancing that force acting over that manometric fluid on both sides. of the manometer leg. So, that is why you have to calculate what should be the pressure, summation of pressure on that leg one that is in the left leg and what would be the summation of pressure on leg two.

So, here shown in figure in the slide that here the leg 1, here this is leg 1, in the leg 1you will see that this is the fluid whose density is rho 1 that will be coming from the system maybe since it is connected to the process unit of the system and then this liquid will be as what is the manometric fluid, maybe higher density, that density is rho 3, that may be mercury and other part here to be some other fluid may be there. It may be the same of that left leg or maybe other fluid also, whatever it is, but its density will be certain there.

If it is not same from that left leg, then maybe other denser fluid like as density rho 2. So, at this leg, we are having what is that some P2 here, pressure due to that this fluid of rho 2 and the pressure due to this fluid rho 3, and at this leg, the left leg, leg 1, you will see that pressure will be exerted from that system and then pressure will be exerted by this fluid of density rho 1 and here also you will see that what would be the pressure at this point.

Now, very interesting point here that you have to some datum line at a particular datum line from which you have to calculate that summation of pressure on the left leg and summation of the pressure on the right leg of this manometer. So, that datum line or reference line is to be considered, otherwise it will be very difficult to calculate. You can decide that datum line anywhere in this manometer leg, maybe you can consider at the bottom of this manometer leg here itself.

See, I can show you like this, but you can conveniently decide this datum line here at this fluid interface of this manometric fluid and the other fluid inside the manometer. So, it will be better to consider the datum line here at this point or manometric fluid and other fluid give that interface. Otherwise, you can also try it, you will get the same results if you are considering the datum line at this bottom. So, from this bottom, you have to know what will be the distance there, that distance you have to calculate from this bottom line.

Now, if I consider that bottom line as shown here in the slide as dotted line like 1, 2 and what should be then total pressure at this bottom leg of this manometer. It will be here at this point here, this is P1 and the hydrostatic pressure that is exerted by the fluid of density rho 1 and its height is regarded as h1. So, its hydrostatic pressure will be rho 1 into g into h1. So, it will be your hydrostatic pressure that is exerted by fluid of density rho 1. Now, this is your up to this datum line, what would be the total pressure.

Now, if you consider the right leg of this manometer about this datum line, you will see that above this datum line, this manometric fluid is rised up to what is that h here. So, from this to this point the height is h, and from this to this point that height is h2 and above this h2, above this point, this pressure is P2. So, in this case, total pressure will be the summation of this P2 and pressure exerted by this fluid of rho 2 of height h2 and the pressure exerted by this manometric fluid of density rho 3 of height h.

So total pressure will be equal to P2 + rho 2 into g into h2 + here rho 3 into g into h. Now both the total pressure will be same at its static condition of this manometric fluid inside this manometer. So, from which you will be able to calculate what should be the pressure difference between P1 and P2. So, from this equation, we can say that P1 minus P2 will be is equal to here rho 2 g into h2 + rho 3 g into h minus rho 1 g into h1. So, in this way, you can calculate what should be the pressure between two points if this manometer is connected to a certain system.

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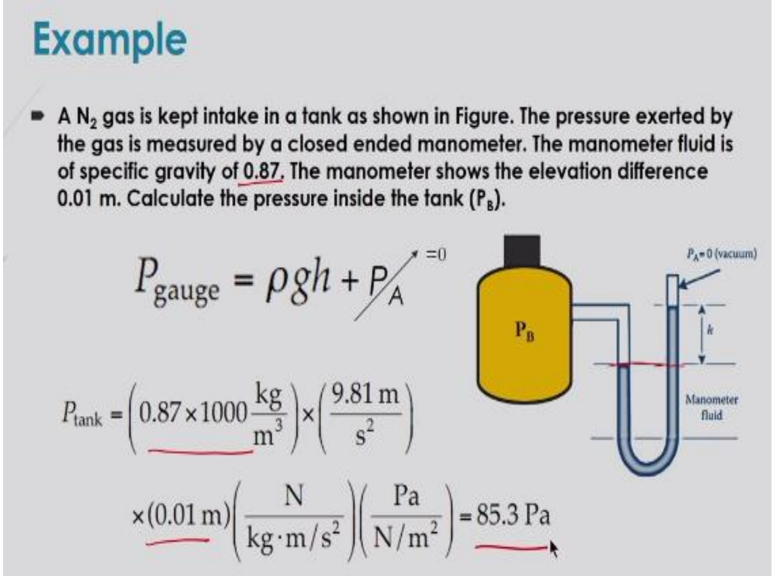

Like here one example is given to you, like a nitrogen gas is kept intact in a tank as shown in figure here. The pressure exerted by the gas is measured by a closed ended manometer. The manometer fluid is of specific gravity of 0.87. The manometer shows the elevation difference of 0.01 meter. So, in this case what should be the pressure inside the tank? Now, what you have to do, you have to calculate the gauge pressure inside the tank. Now, this gauge pressure will be is equal to what?

So, it will be is equal to that rho g into h that is given by this manometric fluid rised from this interface that is at h whereas inside this that manometric fluid, there will be a vacuum that will be PA will be equal to atmospheric pressure will be is equal to 0. So, that will be your tank pressure here. So, what will be that tank pressure here that will be is equal to 0.87 into 1000 into 9.81 okay because here h is given to you, you know that and also what is that specific gravity is given to you and also this gravitational acceleration is there.

So, what is that specific gravity is 0.87 if you multiply this specific gravity with the density of water, you will get the density of fluid of this manometric fluid and then g is there and height is given 0.01 meter. So, finally, it will be coming as 85.3 Pascal.

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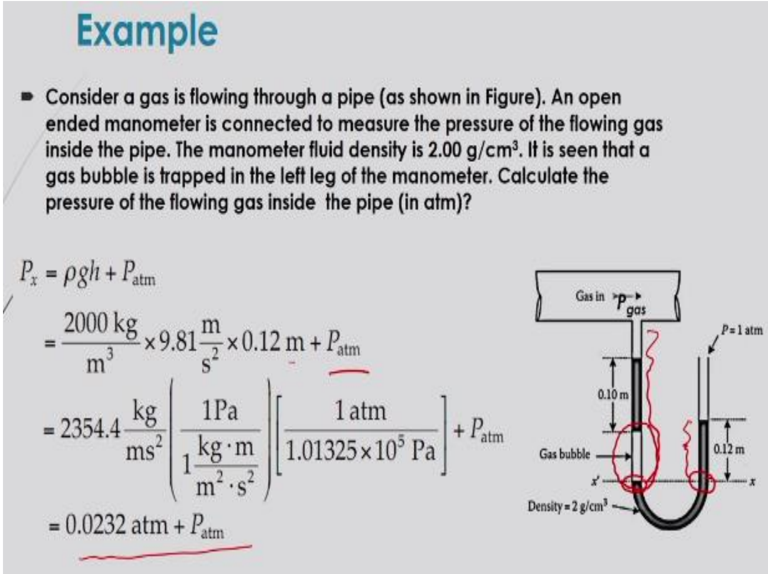

Then, another example. If suppose gas is flowing through a pipe as shown in the figure here in the slide. An open ended manometer is connected to measure the pressure of the flowing gas inside the pipe. The manometer fluid density is 2.0 gram per centimeter cube and it is seen that gas bubble is trapped in the left leg of the manometer here, gas bubble is trapped here. Now, in this case, you have to calculate the pressure of the flowing gas inside the pipe, how to calculate? So here very interesting that the manometric fluid will be there inside the manometer, but during that flow, some gas bubbles is trapped inside the manometer.

Now, because of this trapping of this gas bubble, there will be pressure whatever pressure will be exerted here that will be balanced by this here manometric fluid up to this rise. Now, if it is there, then how to calculate that pressure here? In this case, if we consider that the datum line as x dash x here at this interface. So, we can say that at the left leg, what should be the pressure that will be at x in the right leg that will be x as Px, Px will be is equal to what here, rho gh + atmosphere because this rise is given because of this what is that total pressure and this left leg and this pressure is coming because of this gas inside the pipe.

Now then, what will be the Px here at this that will be is equal to rho into g into h + this atmospheric pressure. So, rho is density that is given to you and g is given to 9.81 and h is

0.12 meter it is given to you and then atmospheric pressure you have to add. So, finally, you are getting 0.0232 atmosphere + P atmosphere, that is atmospheric pressure.

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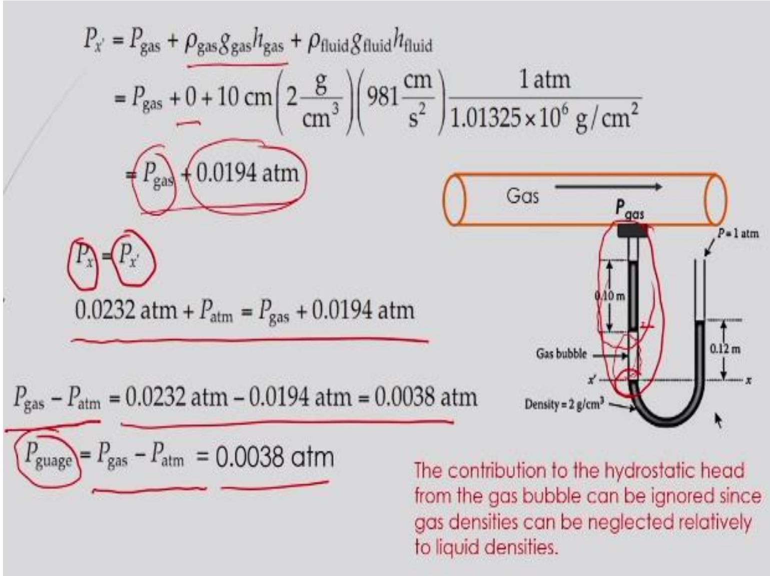

After that, you have to calculate what should be the pressure at that left leg of this manometer, that is at point x dash that is Px dash, it will be equal to here P gas + here P gas here and also what is that in this case gas rho gas into g as gas into h gas, this is also hydrostatic pressure because of this gas present here and also fluid like this here, this fluid, this is 0.10 meter here fluid, so in that case, rho fluid into g fluid into what is that h fluid you have to calculate.

So, finally, you can get that this P gas plus here at this condition, gas bubble, there is no pressure. Here also there will be no pressure. So, finally can say that this portion will be is equal to 0 or as here, since it is here what is that there will be manometry fluid here at a certain height of the 0.1 meter. So, you can calculate what would be the pressure there. So, it will be coming as P gas + 0.0194 atmosphere. So, finally, at the equilibrium condition, you can say that Px will be is equal to P dash.

So, if you substitute that Px and Px dash here, we can say that P gas minus P atmosphere that will be coming as 0.0038 atmosphere. So, finally, this will be regarded as gas pressure, if you subtract the atmosphere pressure from this absolute pressure, then you can calculate what should be that gas pressure, it will be P gas minus P atmosphere. So, it will be 0.0038 atmosphere. Now, the contribution to the hydrostatic head from the gas bubble can be ignored since gas densities can be neglected here relative to the liquid densities. So, that you have to remember.

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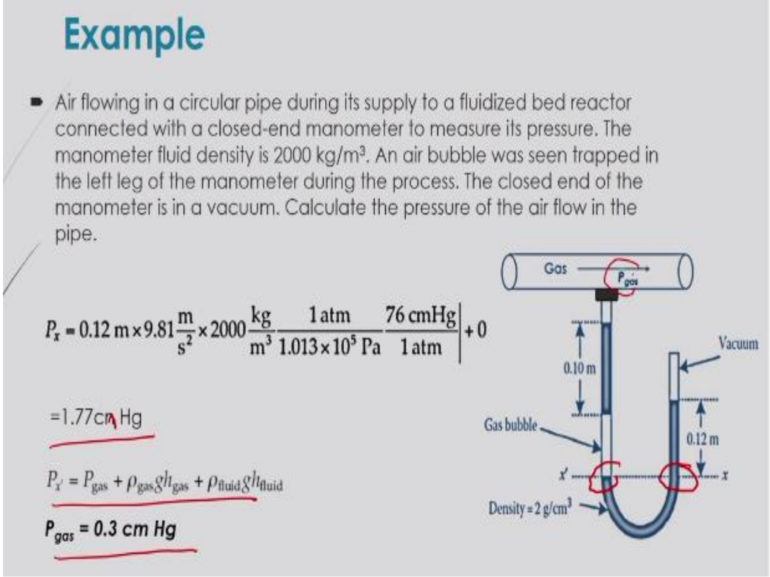

Another example is given here. Air is flowing in a circular pipe during its supply to a fluidized bed reactor connected with a closed end manometer to measure its pressure. The manometer fluid density is given to you. An air bubble was seen trapped in the left leg of the manometer during the process. The closed end of the manometer is in a vacuum. So, what should be the pressure of the air flow in the pipe. Similarly, you have to calculate the pressure at its x point and also pressure at its x dash point here.

So, similarly you can get that Px as 1.777 centimeter mercury, whereas Px dash you can get that here 0.3 centimeter mercury. So, after balancing these, you can easily calculate what should be the gas pressure inside the pipe.

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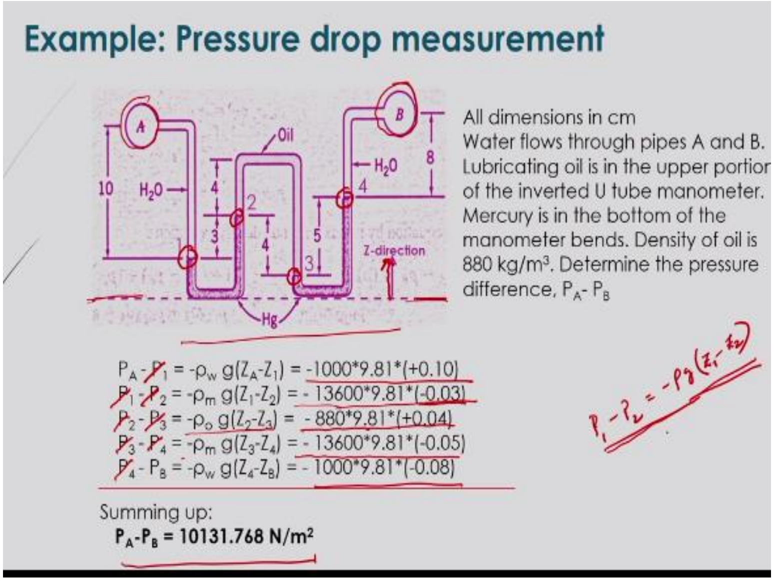

Another example where you will see that to measure the pressure drop if you are using multiple of fluid as well as you are using that manometer in different way, to design the manometer in different way, how to calculate that pressure drop measurement. Now, as shown in here in the figure, you will see that you have to measure the pressure between two points of pipe A and B and the manometer like this designed here as shown in figure. It is connected to this process unit at point A and B and you have to calculate what would be the pressure difference between A and B.

Now, in this case the manometer is filled with some portion is with water, some portion is with mercury, some portion will be filled with oil, and again some portion will be as mercury and water like this. So, here 3 different fluids are there inside the manometer. So, you have to calculate that pressure between A and B. Now, you have to use that general equation of that hydrostatic pressure that we know that P1 minus P2 that will be is equal to minus rho g into Z1 minus Z2. So, this is your general equation.

If you apply the general equation, you can easily calculate what should be the pressure difference between A and B. Now how to apply? Before going to apply these things you have to mark it out at different interfaces of the fluids inside the manometer, here like this, her, this is 1 that interface, this is regarded as 1. This is another interface, that is regarded as 2 and another interface 3 and like this another interface 4. So, after giving these marking up 1, 2, 3, 4, we have to calculate the pressure between these points like here if we consider first the point A and 1.

So, what should be the pressure between these two points A and 1? That means here, according to this hydrostatic equation, it will be PA minus P1, so for that minus rho into g into Z1 minus Z2, what would be that, here in this rho will be of water because this portion is filled with water. So, that is why minus rho w into g into ZA minus Z1. What is ZA, here we are taking the reference line or datum line from bottom of this manometer and the Z direction is upward direction, here this is positive direction.

So, if we consider that ZA minus Z1 it is simply what is the positive value. So, what is the length of that, it is given here 10 I think centimeter, so what would be the meter 0.10. So, finally after substitution of that water density and the gravitational acceleration and then finally we are getting this equation. Similarly, if you consider this point 1 and 2, then you will see that here density of the fluid will be mercury density like this rho m or else the distance between these 2 points here Z1 and Z2, in this case here see Z1 is lower point whereas Z2 is higher point in the positive Z direction.

So, here the difference will be negative. So, that is why it is coming as here in this case after substitution of density of mercury, gravitational acceleration and difference of Z1 minus Z2, it will be minus 0.03. Similarly, between you know 2 and 3, here again P2 minus P3, it will be like this, density will be of fluid oil. So, in that case here again after substitution here in this case Z2 minus Z3, it will be positive, so it will be +0.04. Similarly, for others P3 minus P4, it will be between 3 point and 4 point.

So, here it will be is s equal to again here density of the fluid will be of density of mercury. So, here after substitution of that and what will be the distance between that is given will be 0.05, but it will be negative because here 4 point is higher than that point 3 in the positive Z direction. Similarly, here P4 minus PB between this point 4 and B, it will be coming there. Here again, this fluid element will be only water, so because of that, you have to consider the density of water there.

So, finally, if you sum it up all those pressure differences at a different points, you will see that after summing up, here you see cancelling of this P1 P1 here and P2 P2 here, P3 P3, P4 P4. Finally, you are getting the PA minus PB, that will be exactly after calculating from this right hand side of this equation and summing up, you will get this 10131.768 Newton per meter square.

See how you know simple this calculation of the pressure drop from its system by using different design of that manometer by using multi-fluid inside the manometer, just by using simple hydrostatic equation of P1 minus P2 will be is equal to minus of rho g into Z1 minus Z2, this equation.

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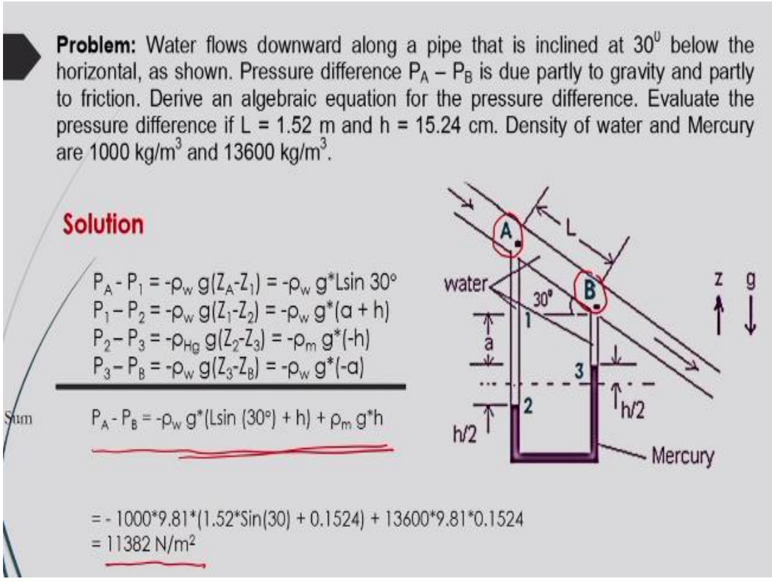

Another example here given if it is suppose inclined to you, also you can calculate, please go through the slides here also. In the same way, we have calculated that here what will be the pressure difference between A and B if the fluid is flowing through the inclined pipe up 30 degree angle there and the length between these 2 points is given as L and at different interfaces of the fluid whatever it is being given, the length is given there. So, finally, the same principle you can use in this problem to calculate the pressure differences as PA minus PB and you can get this equation and finally you can get this pressure difference here.

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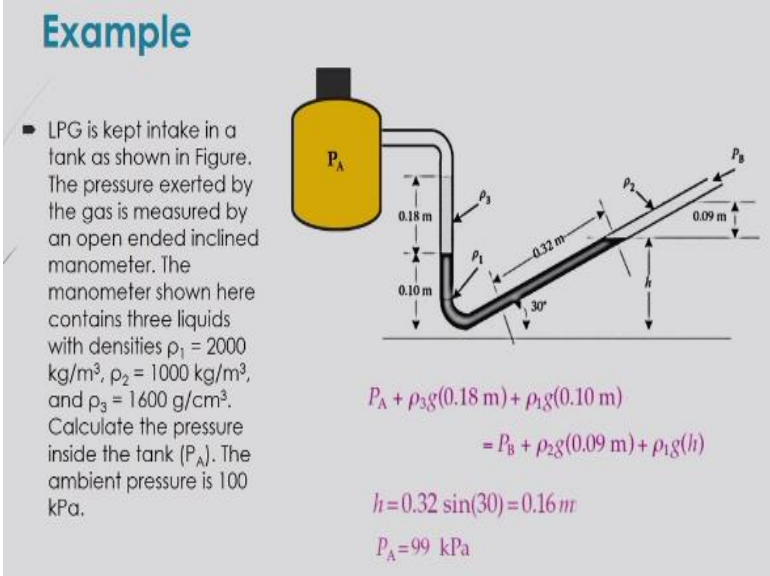

Similarly, another like LPG is kept intact in a tank as shown in a figure here. So, what should be the pressure exerted if you are using that inclined manometer. Here also same way you have to calculate, but only thing is that height will be considered as what is that height here from the inclined length that you have to calculate. So, accordingly you can get the pressure difference.

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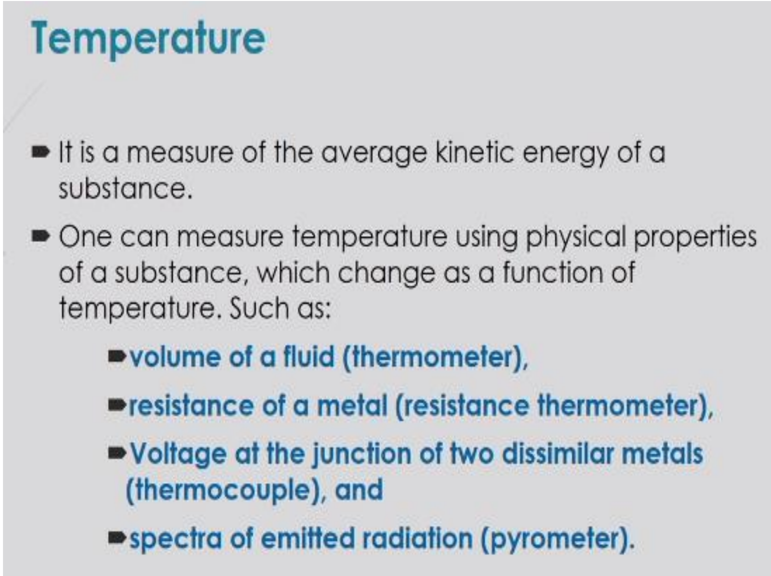

Now temperature. You know that for the process analysis, temperature is one of the important variables because this temperatures of course will influences that reaction, even other processes, even physical separation process, reactive separation process, even many chemical engineering operations, those are actually depending on the temperature. So that you have to know the temperature, how the temperatures will be distributed, even how the temperature will be measured, and also what are the different units that are considered to calculate that temperature in a particular system.

Similarly, the same way different systems you can get as pressure also. Temperature you can measure by different unit, even some sophisticated instruments like thermocouple you can use, even the thermometer you can use, even other different types of sophisticated instrument of measuring this temperature are available and devices are available to measure this temperature.

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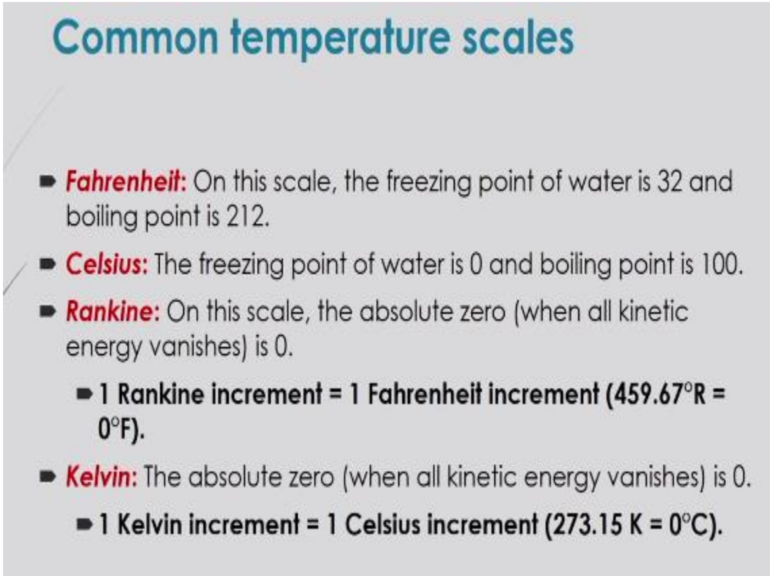

There are different systems like Fahrenheit, Celsius, Kelvin, even Rankine. These are the different units that are generally be used to express the temperature like this.

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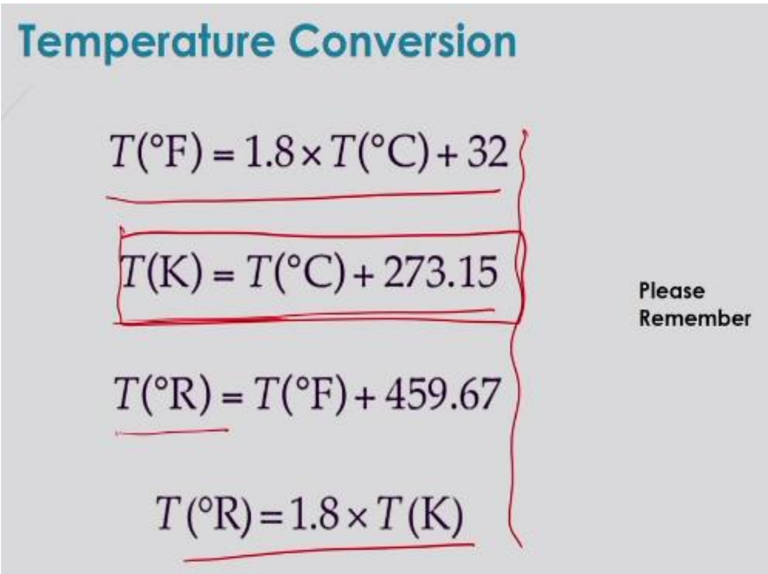

There is a certain conversion factor to convert one system to another system for this temperature. So, please remember this conversion equation of this temperature from degree Fahrenheit from this centigrade Celsius, even temperature in Kelvin from Celsius, even temperature from Fahrenheit to Rankin, even temperature from Kelvin to Rankin like this. So, these equations will give you that the how to convert this temperature unit from one system to another system.

Basically in SI system always you have to use that Kelvin unit and if any problem is given in terms of Celsius, then you have to convert it to Kelvin just by adding to 273.15. So, we have discussed this process variables of pressure and temperature in this lecture and how to estimate the pressure or calculate that pressure from the basic fluid static equation and how to derive it we have discussed.

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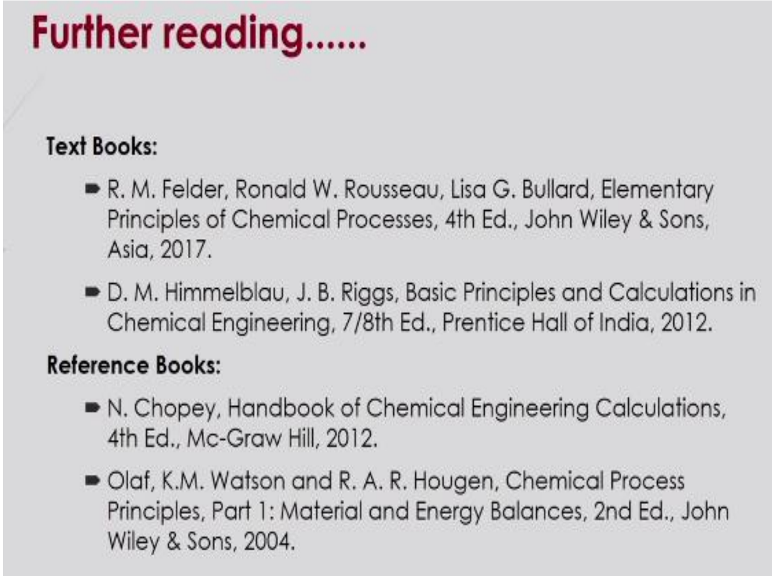

I think it would be helpful for your further understanding of the calculation of the process and you have to remember certain things of that hydrostatic equation and also how to use that hydrostatic equation to calculate the pressure by the manometer. So, next lecture, we will discuss other things of that basic calculations of this chemical engineering, like what are the rate of different process, how to calculate that rate of different processes, which are involved in chemical engineering system. Thank you.