Introduction to Fluid Mechanics and Fluid Engineering
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Lecture - 07
Surface Tension (Contd.) and Fluid Statics

Last time, we were discussing some of the fundamental concepts of surface tension and we will continue with that. Let us say that we want to see some application of surface tension as a very simple case.

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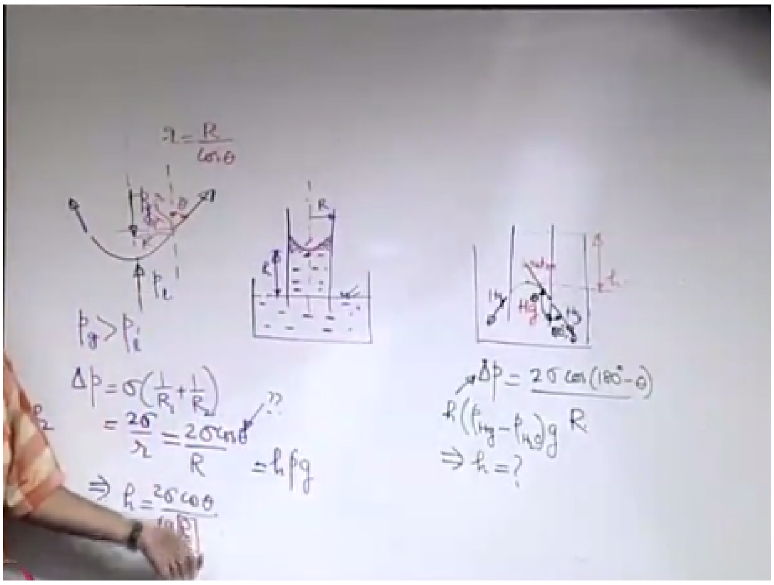

To do that we will take an example when there is a capillary tube which is small in radius, it is dipped into a larger volume of fluid and let us say that this was the initial level of the fluid and now once this capillary is introduced these fluid is expected to either rise or fall and we will see that what dictates that it should rise or fall. To understand that let us assume that the fluid is rising over the capillary.

If it rises over the capillary, then what dictates is rising and to what extent it should rise? Let us try to make an estimate of that. First question should come that why it should rise or why it should fall? When there is a fluid it is a collection of molecules after all and these molecules are subjected to various interactions. One type of interaction is the intermolecular forces of attraction between the similar types of molecules which are like so called cohesive forces.

The other one is the intermolecular force of interaction between the molecules of the fluid and the molecules at the boundary. So when you have that type of interaction that is known as addition. So it is between 2 different types of entities. Now, if the addition wins over the cohesion then that means the surface at the end has a net attraction towards the fluid and it likes the fluid.

Earlier we used a terminology called as hydrophilic material. So such types of substrates which like water are called as hydrophilic ones. A better terminology would be waiting because when we say hydro it means water so to say. But it may be any other fluid also. So better we say that those are waiting surfaces. So the surface is which want to be wet with the fluid that is there.

Let us say that there is a waiting fluid and it has formed a meniscus like this. This meniscus can be of a very complicated shape but let us just for sake of simplicity assume that it is a part of a hemisphere or like it is a hemispherical gap so to say. Now, if you try to identify that what are the various forces which are related to the development of this meniscus. We have discussed about this earlier.

So, just if we reiterate that if you have a meniscus like this loosely speaking there will be a force because of surface tension which is acting over the periphery. There is a pressure acting from this side, there is a pressure acting from the other side, the bottom side and it is basically filled with the same fluid which is also there in the reservoir.

So, if we say that at the top there is some gas or vapor and at the bottom there is a liquid then let us say this is P liquid and let us say this is P gas. So, which one will be better here P liquid or P gas in this configuration? Do you expect P gas to be more? because it has to balance the P liquid and the component of the surface tension in that direction. So, if you have P gas > P liquid that means there is a pressure differential across the meniscus.

So, if you have the pressure in the gas and the atmospheric pressure obviously the pressure in the liquid is not atmospheric pressure across the meniscus and there is a differencing pressure and that difference how do you relate? We had derived a formula delta P = sigma * 1/R1+1/R2. So, if we consider it a part of sphere R1=R2=R. So we are approximating the shape of the meniscus in that way.

Otherwise it may have different curvature at like different planes. But this is a simplistic assumption so if R1=R2=say small r, the small r is not same as the radius of the capillary. So this is different because the small r is the radius of curvature of the meniscus which is not same as the radius of the capillary. So, we have this as 2 sigma/small r, obviously we need to relate small r with capital R.

And to do that we can say have a small geometrical construction. Let us say that this angle is theta. So, when you have this angle as theta this is the angle made by the tangent to the interface with the vertical. So that should be same as the angle between the normal to the interface and the horizon. So, let us say that that is theta. This normal is in the direction of the radius of curvature of the interface.

So, this length is what small r and what is this length? This is capital R because this is say the central line of the tube. So this is capital R. So, how you can relate small r with capital R? So, small r will be capital R/cos theta. So we can simplify these 2 sigma/r as 2 sigma/capital R and then cos theta will go in the numerator. And what is this delta P? This delta P is the difference in pressure between the outside atmosphere and what is there just inside.

What is the pressure at the outside atmosphere? The pressure at the outside atmosphere is same as what is the pressure at this level. So, if you know what is the pressure at this level then from that you can find out a relationship between the pressure difference of these 2 and that pressure difference is nothing but because of the presence of this much of liquid color. So, if this is let us say that it has average height of h.

So, this is nothing but h * rho of the fluid * g. From here you can find out an expression for h which is 2 sigma cos theta/rho gR. This expression is very simple and this expression is valid only if this meniscus is under a static equilibrium condition. It is not moving but still it gives a lot of good insight because it tells you that if there is a capillary rise say in these kind of a situation we call it a capillary rise because as if the fluid is rising from the reservoir towards the capillary.

So, that capillary rise this dictated by many things one of the features of course is the angle theta which is the contact angle and which depends on the combination of the fluid. So, if we say that for a glass water combination, glass water air combination say this theta is close to 0 may be. So, that means that it requires 3 different phases so to say, I mean glass is the solid phase which forms the surface of the capillary they do have water here and may be air here.

But if you replace water we say mercury it may be something different and it may be possible that instead of a rise it has a fall. That is dictated by the competition between the adhesion and the cohesion force and eventually it is manifested by what is the value of the contact angle. So, in that case say if the contact angle say is 140 degree which is like if it is mercury, glass, air that may be like one of the possibilities.

So, when you have these one that means you will get if you have theta in that range obviously h is negative. That means instead of rise it is a fall, the meniscus shape also will be just (()) (10:39). The other important factors which is one of the decisive factors is what is capital R. Because in capital R is large then no matter what ever is the contact angle this effect will be small and we will virtually be that.

At the same time, if R is very small then this h can be very, very large. We get such examples in nature very nicely. That is if you have trees, these trees absorb water from the ground there is no pump which is existing in the nature as an artificial mean of pumping the fluid from the root to the topmost leaves and branches but you will see tall trees also get nutrient from the ground.

So, when they are transported by the fluid medium which is the so called ascent of sap in terms of the biological terminology. It goes vertically such a large distance; it covers such a huge height just with the consideration that this R is small. So those are really very narrow capillaries and then the capillary acts like a pump. So, just because of the surface tension it can attain a large height of transport.

And that kind of very beautiful mechanism prevails in nature and that makes the plants at least the tall trees sustain their lives. Now, just to have a slight variation from these let us consider an example when you do not have just one fluid as liquid and another fluid as gas but may be both of the fluids are liquids and they are immiscible ones. If they are miscible liquids obviously when you put them one with the other they may mix with each other.

And the clear meniscus may be not found. But if they are not miscible with each other there may be a clear meniscus that is form. Let us look into an example with the short movie and let us try to see that what kind of meniscus may be form with such an example. So, in this example what we will try to see is that if there are 2 different liquids which are there side by side then when these 2 different liquids are put in a capillary tube sometimes magically because of the result in surface tension transport that is created.

The entire column may move from one end to the other end and we will see one such example here. So there will be 2 different fluids, those liquids which have already been put and see that it is just like moving magically. It is not that there is a pump that is being put or there is no other driving force that has been created to induce the motion. Here we will not first be bothered about the motion we have first considering the equilibrium.

So, let us consider such a case but not a moving case but 2 different liquids which are keeping meniscus in equilibrium. So, let us say that you have a capillary tube. In the capillary tube now you have say 2 liquids on the top you have say water and in the bottom say you have mercury. With the given tube materials say it is glass, it assumes this particular meniscus shape. The outside is say filled up with mercury. So there is mercury in the outside and water is being poured from inside.

Now, if you see let us concentrate our focus on the meniscus. Let us say that the water is being poured from this height and there has been a so called depression of the meniscus from the top levels. Let us say that this is h. Again when you see such a simple analysis you should keep in mind that this has many approximations. When I say that this height is h obviously it has no sanctity because we are disregarding the variation in height from one end to the other when we calculate the pressure difference.

Whenever we calculated the pressure difference here delta P as h rho g that h, we assume some average height may be the center one we took as a reference. But it is not actually a uniform height. The entire meniscus has a variation in height and one of the approximations maybe that not to use this as the height but use the center line one in state. Just like what we did in the other example. So maybe take this as h. What is the error in these?

When you are concentrating this as the h if you referred to such a figure you are neglecting the shaded volume. So the shaded volume has a contribution. Effectively if you see it is the weight of the volume of the liquid that has been sustained through the surface tension and the pressure differential. And there these shaded volumes also have their own roles. It is only an approximation by which we are neglecting it.

There may be cases when this gives rise to some significant error and fortunately in most cases it does not give rise to that much error. So it is fine as a practical approximation. Now, if you consider this surface and try to see that what are the different types of forces which are acting on this surface you may evaluate the surface tension force just like what you did in the previous example.

So, when you are considering the contact angle say we are interested about the angle that is made by the mercury with the glass. So that is measured with respect to this one. So, this is basically the theta. So, it is important to see what is the sign convention for the definition. So when we are referring to the mercury it should be from the solid with in the mercury domain that is how the angle is there.

Otherwise with a different notation may be 180 – theta also be taken as an equivalent representation of the effect of the contact angle. So, this angle will be 180 degree – theta and for writing the force balance that angle will be useful. So, the same formula will be applicable here. That is if you have delta p again assuming spherical nature and all those things you will have that as 2 sigma cos of 180 degree – theta/R.

So, now on which side the pressure will be more mercury or water? And how can you calculate the differential of that pressure? When you consider the waters height it is basically h * rho water * g. That is the height of the column of water. When you consider the mercury size it is h * rho mercury * g. So the difference in pressure is like h * difference of rho mercury – rho water * g that is your delta p.

So from here you will get an expression for what is h? And this h is clearly a depression in this case that has been by this theta which is roughly 140 degree as an example. So if you know the surface tension coefficient then it is possible to put that in this expression and find out what should be the h under these conditions. So again this has many approximations but it gives some kind of idea that what should be the estimation for capillary rise or capillary depression.

With surface tension one may also have a dynamic nature of the meniscus and when you have a dynamic nature of the meniscus it is not that you just have to consider this type of equilibrium at the interface. You may have to consider overall dynamical nature of one fluid as it is displacing the other and moving in the capillary. In the process there are may be many things. In the static condition we have a contact angle.

In the dynamic condition this contact angle may change and the change of this contact angle may be because of the dynamic nature of the forces which are acting on the system. One of such forces is the viscous force. Then you also have a dynamically evolving may be force of interaction. So it is possible to have all the forces of interaction which are not just like constants but those are evolving dynamically as the shape of the meniscus is changing.

Because as the shape of the meniscus is changing you have different arrangements of the molecules close to the wall and that may dynamically give rise to different contact angles. So, the contact angle that we are referring to in these cases is commonly known as a static contact angle. But when the dynamics is evolving one may have a dynamic contact angle which depends on the relative interplay of various forces which are acting.

And since the 2 important forces dictating these type of capillary advancement in a dynamic condition or the surface tension and the viscous forces. So, there relative interplay has a strong role to play in determining the contact angle that evolves dynamically. Surface roughness also has a strong role to play because that dictates the proper intermolecular interaction close to the surface.

So, there is a very rich physics that takes place close to the interface in a dynamic condition and this elemental study does not focus on that. It gives just a broad idea of if it is a static condition what can be the consequence of surface tension. But at least it gives us an idea that surface tension may be a very important force in our small scale and as the radius becomes smaller and smaller its effect becomes more and more prominent.

With this background, now we will move into more general considerations for equilibrium of fluid elements. Here, whenever we were discussing the surface tension force we were assuming that the pressure is being distributed in a particular way and we were intuitively using some concept of high school physics that if you have a depth of h then what should be the variation in pressure because of that depth of h. Now we will look into it more formally.

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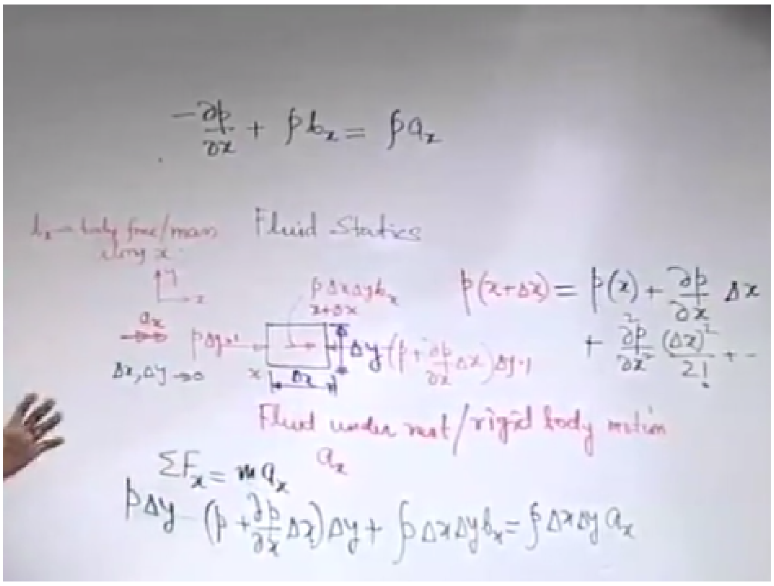

So, we will go into the understanding of fluid statics. We start with an example of a fluid element which is in static equilibrium and we take an example of a 2 dimensional fluid elements just for simplicity. We have taken such examples earlier what these examples signify that you have a uniform width in the other direction perpendicular to the plane of the board. So, let us say that delta x and delta y are the dimensions of this fluid element.

The fluid element is at rest. When this fluid element is at rest that means we assured that it is non-deforming because deforming fluid element is definitely not a fluid element at rest and when it is non-deforming we are clear that there is no sheer which is acting on it. That means there is only normal force which is acting on all the phases of the fluid element.

So, we can designate the state of stress on each phase of the fluid element by pressure. So, let us try to do that. Let us say that we are only writing forces along the x direction. Just for simplicity similar equations will be valid for the y direction. When you have say the left phase under consideration just like these let us say that P is the pressure on the left phase and the force corresponding to that is p * delta y * say 1 which is the width of the fluid element.

When you come to the opposite phase we are bothered about these phases right now because we are only identifying the forces acting along x because we will write equation of the equilibrium along x not that forces are not there on the other phases. So, this is not a complete free-body diagram. It only just shows the forces along x direction. So, if the pressure here is p what should be the pressure here? That is under question.

Will it be p? will it be something different from p in general. We are not really committed to what are the other forces which are acting on it. Then maybe any other body force which is acting on it along x and y. So, if the pressure here is p then the question is will the pressure here be p or something else in general. Special case of may also be p here. But we are talking about a more general consideration.

Mathematically speaking what question we are trying to answer, we have a function here say p we want to find out the value of the function at a different location say this location is x. We are interested to now find out the value of the function at x + delta x in terms of what is the value of the function at x. The function here is p. That means we want to see that what is p at x + delta x in terms of what is p at x and that we can easily do by using a Taylor series expansion.

So that we will do, we will write these as p at x + the first order partial derivate of p with respect to x * delta x + and so on. There are infinite number of terms but as you take delta x very small maybe you may neglect the higher order terms in comparison to the dominating term and the gradient. Keeping that in mind that we are treating with cases where delta x, delta y are very small. So, delta x, delta y all tending to 0.

So, this will become from the expression that we have here what we can write this will be p that will be the pressure here. We will keep this in mind so later on whenever we encounter any function we will use the Taylor series expansion to identify what is the change that is taking place across different cases of fluid elements because that we will have to do very commonly many of our analysis.

So, these multiplied by the area on which it is acting is the force due to pressure on this phase. Let us say that there is a body force which is also acting on the fluid element. So the body force let us say that bx is the body force mass acting along x. So, bx is body force mass along x. So, what will be the total body force which is acting on this?

Along x first you have to find out what is the mass of the fluid element, what is that? It is the density times the volume of the element that is delta x * delta y. So, this is the mass of the fluid element that times the body force with mass gives the total body force along x. So, these are the forces which are acting on the fluid element. Now, let us try to answer another question.

Are these still the force, only forces which are acting if the fluid element is under rigid body motion? That is the fluid element is moving like a rigid body there is no internal deformation but as a whole it is just like a solid that is getting displaced. That maybe displaced linearly or angularly but it is having a motion. But the motion is a rigid body motion. If that is the case, then are these the only forces?

See what forces we have identified? Surface forces we have identified; body forces we have identified. So, the question boils down to that are this is the only the surface forces even if the fluid is under rigid body motion. The answer is what? See, what is the difference between a fluid element at rest and fluid element under rigid body motion? The only difference that when it is under rigid body motion it might be having like velocity acceleration and so on.

But in terms of the surface forces which are acting if the fluid element is non-deforming then there is no sheer component of force. So, for a non-deforming fluid element there is no difference between the surface forces which are presented in this diagram and the surface forces which are there when it is a moving with acceleration. So, this type of forcing description is equally valid if the fluid is under rigid body motion.

So, we identify the situation not just at fluid under rest but also rigid body motion. We will see such examples where the rigid motion of the fluid will be very interesting like you may have rotation of fluid element like a rigid body. We will see that what kind of situation it creates. So, broadly this is also studied under the category of fluid statics not because it is a static condition but in terms of the characteristic of the fluid the deformable nature is not highlighted here.

And that is why we may use broadly similar concepts and we will learn these concepts together under the same umbrella because they are very, very related, in once case it will, it may have an acceleration in another case it may not be. Otherwise it is very, very similar. So, let us say that it is under rigid body motion and therefore let us say it has some acceleration along x. Say ax is the acceleration which is there along x.

So, we can write the Newton's second law of motion for the fluid element and when we do that what do we get the result in force which is acting along x = the mass of the fluid element time x times acceleration along x. So, it is p * delta y – the other term which is there on the opposite phase + rho * delta x * delta y * bx = rho * delta x * delta y that is the mass times the acceleration along x.

Delta x * delta y we will get cancelled from both sides these are small but not = 0 these are tending to 0. So, you can cancel from both sides at the end what final expression you will get? So, these will be the expression which relates the pressure gradient with the body force that is acting and if there is any acceleration that acts on that the fluid element is having. Similar expressions are valid for the motion along y, so we are not repeating it again.

With this kind of a general idea, so this is a very general expression. This general expression just considers that there is a body force and the fluid is having some acceleration in a particular direction subjected to the body force. But it is a non-deformable fluid element. With that understanding we will try to identify that what is the variation of pressure just due to the effect of gravity as a body force in a fluid element at rest.

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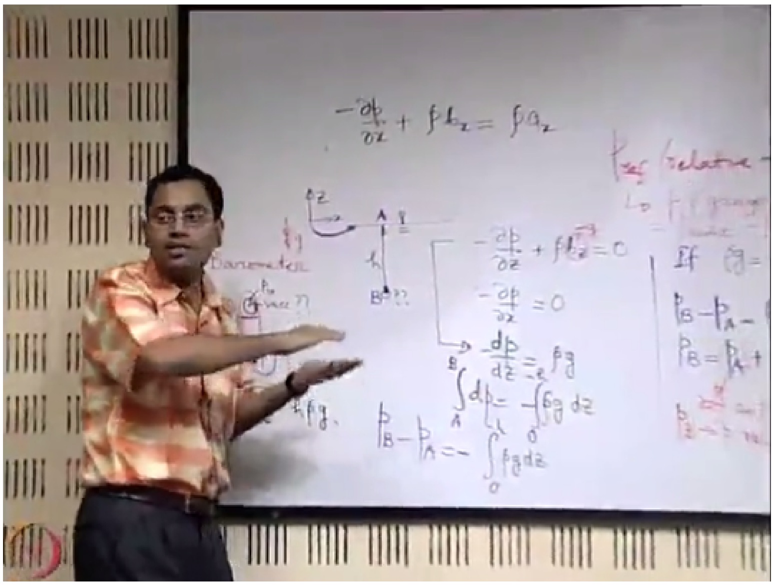

We consider that there is a free surface of a fluid this is a symbol in fluid mechanics that we will be using to designate a free surface. This is a triangle with 2 horizontal lines very short horizontal dashes or lines at the bottom. This is a kind of a technical representation of free surface. We consider that we are interested about some depth usually that direction in which depth varies is typically taken as z direction.

This is just a common notation in most of the books that the vertical direction across which the gravity is acting of course the opposite to the action of gravity because gravity will be vertically downwards and opposite to that is considered as a z axis just as a common notation. Let us try to write this kind of equation for these fluids which is at rest, it is of a substantial depth.

So, we are interested to find out what is the pressure at this point, which is at a depth h from the free surface. This there is no acceleration of these fluids it is under absolute rest. So, the ax or here az term will be 0. So, you will have – this one. When you have the z direction you also have a horizontal direction like x and for x you can write again similar expression.

So, if you write it for x, what is the body force which is acting along x? There is no body force which is acting along x because only body force to which this is subjected is the gravity. There is no body force along x and there is no acceleration that is it is having along x. So, the second expression is even more simple but it gives us a very important in sight.

What is that that if you are not having a body force along a particular direction and the fluid is under rest then pressure does not vary with the same fluid along that direction. That means for a horizontal, along a horizontal line you are not having any pressure variation in a continuous fluid system and this is one of the basic principles that we use for measurement of pressure differentials, as you have seen in examples of manometers earlier.

So, this is something which is of very consequence but it is an obvious conclusion. What we get from the first equation? So we, let us try to replace the bz, what is bz? See this is the z direction and this is acting in the opposite direction. So, this is – g. So, you have from this and since pressure is not varying with x, so you can write this as dp dz in place of partial derivative because it is now just a function of a single variable.

So, you can write this as – dp dz = rho g. So, dp is – rho g dz. So, if you want to find out what is the pressure difference between say 2 points A and B. So you have to integrate it with respect to the z variation from say A to B, when it is a say we take our reference such that the origin is located here that means at Az = 0 at B it is – h. So, you can write PB – PA = - integral of.

Now it is important to see that what is the lengths scale that we are considering over which this variation is taking place. If this h is quite large there may be a significant variation in density over it just like, consider the atmosphere which is above the surface of that. As you go more and more above the surface of that you expect the density to change because the temperature changes and so on.

And therefore the density in many cases may not be treated as a constant. So, if it is treated as a constant then it can only come out of the integral. Similarly, you also are probably working on length scale over with G is not changing. If you are taking a large height like what people who are dealing with atmospheric sciences, for them the length scales are large length scales over which you may have even a change in acceleration due to gravity.

But if you consider that such a situation is not there just for simplicity, so if rho * g is a constant that is the best way to say because a very tough mathematician will say that I do not care whether rho is varying whether g is varying I am happy in bringing this term out of the integrals so long as rho * g is a constant.

So, may be mathematicians' way of looking into it is that rho varies in a particular way g varies in a particular way but those variation effects get cancelled out somehow so that rho * g is a constant maybe very hypothetical but for our case to bring it out of the integral the product being a constant that will solve our purpose. So, then what you have? Then you have PB – PA = rho gh that means PB = PA + rho gh, which is your very well know expression.

Now, important thing is that see we are not expressing the pressure at B just in an absolute sense we are expressing it relative to the pressure at A. Many times this pressure at A say this is atmosphere, so that may be taken as a reference. So, if this is taken as a reference as p = 0 as an example. So, whatever is the atmospheric pressure say we call it 0. That means, any other pressure we are expressing relative to the atmospheric pressure.

So, then in that case PB is the pressure relative to P atmosphere, if p = 0 is the atmosphere. It is not definitely = 0 but if you have p = 0 we, I mean that is just the choice of your reference. So that it expresses any other pressure in terms of that as a reference. So, any pressure which is expressed in terms of the atmospheric pressure that is a relative way of expressing the pressure.

It is not that always you have to express relative to atmospheric pressure but atmospheric pressure being a well know standard under a given temperature. So, reference with respect to atmospheric pressure is something which is a very standard reference that we many times used. So, reference pressure relative to atmosphere, so we are talking about a reference where the reference is the atmosphere then whatever pressure is there at any other point we call that as a gauge pressure.

This is just a terminology. So, gauge pressure means that any pressure relative to atmospheric pressure. So, that means it is nothing but P absolute – P atmosphere. There is a difference between the absolute pressure and the atmospheric pressure that is as good as taking the atmospheric pressure as 0 reference and mentioning the pressure relative to that. So, this is a very simple exercise but from this we learn something. What we learn something?

So, whenever we have an expression we should keep in mind what are the assumptions under which it is valid. So, we will develop the habit of not using any formula like a magic formula.

This is very, very important. Formula based education is very bad. So, whenever you have a formula and you want to use it try to be assured that it is valid for the condition in which you are applying if not exactly but at least approximately.

So, when you are using pressure = h rho g, what are the assumptions under which it is valid? So, obviously rho * g is a constant and there is no other body force which is acting on it and fluid is at rest. That is these are the assumptions that are there with such a simple expression. Now, with this kind of concept one may utilize device, one may utilize this type of concept in making devices for measuring atmospheric pressures just like you have barometers.

Whenever we will be learning a concept we will try to give examples of measurement devices which try to utilize those concepts as all of you know a barometer maybe utilize to measure the atmospheric pressure. So, how it is there? You have say inverted tube and this inverted tube is say put in a bath of some fluids say mercury and let us say that it is there up to this much height.

Now, this much of height is there, there are various forces which are acting on this. So, one is you have, we are of course neglecting the local surface tension effect and the capillary formation. You must keep in mind that as this radius become smaller and smaller the effect of the curvature maybe more and more important because surface tension effect will be more and more important and there may be significant errors in reading because of them.

Now, if we just neglect that effect from the time being then you have atmospheric pressure acting from this side. If you assume that there is a vacuum here, there is a big question mark whether there will be vacuum or not. But let us for the sake of simplicity assume that there is a vacuum. Then whatever pressure is there which is acting from the side that is balance by the height of the liquid column which is there on the top.

So, from that you can get an estimation for what is the pressure here, let us say that P is the atmospheric pressure. So, p * the surface area on which it is acting is the force that is being sustained by the weight of the liquid column. So, that is nothing but that. So, it is like h rho g that * the area and area gets cancelled from both sides. So, you get this P if it is vacuum as the h rho g.

But if it not a vacuum, let us say that there is some pressure here which is the vapor pressure of the fluid which is occupying this and it is common that such vapor pressure will be there. Why? Because if it is a saturated liquid it is likely to have its own vapor on the top of that and that will always exert some pressure. So, it is never a vacuum in an ideal sense. So, we can say that P – P vapor is actually what is being balance by this way, so that is the h rho g.

So, if there is a vapor pressure, you cannot just use h rho g for the estimation of the atmospheric pressure but you have to make a correction because of the presence of the vapor and that is the function of the temperature because vapor pressure varies with temperature. Very commonly the mercury is one of the fluids that is being used for this purpose and why mercury is being used?

Obviously because it is quite dense it will not occupy a very large height for representing the atmospheric pressure. If you use any other fluid it may occupy a great height, so it may be an unmanageable device, unmanageably long device. Also the vapor pressure of mercury is quite small in most of the temperature ranges and therefore this connection is not that severe. These 2 are the important results.

There are many other reasons which are always into the picture when you select a fluid for measurement of a pressure, so like in a barometer. A barometer is a very interesting device we have discuss something quite seriously but I would just like to, I mean share a kind of a story associated with barometer, a very well know story and I am sure that many of you have heard about it.

A long time back in a high school examination there was a question. It was a physics examination and the question was that how can you measure the height of a building using a barometer? Now, all though all of you or most of you have heard about the story you will try to get a morale out of that story and you will try to keep that in mind whenever we are going to learn something.

So, what the student replied in answer, the answer was that you just have a thread you connect the barometer with the thread go to the roof of the house just drop that barometer with the thread and then like the total height that total height of the thread that is required to bring the barometer to the ground maybe + whatever is the portion of the barometer we will give the height of the building.

Now as seen most of the examinations by this student was given a big 0 and the expectation was it was justified that why he was given a big 0 because it was expected that the answer should reveal some basic concept in physics. It was a physics examination but this does not reveal any basic concept in physics, so he was given a 0 but then the student went for an arbitration. It was a democratic system even in that time.

So, the student said that no like, I mean let my answer be reviewed. So, there was a panel. The panel said that okay may be you were not aware that what kind of expectation that we are having from your answer. So, we give you another chance. So, you think about a solution for this question which reflects your understanding in physics and we will evaluate you from that. So, student said that let me be given sometime.

So, he was given 5 minutes to think about that. So, he was thinking for 5 minutes and when he was thinking for 5 minutes and he was still not coming up with an answer then like the evaluators where very happy that he might be failed again. So, they said that no you could not come up with an answer, so we are sorry. Then he said that no actually there are lots of answers have come to my mind.

So, I am not sure that what should I say and that is why I was not giving a response and then he was asking permission that I mean, am I going to be allowed to speak of that remaining answers. Then they said that fine, I mean whatever you have thought you just tell then he said that I will, what I will do is I will drop the barometer from the top of the building and I will measure the time that it takes to reach the ground and h = half g t square.

So, from the time I can measure the height. It reflects some understating of physics but it is a bit distracting because the barometer like it may be damaged and like and so on. Then he said that no then if you want a different answer maybe what I will do, I will try to make a pendulum out of the barometer swing it one in the bottom ground level another on the top level and we will measure the time period.

And this time period difference will give the difference in g between the 2 heights and since g is the function of height it will tell us that what is the height difference between the 2 and I mean, still the examiners were not happy and they were still they were ready to pass him because these were like the reflecting some of the basic concepts in physics.

Then he said that even if I am given different opportunity what I will do is I will climb across the staircase and in the side of the staircase you can just put the barometer one after the other till you travel the entire height. The number of times you put it you multiply with the length it is the basic length measurement principle. So, from that you get that and he said that there are many answers which are coming to my mind.

But given me an entire freedom what I will do I will not really put this much of effort, I will go to house master and tell that see now I have a beautiful new barometer for you I am giving it you please tell me what is the height of the house and the housemaster will obviously tell that because it is like a gift, free gift that the house master is having.

And then he says that perhaps you are not expecting all these answers from me you are expecting to, we to give a very structured answer that the barometer measures the atmospheric pressure. So, from the difference in the level of atmospheric pressure in the 2 heights we can easily say that what is the difference in height between the 2 and since this is the most structured answer I hope that you will be happy with that.

And then of course the evaluators passed him and he was quite successful and the name of the student is Niels Bohr, who later on, I mean like discovered many, many beautiful phenomena in physics. So, the whole idea is that I would always encourage you may be, I mean none of us like Niels Bohr, I mean we are not born with those special abilities but at least whenever you are having an opportunity to think of solutions do not always go for a structured solution.

Try to think about different possibilities whenever you are thinking about designing a measurement principle. Whenever you are thinking about solving a particular problem just try to think about various possibilities some of the possibilities may not be very, very encouraging very, very welcome but at least these possibilities will give us some kind of clue that what could be alternatives. Some of the alternatives may be discarded.

They may not be very smart but they will at least give us a scope of thinking lateral and that is how one may improve in science, technology and research. And such a simple example like barometer, I mean one is always reminded of that kind of a story and I feel that it is not something to bad to share with you. So, what we will do is we will not go further ahead today we will stop here.

In the next class we will just make a plan of what we will do in the next class. Now we have found out a particular way in which you have an estimation of variation in pressure because of a body force which is acting and for fluid element which may be at rest or subjected to acceleration. So, we will utilize this principle to calculate 2 important things. One is if there is a plain surface which is emerged in a fluid what is the total force which is there on the plain surface because of the pressure distribution.

Now we have realized that pressure is like a distributed force because it varies with the depth so at different depths you have different pressures. Therefore, it will be like a simple statics problem where you have a distributed force on surface to find out what is the total force which is acting. If you have a curved surface, we will see that the technique may be a bit different.

But broadly we can utilize some of the concepts of pressure distribution on a plain surface even to calculate force on curve surface. So, in the next class we will see what are the forces on plain and curve surfaces which are there in a fluid at rest and then to see that what are the consequences and we will work out some problems related to that. So, we stop here today. Thank you.