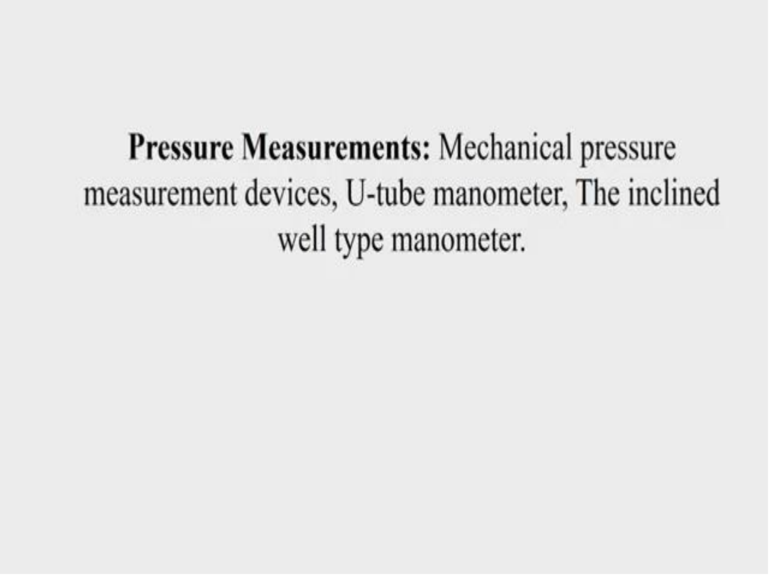
Experimental Methods in Fluid Mechanics
Professor Pranab Kumar Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati
Lecture - 10
Mechanical pressure measurement devices, U-tube manometer, the inclined well type manometer

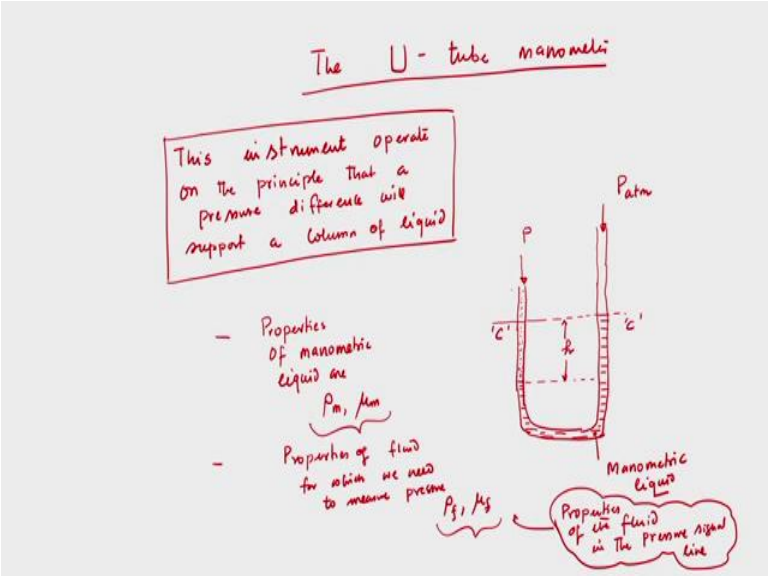
Good afternoon, I welcome you to this session of Experimental Methods in Fluid Mechanics.

(Refer Slide Time: 0:38)



Today, we will discuss about different measurement techniques like U-tube manometer, inclined well type manometer. In fact we have studied in our undergraduate fluid mechanics course these different types of pressure measurement techniques and we will briefly review of the basic types those are common in use. So, today we will start our discussion with a very simple which we have studied in our undergraduate course that is U-tube manometer. So, start with we will discuss that how we can measure pressure using the U-tube manometer.

(Refer Slide Time: 1:14)



So, the U-tube manometer. So, basically the U-tube manometer is again a type of mechanical pressure measuring device and we have studied in detail about this U-tube manometer in our undergraduate course. And before I go to discuss about U-tube manometer, inclined well type manometer, one thing is important that these instruments operate on the principle that the pressure difference will, is very important support a liquid column of the liquid.

So, what I can say that whether it is U-tube manometer or inclined well type manometer these instruments are basically operating on the principle that the pressure difference will support a column of a liquid. So, I can write that this instrument, this instrument will operate, rather I can write operates on the principle that a pressure difference will support a column of the liquid of liquid.

So, this is the operational principle and we will see maybe we cannot, we will not discuss in detail about this because we have studied in detail about these instruments in our undergraduate course, but we will take to review a few of them which are common in use. So, what I will do, I will try to draw U-tube manometer, then will see how we can measure pressure and that too what are the limitations which, what the important considerations we should know while measuring pressure using this device.

So, I will now draw a U-tube manometer that this is kind, like this now this is having two, shape is kind of U and this is having two limb and both are open, I mean say this is, that is what we have studied in our undergraduate course, just we are trying to review the basic types. So, now this is say atmospheric pressure P atm, and this is the manometric liquid mercury or any this is the manometric liquid and this is the pressure signal that is what we would like to measure.

So, now we are measuring in this cross section, we are measuring pressure in this cross section. Say this is cross section C C and this is kind of the fluid stream and the pressure I would like to measure of this stream and say properties of manometric liquid, properties of are density, viscosity.

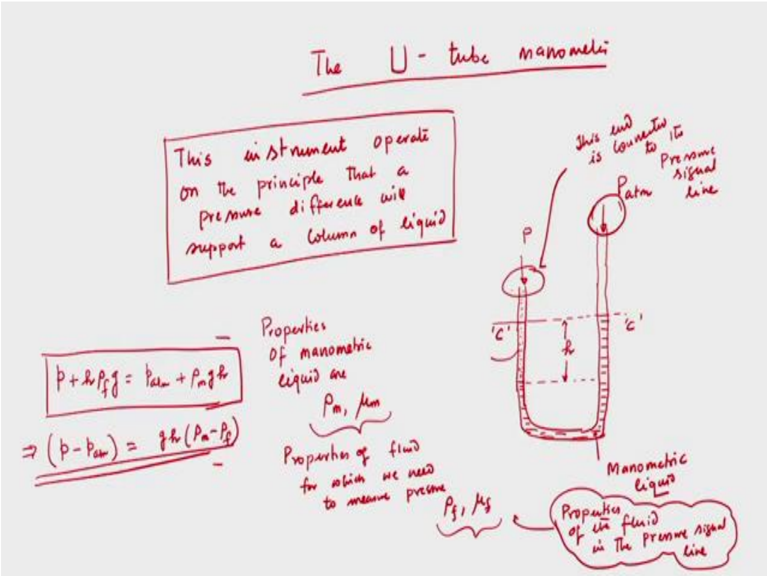
Similarly, we can write properties of fluid, we can say for which we need to measure pressure is rho f, mu f, so this is very important rather properties of the fluid in the pressure signal line. So, which we need to measure, properties of the fluid for which we need to measure pressure is rho f and mu f and rho m, rho m and mu m are the properties of the manometric liquid.

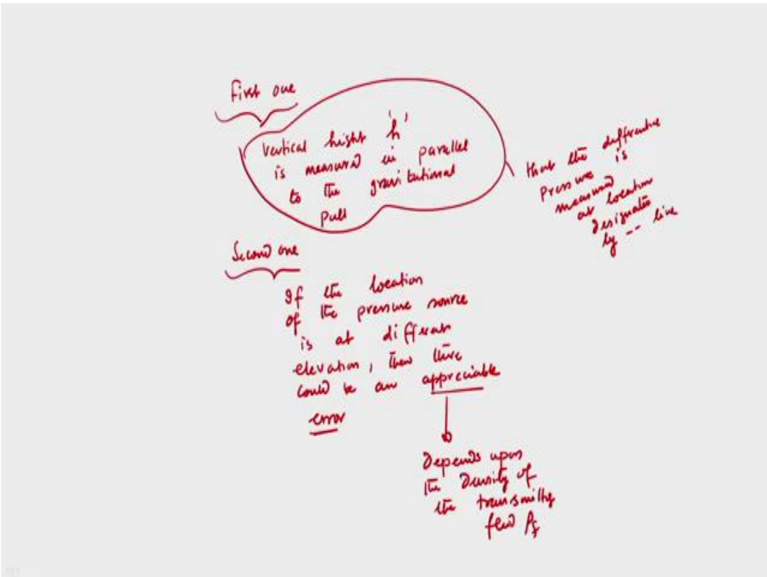
So, basically this is the, these are the properties of the fluid in the pressure signal line. So, this is what is important. So, this is a simple U-type manometer and we have done the schematic we know because we have studied it how you can measure pressure using this. So, we will measure pressure at the section that is designate indicated by the line C C.

So, we are interested in to measure pressure at the line C C and how we can measure. That say, this is the height of the liquid column as I said you that this instrument operates on the principle that a pressure difference will support a liquid column, column of the liquid, so this is say h, height difference h.

And now we will see that simply by if we calculate the equate the pressure at the line C C then we can see how we can measure pressure in terms of the fluid properties, fluid properties means this is the manometric fluid and also the properties of the fluid in the process signal line.

(Refer Slide Time: 9:28)





Now, one, two important things we need to know, first one that h, first one, first one is that the vertical height h is measured in parallel to the gravitational pull. So, this is measured in parallel to the gravitational pull. And second one is also important that it is the location of pressure source at a different that say I write, if the location of the pressure source is at different elevation, then there could be an appreciable error, appreciable error that error, appreciable error that error will depends upon the density of the transmitting fluid, of transmitting fluid rho f, that is what is important.

But now if I try to measure pressure that the pressure of the fluid in rather pressure P that we would like to measure the, in the pressure signal line. So, say we have connected this manometer in a fluidic with a fluidic confinement and we would like to measure and the one end of the U-tube manometer that is open to atmosphere.

So, this is this is end connected to the pressure signal line, while this end is open to atmosphere. Now, because of the pressure, the liquid, signal, liquid in the pressure signal line, this is the pressure signal line so this end I can write, this end should be connected to the pressure signal line, this end is connected to the pressure signal line.

So, now because of the pressure there will be a height difference and that vertical height that we will measure that is in that is that is in parallel to the gravitational pull. Now, just simply I mean we would like to measure pressure at the cross section C C. So, if we would like to equate the pressure at section C C, we can get the what will be the pressure that we would like to measure.

Now, this is very simple that see at section pressure that means if we calculate then P atm plus this very. So, we can write P so we would like to measure, so p plus height of the fluid in the pressure signal line density of the fluid which is coming from the pressure signal line and g we will be equal to P atm if we require pressure at P atm plus rho am g into h. So this is very simple equation, just we are balancing at the cross section C C.

So, now from this we can calculate P minus P atm equal to g h rho minus rho f. So, from this equation we can calculate because we know the properties of the manometric fluid and atmospheric pressure and this height that is what now I will come to the next slide that this vertical height, height is measured in parallel to the gravitational pull. And this height should be measured carefully otherwise we will come up with a pressure measurement which is not the correct one.

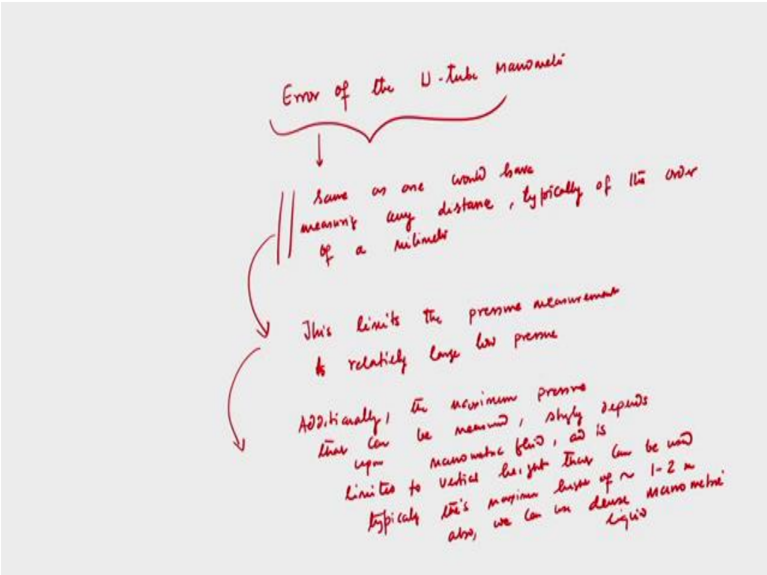
So, this is very important, this is the vertical height of the, vertical height measured in parallel to gravitational pull and that the pressure, that the pressure, that the pressure difference or pressure differential I can write that the pressure, I can write that the differential pressure, pressure is measured at location designated by dash line.

So, now next, second one that is if the location of the pressure source is at different elevation than the designated one, there could be an appreciable error and that error depends upon the density of the transmitting fluid. So, this is very simple we have studied, we have in our undergraduate fluid mechanics course, but there are a few issues which we should know when we use, when we are using this U-tube manometer for measuring pressure.

What are those? From the schematic itself we can say that the U-tube manometer rather U-tube manometers are very simple to use, but only one, thing one should be careful about measuring height that is vertical height. If we cannot, if you are not careful in measuring height, vertical height, then we are not in a position to have correct measurement of the pressure.

So, basically our measurement largely relies on the accurate measurement of vertical height that scale that is there in the U-tube manometer. Now, since then what are the possible sources of error and then of course knowing those possibilities of having errors we can somehow take precaution whenever we are using U-tube manometer to measure pressure.

(Refer Slide Time: 17:23)



So, basically the error of the U-tube manometer that the error is same as one would have measuring any distance typically of the order of millimetre, typically of the order of a millimetre. So, this is the only one problem that we should be careful to measure error, to measure distance and the error of U-tube manometer, same as one would have error in measuring distance would have measuring any distance typically of the order millimetre.

So, them because of this these limits the pressure measurement because of this, because you are largely relying on the vertical height so, and also need to know that we should (care) we should measure that h carefully, this limits the pressure measurement to a, to relatively large low pressure. So, larger side of low pressure, so low pressure if we have, low pressure also having smaller side and relatively larger side.

So, that means because they are typically of the order of millimetre, so, and it is very common that we may have in measurement error, measurement error in with the distance, so one which of the order, which is of the order of millimetre. So, if we cannot measure a millimetre distance carefully then how can we measure very small pressure difference for which the distance will be of the order of even less of the order of micron or even less than that, I mean millimetre or less than that micron level. So, that is why these limits the pressure measurement to a relatively large low pressure.

Another thing that additionally, I can write additionally the maximum so I can say that we cannot measure pressure and that is what if we can recall in my last lecture that we discussed that for the low pressure measurement we have different techniques that we will discuss, but with this U-tube manometer we cannot, we cannot measure low pressure because we may have error in measuring distance that is that will lead to, that will leads to error in the pressure calculation.

So, additionally the maximum pressure that can be measured, that can be measured strongly depends upon manometric fluid and is limited to vertical heights that can be used. Typically I can say the maximum height, typically these maximum height of the order of 1 to 2 meters and also we can use dense manometric liquid.

So, if you use U-tube manometer, we should be careful about measuring height because error of the U-tube manometer is same as one would have measuring any distance typically of the order of a millimetre because if we cannot measure, if we cannot measure the distance accurately, if we come up with a wrong result, wrong value with the height measurement then of course our pressure measurement will not be correct.

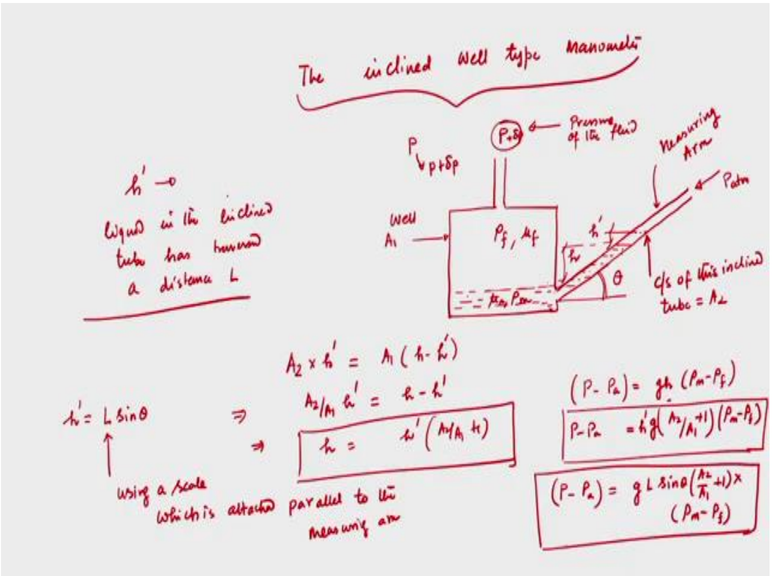
So, that is why this limit the pressure measurement to a relatively larger side of the low pressure, because for small pressure the height, height will be very small. So, displacement of the manometric fluid will be very small, so we cannot measure. Second thing now if you look at the other side that what will be the maximum pressure that we can measure using U-tube manometer is again limited by the vertical height that we can have and that is also limited of the order of 1 to 2 metre.

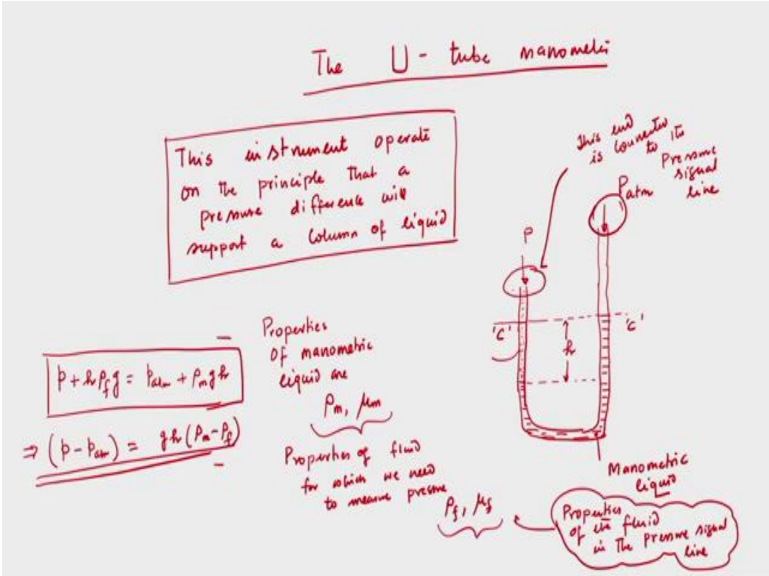
But, but if we use a denser manometric liquid even then we can, even then we cannot go beyond a particular value of this vertical height and considering all this the maximum height that we can use that will be of the order of 1 to 2 metre. So, now what we have understood that U-tube manometer is very common, we can measure pressure but the measured pressure is solely function of the vertical height that we will measure from the calibrated scale.

Now, we have identified that this scale I mean this height measurement is only the error if we have error then we cannot have accurate value of pressure. Now, we cannot go, rather we cannot measure very low pressure because for the low pressure measurement the height resolution will be very small that we cannot measure. And the maximum pressure again I have, we have seen that maximum pressure that can be measured using this U-tube manometer this is again restricted by the vertical height that can be considered.

So, we can even use dense manometric liquid but for that even we cannot go the vertical height which is, we cannot go beyond 2 metre, 1 to 2 metre. So, now we have seen that, we cannot measure low pressure because we need to have high resolution of the height and if we do not, if we cannot measure that height then we cannot measure the low pressure.

(Refer Slide Time: 24:32)





So, that is another type is that is inclined well type manometer is there will discuss the inclined well type manometer. So, again we will draw the schematic that will help us to understand how did the operational principle and again I am telling you that we have studied this in our undergraduate course.

So, this included well type manometer has two different advantages that I will discuss, that I will read rather, write rather. But before that I would like to draw the figure, draw the schematic of a inclined well type manometer. So, let us draw, say this is a gain P that is very important that we know that this is the pressure signal line, pressure of the single, fluid in the signal line.

And say this is open to atmosphere and this is P atm and what we can do, we can consider that this well, this is, this is well and it is having manometric liquid and say this is the manometric liquid, and this is the I mean this will not be the case say because of the pressure height of the manometric liquid will be less and say this is the height here.

And we can have this is the height h, this is the height h and this inclined tube makes an angle theta and say cross section of the inclined tube, inclined A2 and cross section of this well is A1 and this is pressure P that is the pressure in the signal line. So, this is pressure that we would like to measure, pressure of the fluid in the signal line. So, that is what we would like to measure.

Now, if that pressure of course that we would like to measure and we would like to measure, we are interested in measuring the gauge pressure. So, of course that is higher than the atmospheric pressure. So, P minus P atm that is what we would like to measure and that is again very simple.

And if we have a say initially it was an equilibrium condition because of this pressure difference if the, say now what I can say again if there is a slight change in pressure, there will be a slight change in the liquid column in the inclined tube. And if that slight increment is h prime, for that slight increment it h prime the well. So, what I can say this is the condition now there is a slight initially this is the condition because of this pressure in of the fluid signal line and atmospheric pressure.

Now, that h prime that is what I can tell that h prime there will be a slight change in the height of the liquid column in the well. But that h prime again, for that h prime maybe the liquid in the inclined tube has traversed a distance L. So, this is very important that this is height h prime is so small that change in height h prime in the well, because of that the liquid in the inclined tube has traversed a distance L.

Now, what I can write, second thing what I can write if I again do that, if I apply that equation because this equation that is what we have seen in the first case U-tube manometer this equation can be applied for this case again. So, if I write this equation then see A2 into h prime. So, say, now this vertical height say I am telling this is the h prime, see this is vertical height, vertical height h prime.

So, h prime into A2 that will be equal to A1 into h minus h1, h minus h prime, h minus h prime. So, small change in pressure that is what I told you in the last place that U-tube manometer, we cannot have very small pressure measurement because very small change in height we cannot measure because of the accuracy of the scale that is there in the U-tube manometer.

But, now using this inclined well type manometer there will be a slight change in height in the well, but because of this height change, maybe the liquid has traversed a distance L in the inclined tube. Now, the cross section area of the inclined tube is A2, so we can write this that A2 into h prime that volume should be called to A1 into h minus h prime.

So, from there we can write that h will be equal to A2 by A1 into, sorry, this is h prime, I can write that A2 by A1 h prime is equal to h minus h prime. Therefore, we can write that h will be equal to h prime into A2 by A1 plus 1. So, we can write that h, so, what I would like to say here that this is one of the advantages of using inclined well type manometer that small h prime is so small that this, because of this small h prime the height change in the well, the change in height of the liquid in the well is effectively 0, that we cannot see and that is what the problem was there in with the U-tube manometer.

Now, but may be the change in height is h in the well, small h, h prime is the change in height of the liquid in the well, but that is so small that cannot be, as if the effective change in height is 0 for, to the well. But that change in the inclined tube is not very small and that is what we can call, calculate this.

Now, if I apply this again the same formula that is what we have derived in the, in my last slide that P minus P atm is equal to rho, g h into rho m minus rho h. Here also we are having two different fluids, one is the manometric fluid that is this. So, this is rho m and this is rho f and mu f, and this is mu m.

So, we can write that P minus P atm that is equal to rho g into rho m minus rho f that is equal to rho, sorry, g h into rho m minus rho f. Now, this h is now will be P minus P atm g into A2 minus A2 by A1 plus 1 into rho m minus rho f, this is the, this is the into h prime, this is into h prime.

Now, this h prime is the small change in height that change cannot be even measured in a well, as if the effective change in height in the well is 0, but that small change can be measured in the inclined tube whose cross section area is much much less than the cross section area of the well.

And because of this height even for the small height we need not to measure, but we can, if we know the angle inclination angle that h prime is, can be written in terms of the height, the length, this height can be written in terms of the length that the manometric fluid has traversed because of this small pressure change, so that is L into sin theta.

So, therefore, I can write that P minus Pa is equal to g into L sin theta A2 by A1 plus 1 into rho m minus rho f. So, this is the final expression from where we can measure pressure by changing the length that manometric liquid has traversed on account of a very small change in pressure and the small change in pressure will definitely, will definitely leads to a small change in height in the well, but that height cannot, change in cannot be measured but because of the small change we can have measurement in the length of the liquid in the inclined tube.

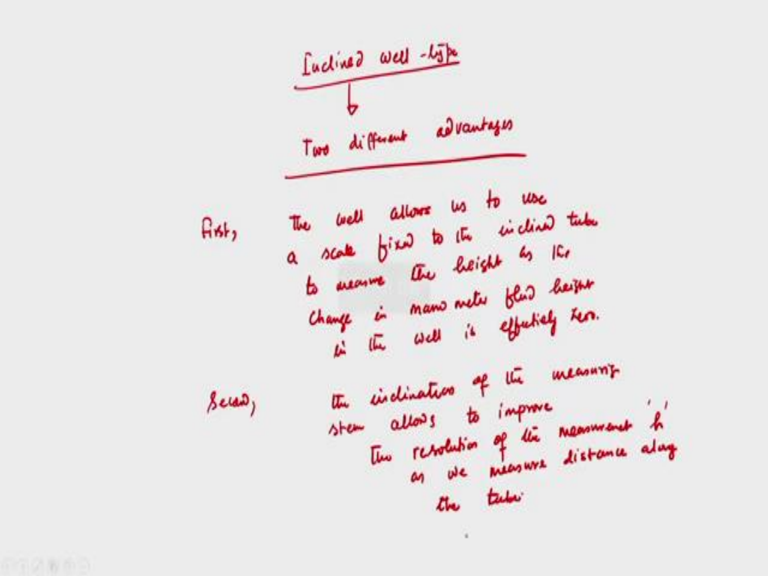
So, now in this case, scale is attached parallel to the measuring arm. So, here this is measuring arm so I can write this is measuring arm, so this is measuring arm and this L can be measured using a scale which is attached, which is attached parallel to the measuring arm. So, this is the procedure.

Now, if we compare this instrument with the normal or simple U-tube manometer then we can see that in case of a simple U-tube manometer a very small pressure change say P plus delta P, P plus delta P. So, because of this delta P, so initially it was P, now it is coming to P plus delta P, so this small pressure change will leads to a small height, change in height in the manometric liquid in the well, but that height cannot be very, cannot be measured in a U-tube manometer because of the, because of so many reason may be the resolution is not so high or we may not have we may have error.

But in case a inclined well type manometer that small height will leads to a change in, that mean we can measure the small height by measuring the length that the manometric liquid has traversed in the measuring arm. Now, this we have studied in our undergraduate fluid mechanics course, but today I have just recapitulated that because we should know.

Because knowing that these instruments are not capable to measure rather these instruments are not capable of measuring pressure, measuring low pressure rather, we need to know what are the different instruments available to measure low pressure. Now, so today I have discussed about two different types that U-tube manometer and then inclined well type manometer. And as compared to the U-tube manometer, the inclined well type manometer is having two different advantageous features.

(Refer Slide Time: 38:55)



First one, I am writing this inclined type, inclined will type is having two different advantages, what are those? First is this well allow, I am writing first one, first the well allows us to use a scale fixed to the inclined tube, inclined tube to measure the height as the change in manometer fluid height in the well effectively zero.

Second is, let me write it, second, the inclination of the measuring arm, measuring stem rather, measuring stem allows us, rather allows to improve, I can write to improve resolution of the measurement h as we measured distance along the tube, as we measured distance along the tube. These two are the different advantages of an inclined well type manometer.

First one this allows to fix a scale to the inclined tube measure the height as the change in manometer fluid height in the well is effectively 0, that is what I said because this very small pressure difference that change in height is effectively 0. So, but the change it height in the inclined tube may not be equal to, may not be that also very small. But the inclination of measuring stems allow to improve the resolution.

Because the, what we measure? We measure the distance that the manometric fluid has traversed. So, because of the small height change, the distance traversed by the manometric liquid is not so small, so that we can measure using the scale which is attached to the inclined tube manometer.

And since, now what I can say depending upon inclination angle, we can have higher resolution, so a small change in height in the well will have, rather will leads to have a significant change in length in the inclined tube so that we can measure the pressure with more accurate value.

So, today we have discussed about two different rather basic types of pressure measurement techniques rather that those we have studied in our undergraduate course. But we have recapitulated, we have reviewed those and these are common in use. And we have seen that in first case we cannot have very small pressure measurement and there are so many issues, that issues means that we need to know accurate measurement, how we can have accurate measurement of the height.

And we have seen that even if for low pressure measurement we cannot use that, we cannot have, we cannot read that measurement in the (sca) with the scale that is attached to the U-tube manometer. On the other hand we cannot even measure high pressure because for high pressure measurement again we need to have a sufficiently, the distance that will measure even a scale should be, should be even, will be more than 2 metre.

So, that is why U-tube manometer is limited or restricted the measurement where the height change in the manometric liquid within the manometer should be of the order of 1 to 2 metre. Now, for the inclined tube, inclined well type manometer we have seen that although the we can measure, even a low pressure using this instrument. But for that may be the advantage is that the small change in height in the well that we cannot measure.

But because of the small height change we can have a significant change in the length of the liquid column that has traversed in the inclined tube that we can measure and knowing the inclination angle we can calculate a height and from there we can calculate pressure accurately, even for the low, in the low pressure region. So, with this I conclude my discussion today and next class we will discuss that how we can measure low pressure using different other techniques. Thank you very much.