Mechanical Measurement System
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Lecture-27
Flow Measurement-1

Hello I welcome you all in this course on mechanical measurement systems, today we will discuss about the flow measurement, in today's lecture the topics to be covered are first of all I will give introduction to the flow measurement and, then we will discuss about the obstruction type of flow measurement, or obstruction type of flow meters not flow measurement.

Now, flow measurement is necessary in many of the engineering applications right, especially were heat transfer takes place because we often calculate heat transfer rate of heat transfer mcp delta T, m is the mass flow rate right.

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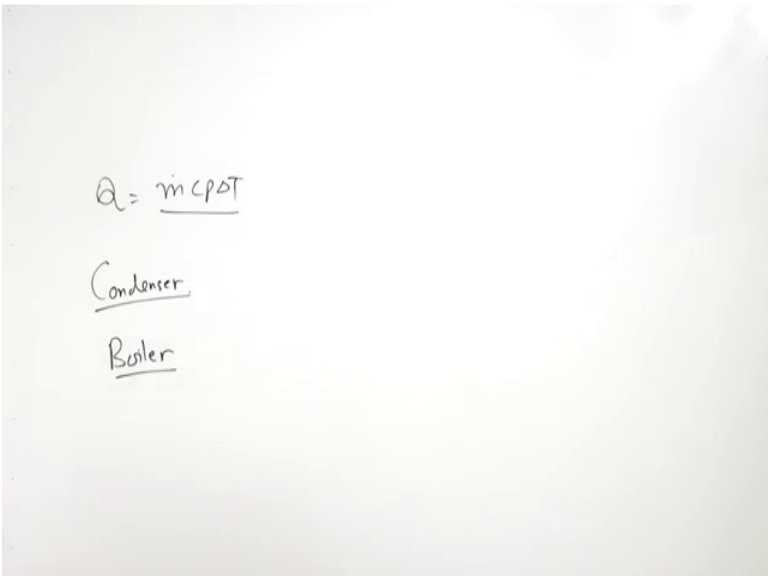

So, it is always required in many of the applications like heat exchanges right and, evaporators condensers even a power plant there is a condenser where, where heat exchange takes place and there is a boiler, economizer and many places.

I mean not only in power plant in air conditioning industries also, the mass flow rate measurement is required right, not for the working of air conditioner, but for the development of air conditioner, we need to have mass flow rate of refrigerant in the system, like wise in many of the engineering application not only in mechanical engineering applications, civil engineering applications, the mass flow rate is required transportation of the coil in the pipe line mass flow rate is required.

So, flow measurement is very important activity in all engineering application, all various types of engineering applications and some of the applications extreme precision is required. So, that is also an issue where, we just want to have the gross value of flow rate right and so, the applications very precise flow rate is required for biological applications for application in the area of medicine or in the area of research where the precise flow rate is required to be metered.

So, selection of the instrument is governed by many parameters and of course, cost is also 1 of the parameter if we are not very much concerned about the accuracy we will not like to go for a very high end type of a flow meter right, there are many methods, there are number of methods through which we can measure the flow rates and, the cheapest and the very reliable method of flow rate is measurement is pitot tube, we will start with the basic device pitot tube, you must have studied in fluid mechanics.

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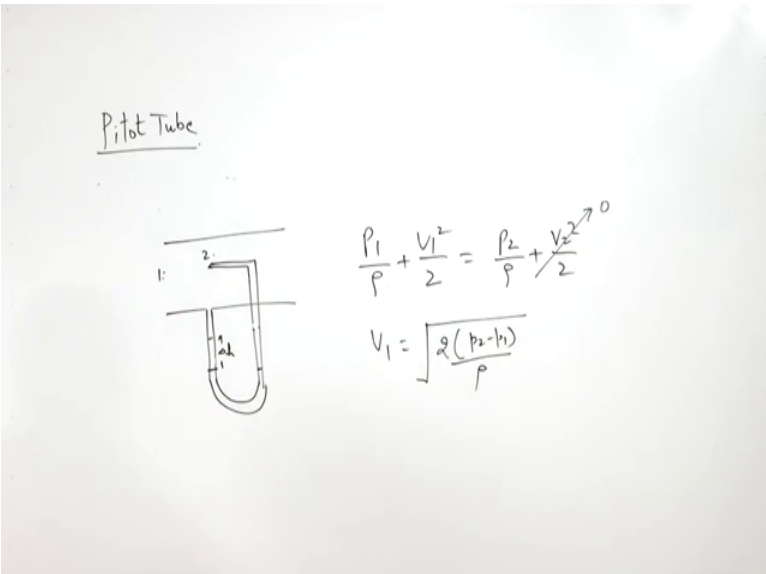

When you want to have flow rate in a pipe suppose, I want to measure flow rate inside a pipe I will use this method from here, I will make a tap for static pressure here, I will make a tap for dynamic pressure, right it they will be connected through a u tube dynamic pressure dynamic pressure means stagnation pressure. And this we can calculate using Bernoulli's equation. Bernoulli's equation says that suppose this is P 1 and this is 2.

So, P 1 by rho plus V 1 square by 2 is equal to P 2 by rho plus V 2 square by 2, if fluid is incompressible if fluid is compressible, then definitely rho 1 and rho 2 will also come into the picture, but water we consider as a incompressible fluid. So, the density remains constant and here at the stagnation point the velocity also turns to be 0 this is 0.

So, V 1 is nothing, but under root 2 times p 2 minus p 1 divided by rho, but if we were able to measure this p 2 minus p 1 the density is known to us. Now, p 1 minus p 2 is nothing, but the pressure between pressure difference between 0.2 and 0.1. Now, this differential pressure can be measured with the help of a there are many ways, but this is the simplest one, if flex if this is steady flow, if there is a fluctuation in the flow.

Then with a manometer it is a problem, then we will have to go for some electronic device or for differential pressure measure pressure measurement, but if it is steady flow then if this pressure is high right. So, this pressure difference this h pressure difference will give the pressure difference and through this pressure difference will be able to make the find the velocity in this pipe. Now, suppose instead of a pipe, there is a plate and, I want to have boundary layer thickness over the plate.

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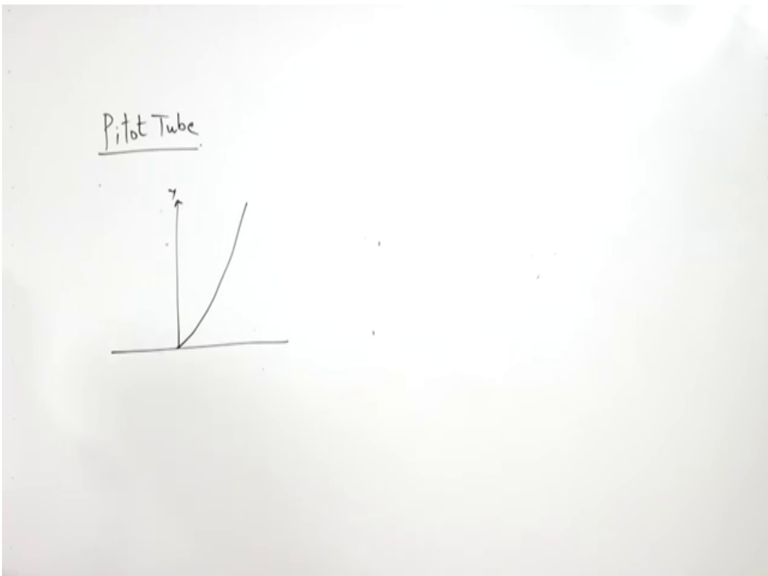

So, if there is a plate and I want to have hydrodynamic boundary layer, or variation of velocity in this direction right. So, what am going to do in a in a stream line flow, I will put the norm the nose of the pitot tube at different location, I will keep on moving in vertical direction, I will be getting different velocities, but in this case for the measurement of static pressure for the measurement of static pressure the design has to be little modified.

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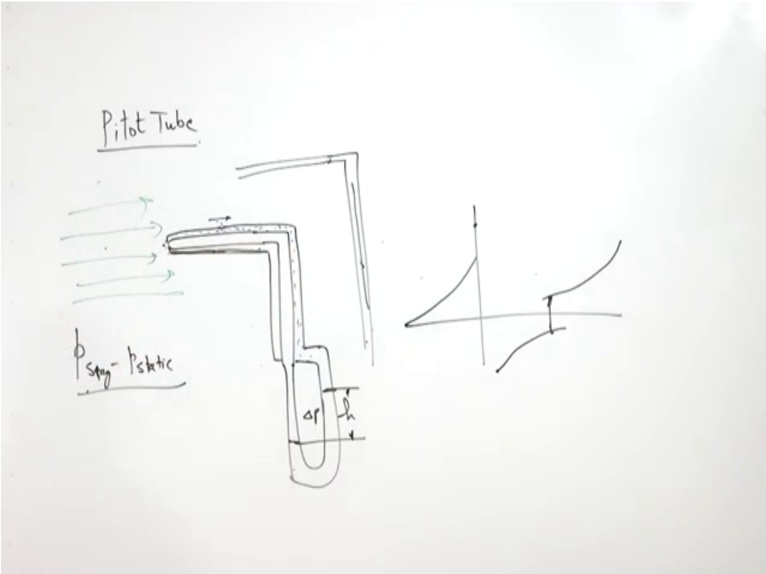

Here there is going to be a nose for a stat stagnation pressure and, it is covered by another tube. So, not a tube another layer of metal and, it has holes like this it is a hole and, then it is coming this way this side. Now, here this is filled with the static air, suppose this air is the medium this is filled with static air.

So, here we will get static pressure when air is blown over this tube, when air is blown over this tube from here we will get static pressure. And from this point we are going to get stagnation pressure and, if these two are again connected by a u tube manometer, then this pressure difference will give the data this is h. So, this h will give the pressure difference or pressure difference between stagnation pressure and static pressure.

Once the pressure difference is known the pressure difference between stagnation pressure and static pressure is known, we can calculate the velocity of fluid. Now, in this case it is air. Now, here the certain scope of errors in the in the measurement, first of all this part of the pitot tube has to be perfectively aligned with the stream line flow, if it is not aligned properly aligned with the with this flow or the flow of the fluid, in that case it is going to affect our output from the pitot tube. Now, the second thing is when this pitot tube is used for the flow measurement in a pipe, same pitot tube.

Now, it will occupy certain this lack of the pitot tube will occupy certain cross section area of the tube and, that will increase the velocity because what is it is doing it is obstruction type of device, wit is which is obstructing the flow over the flow of the fluid. So, due to obstruction or due to reduction in cross section area available for the flow of the fluid, the velocity in the vicinity of this point will increase, the moment the velocity is increased the static pressure will reduce. So, in that case, if we draw the variation of static pressure with length, suppose here we have nose of pitot tube.

So, initially it is stagnation pressure was 0 and at the nose it has increased, at the same time we will find a drop it has increased pressure here, but at the same time because available cross section area has reduced, it will be less than the static pressure the static pressure will reduce. Now, another obstruction in the flow is vertical column of the pitot tube. Now, this column will again act as a (Refer Time: 10:07) body right and, stagnation of air will also take place here.

So, this reduction in pressure will die out of certain length and, at the same time this stagnation pressure will also reduce when we move in this direction, this is the stagnation pressure created by the vertical length of the pitot tube. So, now at this point they are going to neutralize each other and, exactly this should be the position of this point. So, location of the point for the type of static pressure is not arbitrary. And that is why you must have seen this arm or this leg of the pitot tube has sufficient length, we can make it like this also, we can make it like this also.

So, I mean as per principles of fluid mechanisms it should work, but normally this is length is sufficiently long to neutralize the stagnation effect by this leg and at same time this negative pressure is also compensated right. And now after this pitot tube, we will take the another obstruction type of flow meter and in fact, these type of flow meters are cheap and easily are easy be installed that is one of them is venturi meter.

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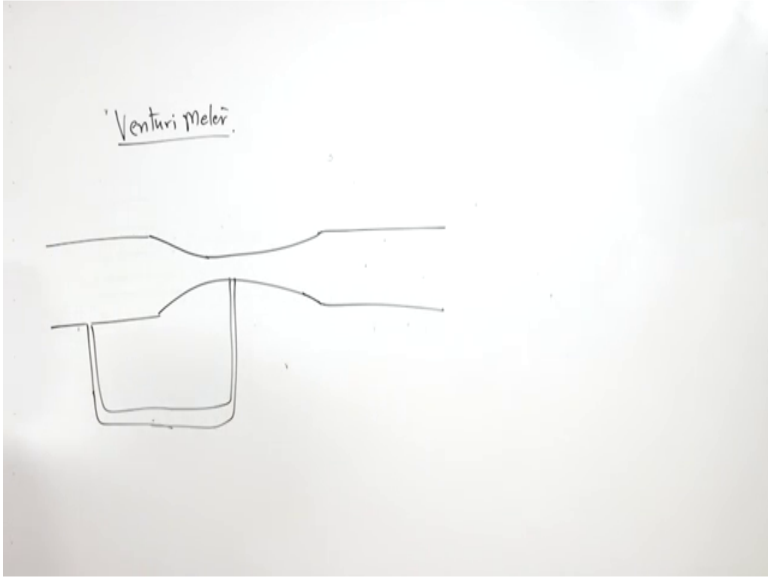

Right it also works on the principle Bernoulli's theorem or, it also works on Bernoulli theorem. In venturi meter the flow meter the physically the flow meter appears to be like this right, there is a upstream pipe and there is a downstream pipe also of constant cross section right.

Now, what we do we take one type from here, and one type from here, because there is going to a pressure difference between this point and this point, because this point the cross section area has reduced, this has caused the increase in velocity right. And due to this increase in velocity the pressure static pressure has reduced in comparison to the static pressure at this point.

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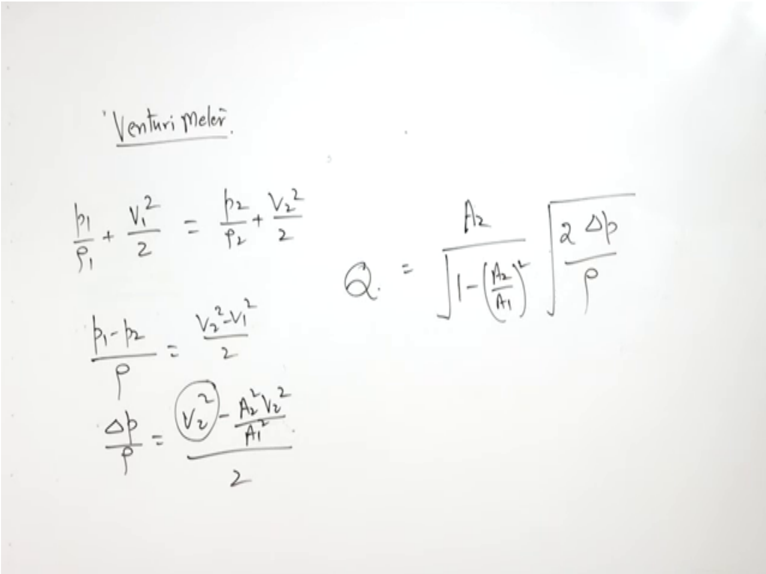

Now, let us take Bernoulli's theorem for 2 points 1 and 2 will always write like this p 1 by row 1 plus V 1 square by 2 plus because they are in the same plane.

So, potential energy they are assuming to be constant if it does not vary, is equal to p 2 by rho 2 plus V 2 square by 2. Now, if it is a incompressible fluid then rho 1 is equal to rho 2 and if it is compressible, then rho 1 and rho 2 are different. Now, here also what we do we simply take the help of this equation and, we calculate the value of p 1 minus p 2 because p 2 has reduced. So, p 1 minus p 2 divided by a rho is equal to V 2 square minus V 1 square by 2.

Now, velocity through a constant cross section velocity, if you multiply velocity with area V A and rho it will give you the mass flow rate right. So, this velocity or when the we can say V 1 A 1 is equal to V 2 A 2, because mass flow rate is constant density is constant. So, for any two points the product of velocity in the cross section area is constant. Now, from here we can take the value of V 1 is equal to A 2 by A 1 multiplied by V 1 sorry V 2 V 2.

Now, this value of V 2 can be substituted here and, then we will get delta p we will write delta p by rho is equal to V 2 square minus V 2 square V 2 square by V 1 square multiplied by 2 sorry this is whole divided by 2. Now, here delta p we have already calculated when we just not calculate, we already determined when we measured the static pressure difference between these 2 points using a u tube manometer. So, delta p is with us A b A 1 and A 2, these values are with us then easily we can find the velocity of fluid in the venture. And this velocity can be written as V 2 is equal to C V 2 is equal to 1 by under root 1 minus A 2 by A 1 whole square under root 2 delta p by row delta p is 1 minus p 2. So, this is how we have calculated because this V 2 will come out 1 minus A 2 by A 1 whole square this will go down right and delta p row multiplied by rho.

Now, this is the velocity and, if you want to have ma this volumetric flow rate and the Q is going to be this multiplied by area 2 this will give the Q volumetric flow rate. And if you further multiply this by density you will get the mass flow rate. Now here the issue is first of all the flow has to be a stable flow. So, upstream side I will rub this off upstream size of the venturi meter, the upstream side of the venturi meter, it has to be around 5 to 10 times of the diameter.

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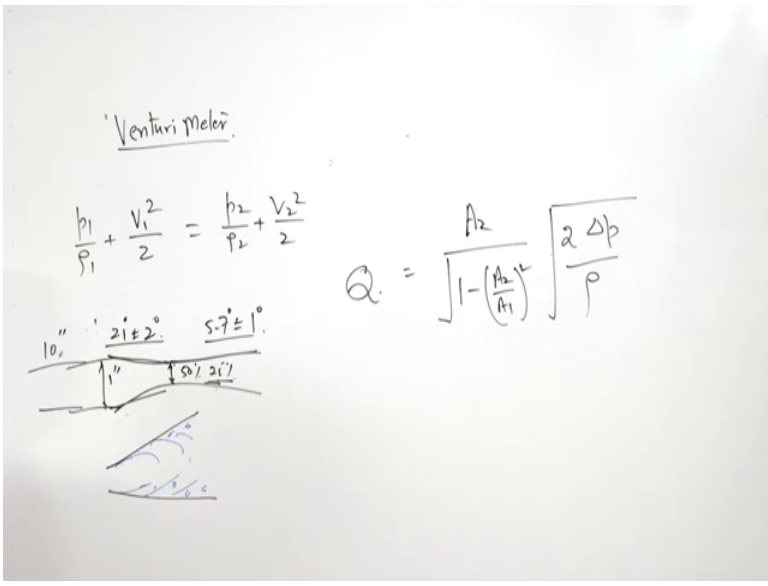

Suppose this diameter is 1 inch. So, upstream side has to be around 10 inch length without any change in the diameter right. So, it has to be a stabilized and the stabilized and the fully developed flow and, the converge angle in order to reduce the loss is the converge angle has to be 21 degree plus minus you can take, 1 degree or 2 degree 21 degree plus minus 2 degree has to be angle of convergence. Diverging angle has to be lower, diverging angle has to be 5 to 7 degree plus minus 1 degree.

Now, why diverging angle is less than the converging angle, the diverging angle has to be less than the more than the converging angle because, when the in the diverging angle there is a tendency of fluid boundary layer to get separated from the surface of the the passage. If so, happens they are going to be losses they are going to be losses here pressure losses here, which are not accepted.

So, that is why in most of the nozzles whether they are used for some other applications in nozzles, the converging passage the length of the converging passage is much less than the length of the diverging passage. Now, this diameter also we have to ensure that it should be the diameter has to be in a range of 50 to 50 percent to 25 percent not less than not less than 25 percent. Now because what happens the when the fluid enters the when fluid enters the passage.

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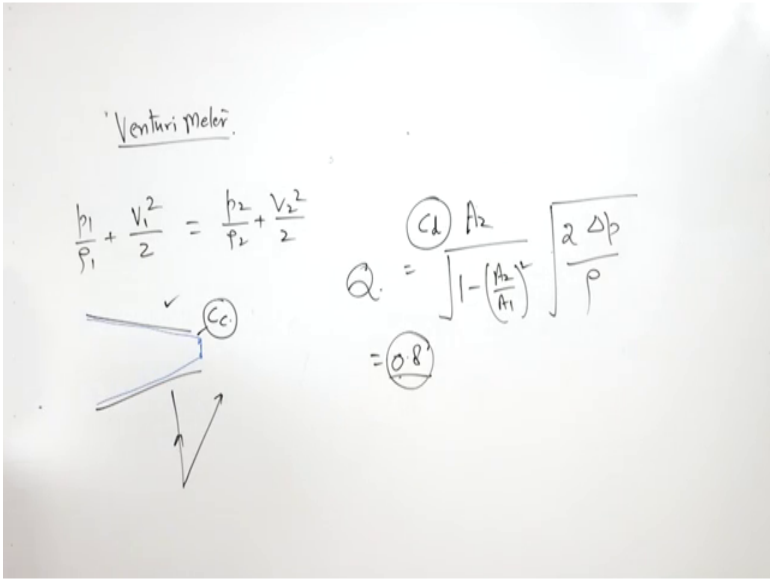

Right in that case vena contractor is formed, vena contractor is formed, it means the actual cross section is this only. So, actual err available cross section area is less than the available cross section area. So, that is why coefficient of discharge is also taken into account coefficient of discharge takes place of this loss due to formation of vena contractor and, other losses due to friction and all.

So, all the pressure all the losses are covered under this coefficient of discharge. So, this so actual discharge because whatever we are calculating from here, actual discharge is less than this and for venturi meter, it is around 0.8 cd is ranges between 0.8 to 0.9; it can be 0.7 also that depends upon the design of the venturi meter.

So, benefit of this type is of obstruction type of instrument is high recovery; recovery is high, I mean the pressure recovery because cd is let us say 0.8. If you compare the cd of orifice meter I will discuss orifice meter also it is quite high, it has well established characteristics thick ok, clogging problem is not there because passage is sufficient has sufficient diameter.

So, clogging problem in such type of flow meters is not there and, they are easy to install and, they can be installed in at any angle, I mean not only in central direction, it can be installed in vertical direction, they can be installed at an inclined angle also at a certain angle also right. So, that is one type of obstruction type of flow meter, another type of obstruction type of flow meter is orifice meter.

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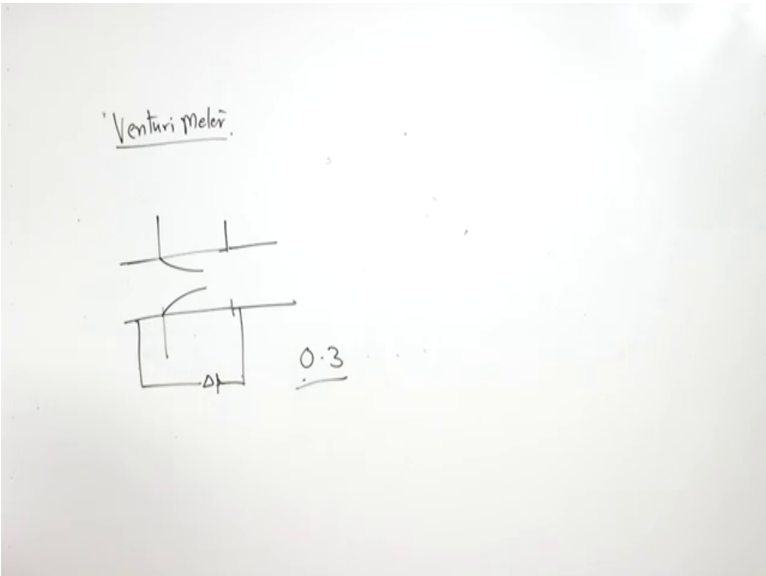

Now, in orifice meter there is no converging or diverging passage, there is a plate which has a circular orifice in the middle right and, working principle is same pressure static pressure here, because here there is there is going to be fall in the static pressure, but in this case and then we take the delta p, I think these instrument you must have studied in the classes of fluid mechanics also that is why am discussing in brief, am not going into the details in orifice meter.

The benefit is we can go for a larger diameter, even we can go for a diameter of 2 feets, I mean of 75 centimeters even 100 centimeter diameter tube, we can put we have what we have to do we have to simply put a plate with a orifice in the middle. So, for large diameter tube flow orifice meter is good, but it is an obstruction type of device and like a pressure recovery is poor, pressure recover loss is high and the coefficient of discharge may be as low as 0.3.

So, it also depends upon design of the no normally for a small diameter instruments which are obstruction type, they are made up of bars right because bars has smooth surface. So, lo losses due to friction are less, but if we have to go for large diameter then, we have to go for other material for the fabrication of this type of instrument. There is another instrument which is known as sonic nozzle in sonic nozzle, if the tube there us a nozzle rest of the fuel is same.

A nozzle is fitted and then again this pressure loss difference in head and then again, but sonic nozzle is a compromised between the ventruri meter and the orifice meter, sonic nozzle is normally used for the gas flow because, when we talk about the gas flow, in that case the density of the fluid change in the density of the fluid has to be taken into account. And in this sonic flow pressure is approximately 80 to 90 percent of differential pressure.

So, pressure recovery is not very high very good in the sonic nozzle, but it is let us better than the orifice meter and, or it is between orifice meter in the venturi meter, it is cheaper, it is cheaper than the venture meter right. Now, we have so, far we discussed about the fluid which is in compressible, suppose fluid is a compressible because, we have to measure many times we have to measure flow of the gas as well.

And the fact for the gas flow also this orifice meter and the venturi meter are used they are not specifically used for the water, or incompressible liquid they are used for the compressible liquid as well, but in case of compressible liquid the governing equation will change. Now governing equation earlier we were writing for incompressible fluid as p 1 by row plus V 1 square by 2 is equal to p 2 by row plus V 2 square by 2 right. Now, this equation is espec if you compare this equation with the first law for open system.

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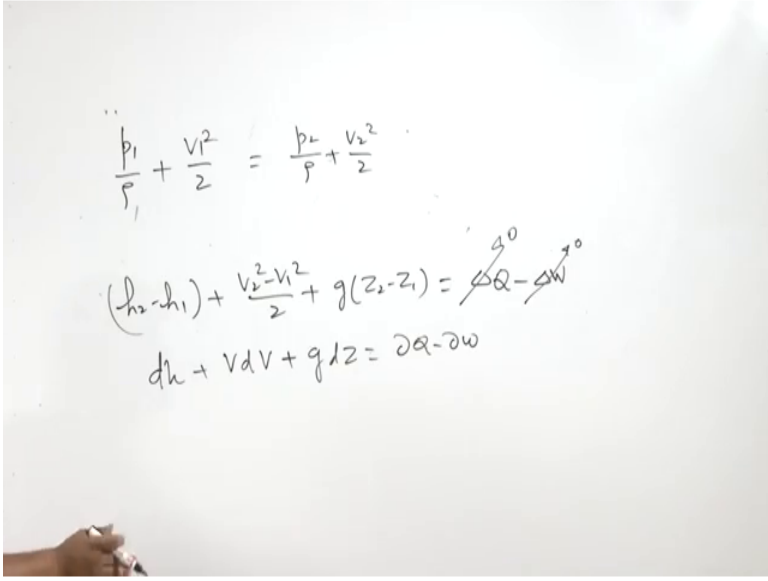

First law for open system is h 1 plus V 1 square by 2 plus z 1 equal to h 2 plus V 2 square by 2 z 2.

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Ha V 2 square by 2 plus z 2. Now here in the first law now this is horizontal. So, this we will always consider 0 because, right now in the first law if you take a specific case of first law, now this is now I will write it again. The first law for open system is h 2 minus h 1 plus V 2 square minus V 1 square by 2 plus g z 2 minus z 1 right. Now this is first law for open system and, this is equal to Q minus W or, delta Q minus delta W or if you want to write in differential form then d h is equal to V d V plus g d z is equal to del Q minus del W.

Now, in fluid flow there is no heat transfer right. So, heat transfer is 0 work is also 0 there is no movement of the boundary of the system. Now we have h 2 minus h 1 V 2 minus V square minus V 1 square by 2 plus g z 2 minus z 1 0, if it is horizontally installed, then this is also 0.

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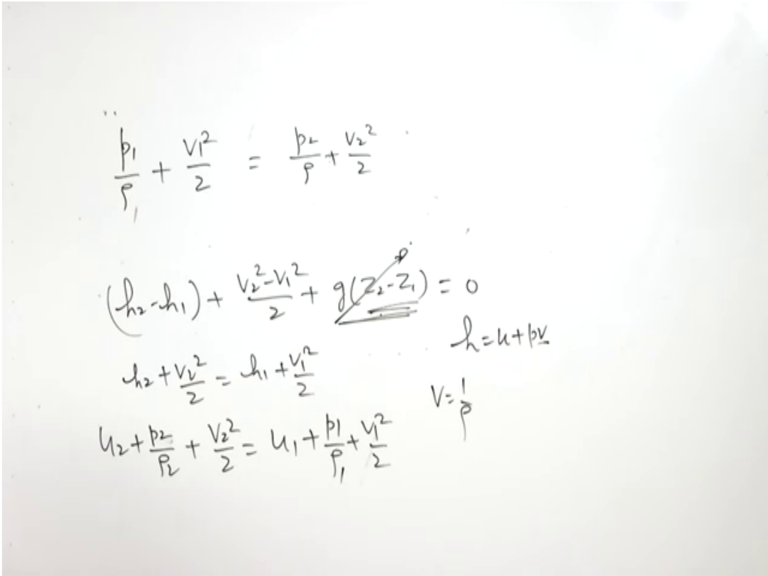

If the measuring instrument is not horizontally installed, as I said in case of venture meter it can be installed vertically, when venture meter is installed vertically, then this will also come into the picture and the same formula cannot be used, then we have to drive from the basics what is going to be the pressure difference between these two and this and how much is pressure due to static pressure generated due to change in the elevation that has to be taken into account right.

So, for here we assume that it is 0; So, h 2 minus h 1 plus V 2 square minus V 1 square equal to 0. So, or h 2 plus V 2 V square by 2 equal to h 1 minus V 1 square by 2, we always know that h equal to u plus p v. So, this equation we can always is right u 1 plus p 1 by row. Now why we are writing V 1 by row because V is 1 by rho here, it is a specific enthalpy. So, this is specific volume meter cube per kg. So, it is going to be 1 by rho plus V 2 square by 2 is equal to u 2 plus p 2 by this is row 1 and this is rho 2 because, it is compressible just a minute wait u 2 plus V 2 by rho 2 plus V 2 square by 2 is equal to u 1 plus p 1 by row plus V 1 square by 2 fine.

Now, this can you can always be written like this, when there is a change in density. Now, if there is no change in density right, then u 2 and u 1 this terms are because it is now and they are neutralized, but since there is change in density, it means compression or expansion has to be in place right. Now, if we take u 2 and u 1 in to consideration.

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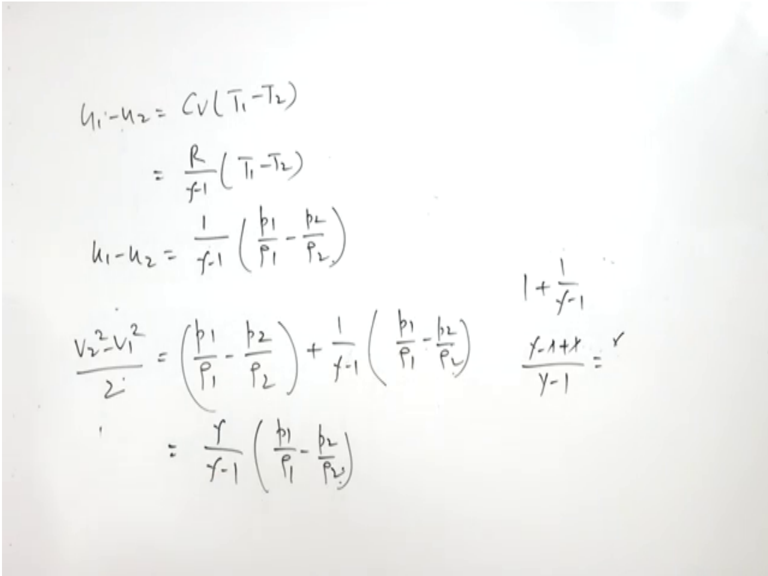

Then u 1 minus u 2 is equal to C V T 1 C V C V T 1 minus T 2 and C V T 1 minus T 2 is R by gamma minus 1 T 1 minus T 2 right. So, u 1 minus u 2 is equal to 1 by gamma minus 1 R T 1, if you use ideal gas equation then assuming that ideal gas is flowing inside the tube. So, R T 1 is equal to p 1 V 1, R T 1 is equal to P 1 V 1, or R T 1 is equal to P 1 by rho because, V 1 is specific volume it is in meter cube per kg and this density is kg per meter cube so, then p 1 by rho 1 minus p 2 by rho 2.

Now, this because p 1 p 2 we are already measuring. So, this will also be incorporated in final expression, this phenomena and look at that expression as V 2 square minus V 1 square by 2 is equal to p 1 by rho 1 minus p 2 by rho 2 plus 1 by gamma minus 1, p 1 by rho 1 minus p 2 by rho 2, this expression because this is due to u 1 minus u 2. Now if you take this out we will get gamma over gamma minus 1, p 1 by rho 1 minus p 2 by rho 2.

If we take 1 plus because if we take p 1 by rho 1 minus p 2 by rho 2 common, will be getting 1 plus 1 by gamma minus 1 gamma minus 1 plus 1 divided by gamma minus 1, then gamma over gamma minus 1. So, that expression has come here, now what is remaining is finding out the value of V 2 and again we will use same relation continuity equation, rho 1 A 1 is equal to rho 2 A 2 here, density will also come into account. So, rho 1 A 1 V 1 V is velocity rho 2 A 2 V 2 right.

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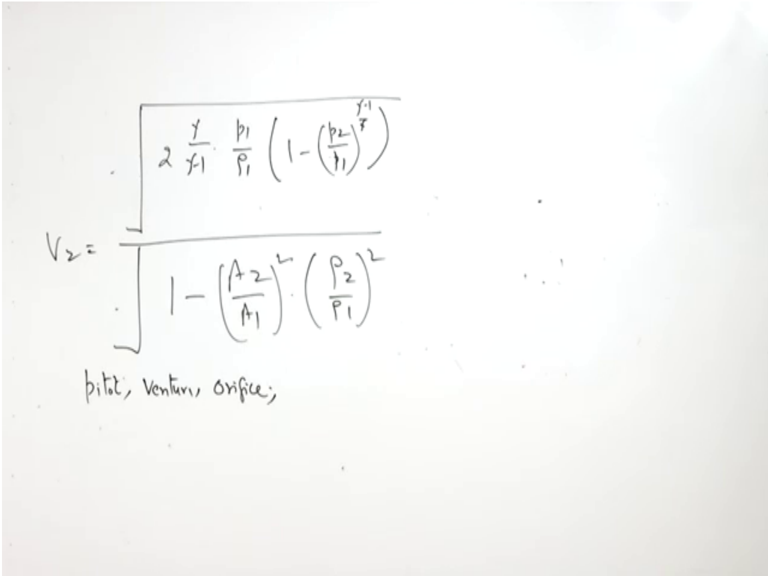

Now, using this equation the final expression can be written as V 2 is equal to under root 2 gamma over gamma minus 1, multiplied by p 1 minus rho 1 1 minus p 2 by p 1 is to power gamma minus 1 whole gamma divided by under root 1 minus A 2 by A 1 whole square, multiplied by rho 2 by rho 1 whole square right.

So, there is going to be an alteration in the expression of V 2, when we take compressibility of the working fluid into account right. So, they are going to be 2 different equations 1 for incompressible and another is for compressible fluid, but working principle is same, we simply take difference between stagnation pressure and, static pressure and this pressure had difference in this energy is assumed to be the kinetic energy change in the kinetic energy of the fluid.

We work on the based on this principle all these 3 instruments. Now, 4 instruments pitot tube, venturi meter and orifice meter, this sonic nozzle sonic nozzle, they work on this principle. This is all for today in the next class we would take up some more flow meters for the discussions.

Thank you.