Chemical Process Instrumentation
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Lecture – 43
Flow Measurement (Contd.)

Welcome to lecture 43. We are talking about flow measurements and in our previous lecture we started our discussion on flow measuring instruments based on fixed area variable pressure drop principles.

So, all such instruments flows through a flow restriction with fixed area and then, we measure the pressure drop across the flow restriction using a differential pressure gauge and relate the flow rate to the measured pressure drop. In our previous lecture we have talked about orifice meter and Venturi meter today we will talk about flow nozzle dull flow tube and pitot tube.

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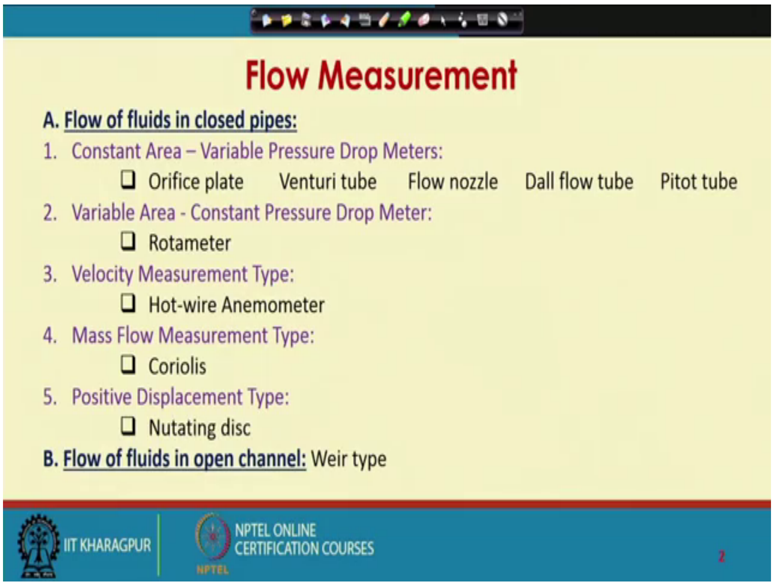

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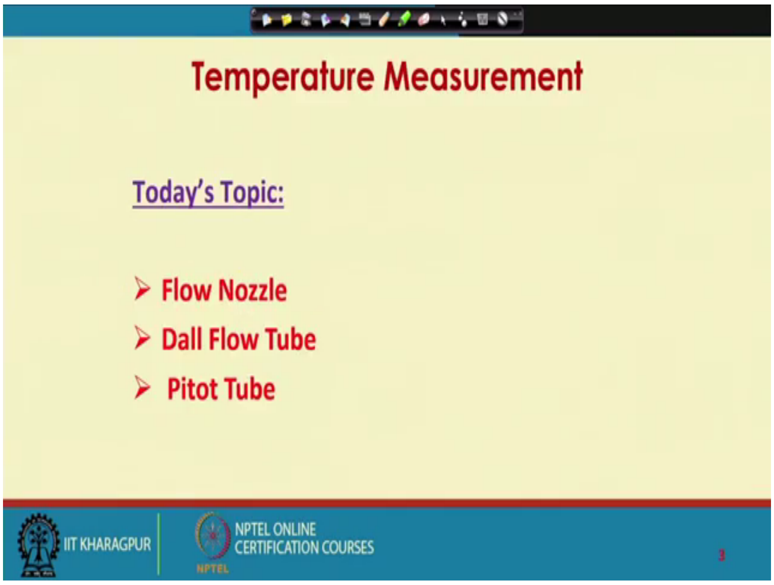

So, today's topic flow nozzle dull flow tube and pitot tube.

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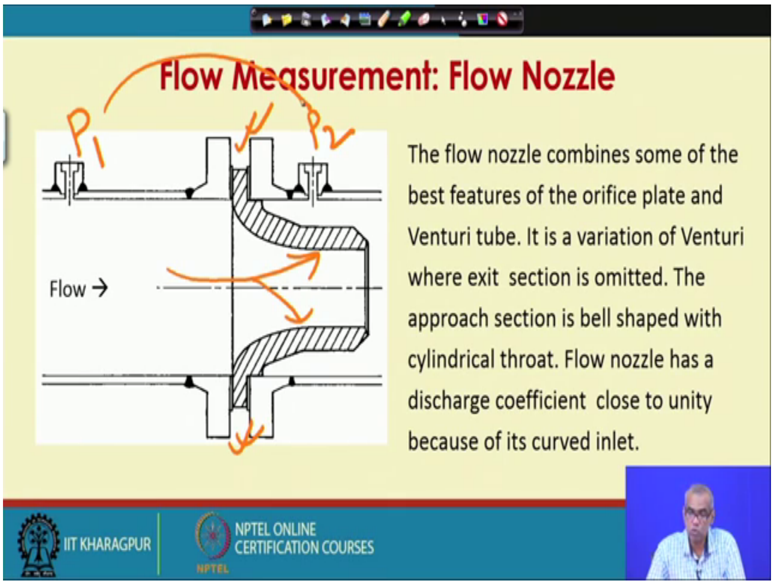

The flow nozzle combines some of the best features of the orifice plate and Venturi tube. It is a variation of Venturi where exit section is omitted; the approach section is bell shaped with cylindrical throat, flow nozzle has the discharge coefficient close to unity because of its curved inlet. So, this is the flow nozzle, you have 1 pressure drop of 1 pressure port here another pressure port here. So, the nozzle is attached is connected in the pipe using flange. So, as the flow approaches nozzle due to flow restriction velocity decreases velocity increases, pressure decreases you measure the pressure drop across the nozzle and then using Bernoulli's equation you relate the flow rate with the pressure drop.

So, the principle is very much similar to orifice or nozzle or Venturi meter. So, nozzle or flow nozzle is some kind of variation of venture, where the exit section is omitted. The approach section is bell shaped with cylindrical throat because of its curved inlet the flow nozzle has a very high discharge coefficient it is close to unity.

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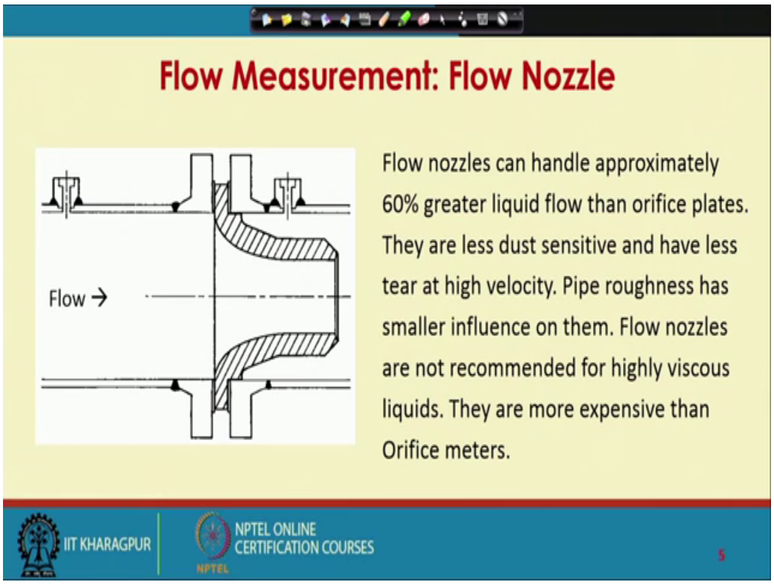

Flow nozzles can handle approximately 60 percent greater liquid flow than orifice plates, they are less dust sensitive and have less tear at high velocity. Remember that we talked about the dependency or sensitivity of the orifice plates to the flow, which has suspended particles because the sharp edge orifice plates can undergo wear and with that can change the calibration because it can change the discharge coefficient.

The flow nozzles are less dust sensitive and have less tear at high velocity pipe roughness has smaller influence on them flow nozzles are not recommended for high viscous liquids they are more expensive than orifice meters.

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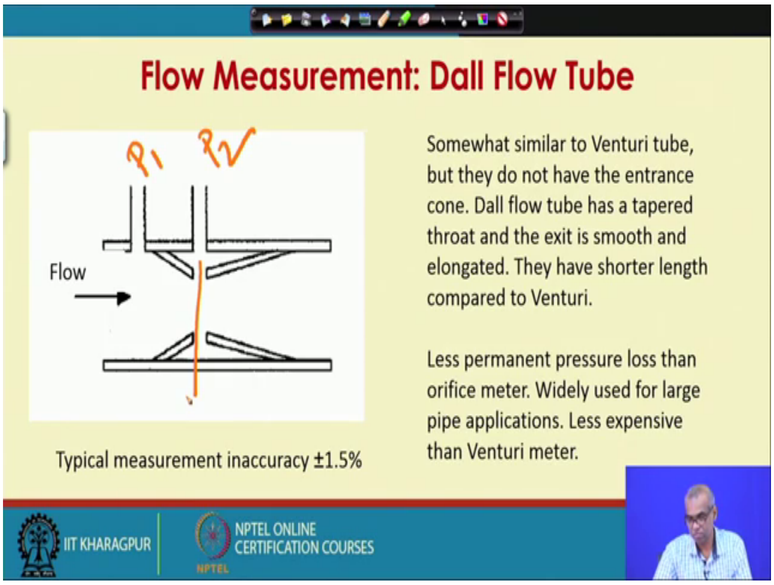

Dull flow tube this is somewhat similar to Venturi tube, but they do not have the entrance cone. Dull flow tube has a tapered throat and the exit is smooth and elongated, they have shorter lengths compared to Venturi. So, you see the exit is smooth and elongated, there is less permanent pressure drop compared to orifice meter, it is widely used for large pile applications and it is of course, less expensive than Venturi meter. So, this is somewhat similar to Venturi tube, but much simpler to Venturi tube and less expensive than less expensive than Venturi meter.

The typical measurement in equivalency is plus minus on1.5 percent whereas, for Venturi meter the inaccuracy is about plus minus 0.5 percent. Again you have 2 pressure connections 1 is upstream here the another 1 is right near the throat.

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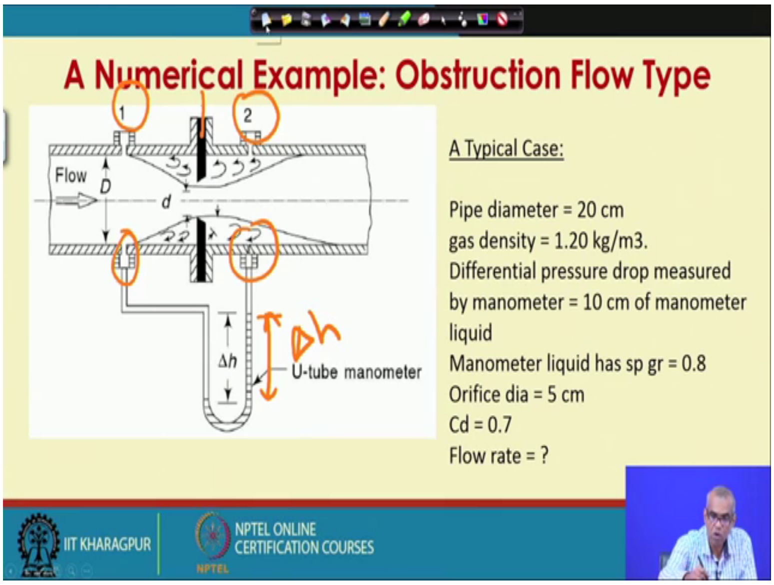

Now, we have talked about the flow abstractions, flow meter flow measuring instruments. We have talked about orifice meter Venturi meter, flow nozzles and dull flow meters. In all these instruments there is a flow restriction whose area is accurately known. Then the resulting pressure drop is measured using a differential pressure gauge. It may be as simple as manometer for simple applications in laboratory or you can also use dp cells or any other pressure transducers which can measure differential pressure.

Then we make use of Bernoulli's equation to relate the flow rate to the measured pressure drop. Now we will take a typical numerical example which is applicable to all such flow measuring instruments. It may be orifice meter, in may be Venturi meter, it may be flow nozzle all flow measuring instruments which are obstruction type; that means, there is a flow restriction and you measure the flow rate by measuring the pressure drop across the flow restriction of known area. So, what the schematic source is an orifice, but the problem that we talked about is applicable to orifice Venturi flow nozzle dull everything all such for obstruction type flow meters.

So, a typical case is like this, you know the pipe diameter, you know the fluid that is flowing you know the density of the fluid that is flowing through the pipe. So, imagine you are measuring the flow rate of a fluid flowing through a pipe using any of these obstruction type flow meters. So, you know the pipe diameter, you know the density of the fluid that is flowing through the pipe. Let us say we are measuring the differential pressure drop or the pressure drop by a manometer. So, you will get a reading in terms of say inches of mercury or centimeter or manometer fluid, then you need to know the manometer liquids density or specific gravity and of course, you will know the diameter of the flow restriction.

Let us say if it is orifice I know the orifice diameter, if it is Venturi I will know the diameter of the Venturi throat. We will need to know the discharge coefficient of the flow meter. Now knowing all these things how do I calculate the flow rate. So, let us take a typical example where I am measuring the flow rate of a fluid which is gas here let us say, which is passing through this orifice plate. The pipe diameter is 20 centimeter, the density of the fluid is 1.20 kg per meter cube, the pressure drop I measure using a manometer is 10 centimeter of manometer liquid. Manometer liquid maybe some oil let us say.

The manometer liquid has specific gravity 0.8. The orifice diameter is 5 centimeter discharge coefficient is 0.7. So, what is the flow rate? So, what I will do is, I have this pressure connections 1 and 2 and I have put this I put both the limbs of the manometer to these ports and the manometer shows me this delta h. So, now, let us see how we solve this problem.

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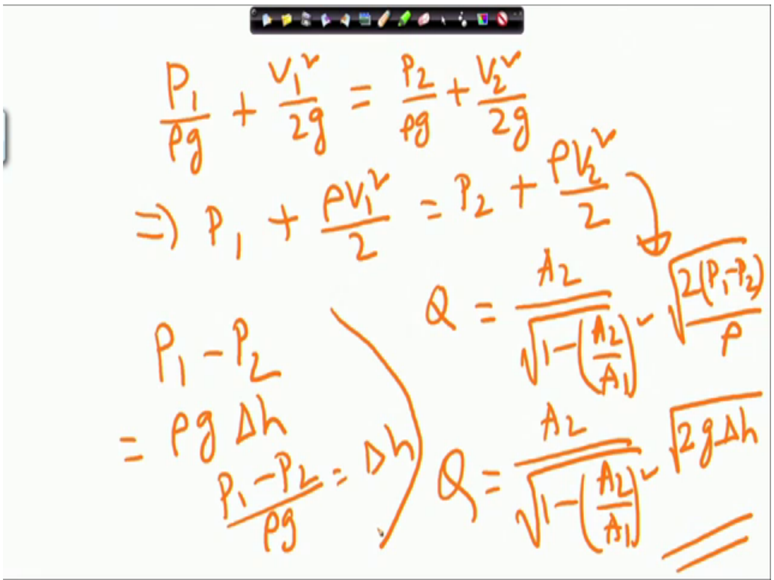

So, between point 1 and point 2 if I write the Bernoulli's equation P 1 by rho g plus v 1 square by 2 g will be equal to P 2 by rho g plus V 2 square by 2 g the flow meter is at horizontal position. So, there is no contribution of h term here if you multiply this equation throughout by rho g I will get P 1 plus rho V 1 square by 2 equal to P 2 plus rho V 2 square by 2.

P 1 minus P 2 can be written as rho g delta h, the differential pressure head delta h can be written as P 1 minus P 2 equal to rho g into h. Now this equation when coupled with the continuity equation e 1 V 1 equal to a 2 V 2, we know that we will obtain Q equal to A 2 by 1 minus A 2 by A 1 whole square into 2 into P 1 minus P 2 by rho. Of course, this can be corrected by multiplying the discharge coefficient term cd, but the point we want to make here is this P 1 minus P 2 term, if it is expressed in terms of the same fluids lane that is flowing through the tube, I will be able to write P 1 minus P 2 by rho g equal to delta h.

So, this equation then can be written as A 2 by 1 minus A 2 by A 1 whole square into 2 g h. P 1 minus P 2 by rho is P 1 minus P 2 by rho is g times delta h. So, this is the equation I can get.

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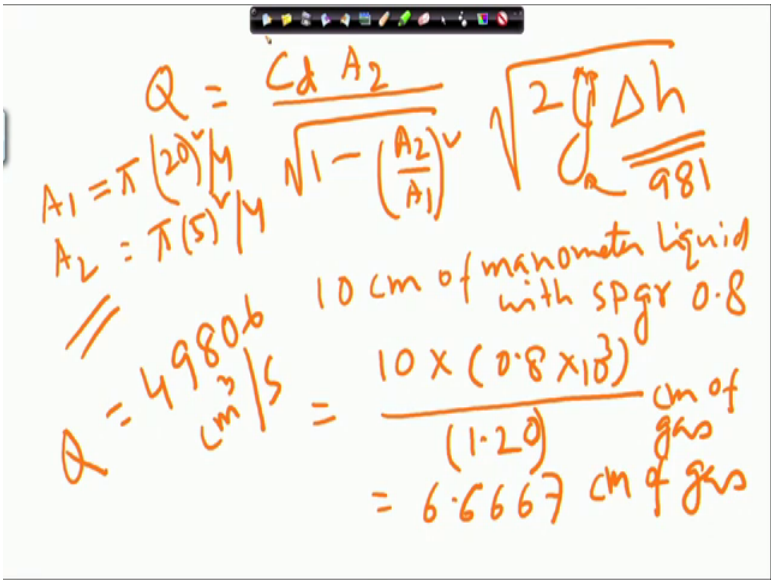

Now, we apply this equation as applicable to the problem. So, what I get is Q is A 2 by 1 minus A 2 by A 1 whole square into 2 P 1 minus P 2 by rho that can be written as 2 g and delta h.

Now, I have been given the pipe diameter is 20 centimeter and the nozzle diameter is 5 centimeter. So, if pipe diameter is given as I can find out this A 1 A 2 term. A 1 term can be find out as pi d square by 4. So, pi 5 centimeter is the dai sorry the 20 centimeter is the pipe dia by 20 square by 4. A 2 is the noz for orifice dia A 2 is the orifice or nozzle or the Venturi throat dia which is given as 5 centimeter. So, pi d square by 4. So, these terms now will be obtained how do I get delta h.

So, the pressure differential indicated by the manometer fluid, pressure difference indicated by the manometer fluid is 10 centimeter of manometer liquid, which has specific gravity 0.8. This is same as centimeter of the gas that is flowing through the flow meter. So, this will come out as 6.6667 centimeter of the gas or fluid that is flowing through the flow meter.

Now, Q equal to this Cd times A 2 by this into 2 gh. So, this I have calculated in terms of now centimeter of the gas that is flowing through the fluid, g is given as 981 centimeter per second square and A 1 A 2 are calculated from here C d is given as 0.7. So, Q can be obtained by putting all these values and if you do that you will get Q as 49806 centimeter cube per second. So, this is how you will be able to calculate the flow rate for all this obstruction flow obstruction type flow meters that we have talked about so far.

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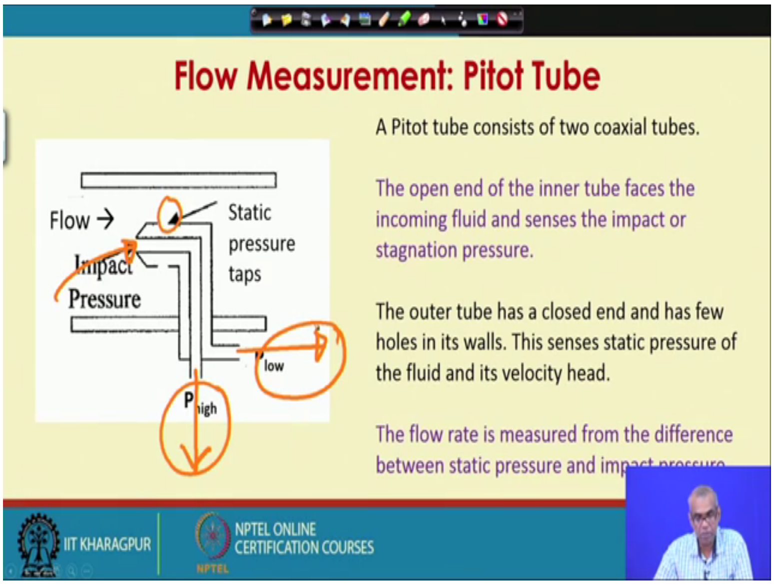

Now, let us talk about another instrument known as pitot tube. The pitot tube consists of two coaxial tubes. So, this is a pitot tube, please note that there are two coaxial tubes.

The open end of the inner tube faces the incoming fluid and senses the impact or the stagnant stagnation pressure. So, this is the stagnation pressure or impact pressure. So, this is a total pressure, the open end of the inner tube faces the incoming fluid and senses the impact or stagnation pressure. The outer tube has closed end and has few holes in its wall these senses static pressure of the fluid and its velocity head.

So, pitot tube consists of two coaxial tubes, the inner tube faces the incoming fluid and this faces this senses the impact pressure or the stagnation pressure. The outer tube has holes in its wall and this senses static pressure of the fluid and is velocity head.

The flow rate is measured from the difference between static pressure and impact pressure. So, this is the inner tube and faces impact pressure, these are the holes on the outer tube which measure static pressure and so, impact pressure and static pressure is higher. So, this is the pressure connection for higher pressure to the differential pressure gauge and this is the lower side of the pressure which measures the static pressure.

So, basically you now have to attach this pitot tube to a manometer or to a dp cell or to a pressure measuring instrument that measures differential pressure. So, the inner tube is the high pressure connection and the outer tube which measure static pressure that is the lower pressure connection. The flow rate is measured from the difference between this impact pressure or the stagnation pressure and static pressure.

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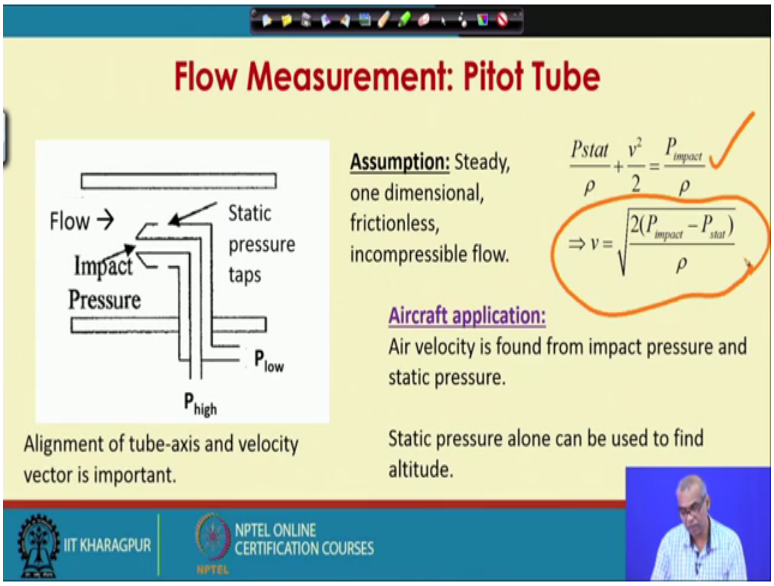

Again we making use of Bernoulli's equation the assumptions, we make we make is usual steady flow, one dimensional flow frictionless and incompressible flow. So, if I apply Bernoulli's equation, I will write static pressure divided by rho plus v square by 2 is impact pressure divided by rho, from which after rearrangement we can get an expression of velocity as follows.

So, velocity equal to square root of 2 into impact pressure minus static pressure divided by density of the fluid. Pitot tube finds an interesting application in aircraft or missiles air velocity is found from impact pressure and static pressure. Static pressure alone can be used to find altitude of the aircraft or missile. Remember that alignment of tube axis velocity vector is important for proper functioning of pitot tube.

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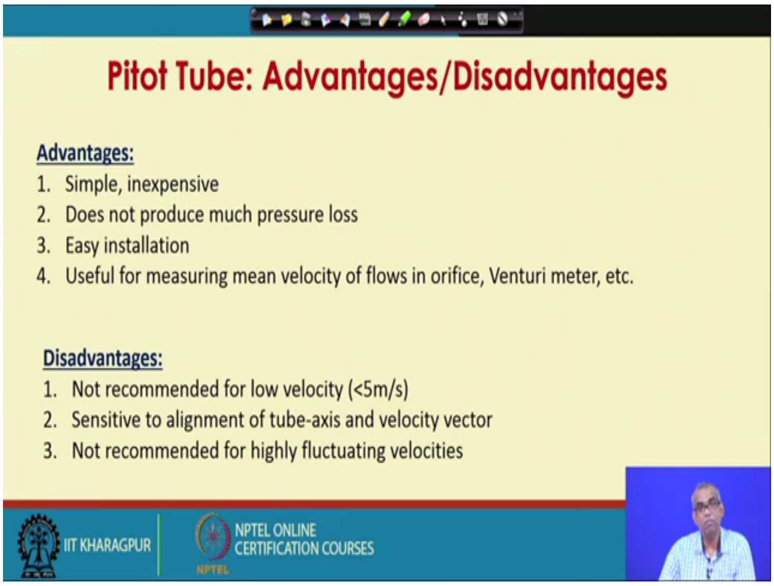

Here are some advantages and disadvantages of pitot tube. Pitot tube is simple inexpensive does not produce much pressure loss, it has easy installation pitot tube is also useful for measuring mean velocity of flows in orifice Venturi meter etcetera. The disadvantages are as follows, this is not recommended for low velocity; velocity lower than 5 meter per second, what will happen is this under such situations measuring the pressure difference will be difficult.

The functioning of pitot tube is sensitive to alignment of two axis and the velocity vector, pitot tube is also not recommended for highly fluctuating velocities.

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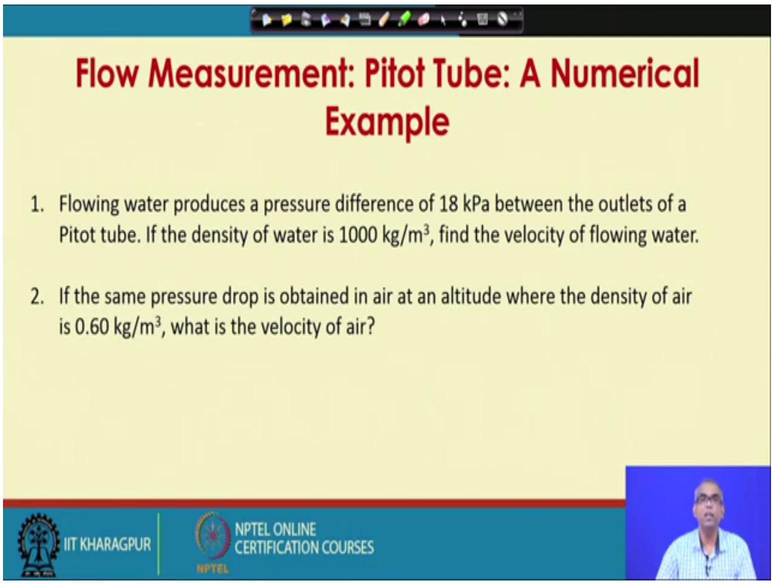

Now, let us take a numerical example on pitot tube. Let us say water is flowing and I am using a pitot tube to measure the velocity of the flowing water. Flowing water produces a pressure difference of 18 kilopascal between the outlets of a pitot tube. So, the pressure difference between the inner tube connection and the outer tube connection is 18 kilopascals. If the density of the water is given as 1000 kg per meter cube, what is the velocity of the flowing water?

So, I am measuring the velocity of a flowing water using a pitot tube, and it has produced a pressure difference of 18 kilopascals, the density of the water is 1000 kg per meter cube what is the velocity of the flowing water. So, how do I solve this problem?

The first thing that we do is, let us write down what are the information's that are available.

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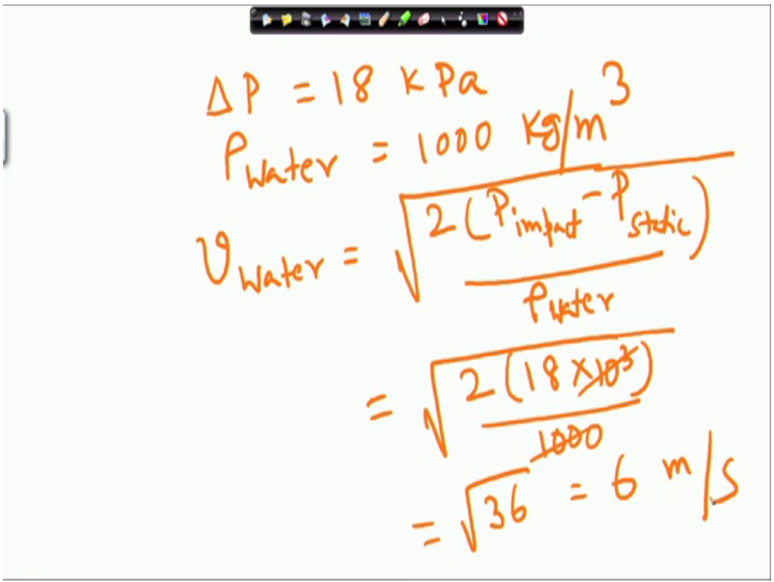

The information that is available is pressure difference between the outlets of the pitot tubes inner tube and outer tube, which measures the two pressures namely stagnation pressure impact pressure and static pressure. Delta P is given as 18 kilopascal; density of water is given 1000 kg per meter cube.

So, let us make use of the equation velocity of water, which is square root of 2 into impact pressure minus static pressure divided by density of water. So, we know all these values 18 kilopascal which is; 18 into 10 to the power 3 Pascal and density of water is given as 1000 kg per meter cube. So, this this cancels out. So, this is 2 into 18 36. So, this is 6 meter per second is the velocity of water.

So, the next part is, if the same pressure drop is obtained in air at an altitude where the density of air is 0.6 kg per meter cube, what is the velocity of the air. So, basically the same problem, now instead of water we have air and again the pressure drop is same 18 kilopascals. So, you have to find out the velocity of the air. If the same pressure drop is obtained in air at an altitude, where the density of air is 0.6 kg per meter cube what is the velocity of air?

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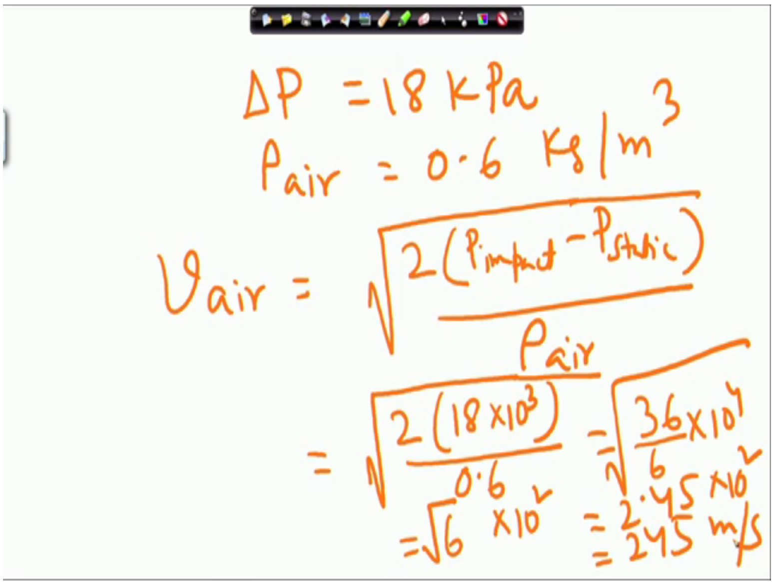

So, you can find it exactly same way again delta P is given as 18 kilopascal and density of air is given as 0.6 kg per meter cube. So, velocity of air is again impact pressure minus static pressure divided by density of air. So, 2 into 18 into 10 to the this is Pascal and density of air is given as 0.6 kg per meter cube. So, this becomes. So, this becomes 36 by 6 10 to the power 4 square root, which becomes 6 square root of 6 into 10 square square root of 6 is roughly say 2.45 into 10 square.

So, it becomes 245 meter per second. So, the velocity of the air is obtained as 245 meter per second. So, this is a straightforward application for the equations of the pitot tube.

So, we will stop our discussion on flow measuring instruments that are based on rest flow restriction type. So, we have talked about orifice plate, Venturi tube, flow nozzles dull type flow meter as well as pitot tube.