Chemical Process Instrumentation
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Lecture – 42
Flow Measurement
(Contd.)

Welcome to lecture 42. This is week 9 and we are talking about flow measurements in your previous lecture, we have seen some sort of classification of flow measuring instruments based on the principle on which they work and we have also briefly talked about Bernoulli's principle.

Now, one the first classification that was indicated was flow measuring instruments based on fixed area, but variable pressure drop. So, if you allow a flow to pass through a flow restriction of known area, then what will happen is there will be a pressure drop across the flow restriction. This pressure drop depends on the diameter of the pipe through which the fluid is flowing it depends on the flow restriction, it also depends on the flow rate.

Now, given a pipe diameter, given a flow restriction the pressure drop becomes dependent on flow rate only. So, thus if I allow a fluid to flow through a flow restriction of known area and I measure the pressure drop using pressure measuring instruments we are familiar with those pressure measuring instruments now.

So, we have to measure differential pressure here. So, there will be two pressure ports on both sides of the flow restriction. So, if I allow a fluid to pass through a flow restriction of known area and take help of a pressure gauge that can measure differential pressure say a dp cell, then I can relate the flow rate with the measured pressure drop.

So, this is the principle on which flow measuring instruments there will be several flow measuring instruments which will use this principle you can make use of Bernoulli's equation and find out have a relationship between the flow rate and the pressure drop.

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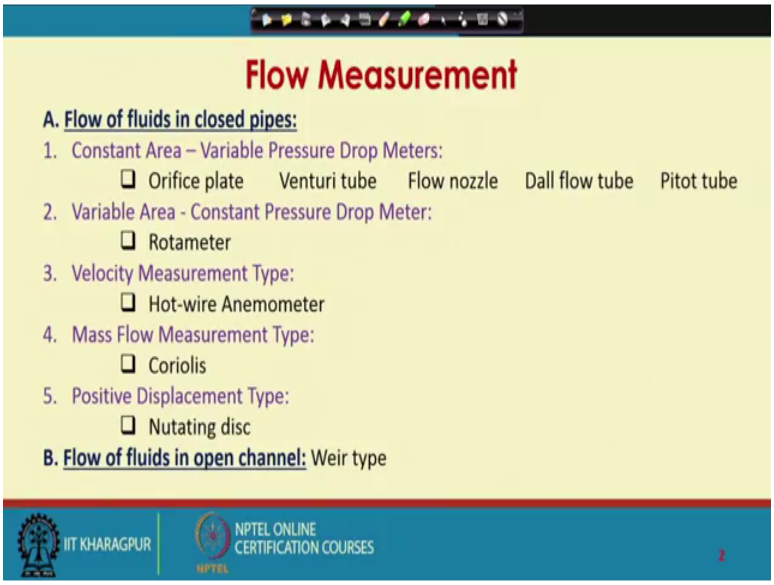

So, this was our classification in our; we discussed in our previous class. So, we have constant area or fixed area variable pressure drop meters.

So, we will start our discussion with such a measuring instruments and specifically how we will first start orifice plate and then we will talk about Venturi tube.

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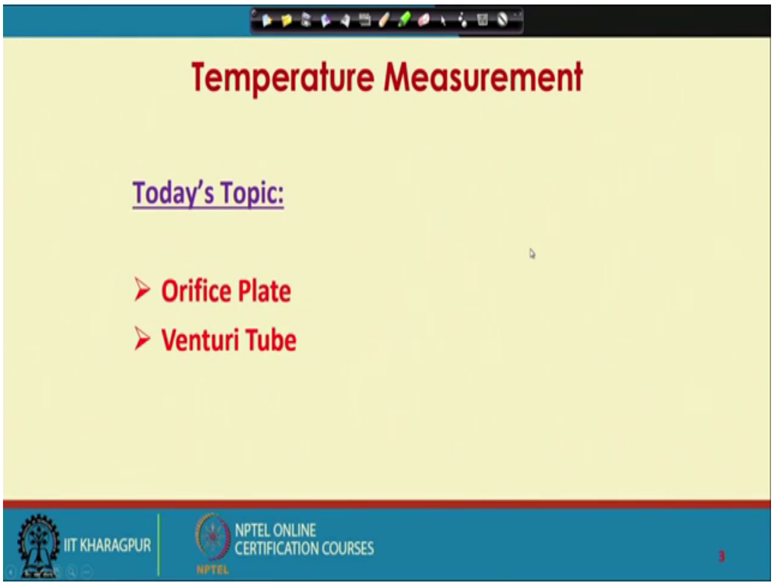

So, today's topic will be Orifice plate and Venturi tube these are also known as orifice meter or venturi meter.

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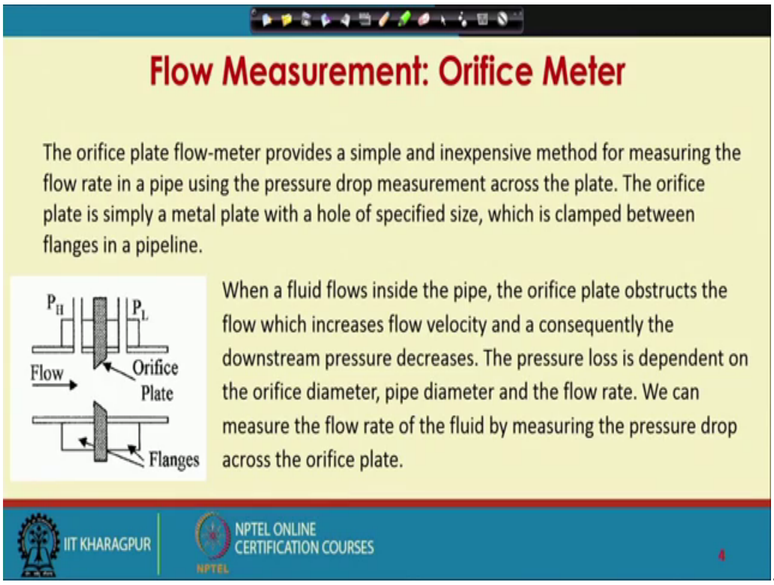

The orifice plate flow meter provides a simple and inexpensive method for measuring the flow rate in a pipe using the pressure drop measurement across the plate. The orifice plate is simply a metal plate with a hole of specified size which is clamped between flanges in a pipeline. So, this is the pipeline through which a fluid is showing and I have inserted this orifice plate with help of flanges. So, this orifice plate is nothing, but a metal plate with a hole of specified size and also in a specific position, as we see just now and this orifice plate is clamped between flanges in the pipeline.

So, when the fluid passes through it as it meets the restriction the velocity increases and consequently the pressure decreases. So, there is one connection for pressure measurement there is another connection for pressure measurement. So, we measure the pressure drop across the orifice plate and I can relate this pressure drop with the flow rate of the fluid. So, when a fluid flows inside a pipe the orifice plate obstructs the flow which increases flow velocity and consequently the downstream pressure decreases. So, this is upstream and this is downstream.

The pressure loss is dependent on the orifice diameter pipe diameter and the flow rate, but for a given pipe diameter a given orifice meter or a given orifice plate the pressure locks becomes dependent on the flow rate. So, we can measure the flow rate of the fluid by measuring the pressure drop across the orifice plate and we can take help of a pressure measuring instrument that measures differential pressure to measure the pressure difference across the orifice plate.

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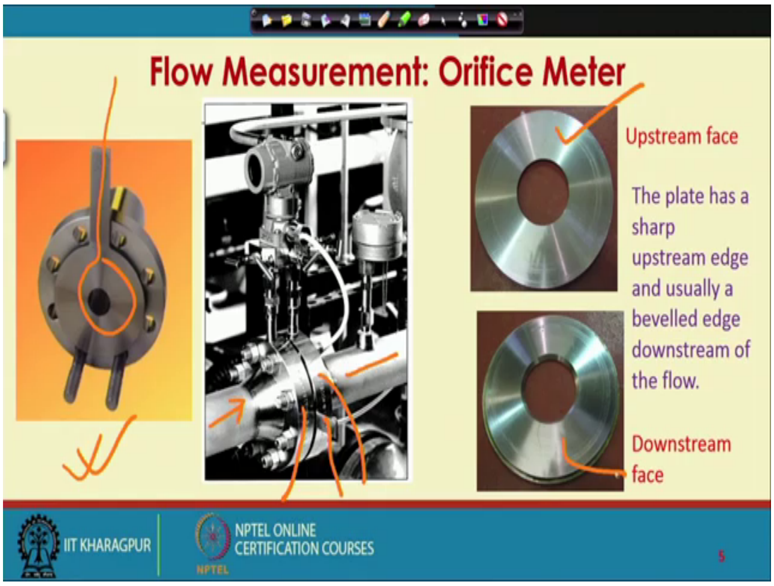

So, this is images of orifice plate. So, this is orifice plate you can see the orifice plate you can see the whole. So, this is flange. This is the pipeline through which fluid is flowing may be fluid is flowing in this direction and this is the orifice plate that has been inserted in between the flange. So, this is the upstream face of the orifice plate and this is the downstream face of the orifice plate.

So, the fluid approaches the upstream face and leaves the downstream face the plate has a sir upstream edge and usually a beveled edge downstream of the flow.

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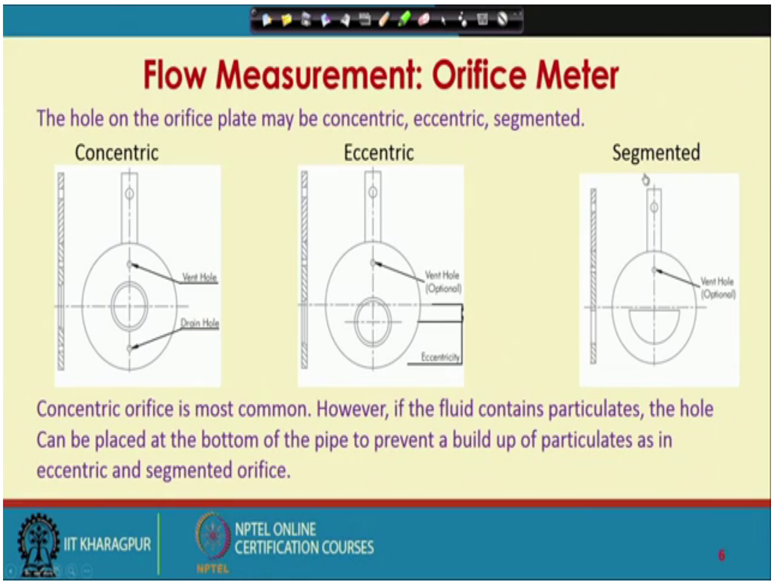

Now, we have said that orifice plate is nothing, but a metal plate with a hole in it and the hole is of specific size and the hole is located in a specific position of the plate the hole on the orifice plate maybe concentric eccentric and segmented.

So, this is a schematic of concentric orifice plate this is the most common one this is eccentric one note. The location of the hole is centrally located here, but here the whole is not located centrally, but towards the lower half of the plate and this is the segmented orifice plate. So, this is also a case where the hole in the orifice plate is located towards the lower half of the plate.

Concentric orifice is most common; however, if the fluid contains particulate; that means, fine particles the hole can be placed at the bottom of the pipe to prevent a buildup of particulates as an eccentric and segmented orifice.

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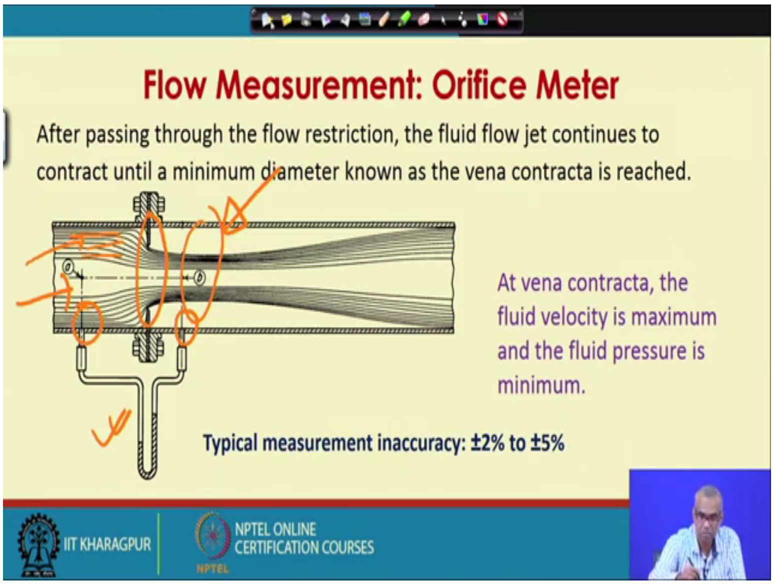

So, again the schematic shows an orifice plate here the fluid flows in this direction you have 2 pressure trappings for measurement of pressure one on the upstream and on the on the downstream. So, I have attached a manometer for measurement of differential pressure you can measure dp cell or any pressure measuring instruments that can measure the pressure difference. Now, when the fluid passes through the flow restriction the fluid flow rate continues to contract until a minimum diameter known as when a contractor is reached.

So, look at the fluid flow jets. Now as it approaches the flow restriction the flow jet contracts, but it is contacts even after leaving to some extent let us say around here and then again it increases. So, after passing through the flow restriction the fluid flow jet continuous to contract until a minimum diameter known as vena contracta is reached. So, this is vena contracta. So, at vena contracta the fluid velocity is maximum and the fluid pressure is minimum the typical measurement in accuracy by an orifice meter is plus minus 2 percent, but sometimes it can go as high as plus minus 5 percent.

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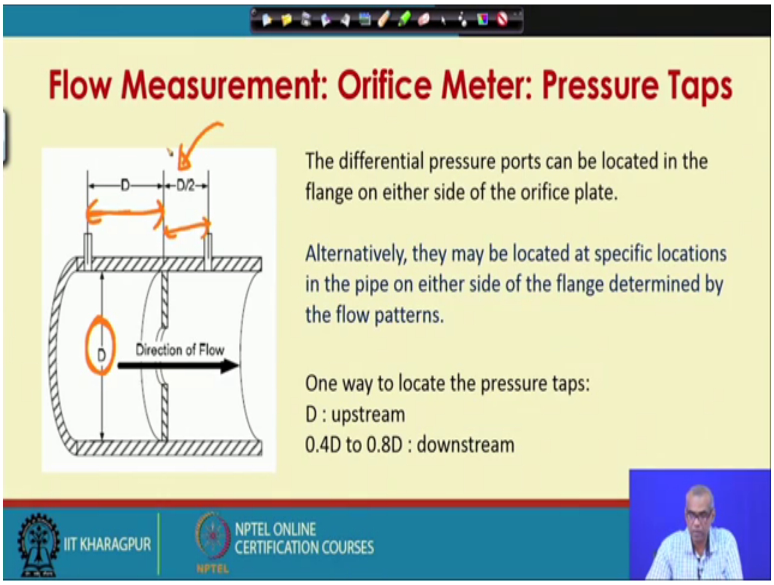

Now, to measure the flow rate using orifice meter we have to measure pressure drop across the orifice plate. So, where do I look at my pressure test the differential pressure ports can be located in the flange on either side of the orifice plate alternatively, they may be located at specific locations in the pipe on either side of the flange determined by flow patterns for example, at vena contracta one common way or one common convention that is followed to locate the pressure test is as follows.

Imagine the diameter of the pipe is D, then in the upstream one pressure tap is located D unit away from the orifice plate now and on the downstream, it is located 0.4 to 0.4 times of the diameter away from the orifice plate very commonly, it is half of the diameter distance away from the orifice plate. So, if this diameter is represented by D, this distance is D and this distance is D by 2. So, it generally varies anywhere between 0.4 D to 0.8 D.

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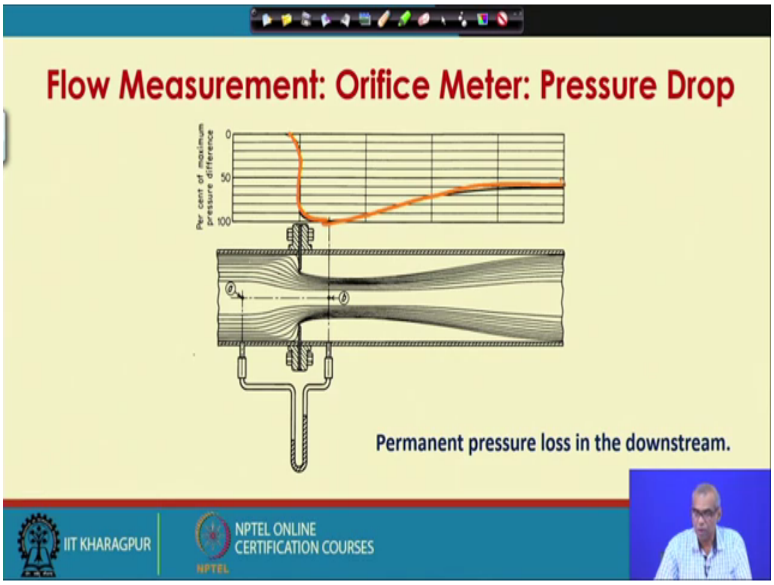

Now, when the fluid approaches the orifice plate the velocity increases and the pressure decreases if you plot the percent of maximum pressure difference along the distance, you see a graph like this, what it basically indicates that there is a permanent pressure loss in the downstream. So, the pressure is not recovered as the fluid passes to flow restriction velocity increases and pressure decreases. So, kinetic increases, but pressure energy decreases, but then the recovery of the pressure is poor here. So, there is permanent pressure loss in the downstream.

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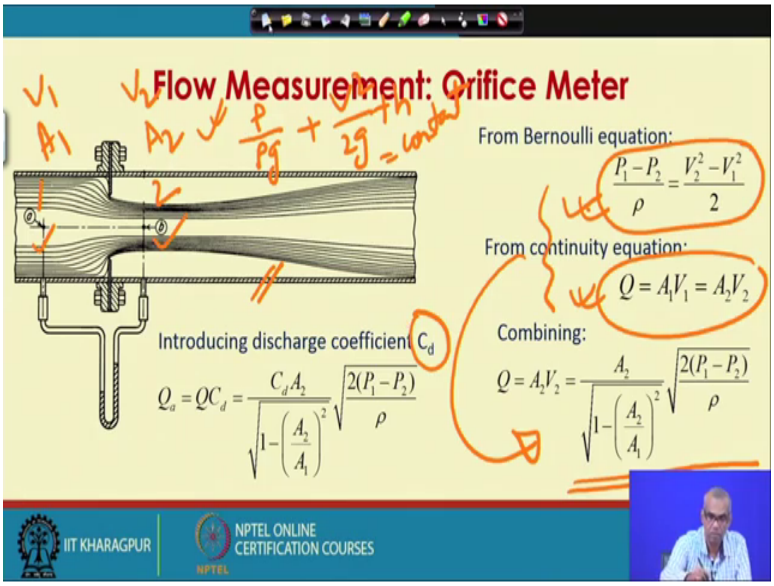

So, how do I measure flow using orifice meter in your previous class we have talked about Bernoulli's equation. So, here you can have derived an expression by step forward application of Bernoulli's equation. So, if you apply Bernoulli's equation, let us say between point 1 and point 2 you will get any questions like this after rearrangement what was the Bernoulli's equation it was P by rho g plus v square by 2 g plus h equal to constant. So, here h on both sides is same.

If you apply this only if we apply this 2 point 1 and point 2, it will be P one by rho g plus V 1 square by 2 g plus h 1 equal to P 2 by rho g plus V 2 square by 2 g plus h 2. Now h 1 equal to h 2 here because the orifice plate is placed horizontally so, after rearrangement you will get this equation which is Bernoulli's equation as applicable in this case.

From continuity equation you can write that the flow here is equal to flow here. So, if the area here is A 1 and the area here is A 2 and the velocity here is V 1 and the velocity here is V 2, I can write Q equal to A 1 V 1 equal to A 2 V 2 where Q is my volumetric flow rate now you combine this and this and you get an equation for flow rate as this basically what you do is Q equal to A 2 V 2 and using this equation you can now get this final form of the volumetric expression for volumetric flow rate.

Now, this equation gives you theoretically a maximum possible flow rate. So, this is an ideal situation this is the maximum flow rate that can be obtained theoretically, but in practice the flow rate will be less than the predicted by this theoretical expression because of the assign because of the assumptions that we make when we apply the Bernoulli's equation the flow is not ideal.

So, it will be taken care of by introducing a discharge coefficient which is generally represented by term C d. So, the actual flow rate will be corrected as Q a equal to QC d where Q is this actual one sorry and sorry Q is the ideal one and Q a is actual one. So, the actual flow rate is corrected actual flow rate is ideal flow rate Q multiplied by a discharge coefficient C d.

So, the final expression is this. So, basically you multiply this equation by discharge coefficient C d this term C d by square root of one minus A 2 by A 1 whole square is called flow coefficient.

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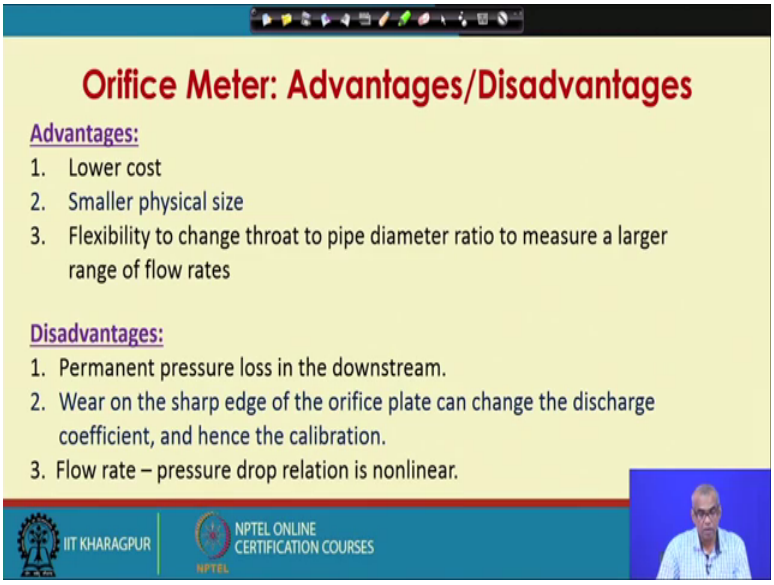

Orifice meter is widely used flow measuring instrument it has several advantages such as low cost, smaller physical size, flexibility to change throat to pipe diameter ratio to measure a larger range of flow rates.

However, there are some disadvantages as well there is permanent pressure loss in the downstream where on sharp age of the orifice plate change the discharge coefficient and hence can change the calibration after prolonged use orifice or when I use the orifice plate for a hot for a long time to measure flow rates of flows which has suspended particles in it. There can be wear on the surface of the orifice plate and this will change the discharge coefficient and hence the calibration. Flow rate pressure relationship is non-linear.

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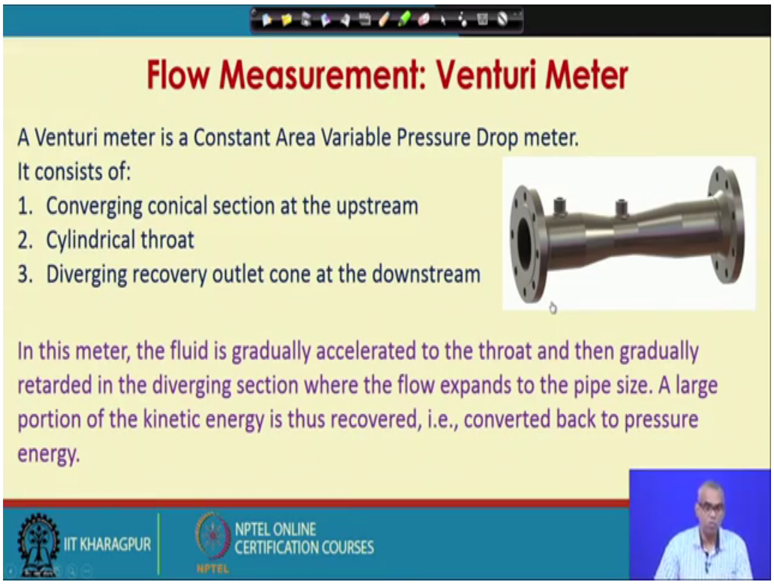

Now, let us talk about another flow measuring instrument which uses the same principle such as flow through a fixed area and then measure the resulting pressure drop across the flow restriction.

We will talk about Venturi meter; a venturi meter is the constant area variable pressure drop meter similar to orifice meter, it consist of a converging conical section at the upstream let us say this is the direction of the flow. So, this is the converging conical section at the upstream this is a cylindrical throat and then diverging recovery outlet come at the downstream.

So, a venturi meter consist of a converging conical section a cylindrical throat and a diverging cone in this meter the fluid is gradually accelerated through the throat and then gradually retarded in the diverging section where the flow expands to the pipe size a large portion of the kinetic energy is thus recovered that is converted back to pressure energy.

So, here pressure recovery is good. So, there is not much permanent loss of pressure is case of venturi meter this is in such contrast to the orifice meter this is possible because the venturi meter has a diverging recovery outlet cone in the downstream.

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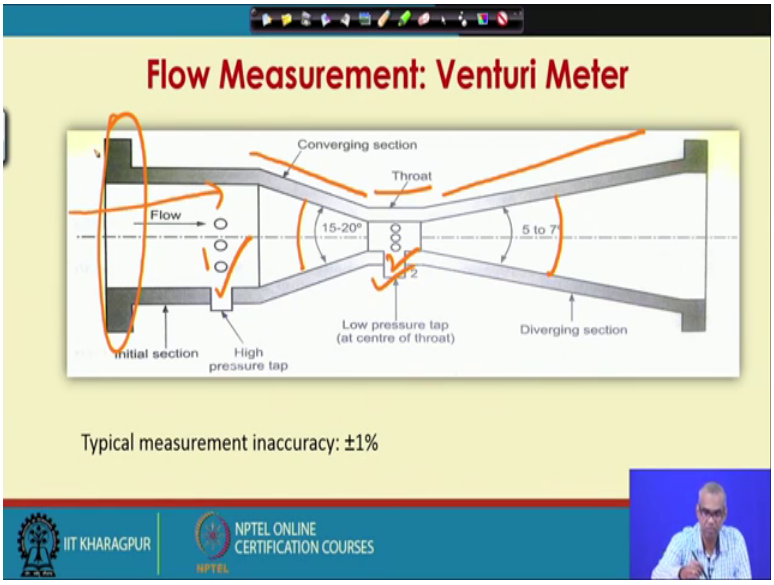

So, this is a typical dimensions of a venturi meter you have the converging section and you have the throat and you have the diverging section these angle is typically around 15 to 20 degree and this angle is typically 5 to 7 degree you have 2 pressure ports, this is one connection for measurement of pressure the other connection for measurement of pressure is located at throat the fluid flow direction is this. So, this side the pressure is high this side pressure is low. So, we have the high pressure tap here and the low pressure tap is at the center of the throat and this is the pipe the initial section to which the venturi meter has been joined.

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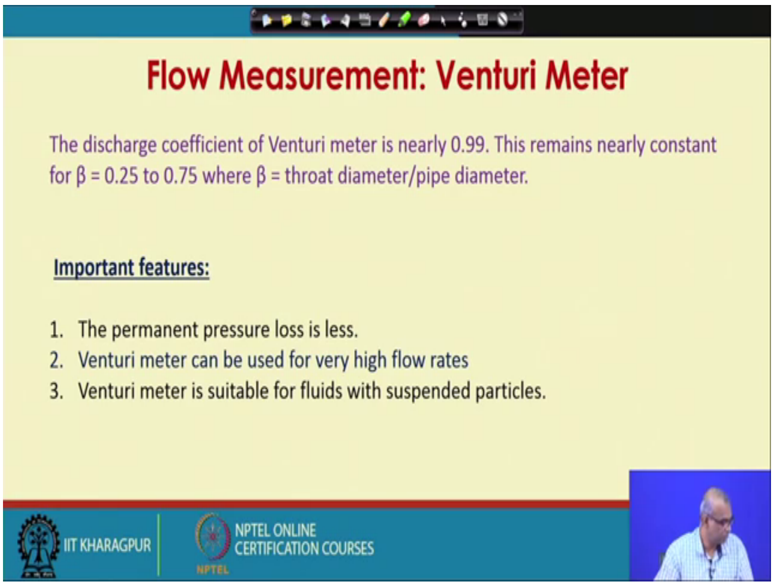

The discharge coefficient of venturi meter is nearly 0.99, this remains nearly constant for beta equal to 0.25 to 0.75 where beta is ratio of throat diameter to pipe diameter, here are some important features of venturi meter the permanent pressure loss is less venturi meter can be used for very high flow rates venturi meter is suitable for fluids with suspended particles.

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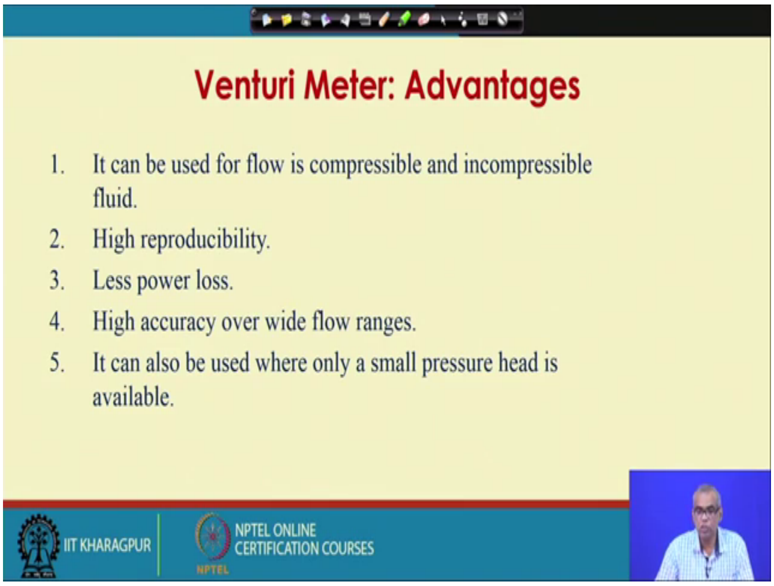

Advantages of venturi meter; it can be used for flow that is compressible and incompressible, it has high reproducibility, less power loss, high accuracy over wide flow ranges. It can also be used where only small pressure head is available.

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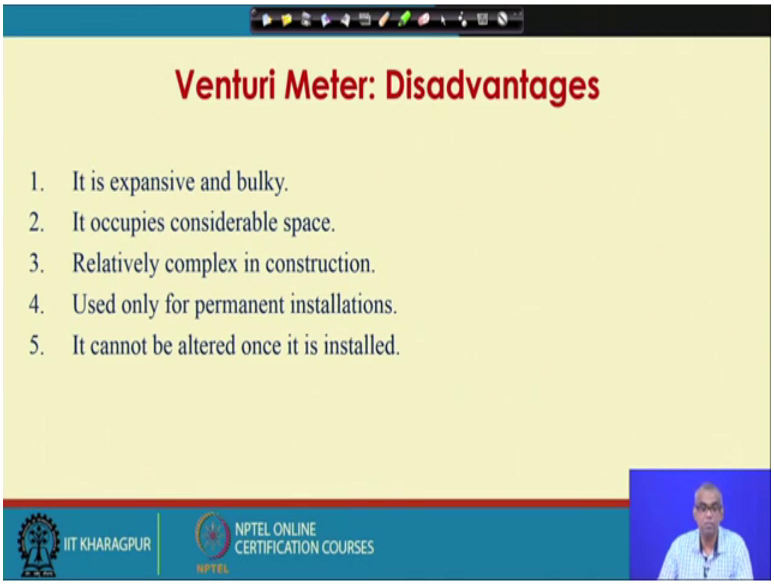

Disadvantages venturi meter is much more expensive than orifice plate it is bulky also, it occupies considerable space; is relatively complex construction compared to orifice plate. Venturi meter is used only for permanent installations; once it is installed it cannot be altered easily.

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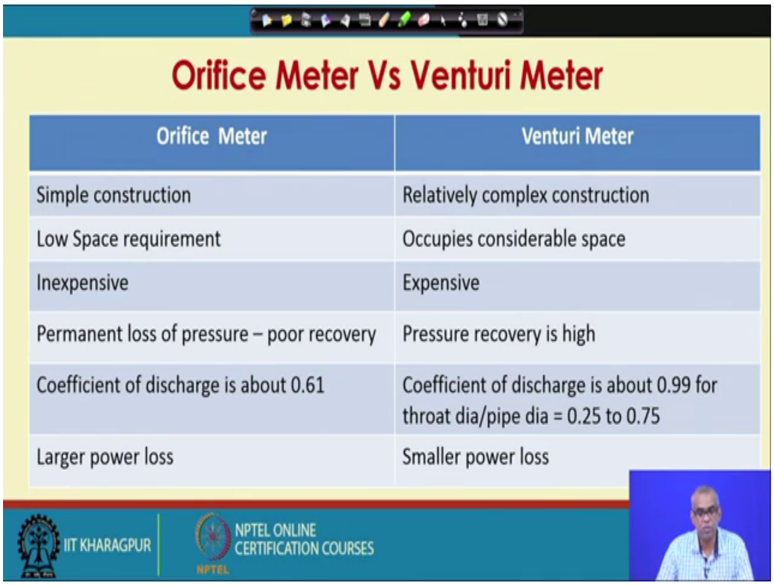

Here is some comparison between orifice meter and venturi meter orifice meter as simple construction, venturi meter has relatively complex construction. Orifice meter takes less place, venturi meter occupies considerable space. Orifice meter is inexpensive, venturi meter is relatively much more expensive. In case of orifice meter there is permanent loss of pressure, there is poor recovery of pressure. In case of venturi meter pressure recovery is high.

In case of orifice meter coefficient of discharge is about 0.61, for several orifice meters although this value depends on Reynolds number as well. In case of venturi meter the coefficient of discharge is about 0.99 for throat dia by pipe dia equal to 0.25 to 0.75. Orifice meter; larger power loss, venturi meter; smaller power loss.

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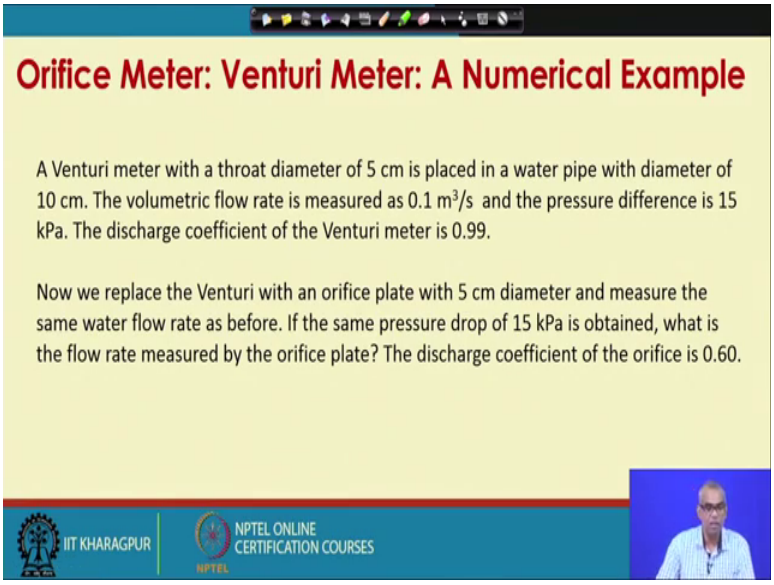

Now, let us take a simple numerical example which involves measurement of flow with orifice meter and venturi meter. The problem is as follows a venturi meter with a throat diameter of 5 centimeter is placed in a water pipe with diameter of 10 centimeter. The volumetric flow rate is measured as 0.1 meter cube per second and the pressure difference is 15 kilopascal.

The discharge coefficient of the venturi meter is 0.99. Now we replace the venturi with an orifice plate with 5 cm diameter and measure the same water flow rate as we pour; that means, water flow is still at point 1 meter cube per second. If the same pressure drop 15 kilo Pascal is obtained, what is the flow rate measured by the orifice plate the discharge coefficient of the orifice plate is given as 0.60. So, the problem is as follows you have a venturi meter of diameter 5 centimeter it has discharge coefficient 0.99 and you are measuring a flow which is point 1 meter cube per second.

So, venturi meter measuring a flow point 1 meter cube per second; now I measure the same flow with orifice of 5 cm diameter note that venturi meter throat has diameter 5 centimeter. The orifice plate also have 5 centimeter diameter, I am measuring the same flow rate the same pressure drop exists. So, what will be the flow rate by the; what will be the flow rate measured by the orifice plate the discharge coefficient of orifices is 0.60.

So, the throat dia of venturi and the orifice plate is same both has 5 centimeter in both the cases same pressure drop measuring the same flow rate coefficient of discharge coefficients at different of course. So, how do I solve this problem?

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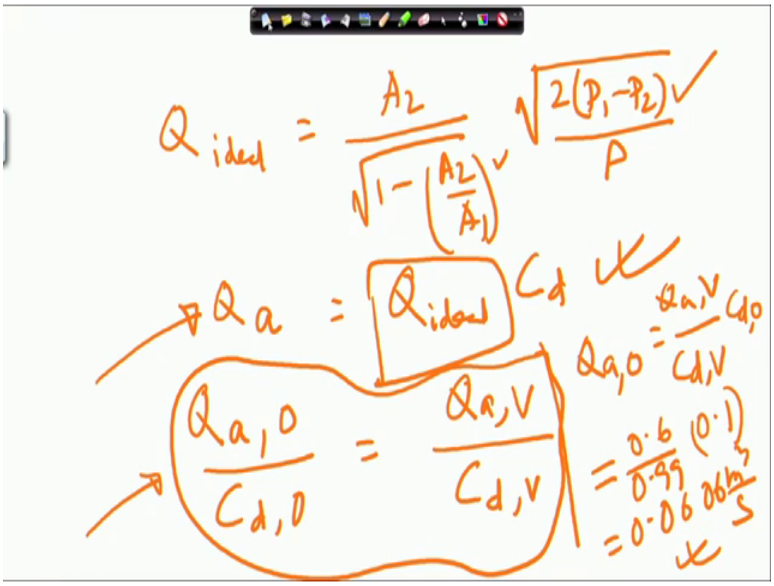

Now, if you remember the ideal flow rate was A 2 divided by 1 minus A 2 by A 1 whole square 2 P 1 minus P 2 by rho and actual flow rate is corrected as Q I dl multiplied by discharge coefficient.

Now, in this case everything is same the situation everything is same the same pressure drop the same flow I measuring which is point 1 meter cube per second. So, if I apply this I can write two equations. So, this I can write for orifice this I can also write for venturi. So, I write this equation for venturi I write this equation for orifice, but this is same for both same flow. So, what we will get is Q a actual flow measured by orifice divided by C d orifice will be equal to Q actual measured by venturi C d by venture.

So, from this I can get Q actual orifice as Q actual venturi divided by C d into venturi multiplied by C d into orifice. So, now, you put all the values C d orifice 0.6 C d venturi 0.99 and the flow rate 0.1 meter cube per second and this will turn out as 0.0606 meter cube per second.

So, basically you apply this equation for both orifice meter and venturi meter and then since you are using the same flow rate, you will get this relationship because you will see that when you equate the flow rates, you will be getting this equation from that you can easily find out the flow rate because out of this four terms three are known.

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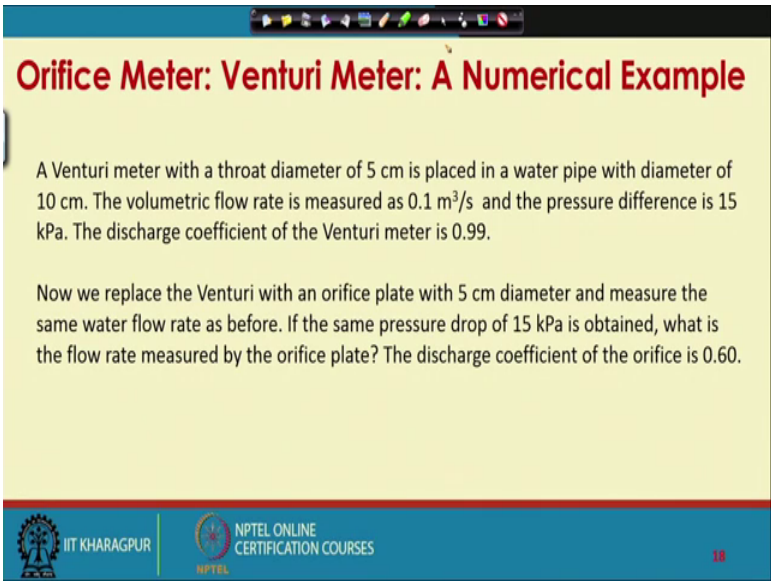

So, now we will stop our discussion on orifice meter and venturi meter here.