Industrial Instrumentation
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Lecture - 12
Flowmeter – I

Welcome to the lesson 12 of Industrial Instrumentation. In this lesson, we will basically study flowmeters. As you know, the three basic process parameters are pressure, temperature and flow. However, if you look at the number of sensors available or the varieties of the, varieties of the particular process parameters like pressure, temperature is much less compared to the flow. The reason is that the flow you will find, I mean not only the, the type of liquid flowing through the pipe or it also basically depends on the what type of liquid is flowing. So, depending on that there are various types of flowmeters available and used in the process industries.

There are, sometimes there are volumetric flow, there are sometimes mass flow, there is sometimes positive displacement flow, there is open channel measurements, there is a closed channel measurements. So, depending on this, all this circumstances, the number of flowmeters are the highest among the, all the process parameters if you look at.

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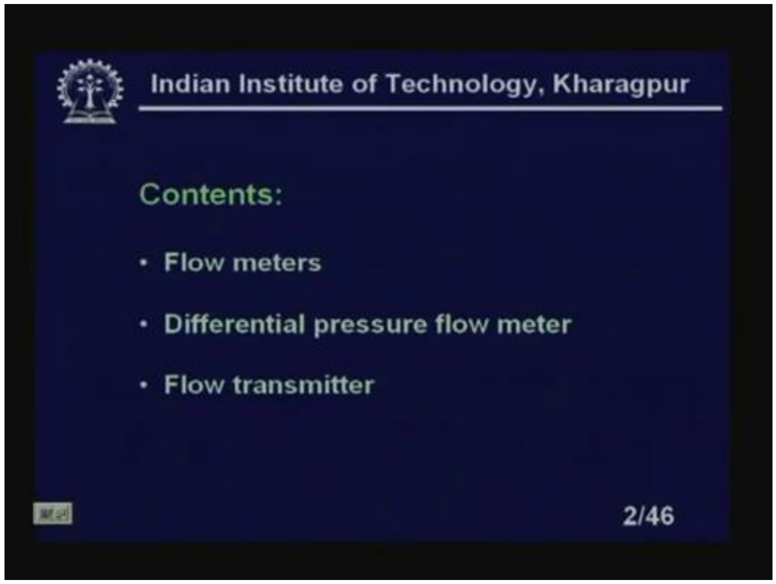

Now, in this lesson, basically we will discuss some, the contents of this lesson, rather is the flowmeters; we will just give the name of the different flowmeters. Then, we will discuss in details the differential pressure flowmeter, flow transmitter also we will discuss in some brief and also we will show the, I mean separate, the separate video on the flow transmitter.

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And now, commonly used flowmeters are like this. We have differential pressure flowmeters, then we have variable area meters. Now, in the differential pressure flowmeters you will find, we have basically most commonly used orifice meter and Venturimeter, then we have elbow meter, then we have pitot tube. These are all basically depends on the differential pressure. We have variable area meters; one of the variable area meter is the rotameter, which is very commonly used in the process to get rough estimate of the flow measurements. Then you have positive displacement meters and positive displacement meter is a meter by which it is a, you can get the, not exactly the flow velocity, but the quantity, quantity of liquid flowing in a particular situation.

One of the common examples of the positive displacement meters is the gas stations or petrol pump. If you go to the petrol pump and take some amount of a petrol or diesel, whatever it may be, you will find that actually I am not interested in the flow rate; I am interested in the total quantity of the liquid. So, that type of situations we need positive displacement meter. There may be turbine flowmeters which is, directly electrical output you will get from the turbine flowmeters. We have electromagnetic flowmeters. It has, all have some relative advantages and disadvantages. We will find the electromagnetic flowmeters is very good, because there is no obstructions and all those things, we will discuss later on.

We have vortex shedding flowmeters, flowmeters. Then, we have ultrasonic flowmeters; well, using the ultrasonic sounds we are measuring the flow and it is basically non invasive and it is like a ….. flowmeter. It has also, it does not create any pressure loss. But, if you look at the other, like differential pressure meter, even though it is used to extensively in the process, we will find it there is a permanent pressure loss in the, in the pipe. We have cross correlation flowmeters also. These are all the, I mean glimpses of the flowmeters available in common or commonly used in the anywhere, I mean like …., water supply or the chemical plant or steel plant, everywhere you will find these types of flowmeters. We have also Laser Doppler flowmeters.

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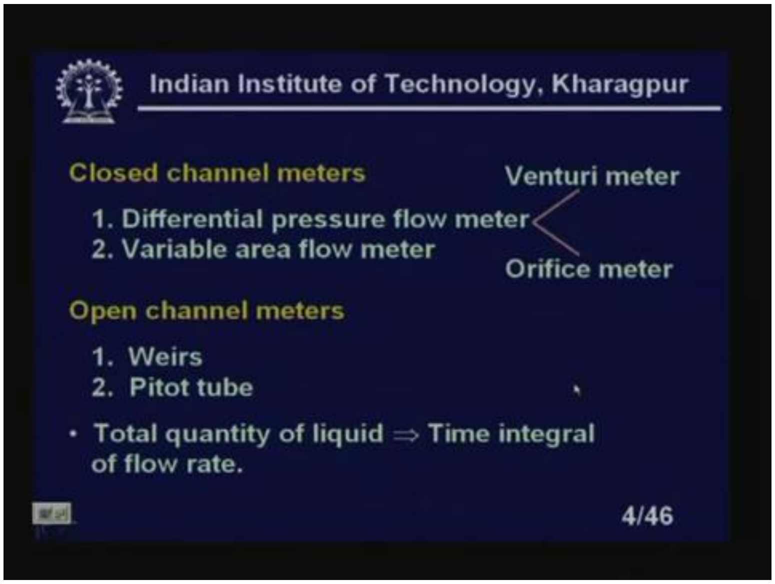

Now, if I look at the closed channel meters you will find that, I will just give you the glimpse, I have not, I have not come exactly to the, I mean details of the, exactly the text of this, our particular this lesson. Now closed channel meters, that means the closed pipe I am interested to measure the flow. In that type of situations we have, obviously we will mostly use the differential flowmeters and the differential pressure flowmeters, we have two - Venturimeters and orifice meters. This we include, discuss in very much details, right? We have variable area flowmeters, as I discussed. This is also closed channel meters and it is a rotameter, … is one of the good examples of the closed channel meters, I mean variable area flowmeters, which is used in the closed channel.

Then, in open channel meters in some situations, we need, we need to measure the open channel, like one of the good example is a, is a irrigation purposes. If I want to, I want to know the flow of the fleet, velocity of the fleet by which we can calculate the total quantity of the liquid which is used for the irrigation, in that type of situations it is open channels. So, in that open channel meters we have basically two types. One, it is the weirs, we have a v notch weirs and rectangular weirs and we have also pitot tube. Now pitot tube is, basically it is, can be used basically for the gases and gases, clean gases rather and it can be used for both open channel and closed channel. That is the advantage of the pitot tube.

But however, in this particular lesson we will discuss basically this differential pressure flowmeters. Others we will try; variable flowmeters, weirs, pitot tube, we will discuss in the subsequent lessons. The total quantity of liquid is obviously what is that? That is the time integral of flow rate. If I measure the time and multiply by the flow rate, if the flow rate is uniform or average, so we will multiply by that, I will get the total quantity of liquid flowing in a, through a particular cross section.

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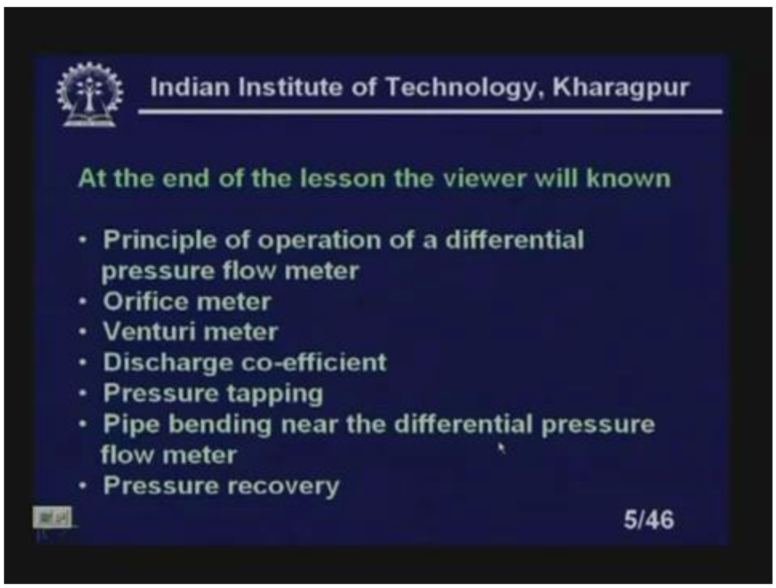

Now, at the end of this lesson the viewer will know the principle of operation of a differential pressure flowmeter, orifice meter, Venturimeter, discharge co-efficient of Venturimeter or orifice meter, then pressure tappings. There are various pressure tapping, available that will be discussed, pipe bending near the differential pressure flowmeter, because whenever you are using any differential pressure flowmeters, there is restrictions of the pipe bendings, both upstream and downstream that you must look at, right? Then pressure recovery, because you see, the differential pressure flowmeters, there is loss of, there is permanent pressure loss and permanent pressure loss means pumping, extra pumping cost, so that you have to take care and this is very crucial in the case of any water supply and all those things, because pumping needs a lot of money involves, so that the, whatever you are supplying, the water or other things, the cost will be increased.

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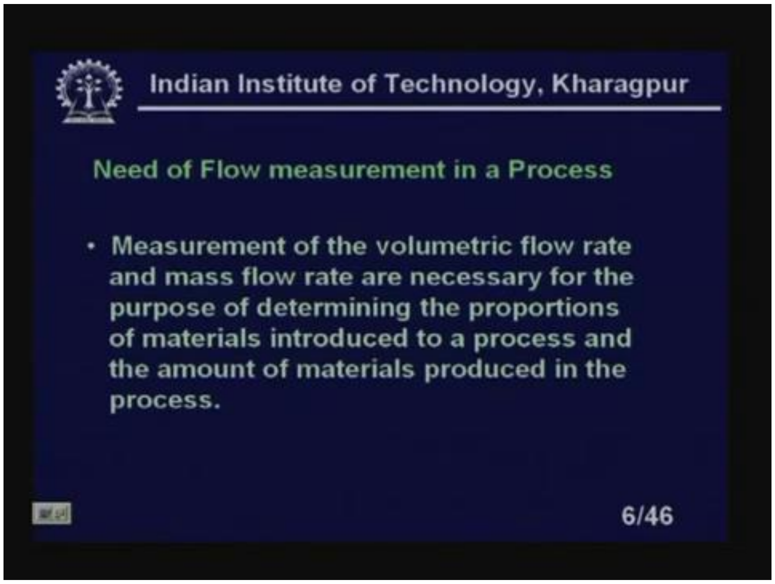

Now, what is the need of flowmeters in a process? The, first of all you now, we know the flowmeters is necessary for the, I mean for suppose in the water supplies flowmeters is necessary, because I know how much quantity of liquid or water I am supplying to the particular town or city. That is one thing, but what is the need actually in the process? Measurement of the volumetric flow rate and mass flow rate are necessary for the purpose of determining the proportions of materials introduce to a process and the amount of materials produced in the process, right?

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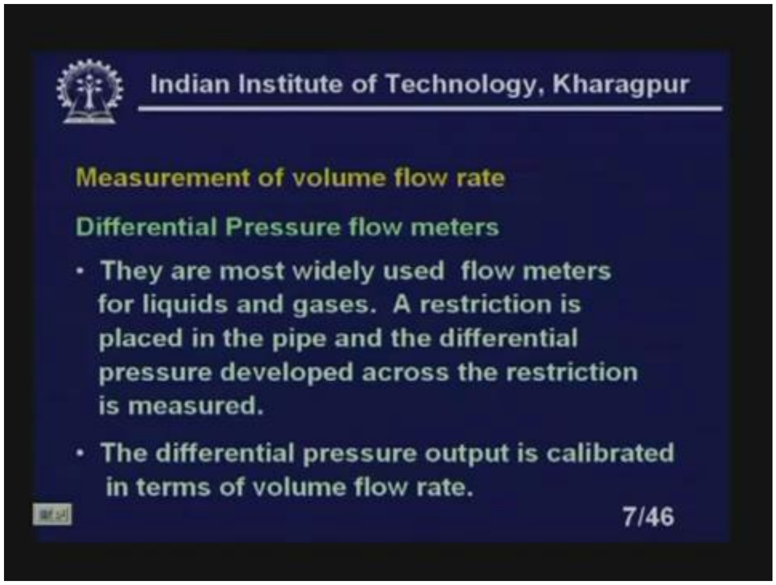

Measurement of volume flow rate if you look at, now differential pressure flowmeters comes under these. They are most widely used flowmeters for liquids and gases. A restriction, a restriction or constriction is placed in the pipe and the differential pressure developed across the restriction is measured; as simple as that. It is very simple, I mean principle is just applying Bernoulli equations you can find the flow rate and the differential pressure output is calibrated in terms of volume flow rate. So, the differential pressure is calibrated in terms of volume flow rate. Then, we will convert into the current and all those things that will be taken care later on.

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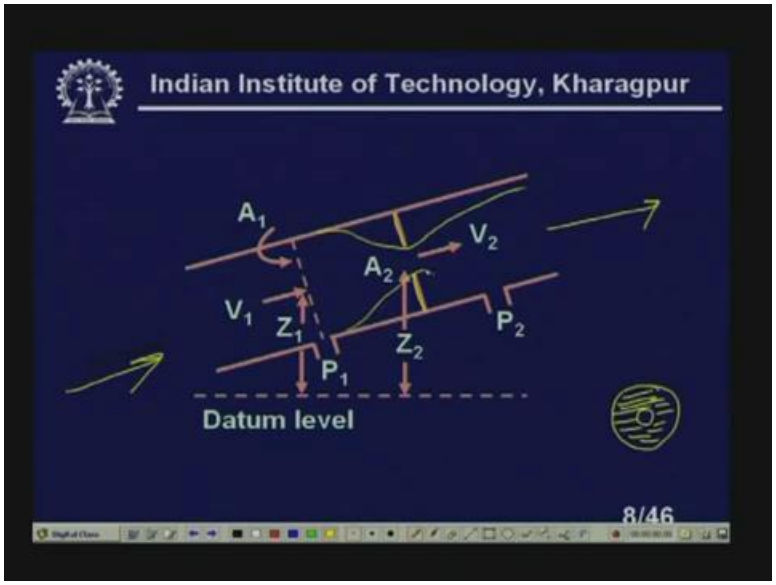

Now you see, this is a typical differential pressure flowmeter. The schematic of the differential pressure flowmeters we can see here. You see, if I look at, I do not know which, fine, these I can take. You see here, this is a pipe. Liquid is flowing through these directions. Liquid is flowing through these directions, it is coming out this direction, clear and you see, there is a restriction; this is our restriction in the form of orifice. It is basically a circular plate. Please note, there is hole in the, a consetting hole in the middle, a circular plate. So, liquid is flowing through this plate. So, liquid is coming and it is flowing through like this one, clear?

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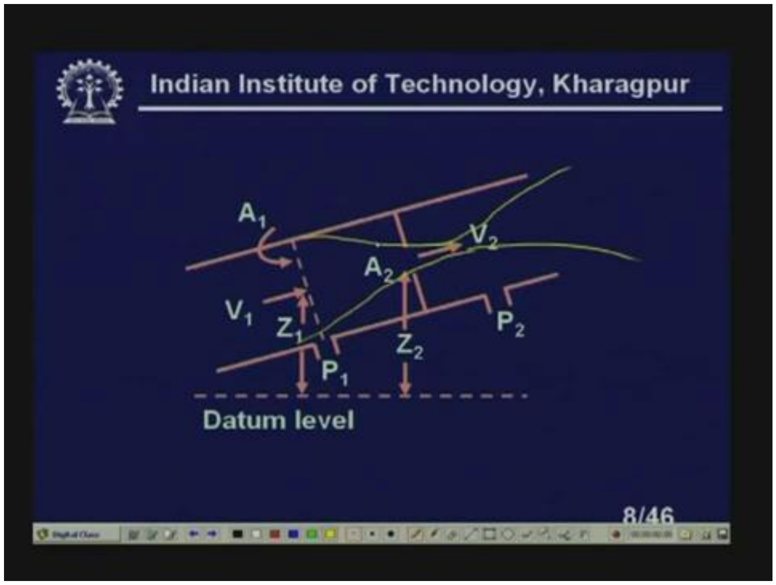

So, it will not be exactly like this one. So, let me go back again. So, so it will look like this one. So, the liquid will flow and there is minimum pressure area after that. So, it will go and after that the liquid will flow like this way, clear? Now, the area of cross section in the upstreams we are taking A 1, area of cross sections of the restrictions, of the constrictions is A 2, P 1 is we are measuring the upstream pressure tap, we are calling it upstream pressure tap, P 2 is the downstream pressure tap. P 2 is the downstream pressure tap, P 1 is the upstream pressure tap and Z 1 and Z 2 is a, is a, is a height of this central point of this area of cross section of the pipe as well as of the other point of measurements of upstream pressures as well as the orifice, orifice plate, right? So, we are making Z 1 and Z 2. Let us go back.

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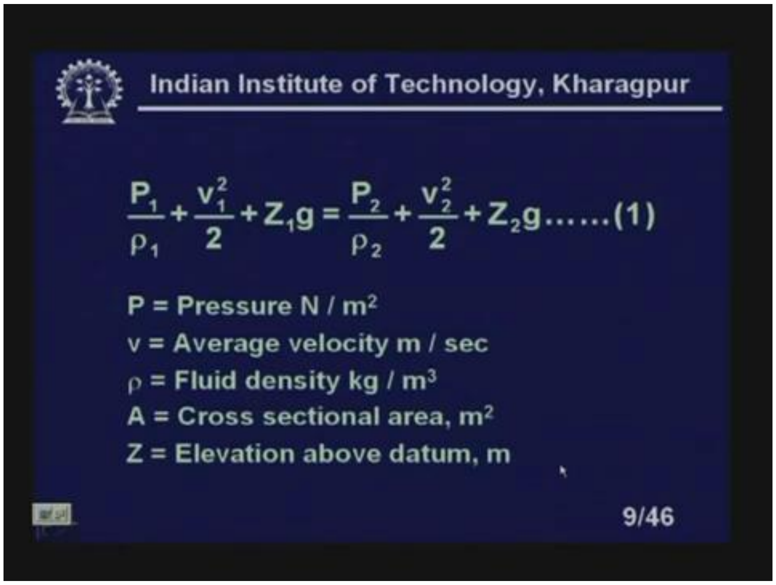

Now, if I apply the Bernoulli equations across these two, I mea sections will upstream and downstream easily I can write P 1 by row 1 plus V 1 square by 2 plus Z 1 into g equal to P 2 by row 2 plus V 2 square by 2 plus Z 2 g. See, unit you can see all the dimensions are equal. It is, all are, it is a meter per second square, a units of the individual. So, it is, we have taken it per unit meter. So, we can write like, Bernoulli equation like this, right? Total height, I mean total height of the liquid at any point is same that is the basic principle. P is the pressure in Newton per meters square, v is average velocity in meter per second. v 1 is a upstream velocity and v 2 is the velocity at the restrictions or the minimum area and row is the fluid density, which is the kg on meter cube, everything is in SI, no problem; A is the cross sectional area, it is in meter square and Z is the elevation above datum level. So, you can take any datum levels, obviously this is not very important if the pipe is horizontal and that is in meter.

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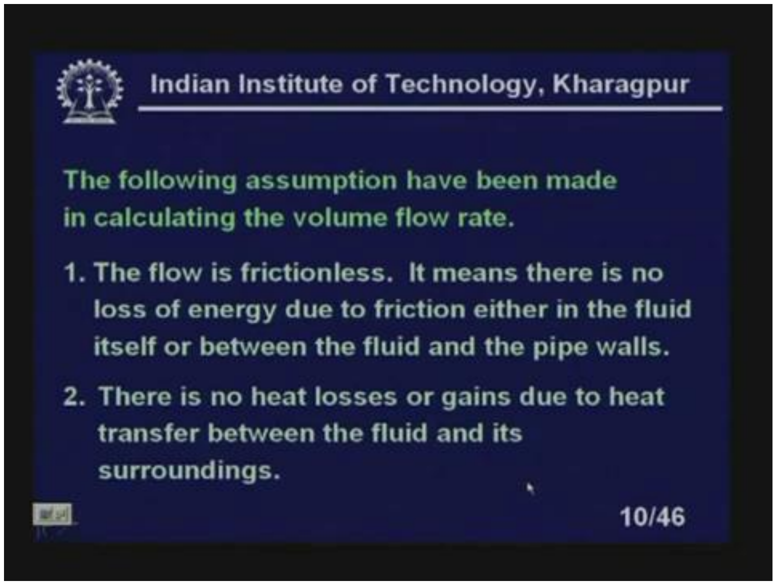

So, the following assumptions have been made in calculating the volume. So, you have to make some simple assumption to calculate the volume flow rate. These are: the flow is frictionless. It means there is no loss of energy due to friction either in the fluid itself or between the fluid and the pipe walls. There is no heat losses or gains due to heat transfer between the fluids and surroundings.

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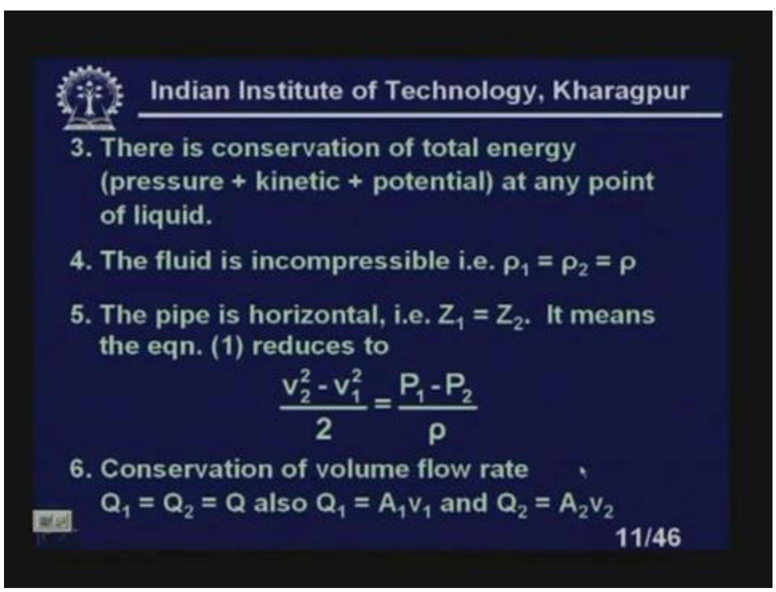

There is conservation of total energy – pressure, kinetic and potential. We have written the Bernoulli's equations from that only, right? So, it is nothing new. So, there is conservation of total energy pressure plus kinetic plus potential at any point of the liquid. The fluid is incompressible, incompressible. So, it is row 1 is equal to row 2 is equal to row, right, so that the density is same everywhere and the pipe is horizontal. That means Z 1 is equal Z 2. So, it means that the equation 1 reduces to v 2 square minus v 1 square upon 2 is equal to P 1 minus P 2 by row.

Now, conservation of the volume flow rate if it is there, so we can write Q 1 is equal to Q 2 equal to Q. That means Q 1 is the upstream flow volumetric flow rate, Q 2 is the downstream, downstream volumetric flow rate. Also we know Q 1 is equal to A 1 into V 1. A 1 is area of cross sections of the pipe and V 1 is the pipe, the liquid flow diameter, flow velocity, Q 2 is the downstream flow velocity. Obviously, Q 1 will be equal to Q 2. This will be equal to the area of cross section of the orifice multiplied by the velocity of the liquid at the orifice.

Obviously, if the P 1 is greater than P 2, that will come in the next slide. Let us go to the next slide.

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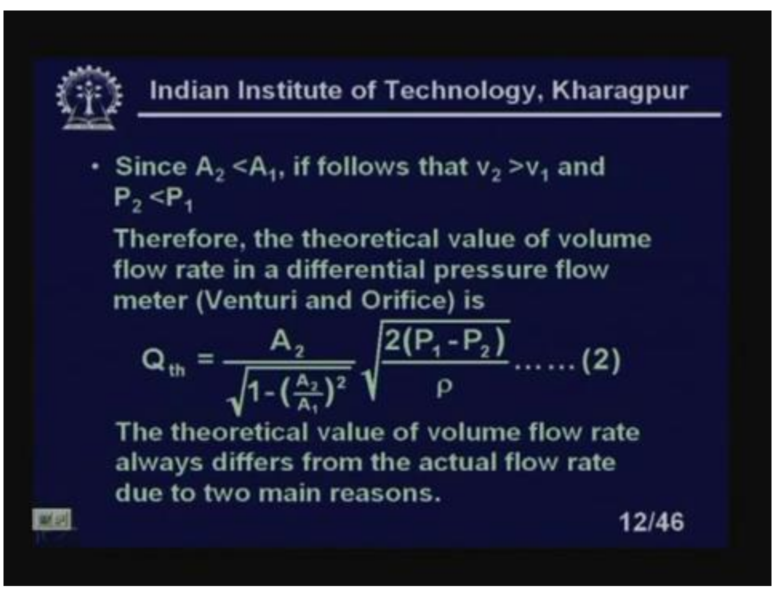

So, since A 2 is less than A 1 it follows that V 2 will be greater than V 1 and P 2 will be less than P 1, right? Since A 2 less than A 1 it follows that the V 2 will be, that is obvious from the last equation V 2 will be greater than V 1 and that means the flow velocity at the restriction or at the, at the, at the minimum area of cross section is high compared to the actual flow of velocity, right? We are not interested in that. We are exactly interested in the volumetric flow rate that is same both in upstream and downstream.

Therefore, the theoretical value of the volume flow rate in a differential pressure flowmeter, both in the case of Venturi and orifice is that Q theoretical we are writing is A 2 upon under the square route 1 minus A 2 upon A 1 square under the square root 2 P 1 minus P 2 by row, this is equation number 2. The theoretical value of volume flow rate always differs from the actual flow rate due to two main reasons.

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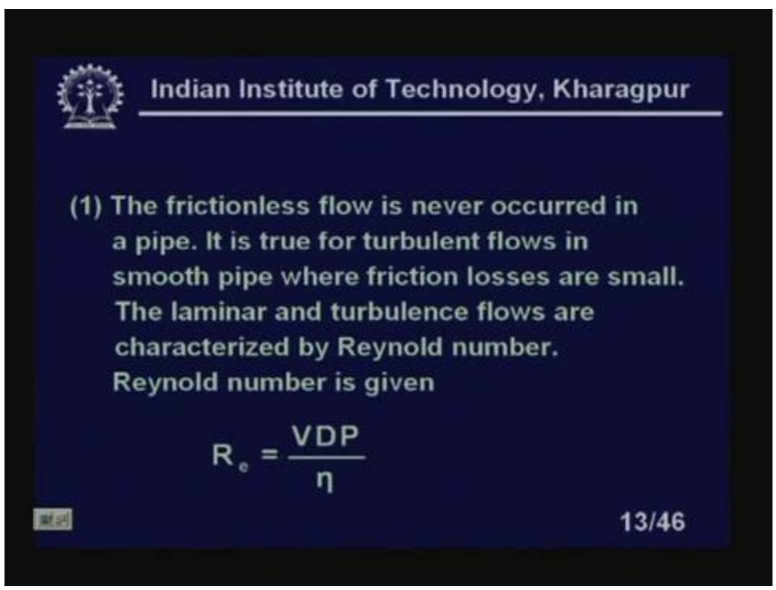

There is some restriction. Why I am calling it theoretical? We will find that we have to multiply by the discharge coefficients with the actual flow rate, actual volumetric flow rate. The frictionless flow is never occurred in a pipe. It is true for turbulent flows in smooth pipe where friction losses are small. The laminar and turbulence flows are characterized by the Reynold number and a Reynold number is given as R e equal to VDP by eta.

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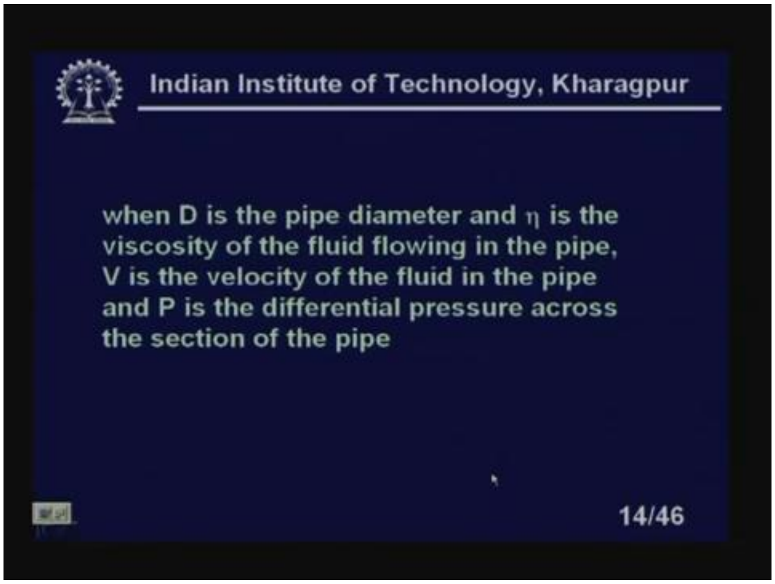

This will give you the Reynold number, where D is the pipe diameter, eta is the viscosity of the fluid flowing in the pipe, V is the velocity of the fluid in the pipe and P is the differential pressure across the section of the pipe, right?

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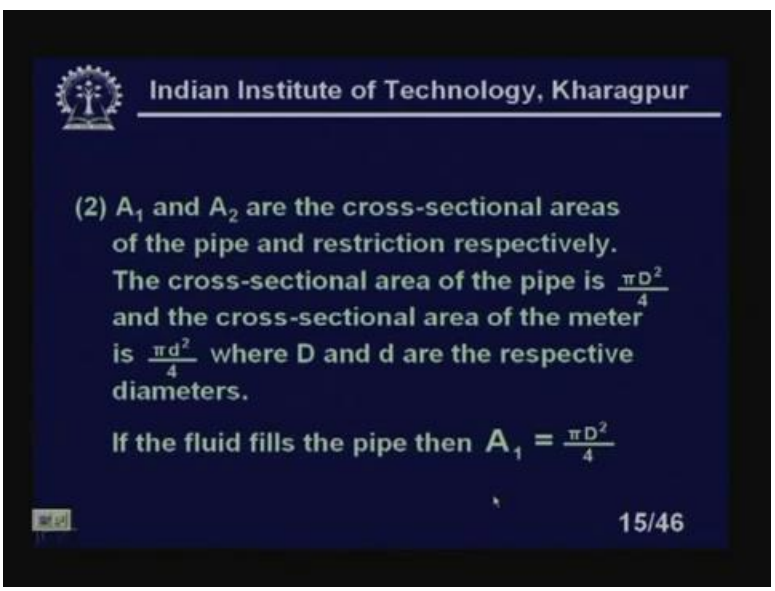

Number 2 is A 1 and A 2 are the cross sectional areas of the pipe and the restriction, respectively. The cross sectional area of the pipe is pie D square by 4, obviously and the cross sectional area of the meter, orifice meter or Venturimeter, it is pie D square by 4, where D and capital D and small d are the respective diameters. That means pipe diameters, internal pipe diameters and this is diameters of orifice or the throat diameters of the Venturi. If the fluid fills the pipe then A 1 equal to pie D square by 4.

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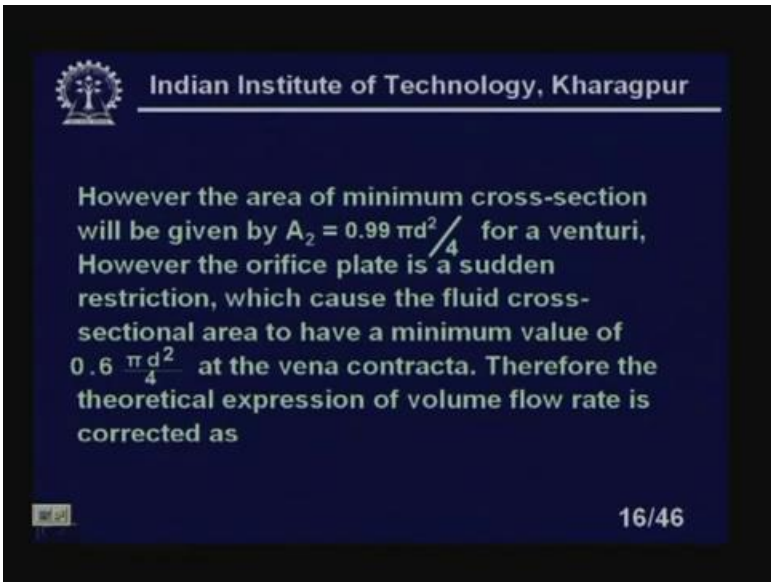

However the area of the, minimum cross sectional area will be not exactly at the, at the restrictions. So, it will be .99 pie d square by 4 for a Venturimeter, because Venturi is a, is not a sudden, I mean restrictions. However, the orifice plate is a sudden restriction which causes the fluid cross sectional area to have minimum value of .6 pie d square by 4 at the vena contracta. That means it is little far off from the, little off from the orifice plate, where you will get the minimum area of the cross section of the fluid, right?

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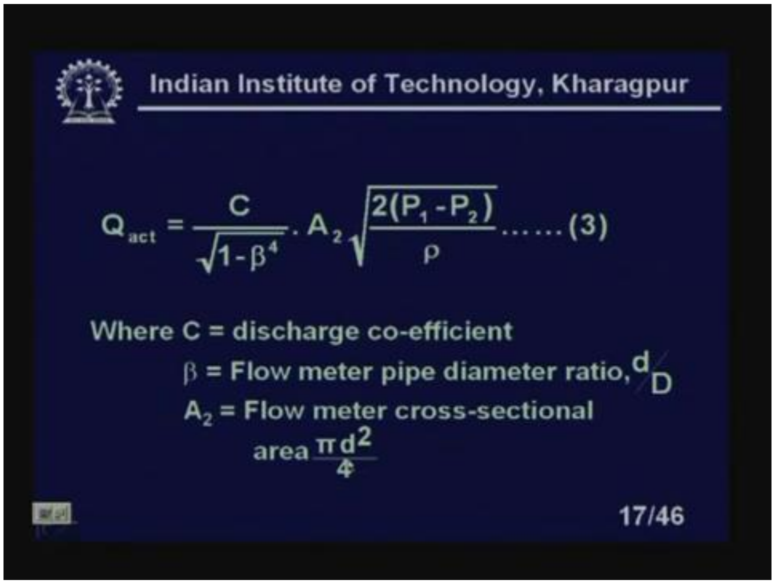

Therefore, the theoretical expression of volume flow rate is corrected as C. We are introducing a new factor C under the square root 1 minus beta to be the power 4 multiplied by A 2 under the square root 2 P 1 minus P 2 by row, where C is discharge coefficient and beta is the flowmeter pipe diameter ratio, small d by capital D and A 2 is the flowmeter cross sectional area. This is equal to pie d square by 4.

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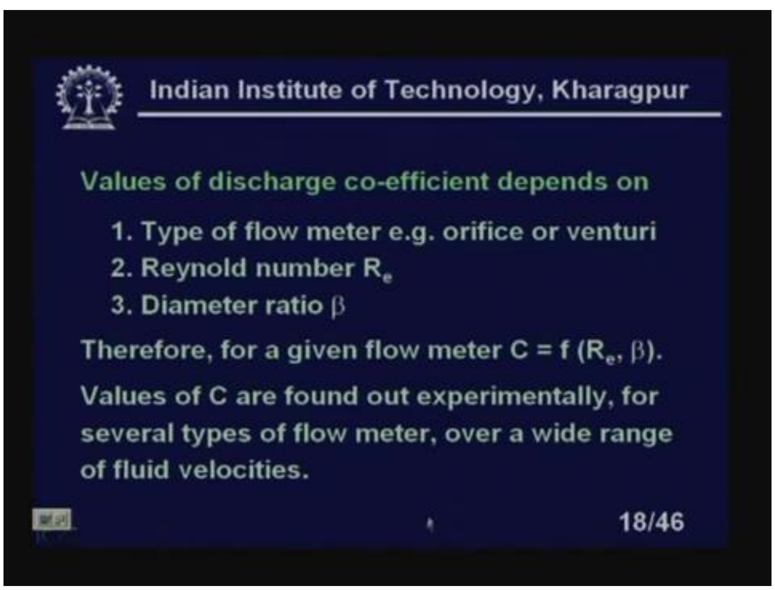

Values of the discharge coefficient depend on type of flowmeter that is orifice or Venturi, Reynold number R e, diameter ratio beta. So, therefore for a given flow rate, flowmeter, I can write C equal to, is a function, C is a function of R e, Reynold number and beta. Values of C are found experimentally for several types of flowmeters over a wide range of fluid velocities, right, because flowmeters velocity should be, C should be known to you.

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For a given fluid and known volumetric rate of fluid flow, C can be found from the equation 3. If the fluid, volumetric rate of the fluid is known, so obviously I can and if the density of the fluid is known, so obviously I can found the, find the value of C. Now, general features of differential pressure flowmeter, what are the general features let us look at. These are most important that is the reason it is used widely in industry for last several decades.

Number 1 it has no moving part, so you look at there is no moving parts. So, it is robust, reliable and easy to maintain and widely established. It is established over the years. It is documented, data are available. So, all these things, all the supports we are getting from the past users, so that is reason it is used widely in industry. Number 2, there is always a permanent pressure loss and the extra pumping energy. This is not a good feature; this is a bad feature, obviously. So, there is always a permanent pressure loss and the extra pumping energy is necessary to overcome it. So, whenever there is a permanent, permanent pressure loss, I have to meet some extra pumping energy. So, obviously this pumping energy needed in the case of orifice meter is more than that of the, that of the Venturi, because in Venturi the permanent pressure loss is much less.

Now, let us look at, you see it very carefully.

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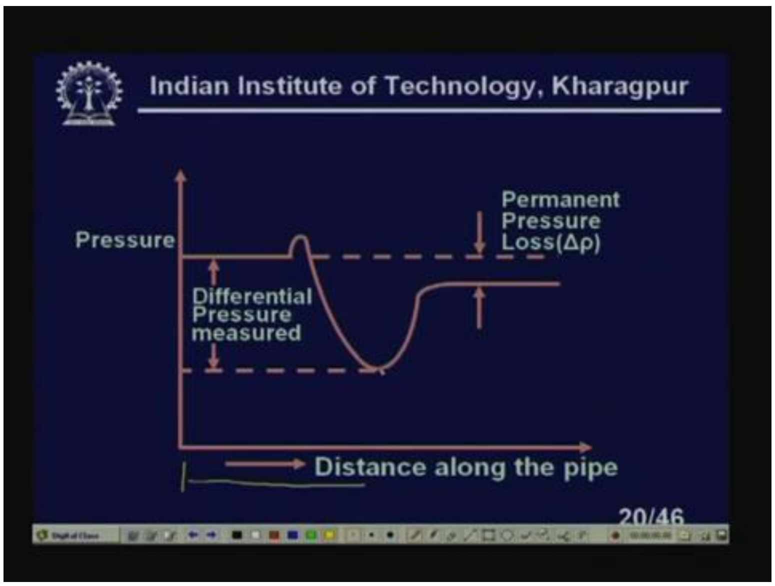

So, you see here that if I look at the, from this one, you see and this is our pipe. This is the distance from the orifice we are taking, orifice or Venturi throat. Here you see at the differential pressure measured, here there is a sudden fall of the differential pressure near the orifice. After that, here this pressure loss is, it is pressure, so this is a pressure recovery. There is a sudden pressure loss. This is good for measurement. So, why ….. the pressure loss if it is temporary that is good for measurement, because we are getting, we can, our sensitivity of our instrument will be higher. Because, if you see here, the pressure loss should be always, would be higher and higher. Here, pressure ….

differential pressure should be higher and higher, because in that case what is the, what is our input?

Input is the flow and output is the differential pressure. So, differential pressure by flow if it is higher and higher, obviously that is better for us, because static sensitivity will be increased in this case, right? But you see, this should not be permanent. That is the problem with the orifice meter. So, you see, there is a permanent pressure loss that will never recover. So, I need extra pumping energy to overcome this pressure loss, right? So, this is most important, right? You see, this is the permanent pressure loss, say this is the temporary pressure loss we are measuring at this point, preferably. Then, there is a permanent pressure loss, right?

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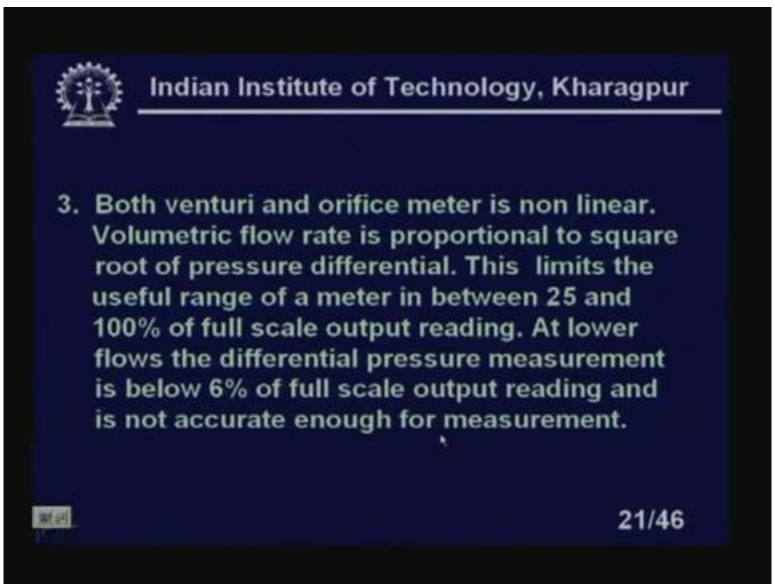

Now, both Venturi or orifice meter is non linear that is most important. If you see, volumetric flow rate is proportional to the square root of the pressure differential, right? So, this limits the useful range of a meter in between 25 and 100% full scale output reading. At lower flows, the differential pressure measurements is below 6% of full scale output reading and is not accurate enough for the measurement.

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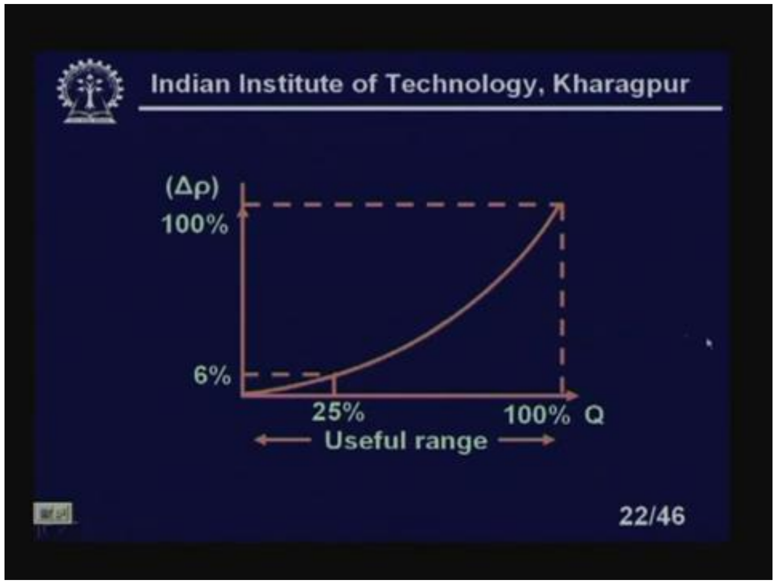

Now, you see there, so useful range. Here you see it is a nonlinear curve. So, because you can see that the flow velocity or the quantitative flow, volumetric flow rate is proportional to the square root of the differential pressure, so obviously it is nonlinear. You can see here that if the flow velocity is less than 25% of the full scale output rating, if the full scale output rating is there, 25% of the full scale output rating, so the, whatever the measurements we are doing that is much erroneous, right? So, it is not very good for the low flow measurements. It is good for the higher flow measurements. That means the, the error will be less in this case, right?

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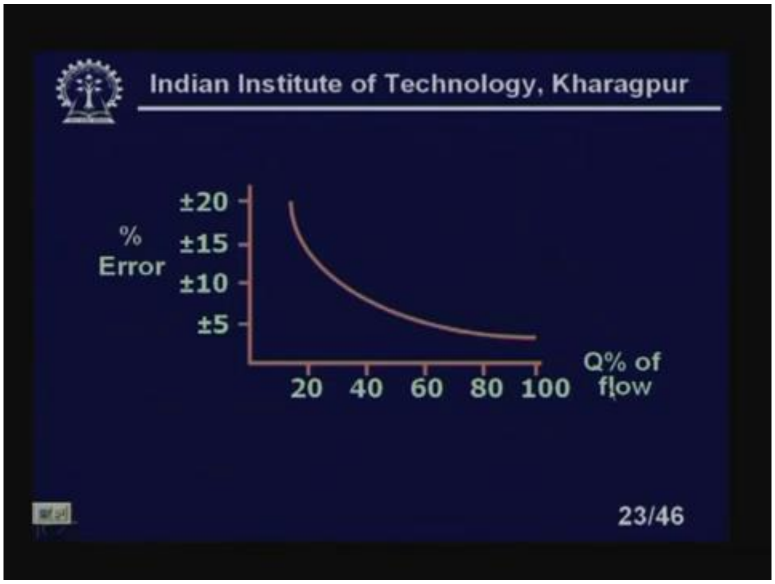

These error you can see here, excuse me, say error you see here, error here is quite low at the low flow velocity, quite low at the, at the high flow velocity and is very high when the flow velocity is, volumetric flow rate is slow.

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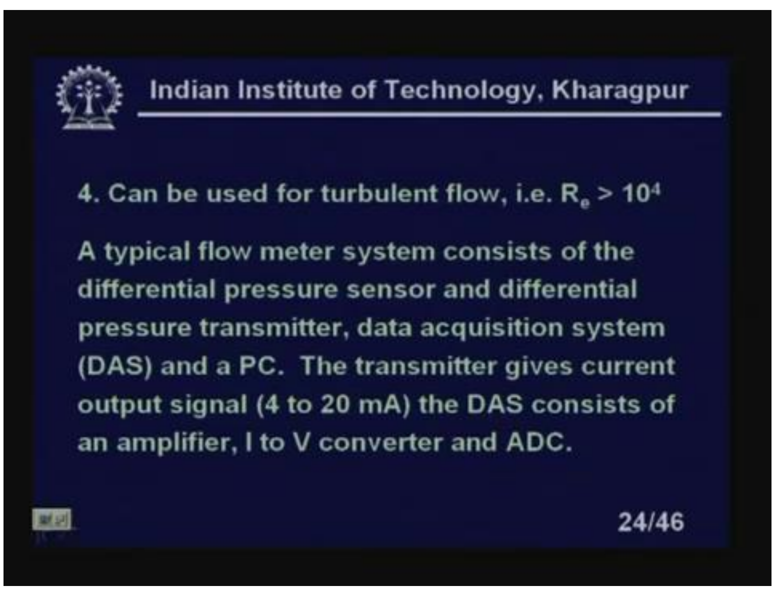

Number 4, it can be used for turbulent flows, because turbulent flow is characterized by when R e is much, is greater than 10 to the power 4, 10,000. A typical flowmeter system consists of the differential pressure sensor, differential pressure transmitter, data acquisition system and a PC. The transmitter gives a current output signal, current output signal of 4 to 20 million ampere and the DAS consists of an amplifier, I to V converter and ADC, right?

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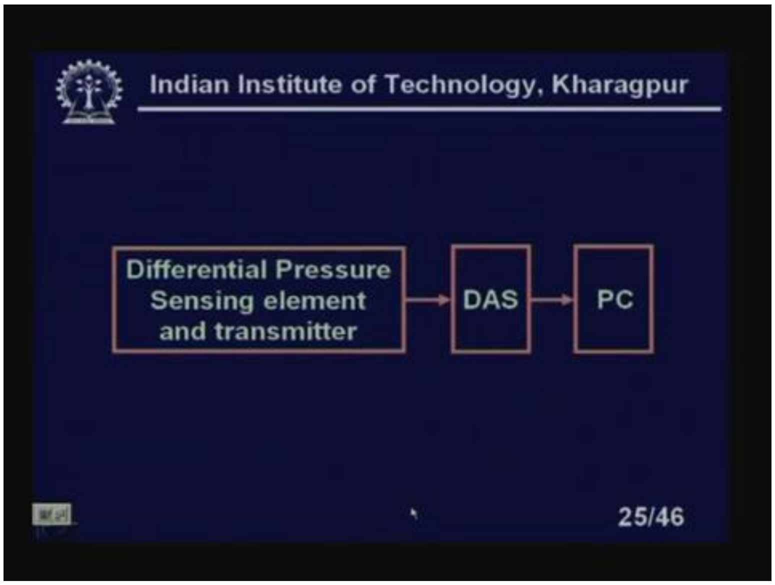

This is our system; you see, differential pressure sensing element and transmitter, data acquisition system and PC. Please note that the, this differential pressure transmitter should be an assembly or is to be installed in the, on the pipe itself just outside the pipe and it should give you 4 to 20 milliampere of current which will go to the computers where the data acquisition card is there, so, through which will convert to the voltage domain and will be used for further processing after conversion to the, I mean digital domain. ……. milliampere of current is obviously is an analog current, right?

Now, let us go to the instrumentation lab and look at one of the transmitters, one of the differential pressure transmitters used extensively in the industry.

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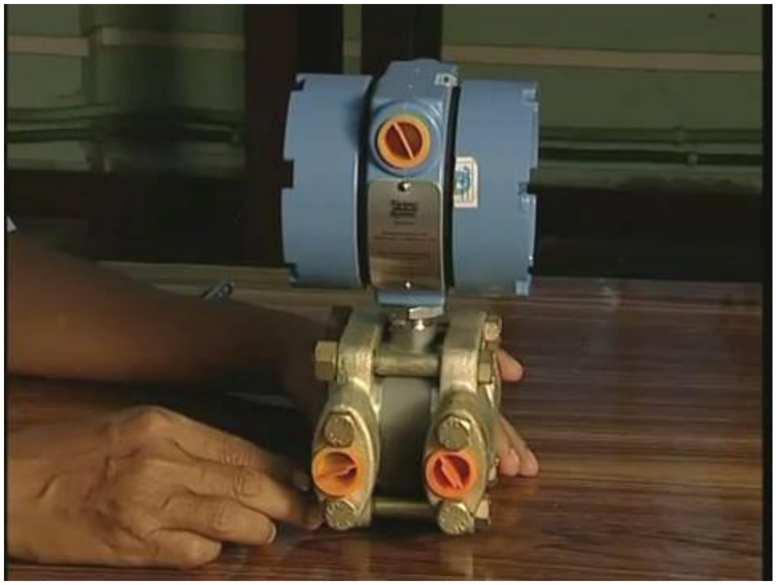

This is differential pressure transmitter. As you know that in the flow measurements, actually the flow is calibrated in terms of pressure. So, in all flowmeters, I mean, I am talking on the variable area like orifice meter and Venturimeter, so there is an upstream pressure tap and downstream pressure tap. We have seen in the class that, we have shown one nanometer sort of thing, by which I am measuring the pressure. But unfortunately in the process, actual process, I need some instrument or some equipment, which will give some signal that will be transmitted to the control room.

Now, for that reasons we need some electrical output. So, what they do? In this case of this differential pressure transmitter, because there are two pressure tap, one is upstream pressure tap, another is downstream pressure tap. Now, you can see here, this is basically a capacitive type DP transmitter. Here we have an upstream pressure tap and here you can see the downstream pressure tap. So, you can open it and connect to the upstream pressure tap here. So, inside what we have? We have a capacitor with movable plates and the inside of the two capacitors are plated with some metal. So, you will get, once the capacitors, suppose this side is high and this side is low, the capacitor movable plates will move on this side. So, I will get a push pull sort of variations of the capacitance, which can be calibrated in terms of pressure and ultimately that will be calibrated in terms of flow. Now, this is basically this capacitive sensor inside and this measurement circuits and signal conditioning circuits are here on this side.

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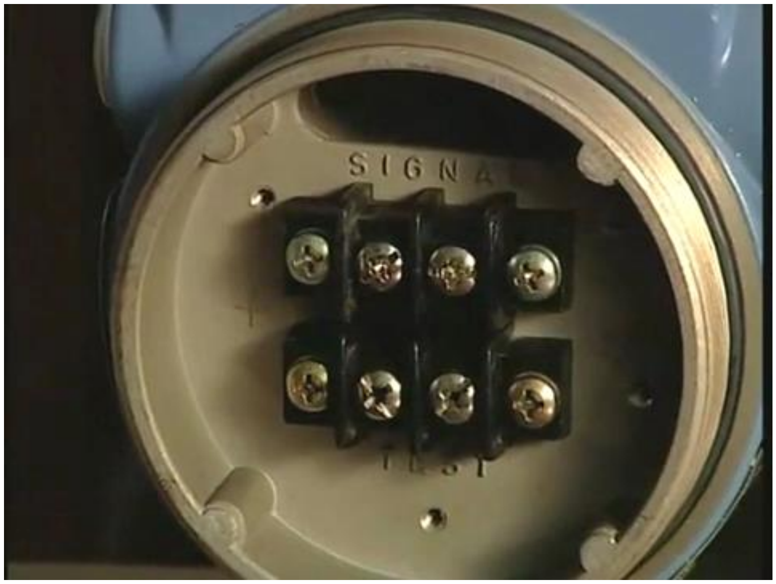

You can see here if I open, there is a connection for the signals. You see here that we have positive signals, because the, in the process the output is 4 to 20 milliampere and the supply voltage maximum is 45 volt DC supply, because in all the process, as you know it is, you cannot give this live voltage much higher. That is also not necessary and it will give the, according to the variation first of all this, this circuit will first measure the variation of that capacitance and that variations of the capacitance will be converted in terms of current - 4 to 20 milliampere of current. So, ultimately that 4 to 20 milliampere of current will be calibrated in terms of flow and the output signal we can take from this side.

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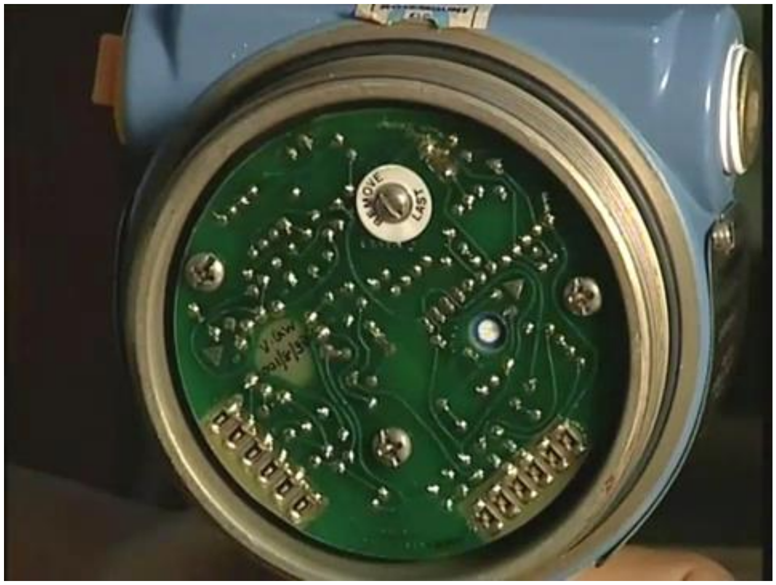

We can open this side and see here the circuitry and we can connect here and there is a ….. things here and this side you can make all the connections sort of things for taking the, both the, giving a signal and taking the 4 to 20 milliampere of current. This circuitry which we, this, this actually the …. which you can take it out for making repairment and all that type of job.

So, now we will discuss a particular, we already, we discussed the orifice and Venturi, but there is some difference between the orifice and Venturimeters and also we discussed Dall tube and flow nozzle and all those things. So, let me first discus orifice meter which is, I think if we look at the flowmeters, it is most widely used flowmeters in the process industry. I should say 80% of the flowmeters are the orifice. If you look at the, if you compare the number of meters like so many meters we have discussed at the beginning, sophisticated meters, all these things, but orifice because it is established over the years, this is one of the very widely used, cheap, easily replaceable meters and quite …. of that is most important thing. Maintenance is also very easy, just replace it. It does not need calibration. Once we have made several orifice of the, from the same lathe machines, so it won't take time. So, just you go and …. if the diameters ratio are correct, if small d by capital D is same as before, if it is square edge or if it is, so there is no question of making any further calibration. That is great advantage of this. So, during routine maintenance just replace the orifice. That will simplify. If you look at the other meters it needs lot of, it is expensive also. So, among the differential pressure flow meters orifice is the cheapest. Let us go back to the orifice.

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Now, it is a thin plate square edge orifice, it is the most widely used differential pressure flowmeters. Thin plate number all square edge orifice is the most widely used differential pressure flowmeter in process industry, mainly because of its simplicity, low cost and moreover it is well established over the years and the data are, data are available for its behaviour that is most important thing. Just you cannot have a new, I mean something, somewhere in, in some laboratory in the world I develop some flowmeters, so immediately that cannot be used. It is used over the years and people …

Ultimately our goal is to make our product good, is not it? I told you several times before also, quality of steel, quality of fertilizer, quality of petrol, diesel or quality of a life, you …… anywhere, ….. quality of our drugs which you are producing in the bioreactors, so it does not matter I mean what type of flowmeters you are using. If the product is good, product is pure, so there is no question. So, orifice meter, it is working for several years for all these reasons and we are using it extensively in the industry.

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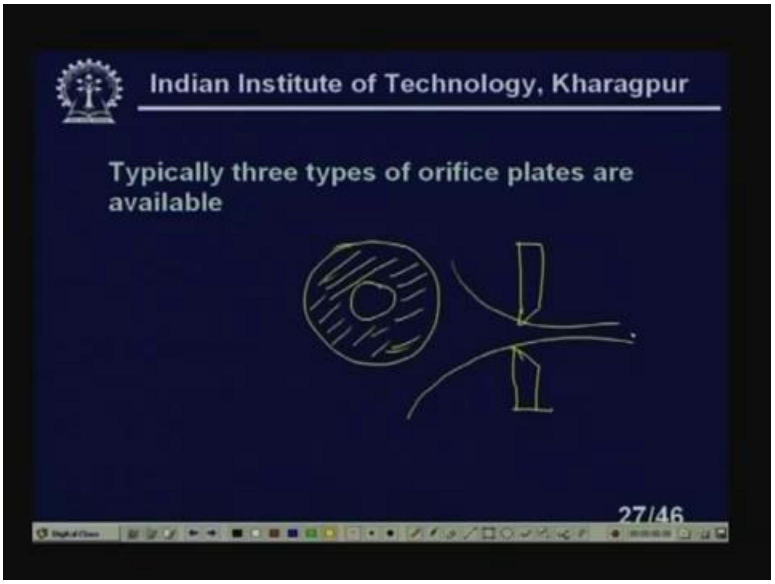

Now, typically three types of orifice plates are available. It is basically a plate. If you look at it looks like this, you see. So, it is a plate here and there is a hole, right? If you look at, so it will be like this. Square edge orifice, so it should be, if I look at, so the liquid is flowing …. through that like this, clear, right?

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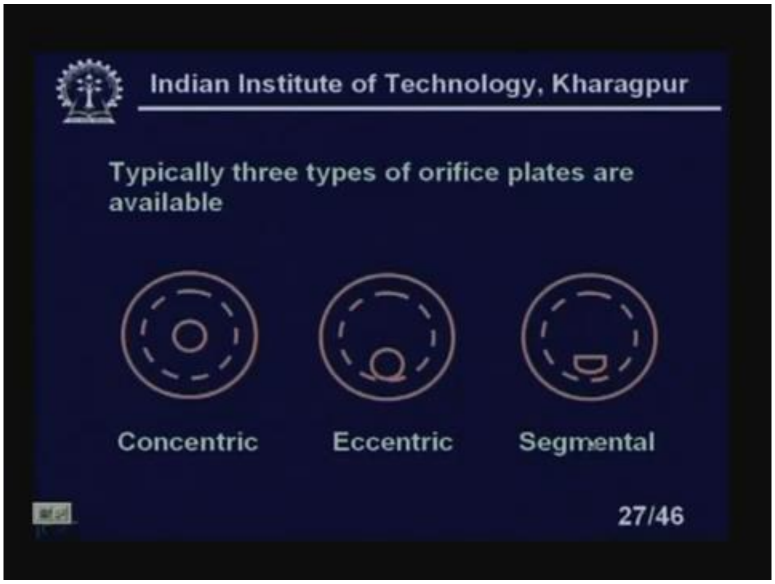

Let us go back again. So, these are the three different types of orifice, if you look at. So, there is a concentric orifice, eccentric orifice and segmental orifice. All has different application that is the reason we are plotted, we are given like this.

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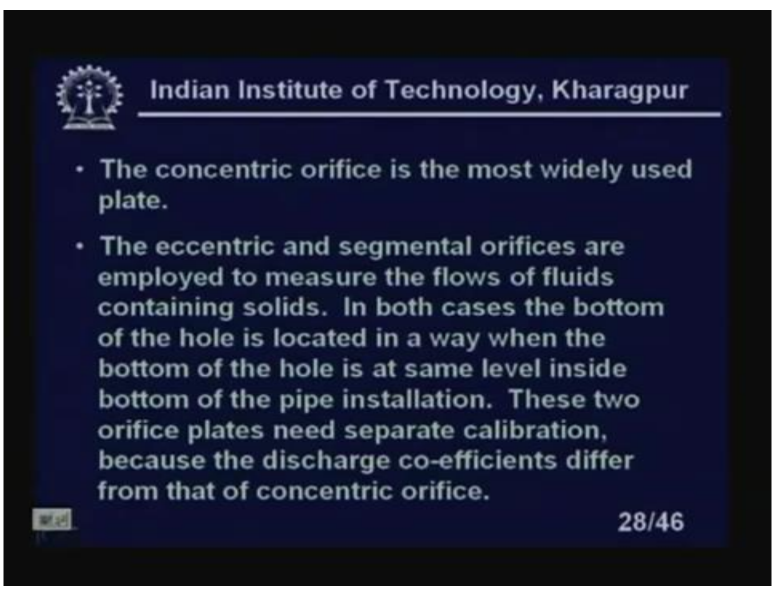

So, the concentric orifice is the most widely used plate. Eccentric and segmental orifices are employed to measure the flow of the fluids containing solids. In both cases, the bottom of the hole is located in a way, when the bottom of the hole is at the same level inside the bottom of pipe installation. These two orifice plates need separate calibration, because the discharge coefficients differ from that of the concentric orifice, clear? I need separate calibration for this one. Suppose I have suspended particles, all those thing, for that reasons if you, suppose you have some slurries, if you use a concentric orifice, so all these things will be deposited at the bottom of the pipe, but if you use eccentric orifice that will be flushed away. So, that is the reason some application of the liquid flow measurements we use concentric orifice, some I mean we will use eccentric and in some will use segmental orifice.

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The concentric orifice plate is installed in the pipe with its hole concentric to the pipe itself. It is a flat metal circular plate made of steel, stainless steel, phosphor bronze, like that. Its thickness is only sufficient to withstand the buckling forces caused by the differential pressure exists across the plate. So, so far that it can I mean withstand that differential pressures you can use a thin plate, but it should not buckle, then your entire calibrations will go wrong. For that reasons if you have …… differential pressure and all those things, we have different types of flow measurements, although that also basically depends on differential pressure flow, I mean differential pressure measurement.

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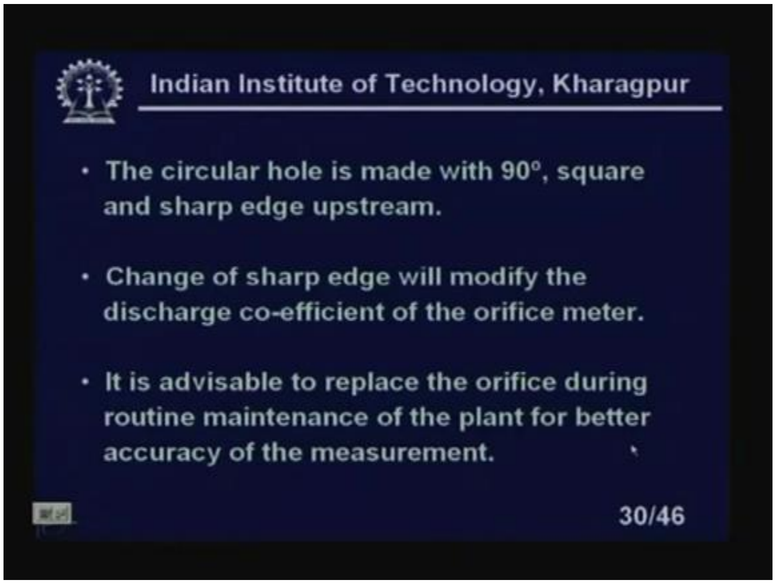

Circular hole is made with 90 degree square and sharp edge upstream. It is a 90 degree that I have shown you and sharp edge upstream. The change of sharp edge will modify the discharge coefficient of the orifice meter and it is advisable to replace the orifice during the routine maintenance of the plant for better accuracy and of the measurement.

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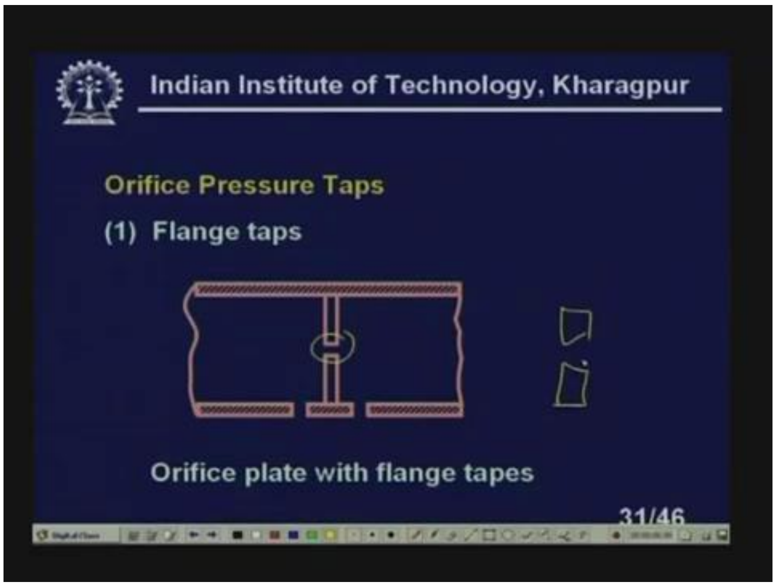

Now, orifice pressure taps, there are various pressure taps available for the orifice. There are, here in this particular lesson, we will discuss three pressure taps. Flange taps, you see there a flange tap, this orifice plate with the flange taps. Even though I have drawn like this one, you can see here, but it is actually as I told you earlier also, so it is I mean drawn like this one, so this is actually, so square edge it is like this one, right? So, but actually we have plotted like this, anyway.

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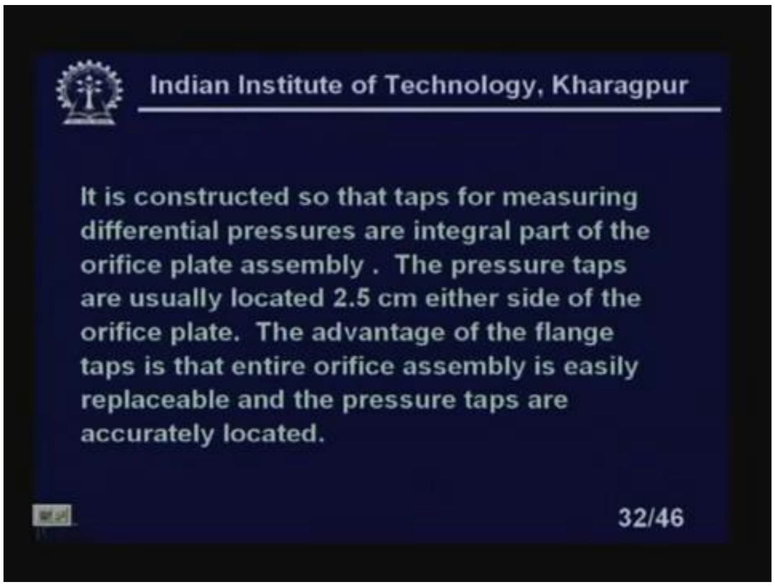

Now, it is constructed so that the taps for measuring the differential pressure are integral part of the orifice plate assembly. It is true, the one thing it is in the, in the orifice itself you have the pressure tap installed; its entire assembly is available, right? The pressure taps are usually located 2.5 centimeter either side of the orifice plate. The advantage of the flange tap is that the entire orifice assembly is easily replaceable and the pressure taps are accurately, are accurately located, right?

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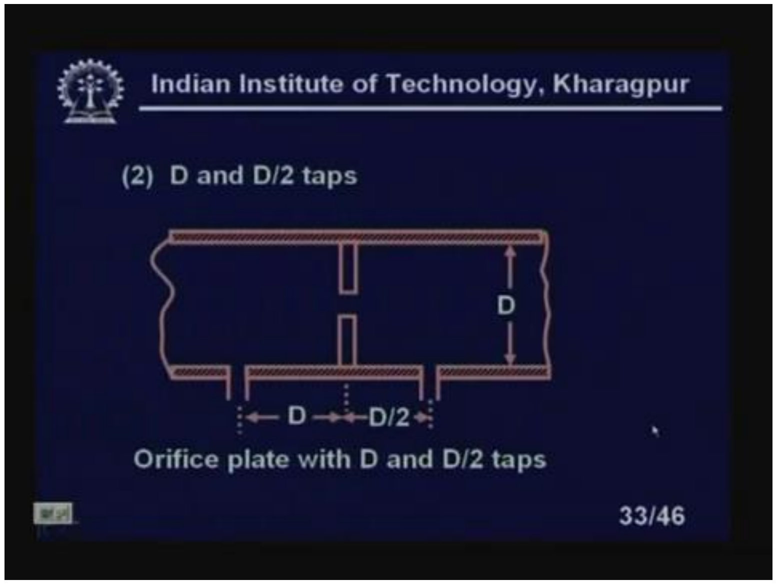

Now, we have an orifice plate with D and D by 2 taps. Here you can see that it is, upstream is D and downstream D by 2 tap. All these have some advantage and disadvantages.

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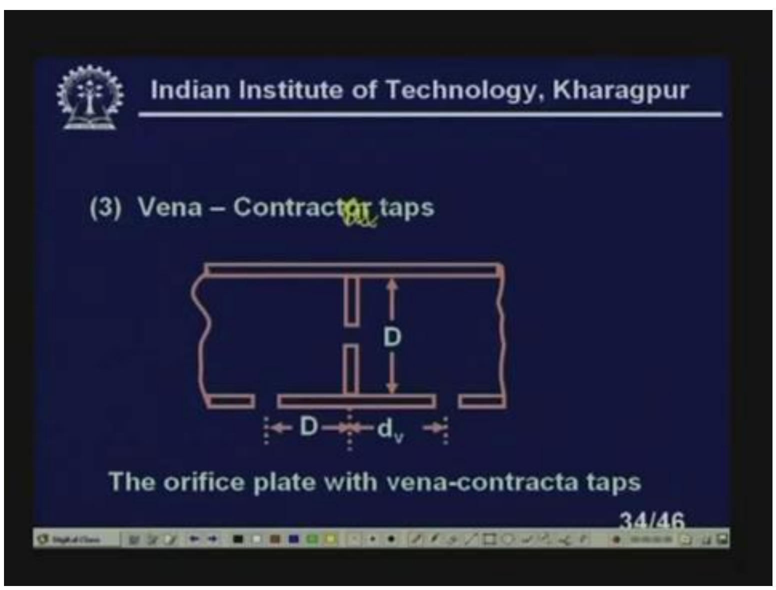

Then we have orifice with Vena contracta taps. I am sorry, this will be vena contracta, contracta, so this will be contracta, vena contracta; sorry this is will be a, vena contracta taps. So, orifice because you know the area of the minimum cross sections does not appear here. It is somewhere away from this one and we always try to measure there at the area of the vena contracta, because the differential pressure will be, will be the, if the area of cross section is low, the differential pressure at that point will be higher, highest. So the, there is ease of measurement. Our static sensitivity of the sensor will be increased. So, that is the reason what the people do. Because, as I told you, the area of the minimum cross section is not here, it is little far away. So, this is the tap where I am measuring that the pressure, downstream pressure at the area of the, at the place of the vena contracta which is the area of the minimum cross section of the fluid flow.

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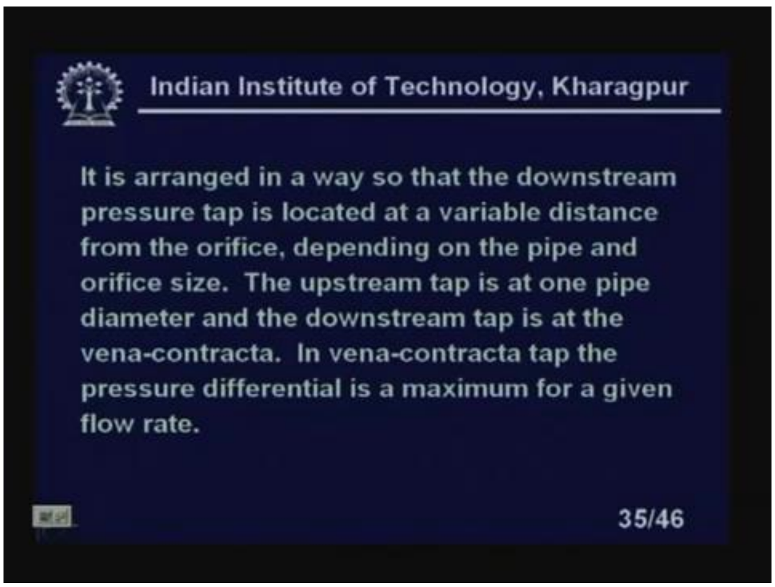

It is arranged in a way so that the volume, so that the downstream pressure tap is located at a variable distance from the orifice, right, depending on the pipe and the orifice size. The upstream tap is at one pipe diameter and the downstream tap is at the vena contracta. In a vena contracta tap, the pressure differential is a maximum for a given flow rate; this is important. At the vena contracta tap pressure differential is maximum for a given flow rate. So, that pressure differential, as I told you repeatedly, what is advantage of that having a large pressure differential, right?

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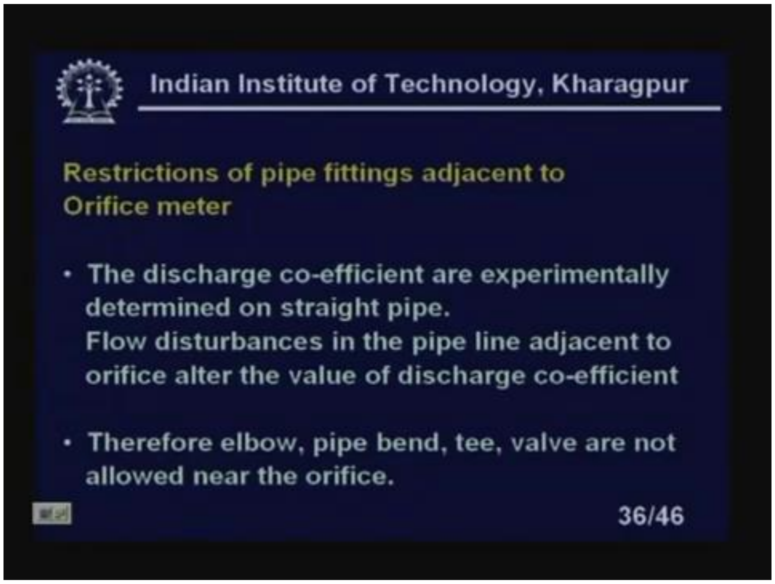

Now, restrictions of the pipe fittings adjacent to orifice meter - this is another most important thing practicing engineers must follow, so as that is the restrictions of pipe fittings adjacent to orifice meter. There cannot be pipe fittings, pipe bendings, tees, bags, etc., very near to the orifice, both upstream and downstream. What are those? Let us look at details. The discharge coefficients are experimentally determined on straight pipes, right?

Now, flow disturbances in the pipe line adjacent to the orifice alter the value of the discharge coefficient. Therefore, elbow, pipe bend, tee, valve are not allowed near the orifice meter. How much near that we will first know or that is what do you mean by near? Nearing that is, I mean this some you must quantify, I mean you cannot say just qualitatively very near or something or very far.

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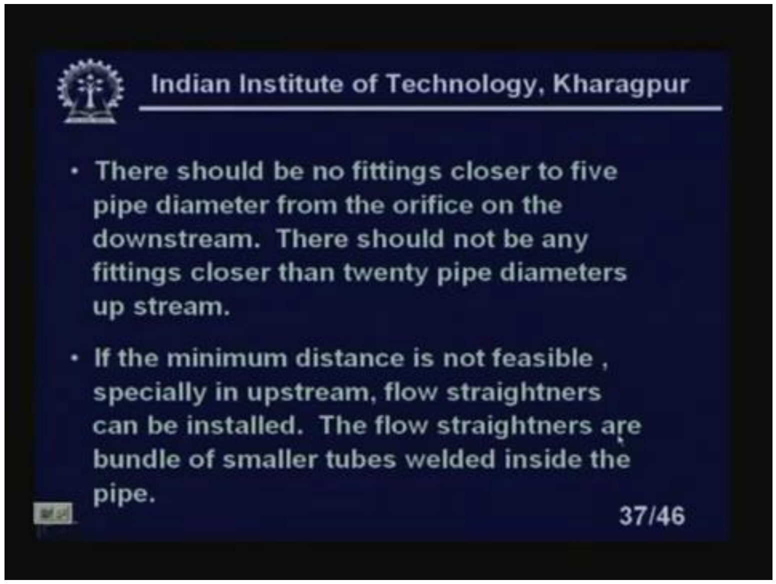

There should be no fittings closer to the five pipe diameter from the orifice on the downstream. Same - no bending, no elbow, no valve, no tee, there should not be any fittings closer than twenty pipe diameter upstream. Upstream is more restricted, that we can see. If the minimum distance is not feasible, in some situation you will find it is very difficult to achieve that, because in the process you will find that the, it is not possible, I mean to have these pipe bendings everywhere, right, I mean you cannot avoid, because there will be some pipe bending. So, in that type of situation when the pipe bending is unavoidable, you cannot avoid the pipe bendings, I have to use some flow straightners both upstream and downstream.

What is those, what are those flow straightners, flow straightners that is clear from this. You see, if the minimum distance is not feasible especially in the upstream, flow straightners can be installed and the flow straightners are bundle of smaller tubes welded inside the pipe. It has the bundle of smaller tubes welded inside the pipe. So, it will make the flow straight, so that the, the problem which occurred that means due to the pipe bending, elbow, tee can be, I mean can be minimized by using the flow straightners.

Now, next type of flowmeters already we have discussed orifice meter.

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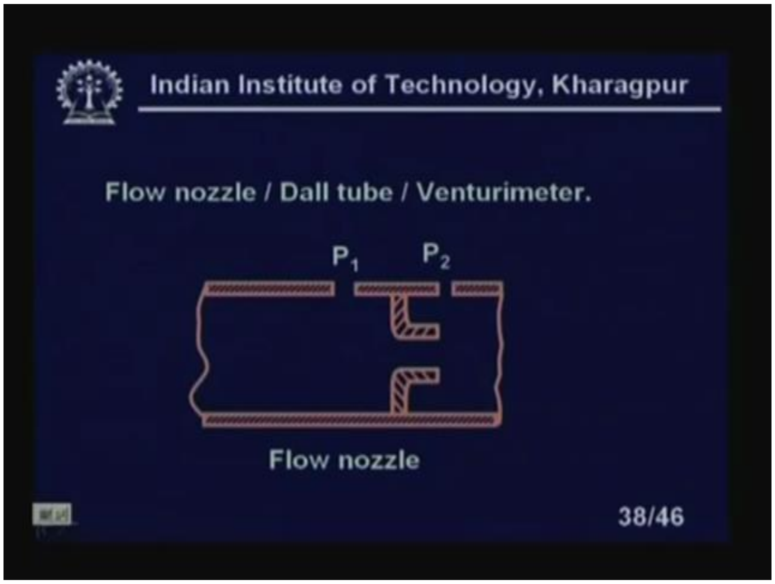

Next type of flowmeters are the flow nozzle, dall tube, Venturi all are same and orifice meter, Venturi meter, flow nozzle, dall tube, Venturi, these are basically same, but all are depends on differential pressure measurements. We will discuss one by one - flow nozzle, dall tube, then we will discuss in more detail the Venturimeters, because that is widely used for the large flow measurements, large quantity, I mean flow or the volumetric flow rate. This is a flow nozzle, you can see. This is a, is a shape like this one. It is a, this is called flow nozzle. We have an upstream pressure tap here, a downstream pressure just at the end of the nozzle outside the pipe. Just here we have upstream, downstream pressure tap, this is upstream pressure tap.

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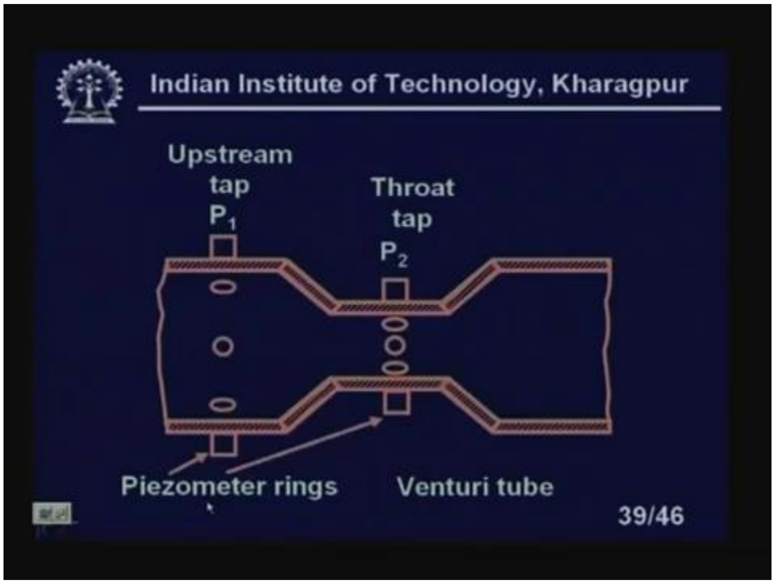

Here you see, this is a, this is our Venturi tube. Venturimeter is something like, this is upstream pressure tap. These are piezometer rings. We want to average the pressures. This is the throat tap. Instead of downstream we are calling it throat tap. This is the area of the minimum cross section, because there is difference of area will be A 1. This is A 1, area of cross section. This is the capital D, this is the small d. So, that ratio will give you the beta. This is the Venturimeter and these piezometer rings is to average the upstream pressure and this is to average the downstream pressure.

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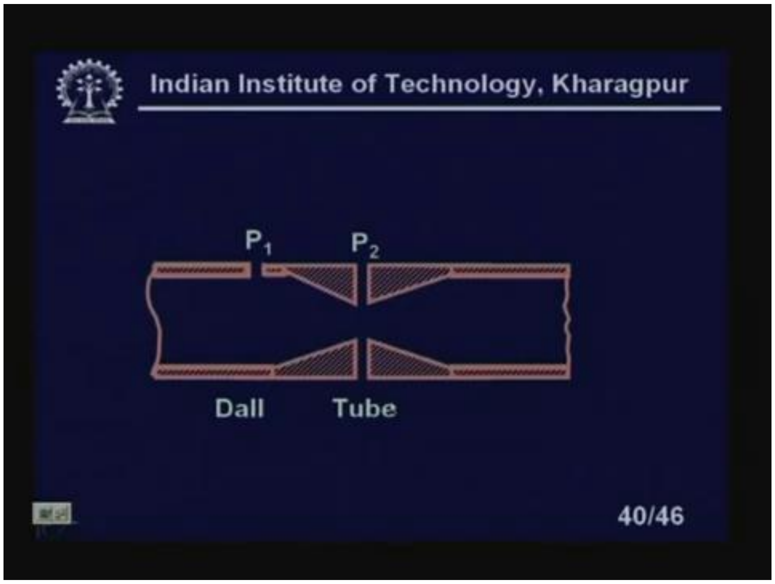

Now, this is a dall tube. So, we have a pressure, you have pressure tap here P 1 and pressure tap here P 2. So, these are all, basically there are some relative advantages and disadvantages in all these types of things. Flow nozzle and dall tube, let us first discuss the flow nozzle and dall tube, compare, then we will discuss the Venturi in details.

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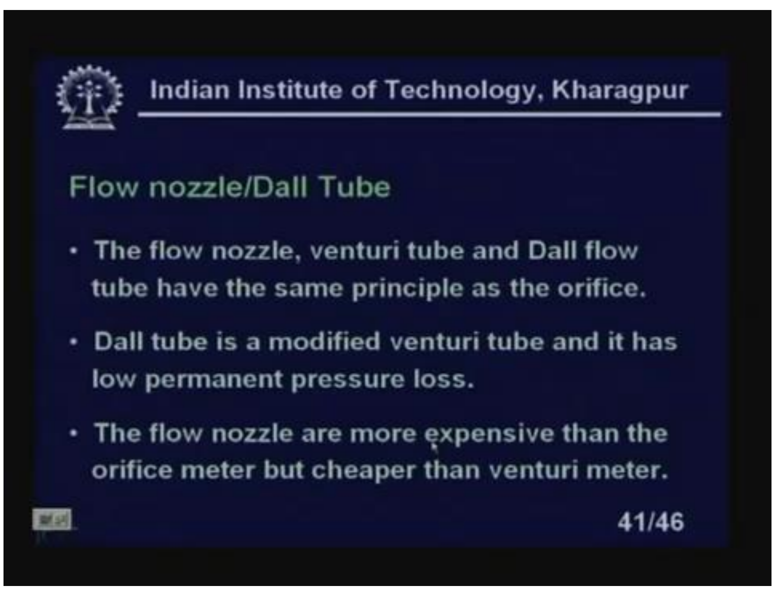

The flow nozzle, Venturi tube and dall flow tube have the same principle as the orifice. Flow nozzle, Venturi tube, dall flow tube have the same principle as the orifice; no difference, same. There is a differential pressure and we will measure the differential pressures. We will calibrate the differential pressure in terms of the volumetric flow rate, so no difference. So, that is the same, exactly same like orifice meter and it is non linear. Any differential pressure, I mean flowmeters are non linear. That means the volumetric flow rate is a, is the square root, proportional to the square root of the differential pressure or if you look at the differential pressure, it is proportional to the square of the volume flow rate.

Dall tube is a modified Venturi tube and it has a low permanent pressure loss; not low like, I mean Venturi tube, but it has a low permanent pressure loss, right? The flow nozzle are more expensive than the orifice meter, but cheaper than the Venturi meter. Venturi is the most expensive, as you know. So, the flow nozzle are more expensive than the orifice, but cheaper than the Venturi.

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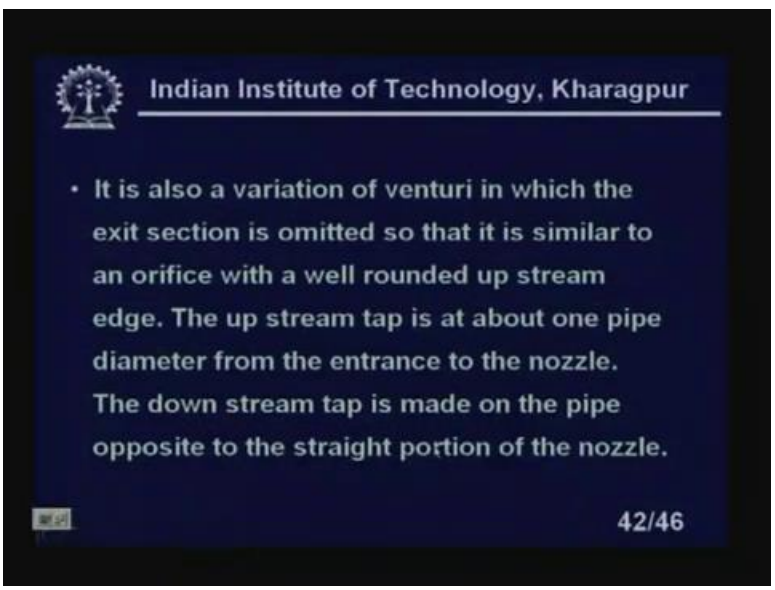

It is also a variation of the Venturi in which the exit section is omitted. We have, do not have any exit section if you look at very carefully, so that it is similar to the, similar to an orifice with well rounded upstream edge. The upstream tap is about one pipe diameter from the entrance to the nozzle and the downstream tap is made on the pipe opposite to the straight portion of the nozzle - that already we have discussed, right? We have shown that thing.

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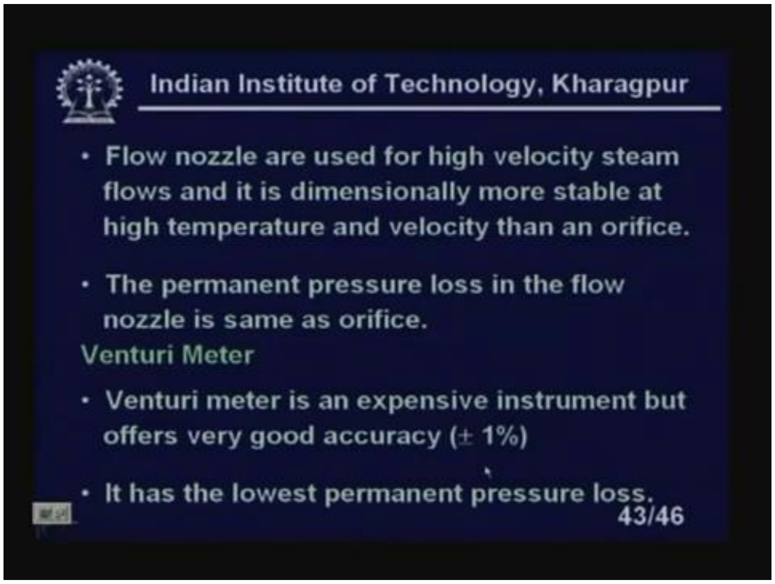

Flow nozzles are used for, because you know that in some situations or there is high pressures and high velocities, sometimes the orifice is not very stable. There is the question of buckling and all these things; that type of situation we have to use the flow nozzle and we cannot spend that money everywhere, I mean to install a Venturi meter instead of the orifice meter. So, in that type of situations you can use flow nozzle, because it is cheaper than the Venturi meter.

Flow nozzles are used for high velocity stream flows and it is dimensionally more stable at high temperature, velocity than an orifice. This is the most salient feature of the flow nozzle. That is the reason for high velocity, high temperatures we can use this flow nozzle instead of using the orifice meter and the pressure tapping is also not that difficult. So, you can have upstream pressure tap at the one pipe diameter, downstream pressure tap just at the end of the straight portions, just at the end, opposite to the end of the straight portion of the pipe, straight portion of the nozzle that will be on the pipe, right? The permanent pressure loss in the flow nozzle is same as orifice. So, there is a permanent pressure loss. It is quite high in the case of orifice meters. So, it is same also in the flow meters. It is the least or minimum in the case of Venturi meter, right? So, whenever there is a savings of the extra pumping cost you have to consider, you must go for Venturi meter; there is no other alternative.

Now if, let us, let me discuss Venturi meters in detail. Venturi meter is an expensive instrument, but offers very good accuracy. It is I should say one of the most accurate flowmeters developed by the mankind. So, it is plus minus 1% accuracy, so you can see that it is quite accurate. It has the lowest permanent pressure loss that I told several times. So, whenever there is question of permanent pressure loss, so you can go for the, this type of sensor.

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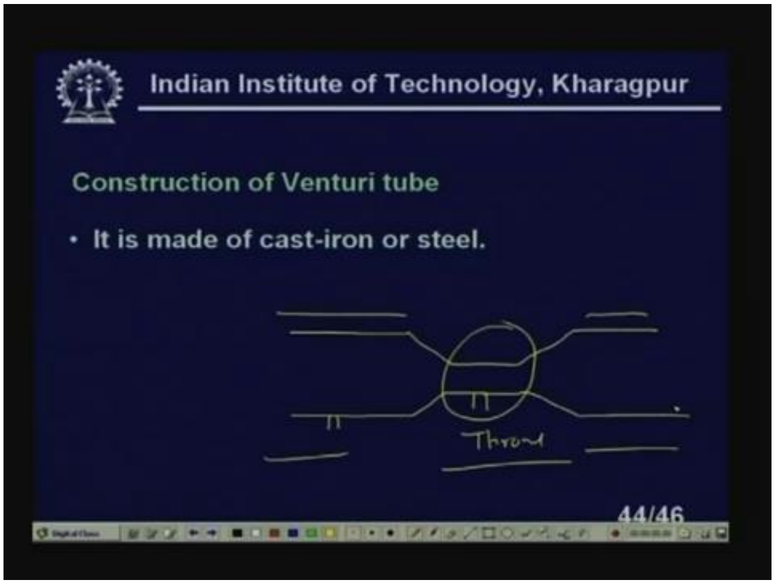

Now, construction of the Venturi if you look, look at the construction how the Venturi actually look like, it is made of cast iron or steel. Sometimes if you have larger, then I need a, it can be made of concrete also; large …… it can be made of concrete, made of cast iron or steel. Sometimes the throat portions of the Venturi, because if you look at the

Venturi it looks like this, isn't it? The Venturi looks like this. This we are calling it throat of the Venturi. We have a tap here; we have a tap here you know, so this is called throat. So, in some application, throats are made of separate metal, I mean it is usually made of bronze, because it is easily replaceable, all those things. The main systems, this, both this and this will be made up cast iron or steel, right and this all about …

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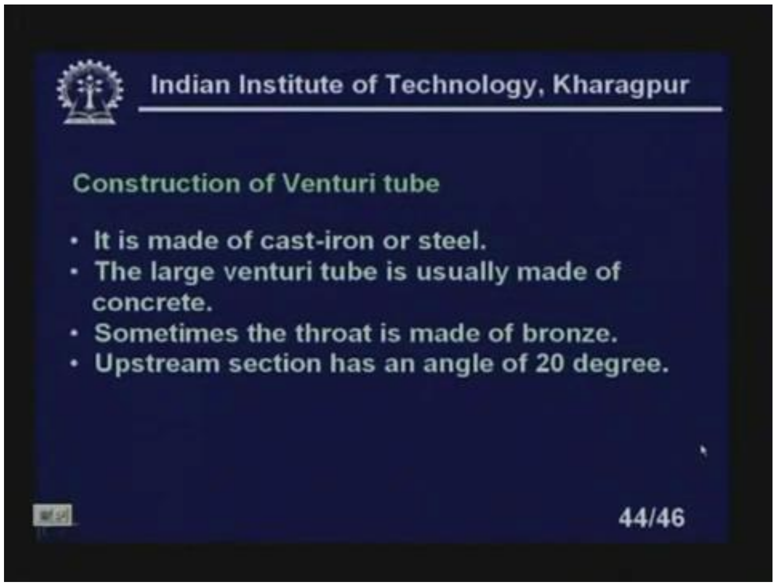

The large Venturi tube is usually made of concrete, because if it is very large, so it is very difficult to make, made of cast iron or steel. In that case we go for the concrete. Sometimes the throat is made of bronze, as I told you earlier, for easy replaceability. Upstream section has an angel of 20 degree, included angle. That means if you look at, so it looks like this.

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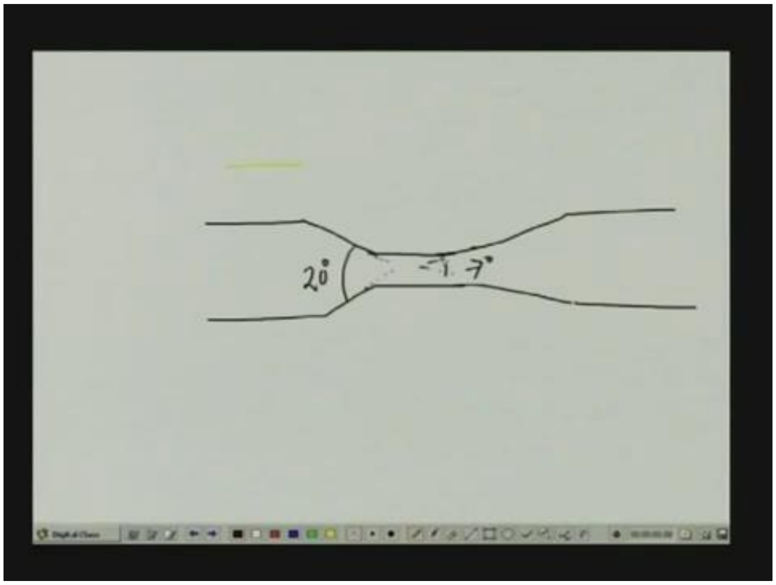

If I take a white page, so it will look like this that, I have to take different colours, so I am talking of this angle. That means if you look at this angle, this angle is 20 degree in the case of Venturi meters and this angle should be 7 degrees. In fact, you will find that basically there are two types of Venturi. One is for the larger downstream portion, another is the smaller downstream portion. You will find that if you, if you make this angle even lower, your pressure recovery will be also higher. So this angle, but it takes large space and all those things; that is the restriction of the Venturi. But, if you make this one large, you will find your pressure recovery also will be large. In fact, pressure recovery in the shorter Venturi is less.

That means the permanent pressure loss will be more in the case of short Venturi than the longer, standard Venturi. So, if this is large, suppose that I mean if you have this, this type of Venturi, then we have that, you will find that the total length might be increased, right; total length has increased, but the thing is that pressure recovery will be better and the permanent pressure drop also will be less. So, this is very important.

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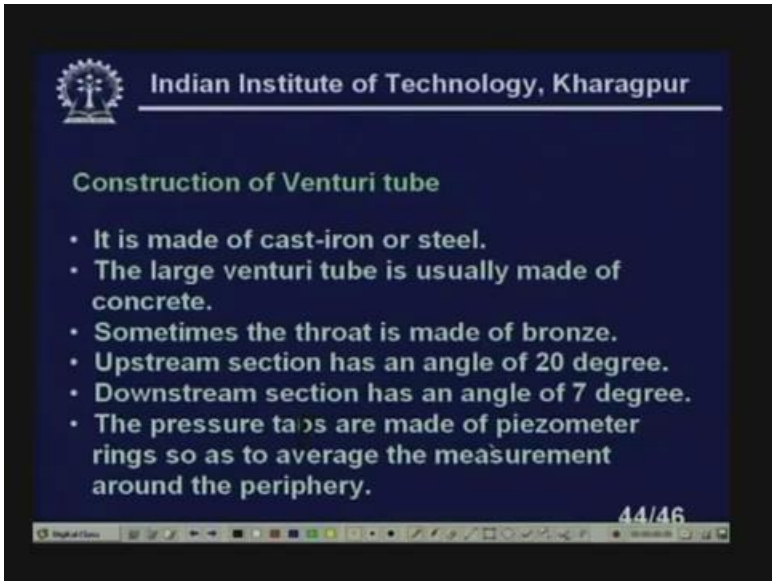

Upstream section has an angle of 20 degree and downstream section has an angle of 7 degree. These are all included angle, right? The pressure taps are, this should be, I am sorry this will be pressure taps, this will be pressure taps; pressure taps are made of piezometer rings, so as to average the measurement around the periphery.

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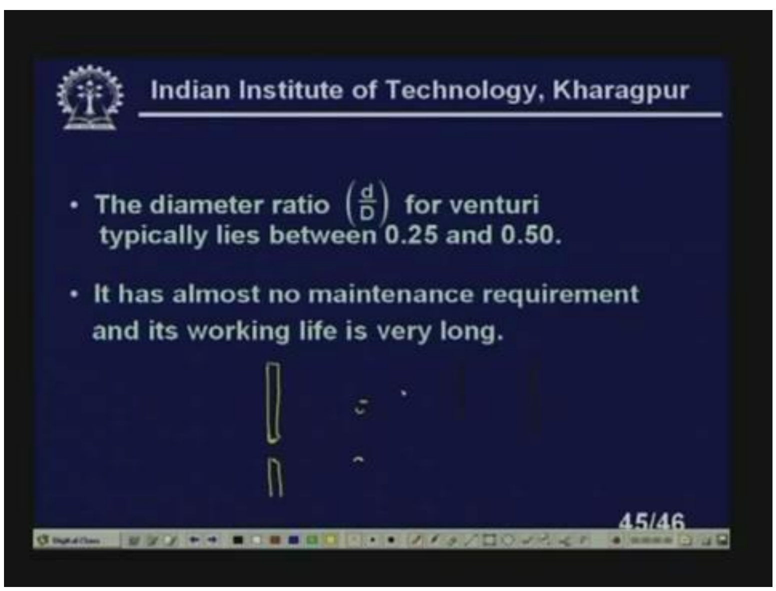

Diameter ratio, small d by capital D for Venturi typically lies between .252 and .50. It has almost no maintenance requirements and its working life is very, very long. So, almost absolutely no maintenance, which is necessary in the case of, in the case of orifice meter, special orifice meter. Whenever there is a routine maintenance you have to check that the square edge section is steel square edge, whether the diameter is exactly it remains as small d, which we have used for calibration purpose. If it is not, then you have to replace it. Usually, I mean during routine maintenance you must exchange this, replace this old orifice with a newer one, which is not necessary in the case of Venturi, because this is permanent, this throat is made out of steel, there is no chance of increasing the throat diameter which is there, because if you, if you after long use that means if I, you look at, that if the orifice is, I do not know; so, you see that we have a, if I take a, if you take like this one, so if this edge has got, I mean instead of like this one it is getting like this one, right and this is getting like this one, right so, the entire calibrations will go wrong. So, that, this, this type of situation does not arise, arise in the case of, arise in the case of Venturi meter. That is the great advantage of the Venturi meters.

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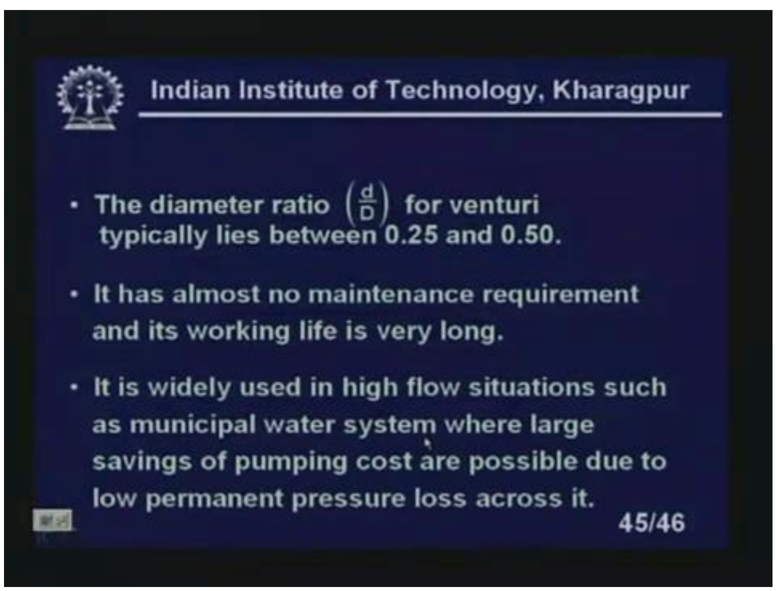

It is widely used in high flow situations such as municipal water system where large savings of pumping costs are possible due to low permanent pressure loss across it.

Usually that type of situations, I mean say, if the, if you look at the range of this flowmeters, orifice meter has a larger range than the, Venturi meters are larger than the orifice meters. So, this is the two great advantage of the, except the cost, the main advantages of the, this Venturi meter is that it is reliable, its range is very high, very, very high compared to orifice, any other permanent pressure drop is also very low. So, keeping all this in mind and whenever you are, I want to use, because you have to, whenever you want to this type of meters where the accuracy is very important, so I have to use this Venturi meter, there is no other alternative, right?

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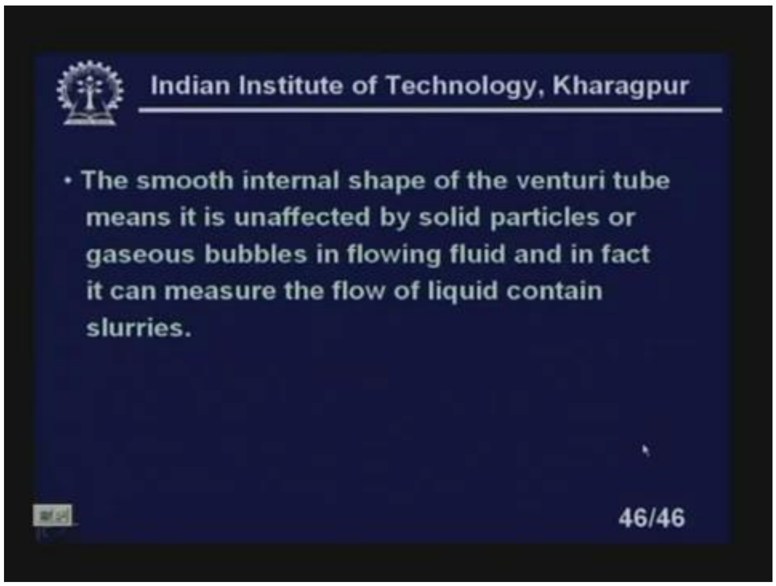

Now, the smooth internal shape of the Venturi tube means it is unaffected by the solid particles or gaseous bubbles in flowing fluid and in fact, it can measure the flow of liquid containing slurries. You see, this is very important. Even though in the case of, you will find that in future also you will, some flowmeters, electromagnetic flowmeters and electromagnetic flowmeters are there, so where you can use the, even if the liquid has some suspended particles, because since there also, there is no abstraction type of things. In the Venturi also there is no abstraction unlike your orifice meter, though both depends on the, both the, they depend on the differential pressure meter, you will find, differential pressure principle you will find that the, if the liquid contains the gaseous bubbles, we have tried, you see that we have seen already, discussed in the orifice meters we have eccentric orifice, we have concentric orifice, we have segmental orifice, but this does not suffice. In many situations, you will find it does not work. If you have, as … as the liquid is clean it is very difficult to measure with the orifice meter, right? That type of situation does not arise in the case of … Even though I am saying that the, you, you can do it with electromagnetic flowmeter, but electromagnetic flowmeter has problems. That means the liquid should have some conductivity levels. So, without that suppose in the case of hydrocarbon industries you cannot use electromagnetic flowmeters, because the conductivity is very poor there, right?

So, that type of situation does not arise in the, in the case of Venturi meter. It does not matter whether it is conducting liquid or not. Not only Venturi, orifice also, whether it is conducting liquid or non-conducting liquid does not matter, right? So far there is a differential pressure, I can measure it, right and since we are not measuring with manometers, we are using u tube manometer, we are using some differential pressure transmitter, so even though the liquid has some suspended particles, some slurries, it does not affect our pressure measurement, right, because you are, basically we are using a separate type of, I mean capsule type differential pressure transmitter, so which will sense some signals and give 4 to 20 milliampere of output.

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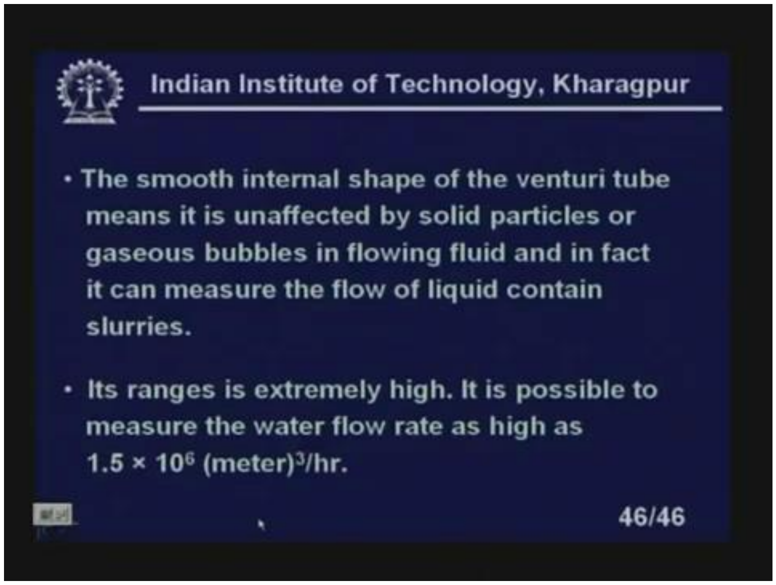

Now, its range is very high. You can see its range is extremely high. It is possible to measure the water flow rate as high as 1.5 into 10 to the power 6 meter cube per hour. No other flowmeter will give you this huge range. The dimensions will be quite big that I agree, but the thing is this type of high fluid flow rate or the volumetric flow rate, we will never achieve in any other flowmeter. This is very important, right and this is also, please note that this is also needed in some type of situation, because in that type situations you will find that I need flowmeters where I need differential pressure output as well as I need flowmeters, where I need large quantity of the volume flow rate. In that type of situations I have to use the Venturi flowmeters. So, this is very important measurements, right?

Now, another thing, please note in the case of Venturi flow, I mean orifice meters, once you install, the advantage of the Venturi meter you cannot even find that if you go to any process industry you may find one or two, I mean Venturi meters, but you will find hundreds of orifice meters, because of its easy replaceability. It is very easy to replace it. Just take out the plate and replace the plate of the same diameters and same thickness, so you do not have to recalibrate your sensor. That is if it is square edge orifice, if the small d is same, so there is no question of recalibration and in the case of Venturi meters there is no question of that type of calibration or anything because its life, I say, it is just, if there is no weir, or the surface, the internal surface or if there is no chances of increasing the internal diameters of the pipes, so there is no question of changing of beta. So, these, all these advantages, I mean make these two particular flowmeters, even though we are, you will find that there are many different types of flowmeters - electromagnetic flowmeters, we have …… flowmeters, ultrasonic flowmeters, …… flowmeters, but this does not used much in the any process industry.

What we are using actually you will find that this type of signal in, in large I mean this type of sensors that means Venturi and flow in large number. Only disadvantage of this type of meter if you look at that is orifice and Venturi, everywhere you need a transmitter. I need a transmitter, both in the orifice and Venturi I mean a system, not only a system, because here the output is not electrical, unlike your turbine flowmeter, unlike your electromagnetic flowmeter, where the output is direct electrical. Basically it is pneumatic output, which is coming in the case of, in the case of, or hydraulic outputs which is converted by capacitance change and we are getting 4 to 20 milliampere of current from the transmitter which is transmitted, but if the electrical output is there either in voltage or current, directly that can be transmitted. If it is the case of voltage, we will convert to the 4 to 20 milliampere of current and transmit.

These are the some advantages of the, of the non differential type of flowmeters, but …… differential flowmeters, see we are using it for a quite long, many years in the industry. So, it does not matter that the, what is the, I mean how much it is cumbersome. It looks very cumbersome, we have seen already in the, when we went to the lab and see this differential pressure transmitter, so every orifice meter and Venturi meter must have that type of things just above the pipe. So, that should be there.

So, if you, there are suppose 500 orifice meters, so we must have 500 transmitter also. It does not matter you know exactly when you, you are getting the correct measurements. It is easy, ease of maintenance is I mean leaving all these things if you have this type of advantages that I mean pushes us, I mean to a corner, where we have no other alternative than using a orifice meter and all the data are available for the years, for the all different process industries, all different manufacturing industries. So, this helps us to make the use of this particular type of flowmeters.

We have discussed only this orifice and Venturi. There are many other flowmeters, like I told you that this is the only two differential pressure flowmeters we have discussed in this particular lesson. But, please remember we have also differential flowmeters like, pitot tube is also differential pressure flowmeters, Elbow meter is also differential pressure flowmeter. In the next session this will be discussed. So, this ends the lesson 12 of Industrial Instrumentation.