Chemical Process Instrumentation

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Lecture - 45
Flow Measurement (Contd.)

Welcome to lecture 45, we are talking about flow measuring instruments. So, this is the last lecture of this week.

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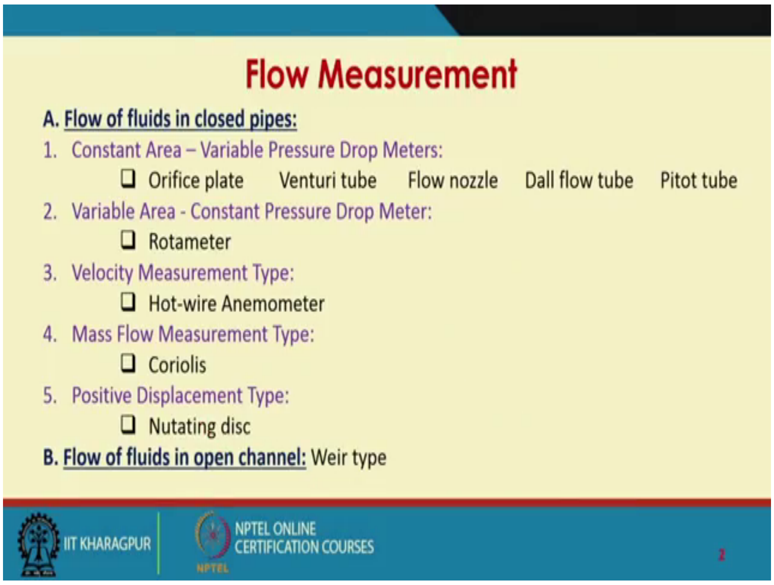

We have talked about constant area variable pressure drop meters we have talked about variable area constant pressure drop meter. So, today we will talk about velocity measurement time mass flow measurement time positive displacement time. Also we talk about wear type flow meters which are used for flow of fluids in open channel.

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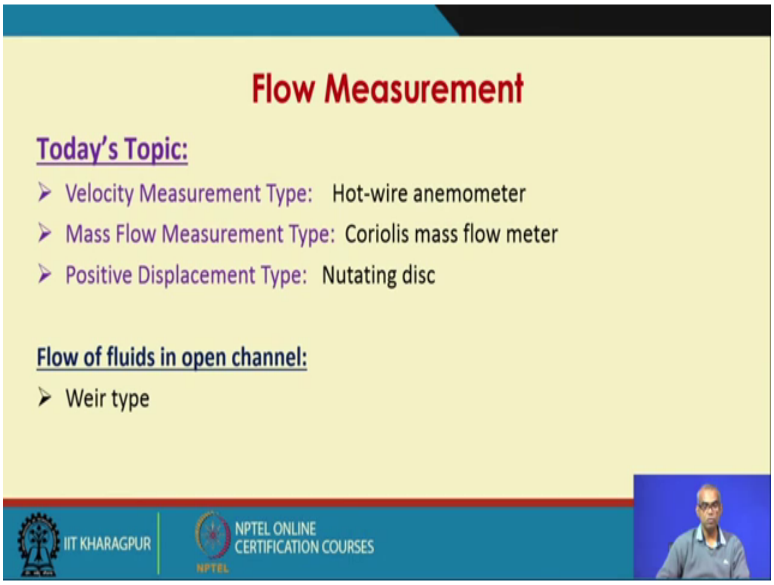

So, under velocity measurement we will talk about hot-wire anemometer and a mass flow measurement type: we will talk about Coriolis mass flow meter, under positive displacement type we will talk about Nutating disc and for flow of fluids in open channel we talk about weir type flow meters.

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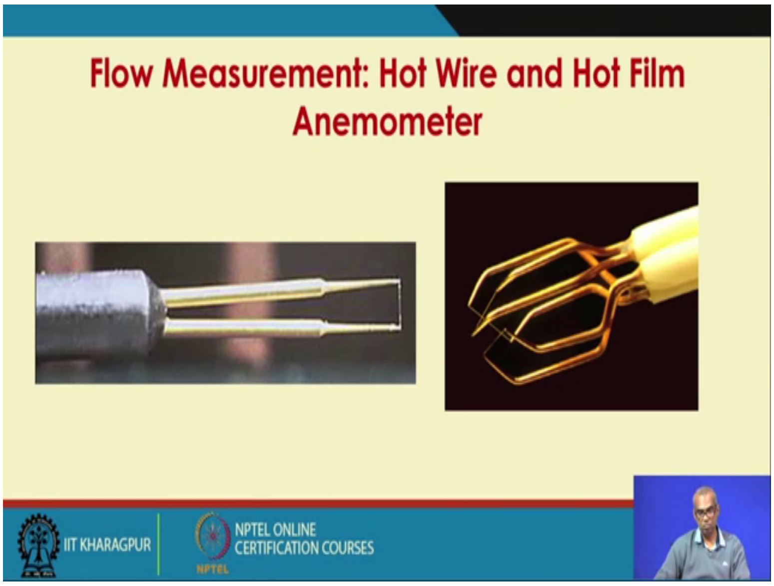

What you see an images of hot-wire anemometer?

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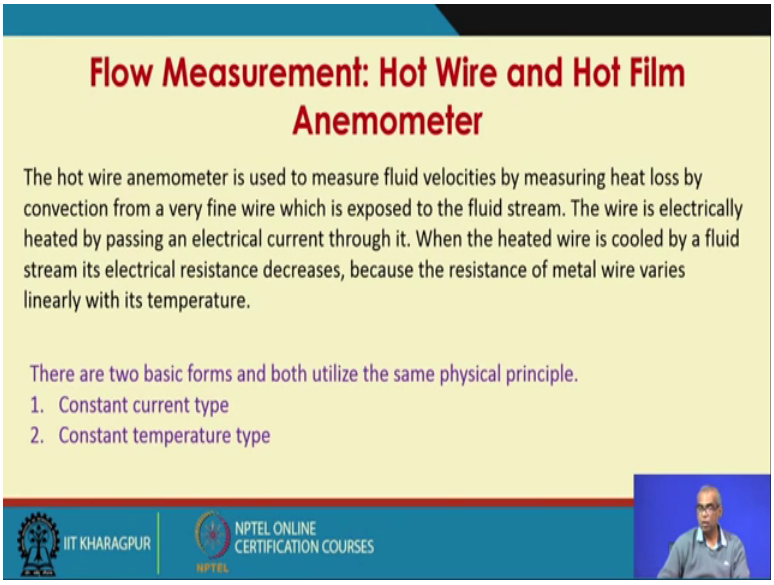

The hot-wire anemometer is used to measure fluid velocities by measuring heat loss by convection from a very fine wire which is exposed to the fluid stream. The wire is electrical heated by passing an electrical current through it.

When the heated wire is cooled by fluid stream it is electrical resistance decreases, because the resistance of metal wire varies linearly with temperature instead of hot-wire. We can also have hot thin film there are two basic forms of hot-wire or hot film anemometers. And both utilize the same physical principles constant current type and constant temperature type let us first talk about constant.

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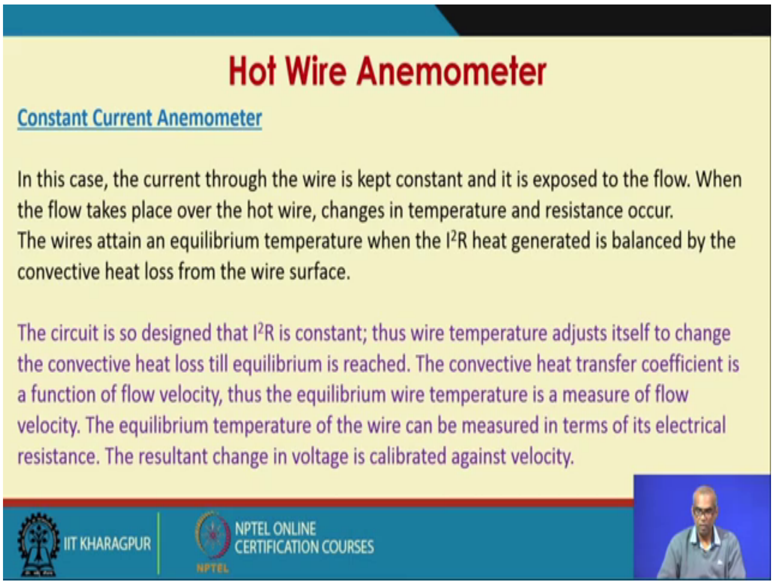

Current anemometer in this case, the current through the wire is kept constant and it is exposed to the flow.

When the flow takes place over the hot wire, changes in temperature and resistance occur. So, when the flow takes place over the hot wire, there will be changes in temperature and accordingly there will be changes in resistance. The wire attain an equilibrium temperature when the, I square R heat generated is balance where the convective heat loss from the wire surface. So, since a current is flowing through the resistance wire there will be heat generated whose amount will be equal to I square into R where I is the current flowing through the wire and R is the resistance.

Now, the hot wire is exposed to the fluid. So, there will be convective heat loss from the wire surface to the fluid medium. So, the wire will assume an equilibrium temperature when there is a balance between the heats generated there is I square R heat generated and the convective heat loss from the wire surface the circuit is. So, designed that I square R is constant, thus wire temperature adjust itself to change the convective heat loss till equilibrium is switched.

The convective heat transfer coefficient is the function of flow velocity thus the equilibrium wire temperature is the measure of flow velocity. So, this is to be understood that the convective heat loss for coefficient is the function of flow velocity. In fact, this is given by kings law thus the equilibrium wire temperature is the measure of flow velocity, because the convective heat loss for coefficient will detect the equilibrium temperature of the wire, because the equilibrium temperature wire will depend on the, I square R heat generated equal to convective heat loss from the wire surface. So, equilibrium temperature will be established, when I square R heat generated equal to the convective heat loss from the wire surface.

Now, the convective heat loss will depend on the convective heat transfer coefficient now convective heat transfer coefficient depends on the flow velocity according to King's law. So, the flow velocity also decides, what will be the temperature of the hot-wire anemometer? The temperature or the equilibrium temperature of the wire can be measured in terms of electrical resistance, because if the temperature changes resistance changes.

So, I can measure the temperature by measuring the resistance using a bridge circuit using wheat stone bridge principle. So, the resultant change in voltage can be now calibrated in terms of voltage sorry in terms of velocity.

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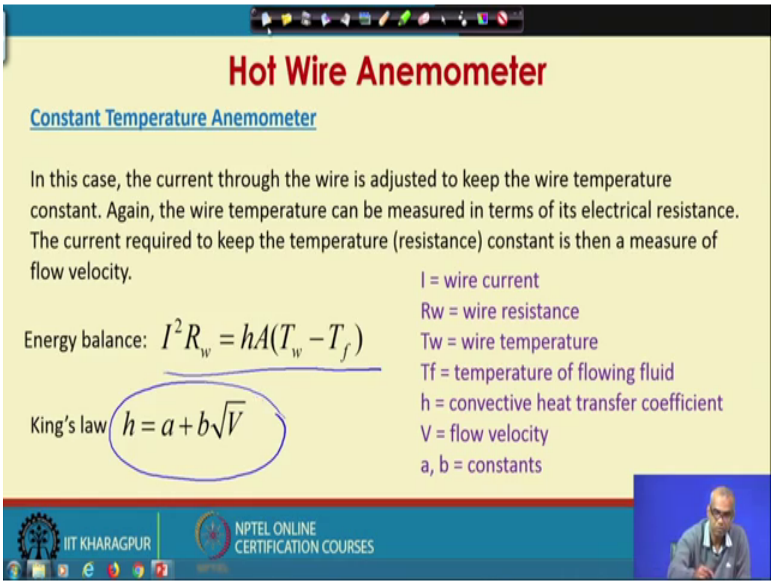

Constant temperature anemometer in this case, the current through the wire is adjusted to keep the wire temperature constant. Again, the wire temperature can be measured in terms of it is electrical resistance. The current required to keep the temperature or the (resistance) of the wire constant is then a measure of flow velocity. So, you can see the both the constant current type anemometer and the constant temperature type anemometer basically uses the same principle, but in a different way.

So, this is the energy balance I square R R w R w is the wire resistance and I is the wire current. So, I square R w is the heat generated and the convective heat loss from the wire surface is heat transfer coefficient h multiplied by the area of heat transfer into the temperature difference between the wire and the surrounding fluid.

So, T w is the temperature of the wire and T f is the temperature of the flowing fluid. So, energy balance I square R is h into A into T w minus T f. The King's law relates heat transfer coefficient with the flow velocity according to this expression, where V is the velocity h is the convective heat transfer coefficient and small a small b are constants.

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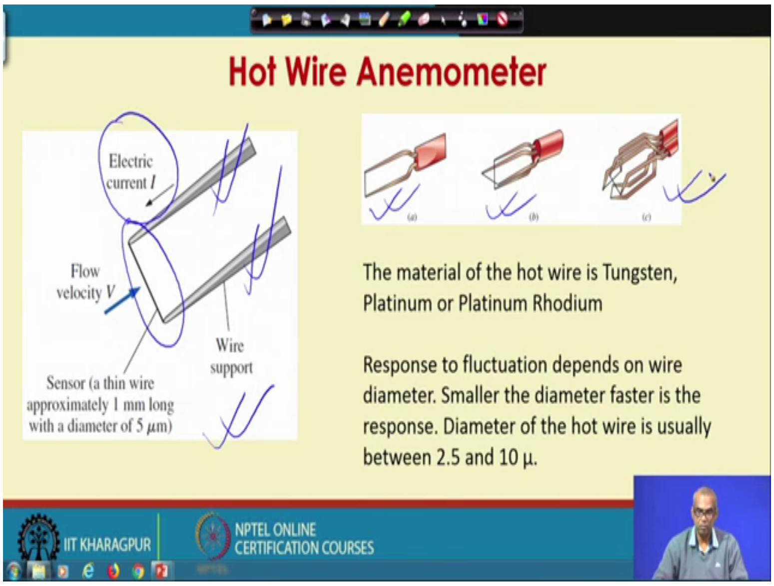

So, this is the sensor. So, this is the theme where which is approximately 1 millimeter long and it has a diameter say approximately 5 micrometer. In fact, the diameter varies between; 2.5 micrometer to 10 micrometer. So, this is the sensor which is nothing, but a thin wire may be a thin platinum wire and you have the wire support.

So, electric current flows through the wire. So, there are different designs and this one goes to one arm of the Wheatstone bridge the material of the hot-wire can be platinum it can be tungsten or it can be platinum rhodium response to fluctuation depends on wire diameter smaller the diameter faster is the response the diameter is small normally in the range of 2.5 and 10 micrometer. Typically, high micrometer is often used, but smaller the diameter faster is the response.

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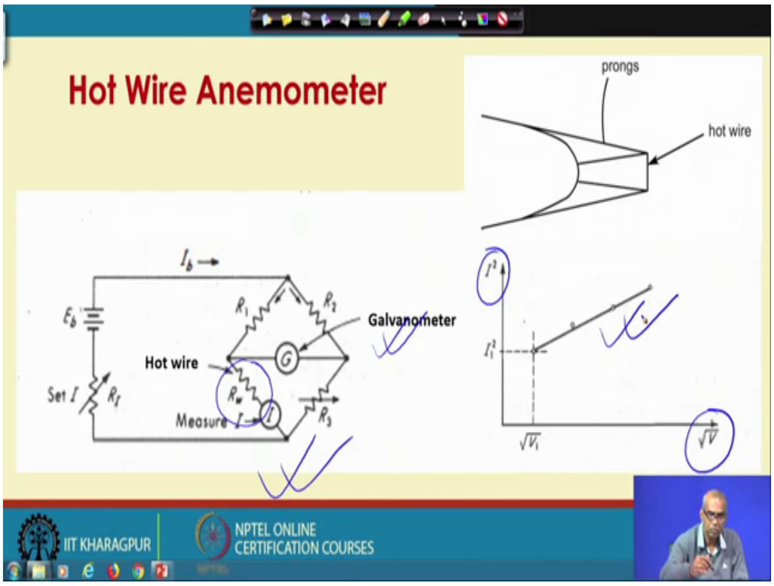

So, this is an arrangement using bridge circuit for measurement of flow velocity. So, I have attached the hot-wire anemometer as one arm of the Wheatstone bridge. So, this is the galvanometer whose readings will be used to relate to the flow velocity. So, the current versus velocity relationship is linear, when I plot I square versus square root of velocity.

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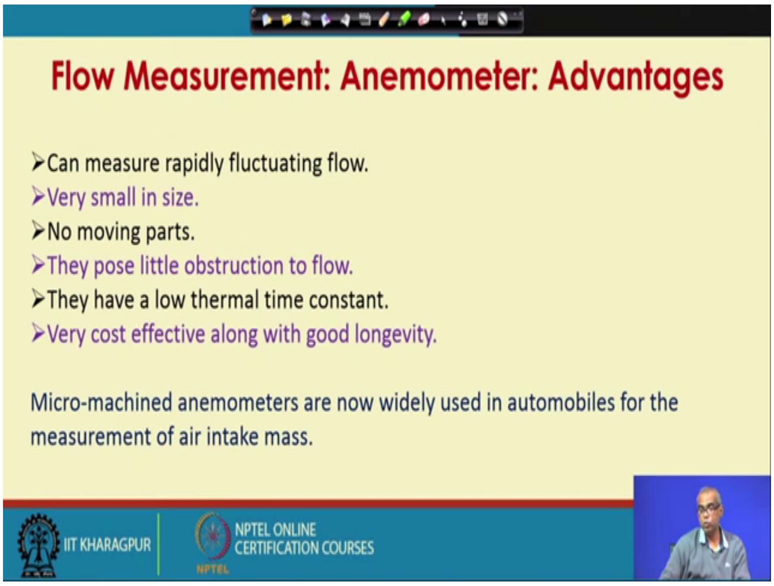

The advantages of hot-wire anemometer it: can measure rapidly fluctuating flow, very small in size, no moving parts, they pose little obstruction to flow, they have a low thermal time constant, and they are very cost effective along with good longevity. Micro-machined anemometers are now widely used in automobiles for the measurement of air intake mass.

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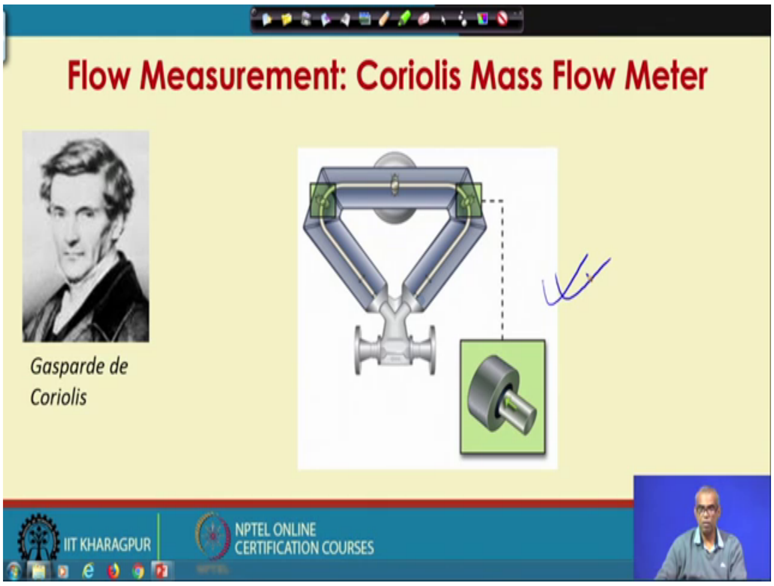

Next we will talk about Coriolis Mass Flow Meter, what you see is an image of a Coriolis mass flow meter. These are very accurate flow meters, but more expensive than several other types of flow meters the principles are based on Coriolis force.

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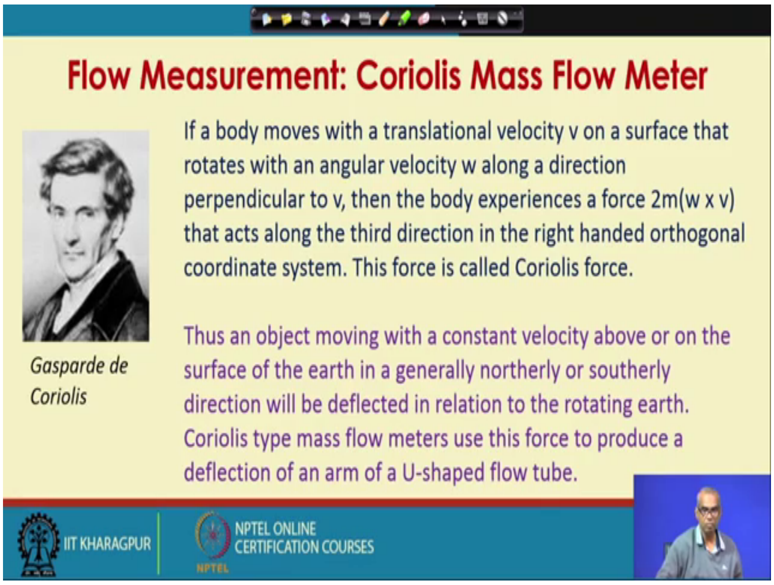

So, let us first try to understand what is Coriolis force? If a body moves with a translational velocity v on a surface that rotates with an angular velocity w along a direction perpendicular to v then the body experiences a force which is 2 times m into w cross v that acts along the third direction in the right handed orthogonal coordinate system. This force is called Coriolis force here a means the mass of the body.

This Coriolis force is named against Gasparde de Coriolis. Thus an object moving with a constant velocity above around the surface of the earth in a generally northerly or southerly direction will be deflected in relation to the rotating earth. Coriolis type mass flow meters use this force to produce a deflection of an arm of a U-shaped flow tube. The Coriolis force is extremely important in several branches of science for example, in atmospheric science.

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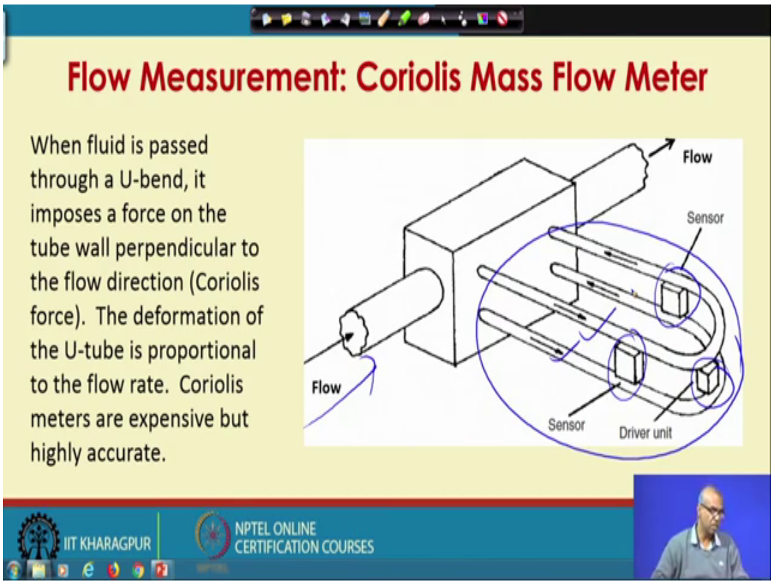

So, when fluid is passed through a U-tube or U-bend. So, you have one U-bend and another U-bend. So, this is a design where two U-bends have been used there are designs of Coriolis mass flow meter which is a single bend you single U-bend if there are several other geometries also possible. When fluid is passed through a U-bend it imposes a force on the tube wall perpendicular to the flow direction this is Coriolis force.

The deformation of the U-tube is proportional to the flow rate Coriolis meters are expensive, but highly accurate. So, note that there are two U-bends here the flow through this pipe is in this direction and this has been attached to the pipe through which fluid is moving. So, there is this driver unit and there is these two sensors. We will now see the role of this driver unit and these sensors in the next slides.

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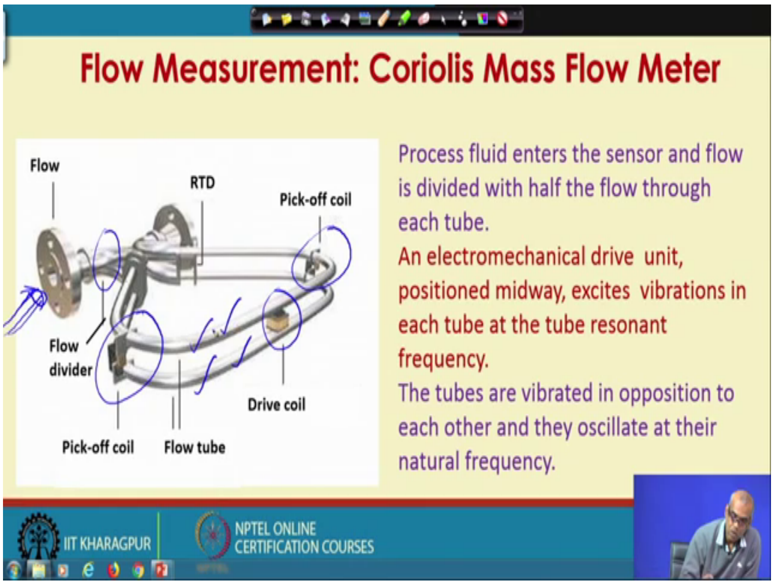

So, this is the connections to the pipe through which fluid is flowing again we are looking at a design which has two U-bends. So, this is one flow tube this is another flow tube. So, this is the drive coil this produces vibrations in each tube and this is one sensor this is another sensor they are called pick off coil we will see what they do in the next slide.

Here, you have flow divider what it does is it divides the flow that is flowing through this equally to this tube and this tube. So, process fluid enters the sensor and flow is divided with half the flow through each tube. An electromechanical drive unit, positioned midway, excise vibrations in each tube at the tube resonant frequency. The tubes are vibrated in opposition to each other and they oscillate at their natural frequency midway from here to here.

So, these two tubes this two sensor flow tubes are anchored here. So, this is mid way from this anchor and this anchor and there are two pick off coils which are basically sensors.

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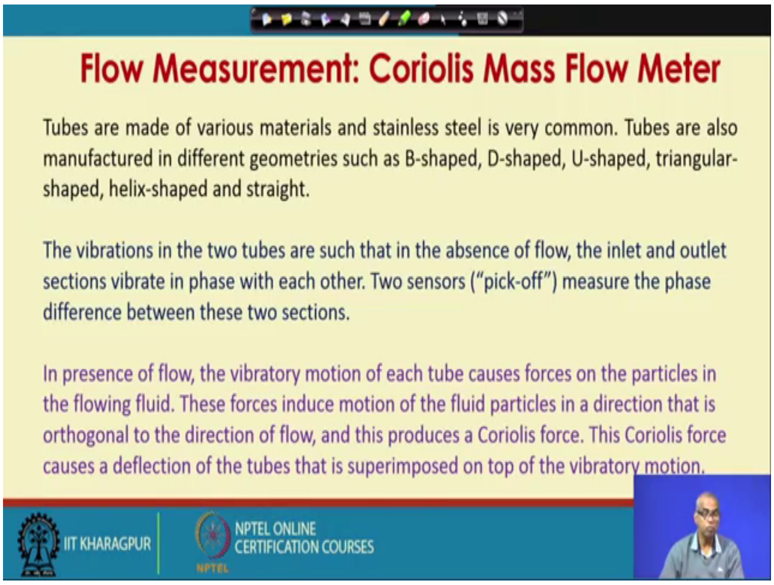

Tubes are made of various materials and stainless steel is very common. Tubes are also manufactured in different geometries such as B-shaped, D-shaped, U-shaped, triangular-shaped, helix-shaped and straight. The vibrations in the two tubes are such that in the absence of flow, the inlet and outlet sections vibrate in phase with each other.

Two sensors which we call pick off measures the face difference between these two sections. So, those two pick off coils or two sensors measure the face difference between these two sections. In presence of flow, the vibratory motion of each tube causes forces on the par particles in the flowing fluid. These forces induce motion of the fluid particles in the direction that is orthogonal to the direction of flow, and this produces a Coriolis force. The Coriolis force causes a deflection of the tube that is superimposed on the top of the vibratory motion.

So, in presence of flow the vibratory motion of each tube causes forces on the particles in the flowing fluid. This vibratory motion was caused by the drive coil. So, the drive coil causes the vibratory motion and this two pick off coil measures the phase shift between these two vibrations in this two sections. In presence of flow, the vibratory motion of each tube causes forces on the particles in the flowing fluid. These forces induce motion of the fluid particles in a direction that is orthogonal to the direction of flow, and these produces a Coriolis force.

This Coriolis force causes a deflection of the rate of the tubes that is superimposed on the top of the vibratory motion.

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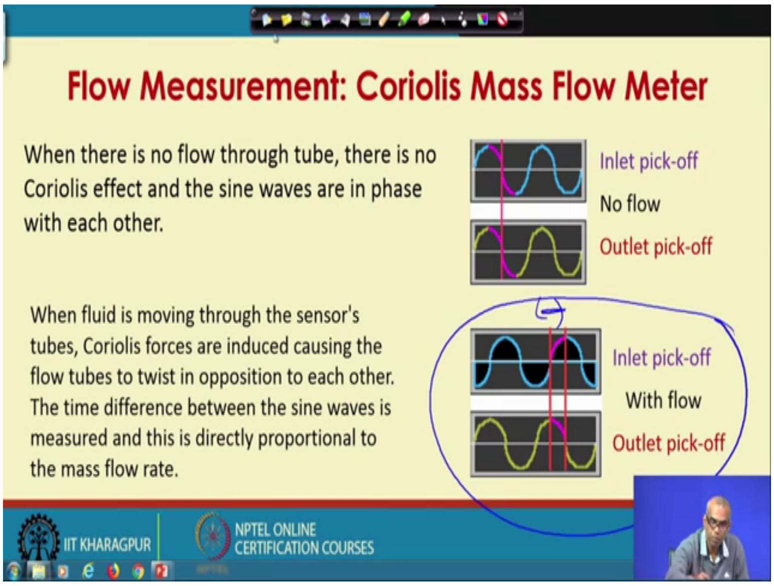

When there is no flow through the tube, there is no Coriolis effect and the sine waves are in phase with each other. So, this pick off coils will measure the phase shift between these two sections. So, you have inlet pick off you have outlet pick off and when there is no flow through the tube, there will not be any Coriolis effect and the sine waves are phase with each other as shown in the figure. See both are in phase with each other when fluid is moving through the sensor's tube, Coriolis forces are induced causing the flow tubes to twist in a position to each other.

The time difference between the sine waves is measured and this is directly proportional to the mass flow rate. So, when there is fluid flowing through the tubes there will be development of a Coriolis force this Coriolis force will cause a deflection in the tube and this flow tubes will twist in opposition to each other the time difference between the sine waves is measured and it is directly proportional to the mass flow rate. So, there will be a phase shift there will be a phase shift which can be measured in terms of the time difference and this is directly proportional to the mass of the fluid flowing through the sensor.

So, this time difference or phase shift is directly proportional to the mass flow rate. So, this is what happens; when you have flow through the sensor tube.

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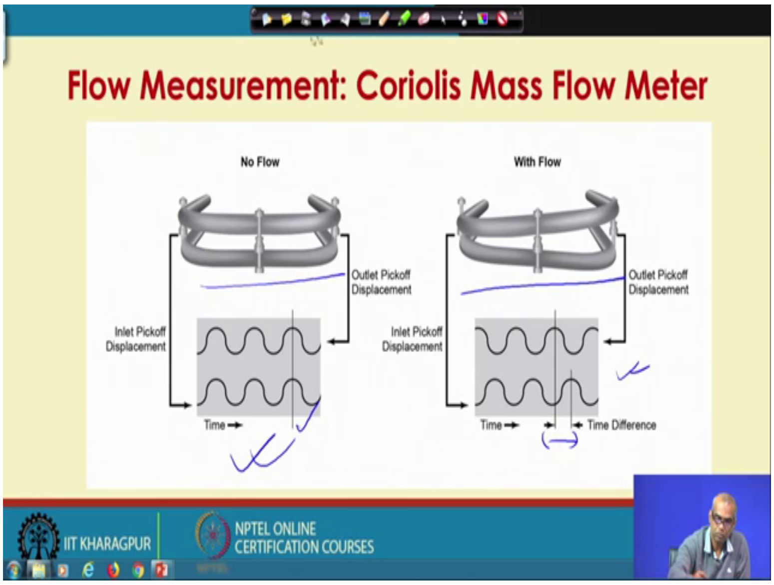

So, this is the same when there is no flow there is no Coriolis effect, but when there is flow there is Coriolis effect there is no phase shift here, but there is a phase shift here. So, this time difference is directly proportional to the mass flow there are various geometries B type.

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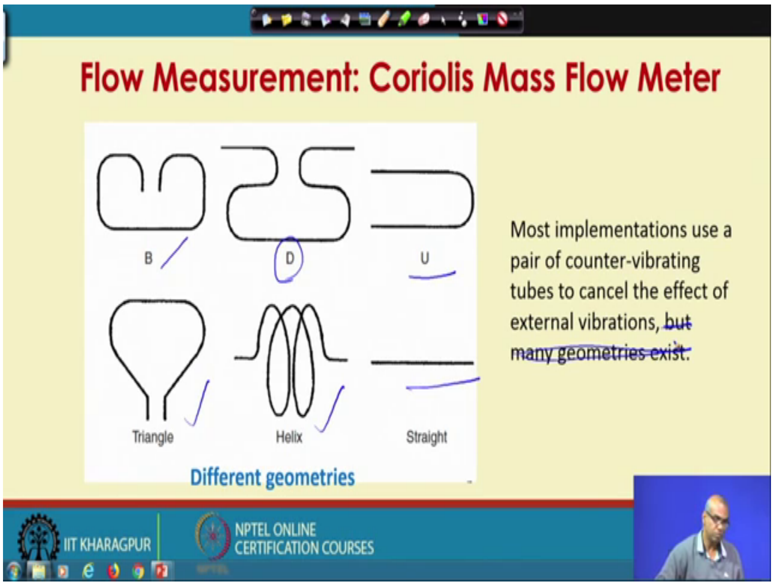

D type, U end triangle helix straight most implementations used a pair of counter vibrating tubes to cancel the effect of external vibrations.

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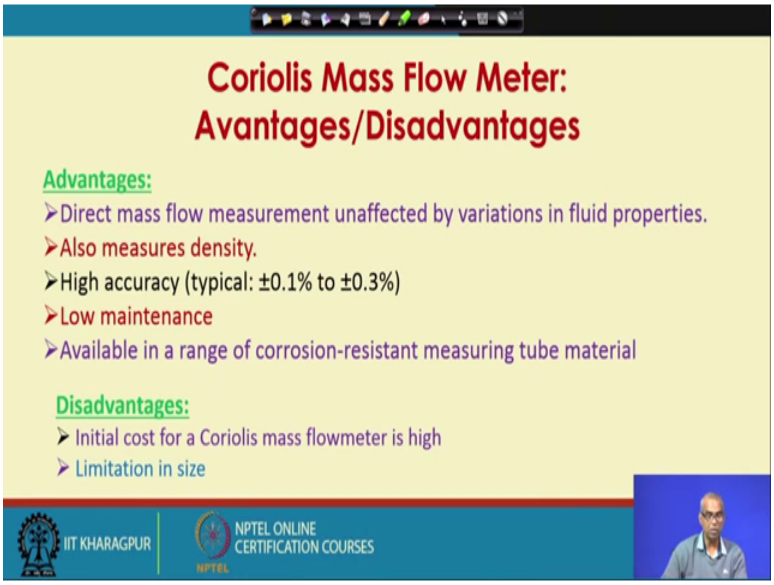

Advantages of disadvantages of Coriolis mass flow meter advantages: Direct mass flow measurement unaffected by variations in fluid properties. Coriolis mass flow meter also measures density high accuracy can be obtained. The typical accuracy is plus minus 0.1 percent to plus minus 0.3 percent low maintenance cost available in a range of corrosion resistant measuring tube materials.

Disadvantages: Initial cost for a Coriolis mass flow meter is high, limitation in size.

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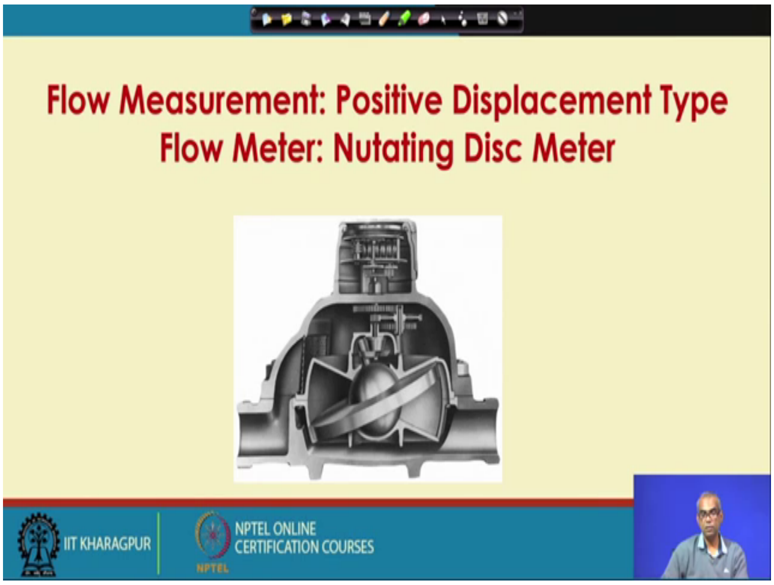

Flow measurement by positive displacement type, flow meter we will talk about Nutating disc meter positive displacement flow meters a direct measurement meters.

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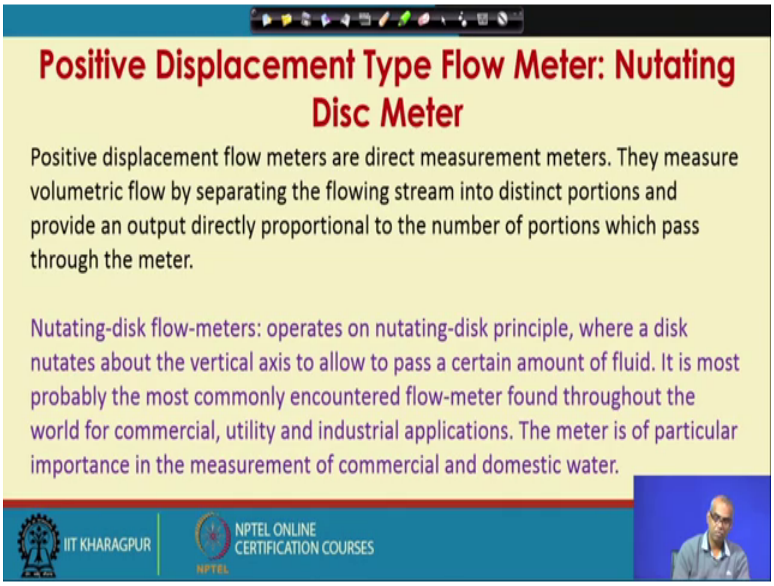

They measure volumetric flow by separating the flowing stream into distinct portions and provide an output directly proportional to the number of portions which pass through the meter.

Nutating-disc flow-meters: operates on nutating-disk principles, where a disc nutates about the vertical axis to allow to pass a certain amount of fluid. It is most probably the most commonly encountered flow-meter found throughout the world for commercial, utility and industrial applications. The meter is of particular importance in the measurement of commercial and domestic water.

Note that nutating-disk is not same exactly rotating disc. So, if the disc is nutating; that means, with while it is rotating it is swaying oble is another term used for nutating.

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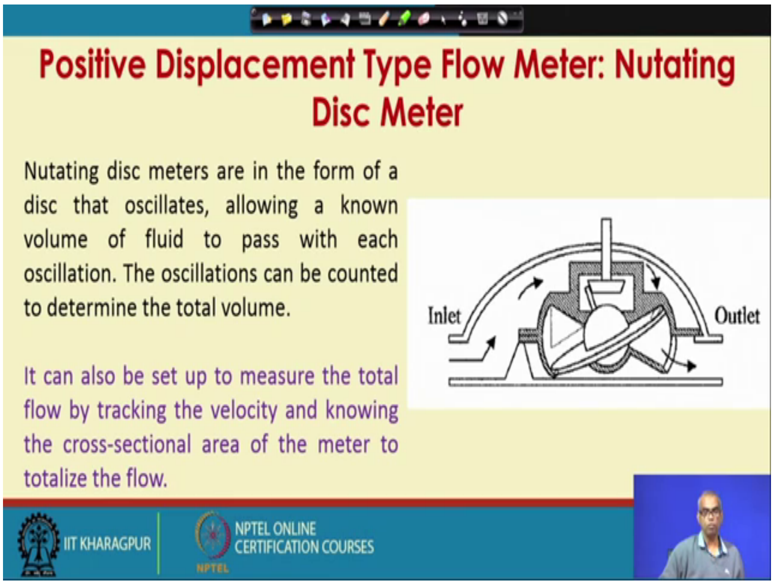

Nutating-disc meters are in the form of a disc that oscillates, allowing a known volume of fluid to pass with each oscillation. These oscillations can be counted to determine the total volume. So, this is the disc which oscillates or nutates and it allows a known volume of liquid to pass through it with each oscillations.

So, if I count these oscillations I can determine the total volume. It can also be set up to measure the total flow by tracking the velocity and knowing the cross-sectional area of the meter to totalize the flow.

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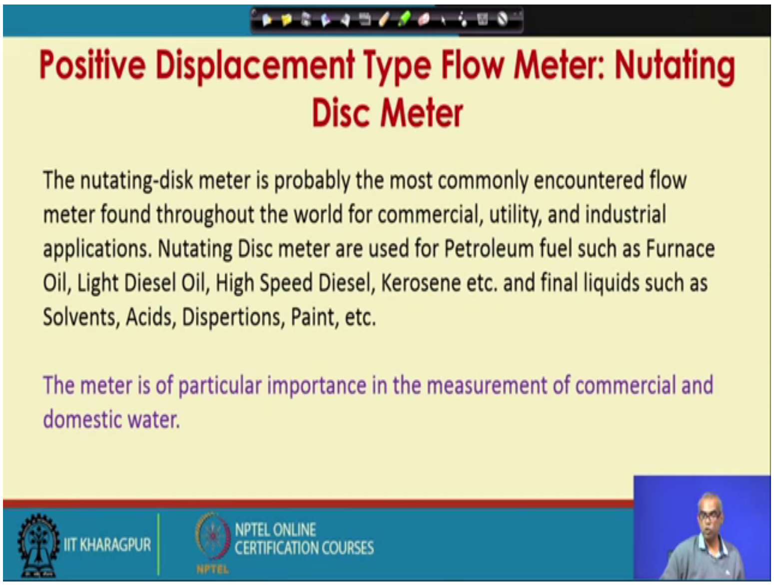

The nutating-disk meter is probably the most commonly encountered flow meter. nutating-disk meter are used for petroleum fuel such as Furnace Oil, Light Diesel Oil, High Speed Diesel, Kerosene etc. and final liquids such as Solvents, Acids, Dispertions, Paint, etc.

The meter is a particular importance in the measurement of commercial and domestic water.

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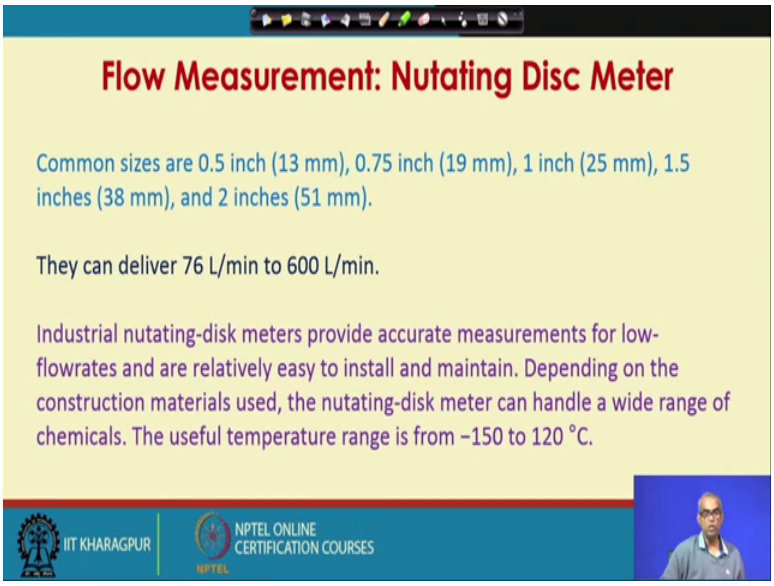

The common sizes for nutating-disk meters are 0.5 inch, 0.75 inch, 1 inch, 1.5 inch and 2 inches. They can deliver flows in the range of 76 liter per minute to 600 liter per minute. Industrial nutating-disk meters provide accurate measurements for low-flow meters and a relatively easy to install and maintain.

Depending on the construction materials used, the nutating-disk meter can handle a wide range of chemicals such as, acids slurries etc. The useful temperature range is from minus 150 degree Celsius to 120 degree Celsius.

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Finally, we will talk about flow in opposite channel and we will talk about weir what you see is some images of flow through open channel.

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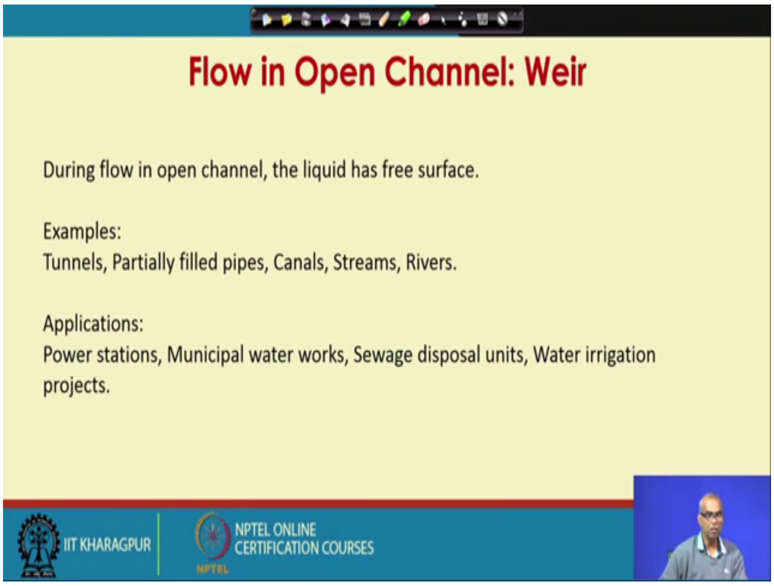

So, what is flow through open channel? So, during flow in open channel, the liquid has free surface. There are natural flows in open channel there are artificial creation as well. So, examples of flow in open channel Tunnels, Partially filled pipes, Canals, Streams, Rivers, etc. There are several useful applications of flow meters in flow in open channels such as Power stations, Municipal water works, Sewage disposal units, Water irrigation projects etcetera.

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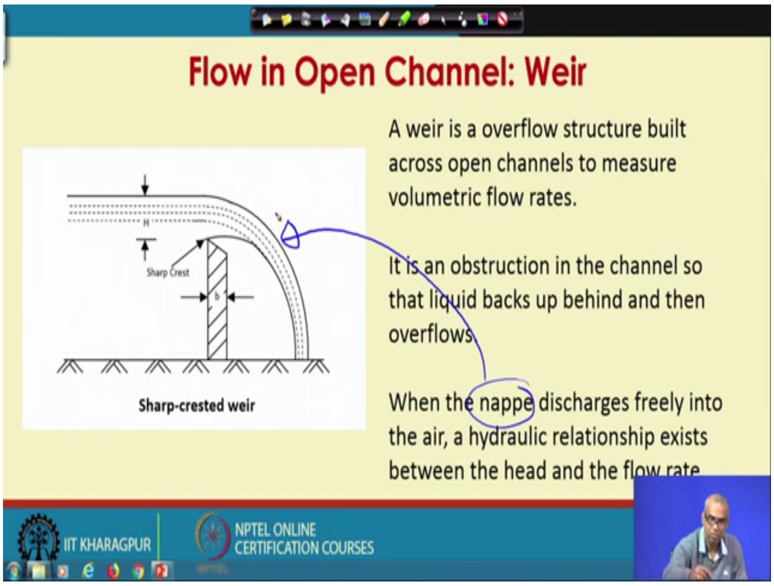

We will talk about a flow meter called weir which will use which it can be used to measure volumetric flow rate in flow in open channel. A weir is a overflow structure built across open channels to measure volumetric flow rate. Basically, it is an obstruction in the channel so that liquid backs up behind and then overflows.

When the nappe discharges freely into the air, a hydraulic relationship exists between the head and the flow rate. So, that helps me to find out the flow rate this nappe is basically this. So, when nappe discharges freely into the air a hydraulic relationship exist between the head and the flow rate.

So, we can measure the head is a pressure head we can measure and then since there is a relationship that exist between the head and the flow rate I can measure the flow rate.

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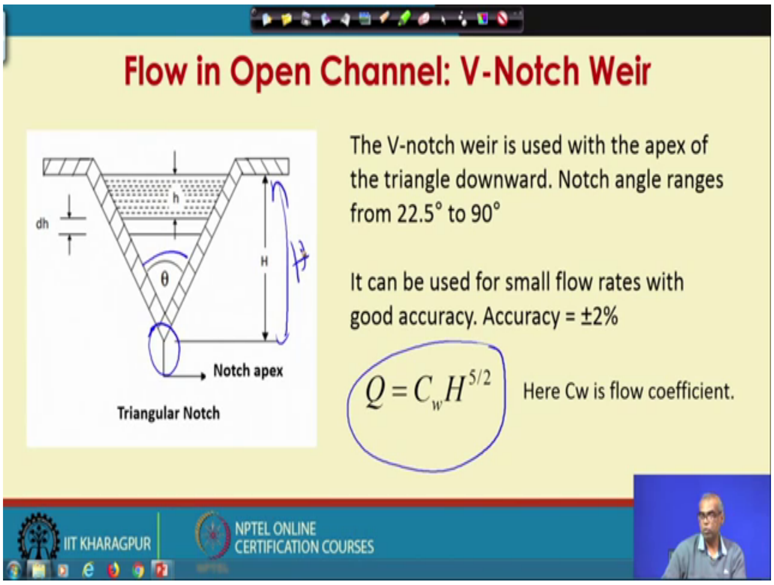

V-notch weir the V-notch weir is used with the apex of the triangle downward. This is the apex of the V-notch weir. So, V-notch weir is used with the apex of the triangle downward. The notch angle which is theta here, where is in the range of 22.5 degree to 90 degree. V-notch weir is used for measurement of small flow rates with good accuracy.

An accuracy of plus minus 2 percent can be achieved. So, this is a relationship that relates the volumetric flow rate with the head H, in case of V-notch weir. So, Q equal to C w into H to the power 5 by 2 C w is a flow coefficient.

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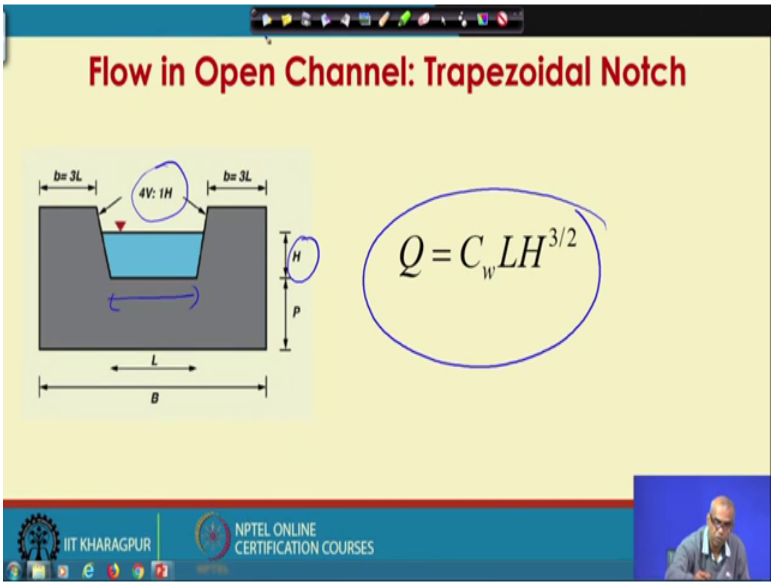

This is another geometry for weir trapezoidal notch there is a triangular weir as well. So, this is in between V-notch and rectangular notch. So, some typical dimensions are shown V stands for vertical and H for horizontal. So, 4 units of vertical length is to 1 unit of horizontal length.

The relationship between the flow rate the length L of the trapezoidal notch and the height is given as Q equal to C w into L into H to the power 3 by 2; where again C w is the constant or coefficient for this trapezoidal notch I just want to show you one slide.

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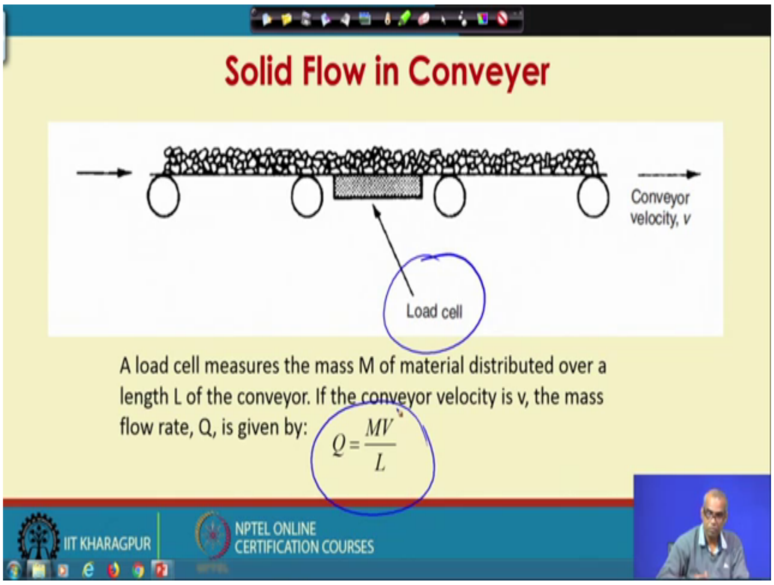

About solid flow in conveyer solid flow in conveyer is an important application in chemical process industry we can measure the solid flow in conveyer by using a load cell. So, here is a load cell which measures the mass or material distributed over the length of the conveyer say M is the mass of the material distributed over a length L of the conveyer. And the conveyer velocity is v, the mass flow rate can be expressed as M into V by L where M is the mass V is the velocity and length is the and L is the length over which the mass M is distributed.

So, this is how you can measure the mass flow rate for solid flow in conveyer you can also use nuclear mass flow meter for measurement of solid flow in conveyer the nuclear mass flow meter will make use of a gamma ray. So, gamma ray will be sent and from the other end there will be a detector which will find the; which will again detect the gamma ray. So, it is obvious that such operation will involve safety concerns will involve safety concerns, because you are using gamma rays. So, use of load say to measure solid flow and conveyer is a very convenient and common application.

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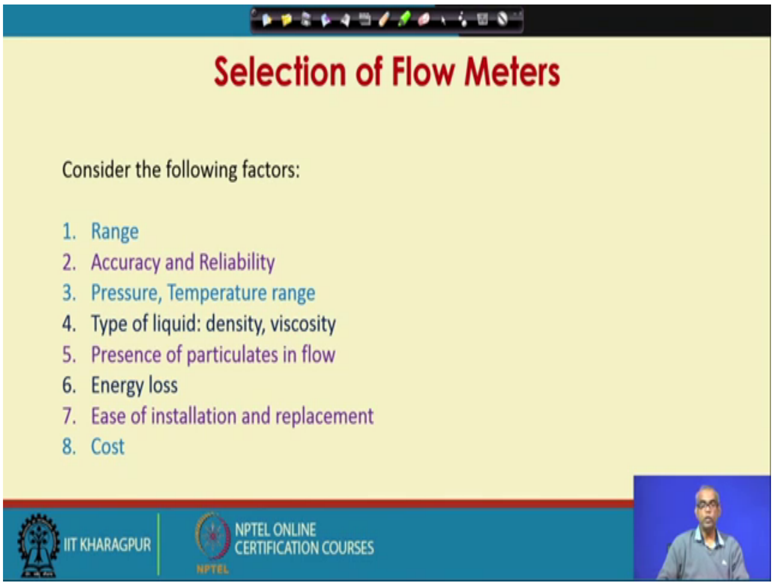

Finally, we want to ask how to select a flow meter for my application we must consider the following factors: range, accuracy and reliability, pressure range, temperature range. Type of liquid such as: density, viscosity, presence of particulates in the flow, where there are particulates present in the flow or not loss of energy, eases of installation and replacement, and finally, cost.

So, this completes our discussion on flow measuring instruments.