Chemical Process Instrumentation
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Lecture - 44
Flow Measurement (Contd.)

Welcome to lecture 44, we are talking about flow measurement this week. As of now we have talked about flow measurements where the area of flow restriction is constant and we measure the pressure drop across the flow restriction to relate the flow rate.

Now, we will talk about a flow measuring instrument, which is of variable area constant pressure drop type and specifically we will talk about rotameter.

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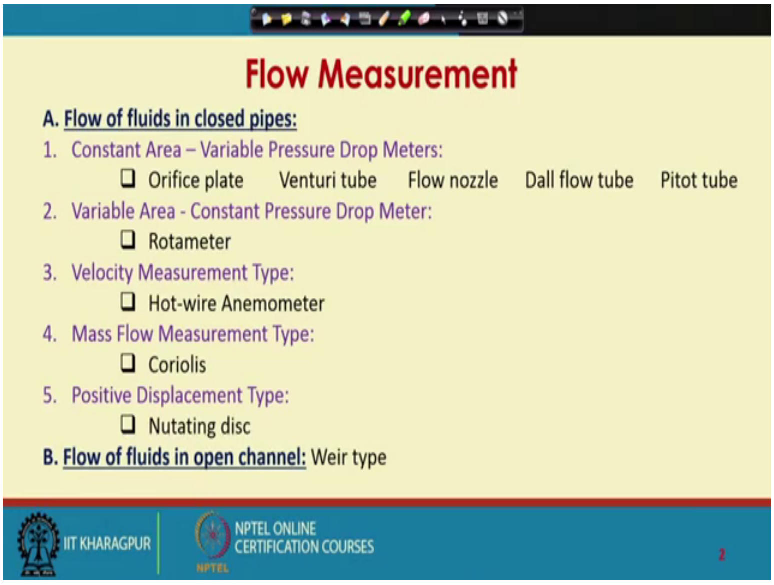

So, this is our classification, we have talked about Orifice plate, Venturi tube, Flow nozzle, Dall flow tube, Pitot tube.

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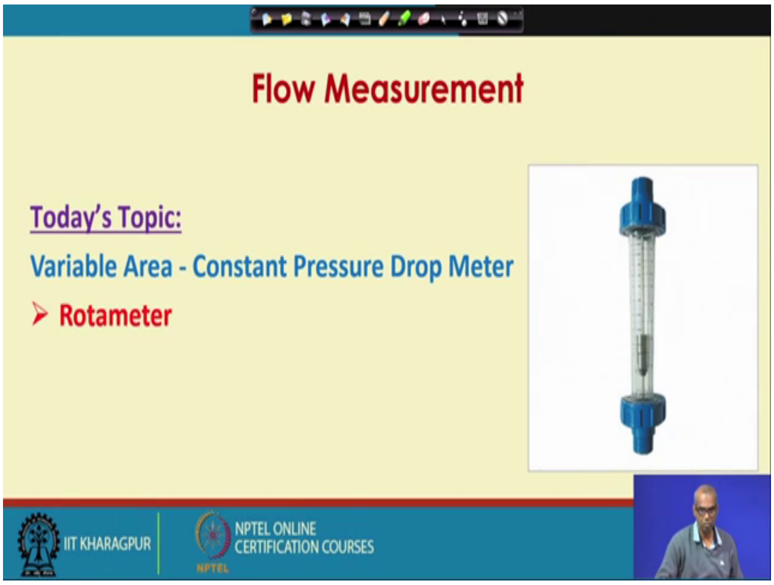

So, today we will talk about Rotameter. So, today's topic will be rotameter, what you see on the screen is an image of a rotameter.

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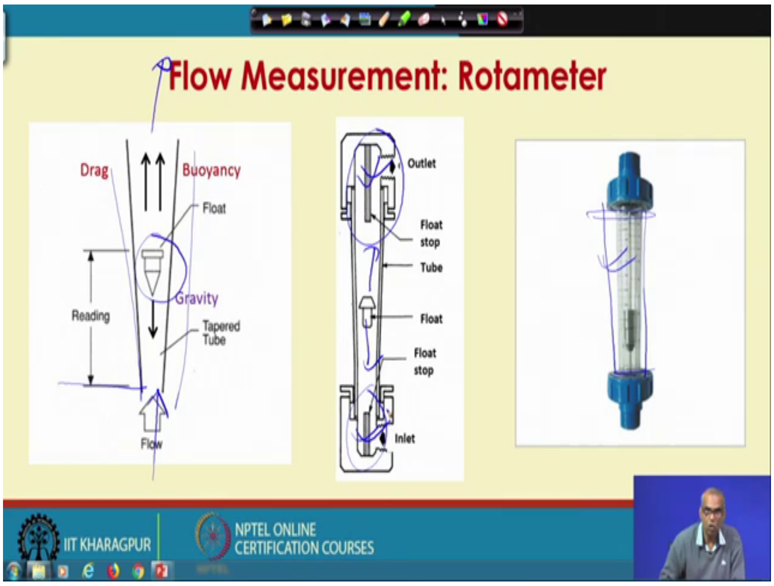

So, rotameter is a very simple instrument. It measures volumetric flow rate, it is essentially a tapered tube generally made of glass and you see that there is a flow inside the tube this flow is also called bob.

Rotameter is always installed vertically. So, here you have the flow that goes through the meter and here the flow comes out from the meter. Now, there are certain courses which are acting on the flow and depending on the particular flow rate, there will be a balancing forces and the float we will assume an equilibrium position. This equilibrium position is the measure of the flow rate. The forces that are acting on the floats are drag and one see, which are acting in upward direction and the gravity and force works in the downward direction. So, the reading of the rotameter is the equilibrium position of the float from this reference point.

So, there will be a scale graduated on the glass tube of the rotameter. We also see that the rotameter tube is tapered in you it is always this side we will have higher diameter or dimension than this side. So, here you can also see that direct to float stops at the inlet and at the outlet. So, this ensures that the float remains within the tube. So, the float will change its position depending on the flow rate, higher the flow rate higher will be the position of the float.

Lower the flow rate the float will come down if the flow rate increases the float will go up. So, this two floats stop ensures that the float is always within the tube or rotameter.

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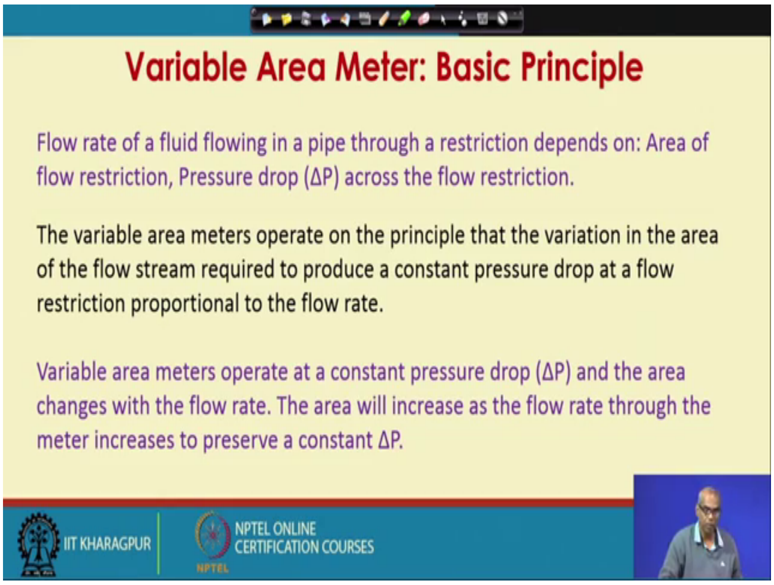

So, flow rate of a flowing fluid in a pipe through a restriction depends on area of flow restriction pressure drop across the flow restriction. The variable area meters operate on the principle that the variation in the area of the flow stream require to produce a constant pressure drop at a flow restriction proportional to the flow rate.

So, this is just opposite to the constant area variable pressure drop meter, such as venturi meter, orifice meter, nozzle etcetera. There we maintain the flow restriction constant and measure the pressure drop. Here what we are doing is, we are trying to maintain the pressure drop constant and measuring the flow area.

Variable area meter operate at a constant pressure drop and the area changes with the flow rate. The area will increase as the flow rate through the meter increases to preserve a constant pressure drop.

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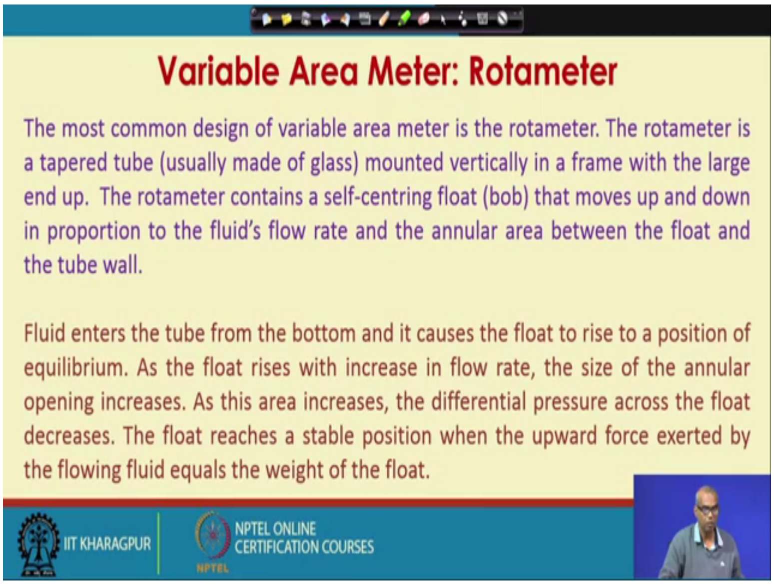

The most common design of variable area meter is the rotameter. The rotameter is the tapered tube usually made of glass mounted vertically in a frame with the large end up. The rotameter contains a self centering flow, which is also known as bob that moves up and down in proportion to the fluids flow rate and the annular area between the flow and the tube wall. Since the tube is tapered the annular area changes.

Since the upper side is up or in other words the large end of the tapered tube is towards the upside as the float moves up, the annual flow area between the float and the tube wall increases as the float comes down this annual full flow area decreases. So, annual flow area increases as the float goes up and, float goes up with increasing flow rate.

Fluid enters the tube from the bottom and it causes the float to rise to a position of equilibrium. As the float rises with increase in flow rate, the size of the annular opening increases. As this area increases, the differential pressure across the float decreases. The float reaches a stable position when the upward force exerted by the flowing fluid equals the weight of the float.

So, the upward forces that are acting on the float are buoyancy force and the drag force and the downward force that is acting on the float is the gravity force or weight of the float. So, the float which assume an equilibrium position, when these forces balance each other. So, some of buoyancy drag force will be equal to the gravity force at the equilibrium position of the float.

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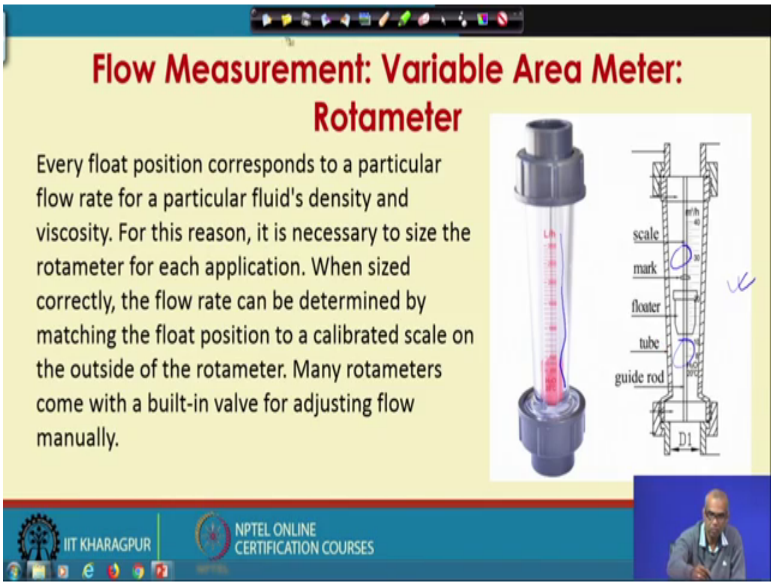

Every float position corresponds to a particular flow rate for a particular fluid density and viscosity. For this reason it is necessary to size rotameter for each application; when size correctly the flow rate can be determined by matching the float position to a calibrated scale on the outside of the rotameter. Many rotameters come with a built in bulb or adjusting float manually.

So, you can see the scale on the glass tube of the rotameter. On this schematic you see that there is a rod connected to the float, this is known as guide rod. So, this guides the float as it goes up or goes down.

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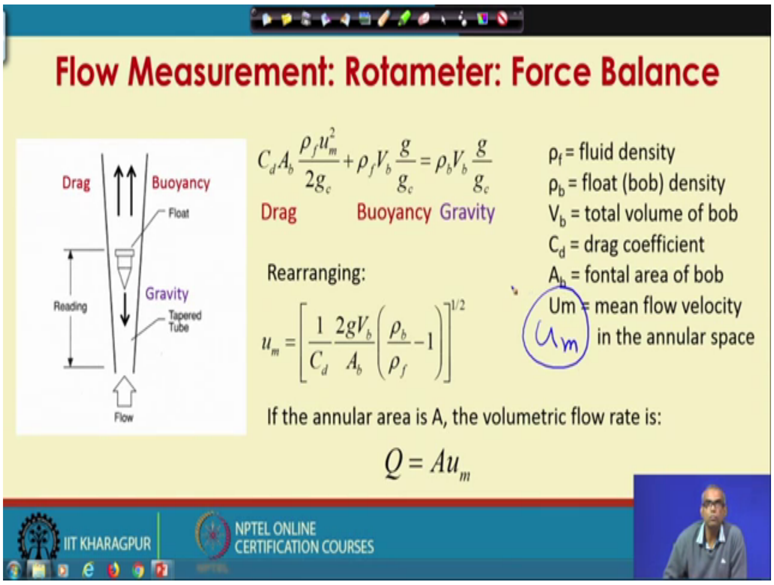

Now, let us look at the force balance equation of the rotameter. So, look at the schematic of the rotameter, three forces are acting on the float of the rotameter. So, the float goes in this direction and the flow comes out from here.

As the flow rate increases, the float will go up and it will be in an equilibrium position when the drag force and the buoyancy force acting on upside, we will equate the gravity force which is acting downward. Now, what is the expression for the drag force? If the mean velocity of the float in the annular space is u m, the drag force can be written as C d A b rho f u m square by 2 g c. Where C d is drag coefficient, A b is frontal area of the bob, rho f is fluids density and u m is the mean flow velocity in the annular space.

So, this is working upward. Buoyancy it is volume of the float multiplied by the density of the fluid, because the float will displace a liquid which has the volume same as the volume of the float.

So, if b v is the volume of the float or volume of bob and rho f is the density of the fluid, there is passing through the rotameter rho f v d and similarly the gravity force you can compute from the mass of the float or bulb. So, if the density of the float material is rho b and float volume we have said as v v. So, rho v v v g by g c will be the gravity force. So, drag force plus rho m c force must be equal to gravity force.

So, if you rearrange, you can get an expression for the u m as follows. So, we have got the mean flow velocity. So, if I know the annular flow area, let us call the annular float area A the volumetric flow rate will be A into u m. So, flow area multiplied by the mean velocity gives me the volumetric flow rate. So, the annular area is A, I have already got the mean flow velocity as u m

So, the volumetric flow rate becomes A times u m. Note that the annual flow area is changing as the float is going up or coming down.

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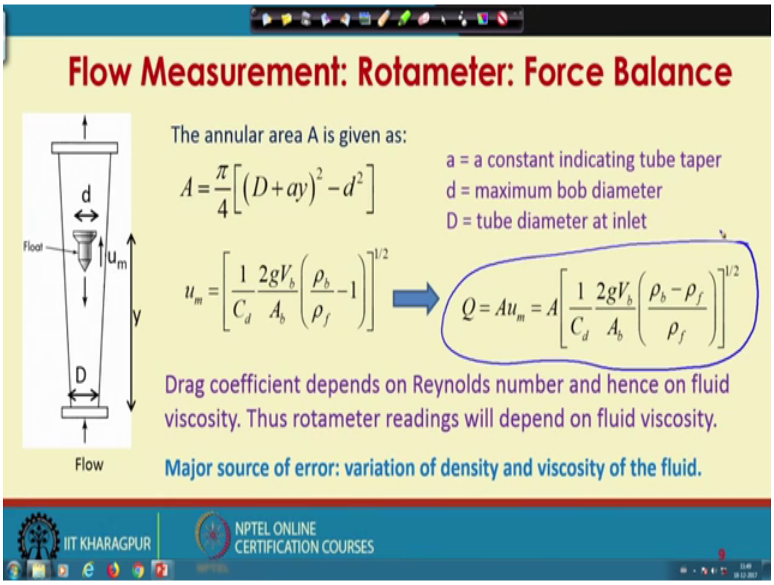

The annular flow area can be given by this expression, which is pi by 4 into D plus a y square minus small d square. What is this capital D and small d? Capital D is the tube diameter at the inlet and small d is the maximum float or bob diameter. So, this is small d and if a is a constant that indicates the taper of the tube and y is the float reading; that means, the position of the float from the zero of the scale.

Then here the annular area a is given as pi by 4 into D plus a y whole square minus d square. I have already got an expression for u m as follows. So, just multiply A with this expression to get the volumetric flow rate. Note that I have done this simplification to get rho v minus rho f by rho f here. So, finally, I get the volumetric flow rate expression for the rotameter as this.

That coefficient depends on Reynolds number and hence of fluid viscosity thus rotameter reading will depend on fluid viscosity. Major source of error for a rotameter is the variation of density and variation of viscosity of the fluid.

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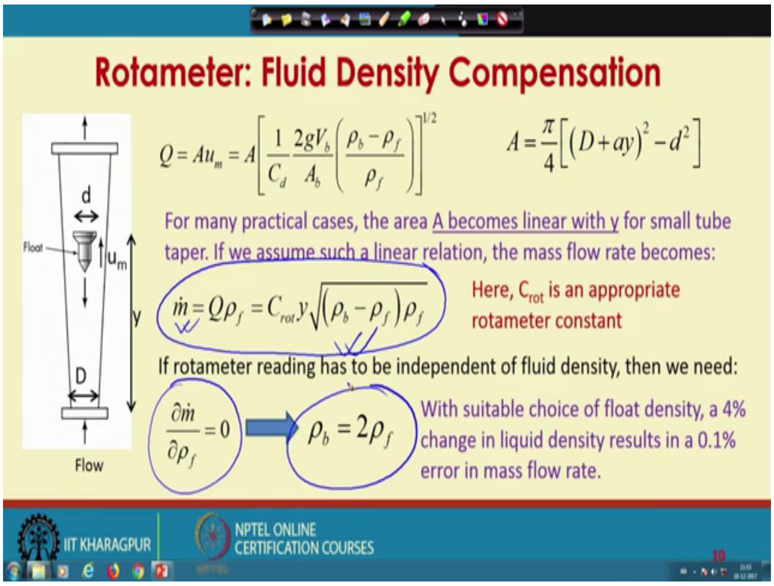

So, how I make compensation for variation of fluid density in rotameter? So, this is the expression I have got for the volumetric flow rate for rotameter with A given as this. Capital D is the diameter at the inlet and small d is the maximum diameter of the floater bob, y is the rotameter reading and a is a constant which takes care of the taper of the tube.

For many practical as cases the area A becomes linear with y for actual dimensions of the rotameter many practical cases for actual dimensions of the rotameter the area or the annular area A becomes linear with y. Although this expression does not show a linear relationship, but for many practical cases thus this flow area a becomes linear with y for particularly for tube with small taper. If we assume such a linear relation the mass flow rate becomes mass flow rate.

We will obtain if you multiply the volumetric flow rate by the density of the fluid that is flowing through the rotameter. So, Q is the volumetric flow rate of the fluid that is passing through the rotameter, if I multiply the volumetric flow rate with the density of the fluid that is passing through the rotameter I will get the mass flow rate of the fluid. So, the mass flow rate is Q into rho f which can be written as now this.

Why this? This y is coming from this A with the assumption that this is going to give a linear relationship, all other combinations of these constants has been clubbed into a constant called rotameter constant and this part after you have multiplied by rho f will become rho v minus rho f. Rho v minus rho f multiplied by rho f because we have multiplied by rho f.

So, within the square within the square root rho f square will go and then it will be this expression. So, mass flow rate becomes a rotameter constant into rotameter reading square root of rho v minus rho f multiplied by rho f. Note that the volumetric flow rate similarly can also be written as C rotameter, which is constant multiplied by y which his rotameter reading square root of rho v minus rho f divided by rho f.

Now, if the rotameter reading has to be in dependent of fluid density, then basically what we are looking for is that derivative of this mass flow rate with respect to density of the fluid will be equal to 0. We do not want the mass flow rate to be dependent on the density of the fluid.

So, basically we are asking for del del rho f of m dot is equal to 0. If you compute this derivative from this and set equal to 0, you will get dense rho b equal to 2 rho f. So, if I choose the density of the rotameter float as twice the density of the rotameter fluid, the variation of fluid density will be fully compensated for.

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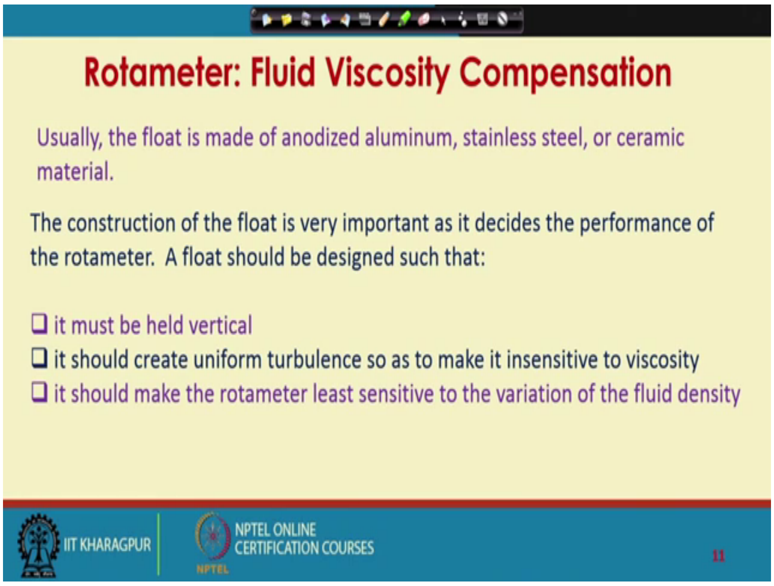

Next rotameter: Fluid Viscosity Compensation. Usually, the float is made of anodized aluminum, stainless steel or ceramic material. The construction of the float is very important as it decides the performance of the rotameter, a plate a float should be designed such that it must be held vertical, it should create uniform turbulence. So, as to make it insensitive to viscosity, it should make the rotameter less sensitive to the variation of the fluid density.

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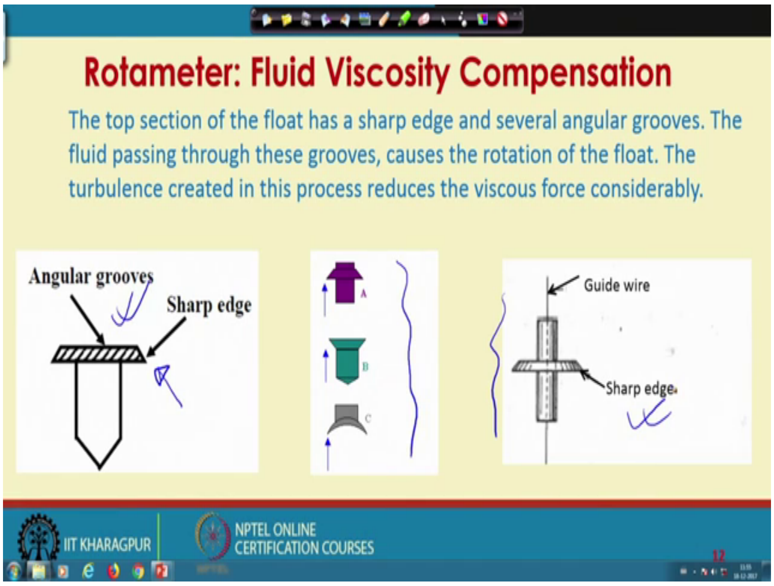

The top section of the float has a sharp edge and several angular grooves. The fluid passing through these grooves causes the rotation of the float. The turbulence created in this process reduces the viscous force considerably.

So, these are the angular groves and this is the sharp these are the sharp edge, some other design of the float you can see the sharp edge this sharp edge will create similar turbulence for low flow rate as well as high flow rate.

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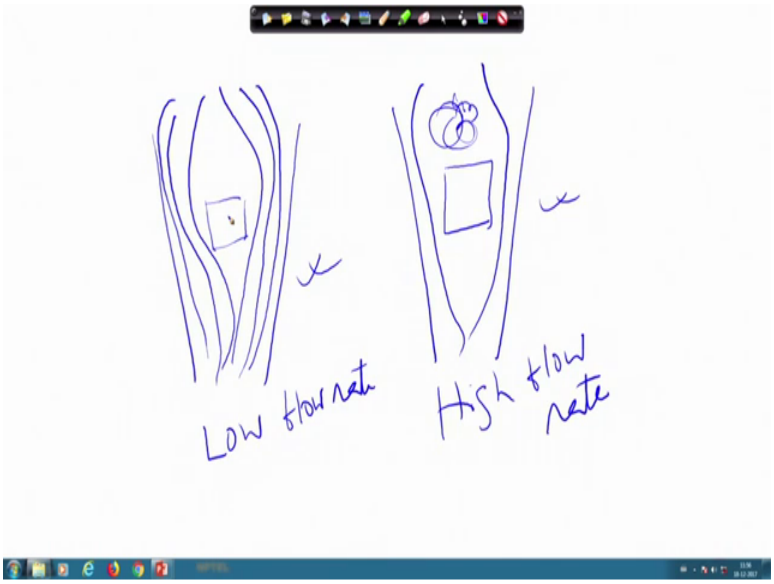

Imagine a float which is not sharp or which does not have any sharp edge. So, you will have the fluid flow like this in case of low flow rate. If you have high flow rate you have you have some turbulence here. So, this is for high flow rate. So, this viscous force is different here and here because different kind of turbulence is present in two cases.

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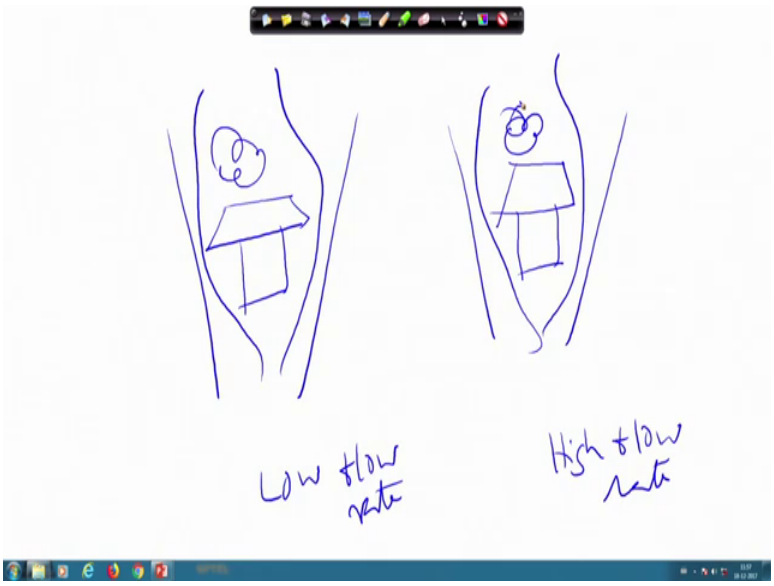

But if I design a flow such that at low flow as well as high flow, low flow low flow rate high flow rate and in both the cases I have kind of similar turbulence, then my situation becomes insensitive to viscosity. So, this is a way to compensate for the effect of fluid viscosity by suitably designing of flow.

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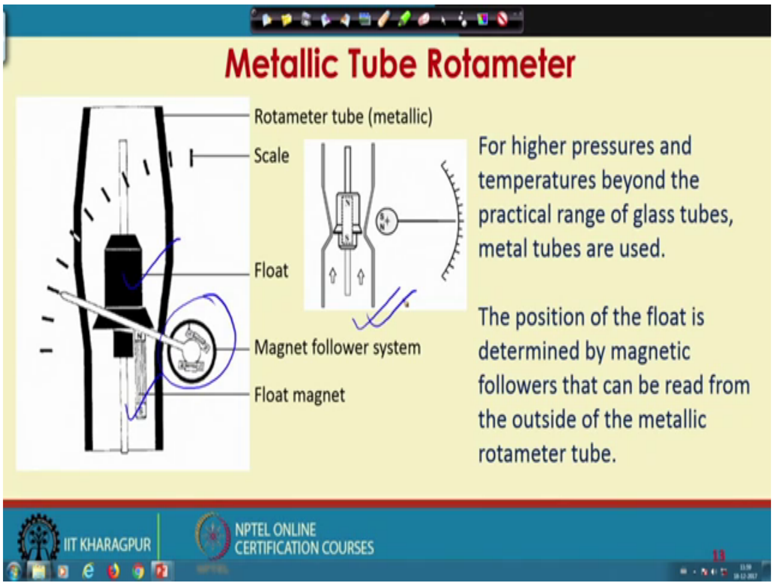

Basically you will have a flow with sharp edge. For higher pressure and temperature beyond practical range of glass tubes we have to use metal tubes. Once you use a metal tube you cannot break the float position directly as you can, when you are using a glass tube, though arrangement as shown in the figure can be used for indication of the flow. The position of the float is determined by magnetic followers that can be rate from the outside of the metallic rotameter tube.

So, you have this float, you have a magnet attached to the float. So, as the float moves up or comes down with change in flow rate the float magnet also goes up or comes down. So, there is a magnet follower system which will follow the magnet, which is attached to the float inside. So, these magnet follower systems will actuate a pointer against the scale. So, you can that scale can be calibrated in terms of flow units.

So, this is another schematic for the same concept. So, it is basically you have attached a magnet with the float and the magnet changes its position as the float changes its position with flow rate. Now, you have a follower magnet from outside the tube and the follower magnet can actuate the movement of the pointer against the scale. So, this way you can read the float position from outside.

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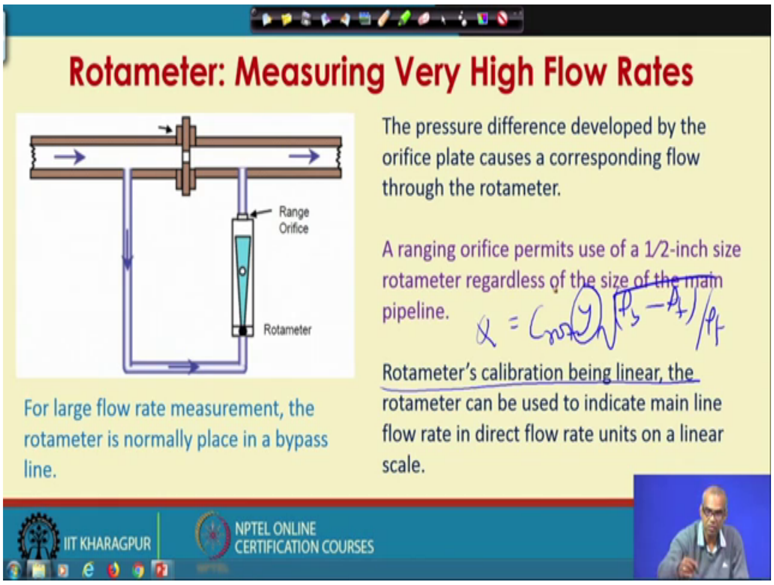

We can use rotameter for measuring very high flow rates by using a bypass line. So, for large flow rate measurement the rotameter is normally placed in a bypass line. So, you have a very high flow rate, which passing through this pipe and look that the rotameter has been placed in a bypass line. The pressure difference developed by the orifice plate causes a corresponding flow through the rotameter. This orifice will create a pressure difference across it. So, this will cause a corresponding flow through the rotameter.

Arranging orifice permits use of a half inch size rotameter regardless of the size of the main pipeline. Rotameters calibration being linear, the rotameter can be used to indicate mainline flow rate indirect flow rate units on a linear scale. This we have seen that the flow rate Q was given a C rotameter into y into rho b minus rho f by rho f. So, please note that the rotameters calibration is linear with y which is the rotameter readings.

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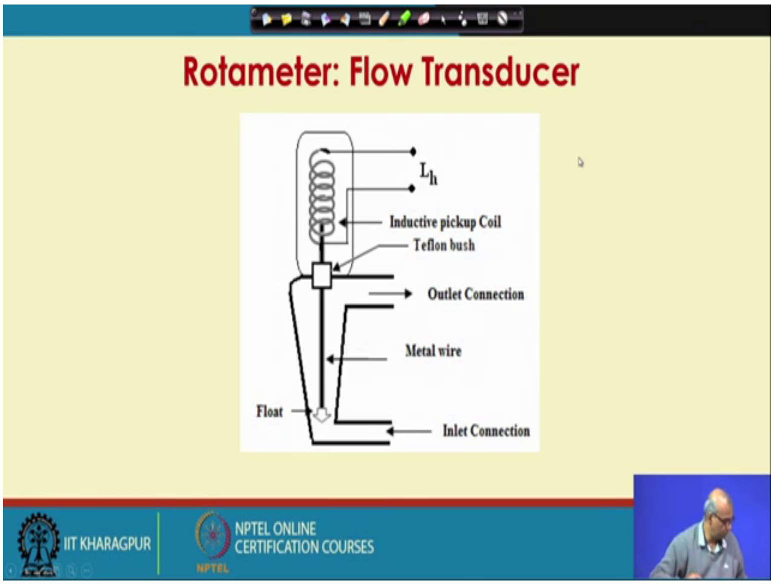

You can have a flow transducer or flow transmitter using a rotameter. So, what you have to do is imagine that this float with this float, you have attached a metal wire which passes through an inductive coil.

So, imagine. So, try to remember our discussion on linear variable differential transformer. So, that was the displacement transducer. So, similar to this in fact, you can attach LVDT here as well. So, I have attached a metal wire with the float and as the float changes its position, the metal wire goes up or comes down through this inductive coil. So, accordingly a electrical output will be produced here.

So, this is very much you can you can also you can also have an LVDT here and as the metal wire which can which will work as let us say you replace this metal wire by a soft iron core, and as the soft iron core moves up or comes down the e m f will be produced accordingly, as you have seen in case of linear variable differential transducers.

So, this way we can convert the rotameter into a flow transducer or flow transmitter.

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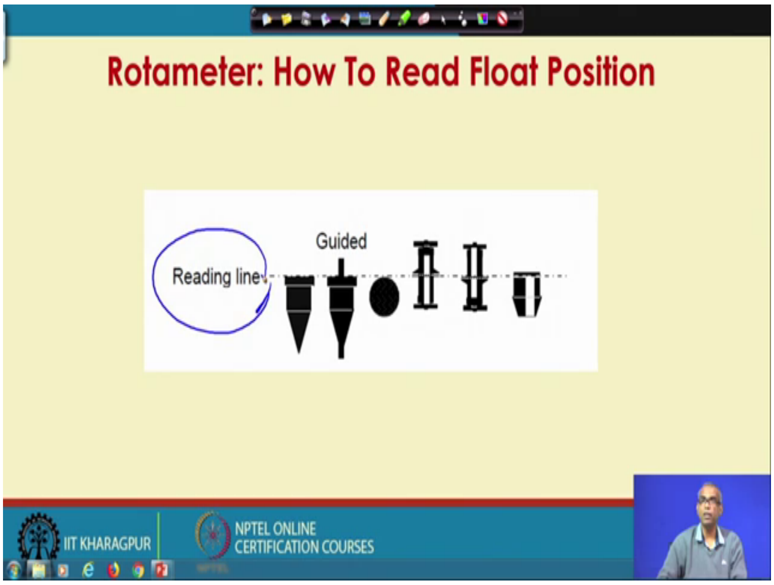

So, here are again some schematics of different designs of rotameter floats and the correct way of reading the float position. So, this is the reading line and we need to read the float position along this reading line.

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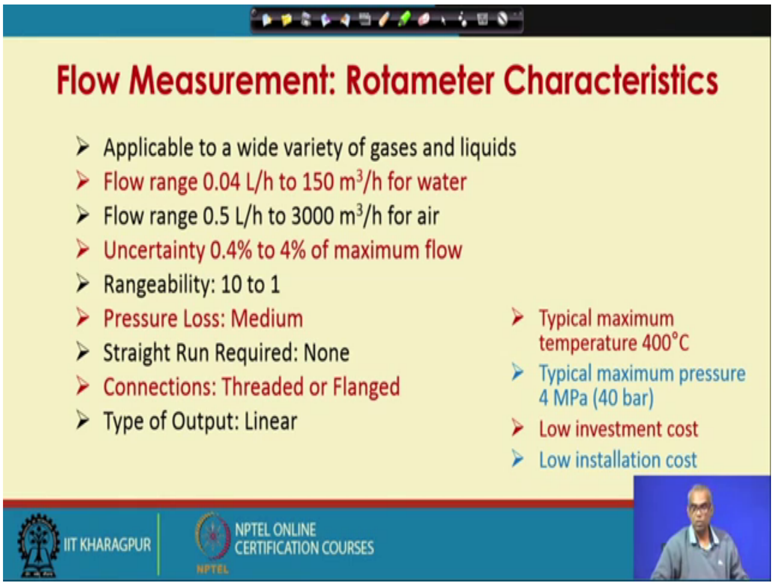

There are some important rotameter characteristics we will talk about is applicable to a wide variety of gasses and liquids, flow range 0.04 liter per hour to 150 meter cube per hour for water, flow range is 0.5 liter per hour to 3000 meter cube per hour for air, uncertainty is 0.4 percent to 4 percent of maximum flow rangeability is 10 to 1, pressure loss medium straight run require none connections threaded or flanged type of output linear.

Typical maximum temperature 400 degree Celsius, Typical maximum pressure 4 mega Pascal's or 40 bar, low investment cost, low installation cost.

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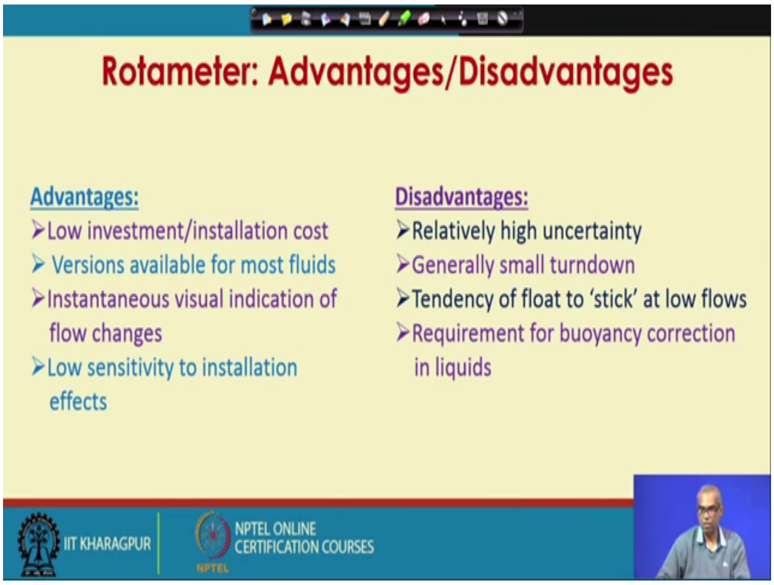

Advantages: Low investment cost, low installation cost, Versions available for most fluids, Instantaneous visual indication of flow change is possible, Low sensitivity to installation effects.

However, there are some disadvantages relatively high uncertainty compared to some other flow meters, generally small turn down tendency of float to stick at low flows requirement of buoyancy correction in liquids. So, we will stop our discussion on rotameter.