Principles of Mechanical Measurement

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Module – 09
Flow Measurement
Lecture – 2
Obstruction meters & volume flowmeters

Hello everyone. Welcome to the second lecture on the topic of Flow Measurement, which we are doing in this week number 9 of our MOOCs course on the Principles of Mechanical Measurement. Now in the previous lecture we have discussed about or I should say we have summarized the different methods of flow measurement into a few categories. And out of which we have discussed about the obstruction flow meters. Of course, before starting there to discussed about a few fundamental concepts of fluid mechanics like the streamlines path lines steak lines stream tubes.

And then the development of the Bernoulli's equation which is one of the very important equations from measurement point of view, particularly about the obstruction flow meters which you have discussed in the previous lecture. Under obstruction flow meter we have discussed about three different kinds of meters namely the orifice flow meter or orifice meter flow nozzles and the venturi flow meter. Today we shall be discussing a bit more on that. So, that we shall be able to solve some numerical problems and then we shall proceed to discuss about a few other devices.

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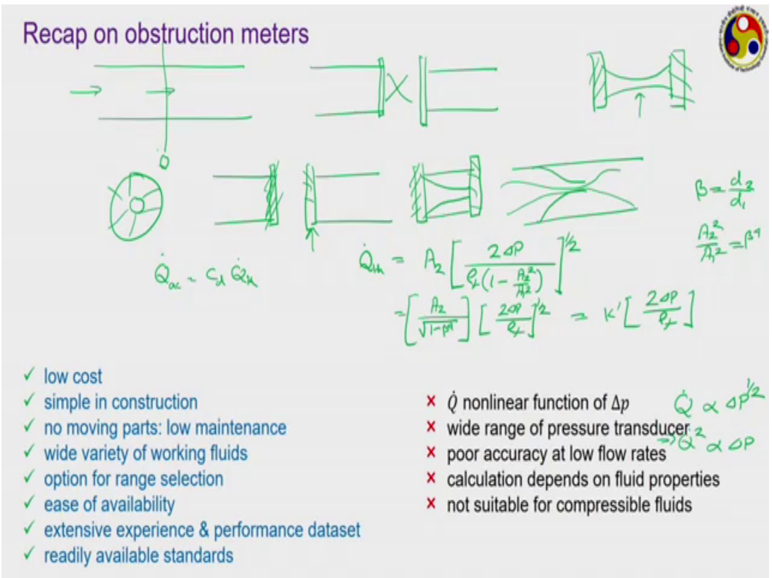

Just a quick recap on the obstruction meters; here our objective is to decide or determine the flow through a pipe like this. Suppose we know that some liquid or gaseous fluid is flowing through a pipe in this particular direction and you want to measure the flow through this pipe under say steady state condition. Let us choose one particular cross section. So, this is the section where you want to get a measure about the flow rate that is Q dot as per our notation.

Now, let us now break the pipe along the cross section or the selected cross section into 2 pipes like this. This is one of the pipe section and this is the remaining section of the pipe and let us put couple of flanges address couple of lounges here. Now instead of having a single pipe we have blocking the pipe in your 2 sections, and we have attached one flange to each of the sections. Then whatever may be a flow measuring device that you have to incorporate into this particular portion. Whether that is an orifice kind of flow meter or venturi meter or maybe not an obstruction type at all may be some other kind of flow meter that will go into this crossed portion.

So, if we are selects are talking about say orifice flow meter, then between these two flanges what we are going to incorporate is just a plate having same outer diameter as this original tube something like this, and with a small orifice in between like this portion is solid. So, that which is blocking the flow and only the in between small circle is the one which is allowing the fluid to flow through. This is what we have in case of an orifice meter. Instead of a flow in case of a flow nozzle in case of a flow nozzle we select a pipe section having the same diameter as the original tube which is again have flanged on either side, this particular flange will be coupled to this one and this particular flange will be coupled to this one. And in between we have a nozzle kind of thing a section of reducing cross section area.

So, once we connect these connect this one to the original channel your flow section looks somewhat like this. So, the fluid on our I should not pull this particular line that way. So, it is somewhat like this. So, fluid on the upstream side is able to flow through this way and there is a smooth transition smooth reduction in the cross section area on the upstream side, but that is not the in the downstream side. Whereas, in case of a venturi meter we put a proper meter there where, we put a convergent divergent flow channel of something like this. Whether this particular portion is that again attached to this particular fluid flange this flange is attached to this particular flange and in between we have that throat which is the smallest cross section area.

So, this is what we have in case of a venturi meter. And we have discussed about the application of Bernoulli's equation to get a mathematical form and just repeating from there we have seen that the theoretical flow rate can be given as A 2 where A 2 refers to the cross section area at the location number 2, which is the second one of our selected location for pressure measurement. Or, you can also say this is to refer to the location where we have the downstream pressure trap into 2 into delta P, delta P is the pressure sensed by your differential pressure transducers divided by rho f for the fluid into 1 minus A 2 square upon A 1 square.

A 1 referring to the area corresponding to the first location of the pressure tapping; quite often we use the symbol beta particularly if you are dealing with the tuber called circular cross section, then you use a symbol beta as sorry as d 2 upon d 1 that is the diameter corresponding to the smaller cross section area divided by the ammeter corresponding is the larger cross section area. Accordingly, A 2 square upon A 1 square can be written as beta to the power 4.

And hence this particular relation becomes now if we take everything out or the constant part out actually it becomes A 2 upon root over 1 minus beta to the power 4 into 2 delta P upon rho for the fluid whole to the power half. And this portion is a constant generally for a given venturi meter or given obstruction type flow meter. So, this can also be written as sum K prime into 2 delta P upon rho f. Now, rho f depends upon which kind of fluid you are dealing with and delta P will be the actual measurement that you are doing using a differential pressure transmitter. And, then the actual flow rate will be the distress coefficient times the theoretical flow rate.

So, we have of course, discussed about the relative merits and demerits of all these 3 obstruction meters, but let us summarize them to get a common features of all the obstruction meters. All the obstructions meters generally are the low cost devices, orifice meter is a particular one or orifice meter is the one with very low cost. Generally venturi meter is more costlier compared to the other 2, but still their costs are much lesser compared to other volume flow meters which we shall be discussing today.

They are all simple in construction again orifice meter is just a plate with a small orifice in between venturi meter is just a convergent divergent channel or convergent divergent nozzle I can say, none of them have a we are having any moving part that is why their maintenance requirements are generally quite low particularly for venturi meter and flow nozzle. However, orifice meter may require certain maintenance particularly if we are dealing with some kind of fluid where there are solid suspensions. Because the solid suspensions or dots may easily blocked off venturi or I should say the throat in case of an orifice meter.

They can be dealt with a wide variety of working fluids. Generally, they are restricted to liquids, but certain situations we can discuss or we can use them for gaseous flow measurement as well. There is option for selecting the range by varying the corresponding coefficients by varying the area ratios that is this beta, we can apply them for different ranges of flow rate or mass flow rate or velocities. They are easily available there are 100’s of manufacturers or suppliers available to supply any of these meters like a venturi meter or orifice meter you can always purchase from market, for the fluid that you are likely to work with and exactly for the flow range which you are likely to deal with.

There are extensive experiments experience and performance database because peoples are you people are using these meters for several decades and more or less we know everything about them what to expect from them. And accordingly we also have really available standards which are the standards to follow, what should be the installation procedure, what should be the calibration procedure, exactly how we should take the flow reading you can always get lots of help about this. However, because of the simplistic nature they also have several disadvantages.

Like the biggest disadvantages the flow rate is a non-linear function of delta P like the expression that I we have derived in the last class, and I have just written here, Q dot actually the flow rate Q dot actual is proportional to delta P to the power half. Therefore, these are non-linear relation and hence as the pressure drop keeps on increasing delta Q dot increases in square, that is Q dot square is proportional to delta P.

So, for a given pressure drop Q dot is or for a given amount of increase I should say suppose in one situation whatever pressure drop you are getting in the second situation you are having double pressure drop. Then corresponding increase in the flow rate only 4 times. So, for a given range of pressure drop which your pressure drop measuring instrument can handled and there can be significantly larger range of flow rate that we may have to deal with.

So, pressure transducer may require very large range for deal flow to deal with a large flow rate variation. Then it is true for any kind of device when you are talking about a large range of operation, then accuracy will always be affected at lower ranges. So, they are not that much accurate when you are dealing with low flow rates. Calculation is strongly dependent about the fluid properties parameters like density and viscosity in particular.

They are not at all suitable for compressible flow because the equation that we are using that we have derived using the Bernoulli's equation which on the first assumption there was the incompressible flow. Of course, not today, but in our next lecture we shall briefly be discussing about the application of this obstruction meters in case of compressible flow particularly for gaseous, means some sort of corrective measure that we can take, but that we shall be discussing in the next class.

And they are generally used only for steady measurement we hardly used venturi meters etcetera for transient measurement because, again the application of Bernoulli's equation is generally more common in steady flow situation. And the biggest point that I would want you to make a note of is an intrusive measurement. Intrusive means we are putting some kind of device within the flow field. Whether it is an orifice or whether it is a venturi kind of channel we are changing the flow field configuration or I should say we are changing the flow conduit configuration. That kind of situation is called an intrusive measurement that is putting something into the flow field. And whenever you are putting some kind of device into the flow field that is whenever you are doing some kind of intrusive measurement there will be some amount of pressure loss.

So, there will be significant amount of head loss, of course, the amount of head loss the magnitude of pressure loss will depend upon the device that you are using like we have discussed in the previous class that the venturi meter can have a quite high pressure recovery coefficient that is on the downstream side it can recover about 90 percent of the initial pressure. But still there is a loss of 10 percent whereas, in cases like in flow nozzles or orifice meter we can have significantly larger pressure loss.

And that is true for any kind of intrusive measurement. We would like to go for non-intrusive measurements where we are not at all going to put anything into the flow field, rather we shall be doing measurement only using some external parameters. Like some examples usually seeing today there we do not have any such kind of pressure loss; so, this pressure loss or because of the intrusive nature of measurement is one big concern with this kind of obstruction meters.

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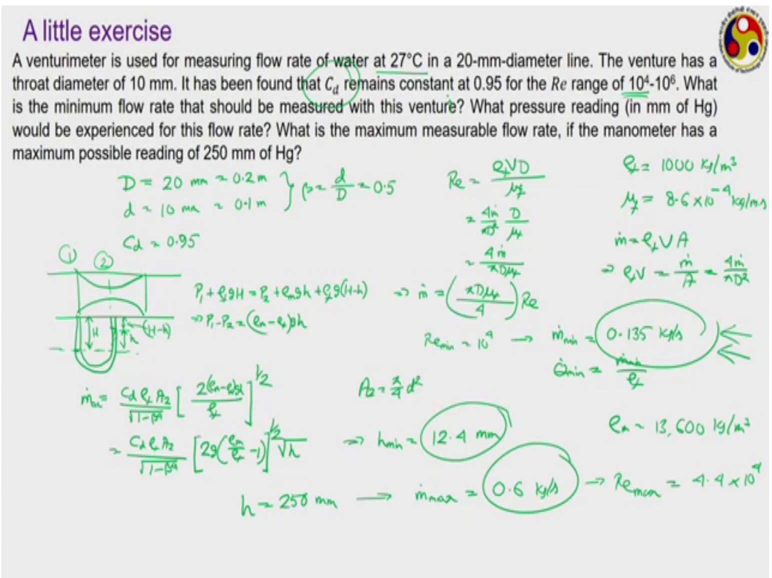

Now, let us solve some numerical examples read out the problem carefully what is given here. Here we are talking about a venturi meter which you are using to measure the flow rate of water at 27 degree Celsius in a 20 millimeter diameter line. So, let us note down the information say capital D refers to the channel diameter which is 20 millimeter that is 0.2 meter. The venturi has a throat diameter of 10 millimeters of the smaller diameter is 10 millimeter.

So, 0.1 meter; that means, your beaten the ratio of diameter small d upon capital D is 0.5 in this case. It has been found that C d remains constant at 0.95 for a particular range of Reynolds number 10 to the power 4 to 10 to the power 6. Actually the biggest concern about using this obstruction type device is the value of this C d. C d can vary with several things C d can vary with the Reynolds number the flow velocities can vary the fluid property and can vary significantly with this beta.

So, we have to be very sure about which C d value to use during the calculation. Because C d is the ratio while your ratio of theoretical or I should say the actual to theoretical flow rates, well theoretical fluid we can easily calculate if we do not know the C d properly then your actual flow rate calculation will be wrong. So, we generally depend upon some kind of experimental charts or certain experimental correlations or empirical relations to get the value of C d. And this particular venturi meter that we are dealing with here is found to have a constant value of C d of 0.95 only in this particular range of Reynolds number.

So, the first thing that you have to find is the minimum flow rate that should be measured with this venturi. It is spelling is wrong it should venturi this venturi meter. So, what we are trying to say here that we would like to use this particular C d value of 0.95 because we do not know any other value of C d for this given venturi meter, but is also said that this particular value we can use only when the Reynolds number is at least 10 to the power 4. Then what should be the smallest mass flow rate that we should measure with this. The smallest mass flow should be the one that gives us this particular Reynolds number that is 10 to the power 4.

Now what is the value for Reynolds number or expression we know that Reynolds number is rho into velocity into the channel diameter by viscosity. Now, property values you need which I have not provided in this particular problem, but I have made a note of these particular properties. In this particular case density, we are going to take as 1000 k g per meter cube. And mu that is viscosity for the fluid that is water we are going to take as 8.6 into 10 to the power sorry 10 to the power minus 4 Pascal second or k g per meter second, which is a standard is saying it yes. So, there for a given value of Reynolds number 10 to the power 4, then this is the expression for this is the we can calculate velocity from there, but our objective is non velocity or the mass flow rate.

Then how can relate velocity is mass flow rate? We know that mass flow rate is equal to rho f into V into the flow area that is rho f into V is m dot by area that is 4 m dot by pi D square if we put it back here now rho f into V becomes 4 m dot by pi D square into you are left with D upon mu f that is 4 m dot by pi d into mu f. From where m dot is equal to pi d mu f upon 4 into the Reynolds number. Now, how we can calculate this one, what are the values given we know the value of mu f that is given capital D the diameter of the pipe is 20 millimeter and Reynolds number. So, if we put Reynolds number equal to 10 to the power 4, which is a minimum workable value of Reynolds number then we get the minimum possible mass flow rate.

If we put the value of pre calculated number as always; so, it will come as 0.135 k g per second you just put the numbers there you will get this value. So, this is the smallest possible mass flow rate that we should deal with. If our interest in the volume flow rate, then we can also calculate the volume fluid from there. Like what should be the minimum volume flow rate if we are looking to calculate Q dot mean what is the relation between mass flow rate and volume flow rate. So, if we divide this mass flow rate m dot mean by density you are going to get the volume flow rate in meter cube per second. So, you have the value now.

Now, to come to the second question what pressure reading in millimeter of mercury ratio will be experienced for this flow rate. Here this pressure drop across this venturi meter is being measured by an u tube manometer. And we can assume it to be u tube manometer which is using mercury as the manometric fluid. And accordingly we have to calculate the pressure drop corresponding to this particular mass flow rate this particular m dot.

And actually not pressure drop not delta we have to calculate the height of the manometric fluid column. If we draw it then let us say this is your channel and this is your venturi portion. So, we are putting a mercury u tube manometer something like this one on the upstream side and other on the downstream side. Or I should say not downstream side exactly at the throat location. So, this is your location one this is your location 2.

Now, where pressure will be higher at P 1 will be higher at P 2 will be higher. Definitely P 1 will be higher because speed is flowing from high pressure to low pressure. So, P 1 is higher. Accordingly, the manometric fluid will may be showing a balance somewhat like this. So, if we see from there this particular portion we are having a manometric fluid or column of height h. Here we are suppose having only the working fluid which is water that column height of capital H then on the other arm here we are having something left of height capital H minus small h of the same water.

So, if you write a pressure balance along this particular dotted line, now then what we can write on one side, we can write P 1 plus rho f g capital H on the other side we can write P 2 plus we have a manometric fluid column of height small h. So, rho m which is manometric fluid density g into small h plus rho f 2 g into capital H minus small h because on top of the manometric fluid column we are having this particular water column that is P 1 minus P 2 is equal to so, rho f g h cancels out.

We are having rho m minus rho f into g h. So, if we take it back to the original expression for m dot m dot actual. So, m dot actual will be equal to C d into rho f into A 2 divided by root over 1 minus beta to the power 4 into 2 delta P by rho f whole to the power half which we which we have just written the previous slide. Now, what is your delta p? In this particular delta P is P 1 minus P 2 which is rho m minus rho f g into h. So, if we so here I have written C 2 mistakenly should be C d.

So, it should be C d into rho f A 2 4 1 minus beta to the power 4 into 2 g into rho m upon rho f minus 1 whole to the power half into square root of h. And we have to find the h corresponding to the m dot minimum which is this value everything else is known here A 2 will be equal to pi by 4 small d square which is the area of the throat. So, if you put everything here smallest value of h mean which corresponds to the m dot mean this particular one will be coming as 12 4 millimeter. So, we can calculate the smallest possible elevation in mercury column that we are going to get in this particular situation.

And then the third part of the question is what is the maximum miserable flow rate of the manometer has a maximum possible leading up to 50 millimeter of mercury. So, in the third part you are given with here your h is 250 millimeter. So, put the values you will you are going to get m dot max in this particular case. And in this case m dot max is going to come as something like 0.6 k g per second approximately. Here of course, our one information I am not given that is the manometric fluid density rho m commonly we take that as 13600 k g per meter cube for mercury.

So, we have solved all the 3 this is the first answer of the first part this is for the second part. This is for the third part, but before you conclude there is one final check that we have to do while calculating this maximum mass flow rate we have used the same Cd value of 0.95; however, we have to check whether this is at all within that particular if mentioned range of Reynolds number or not. So, if you calculate the Reynolds number corresponding to the maximum mass flow rate your r e max will be something like 4.4 into 10 to the power 4. So, this is perfectly within the range; however, if this is coming greater than 10 to the power 6 then the value of C d equal to 0.95 is not applicable. So, you have to be careful in practical application.

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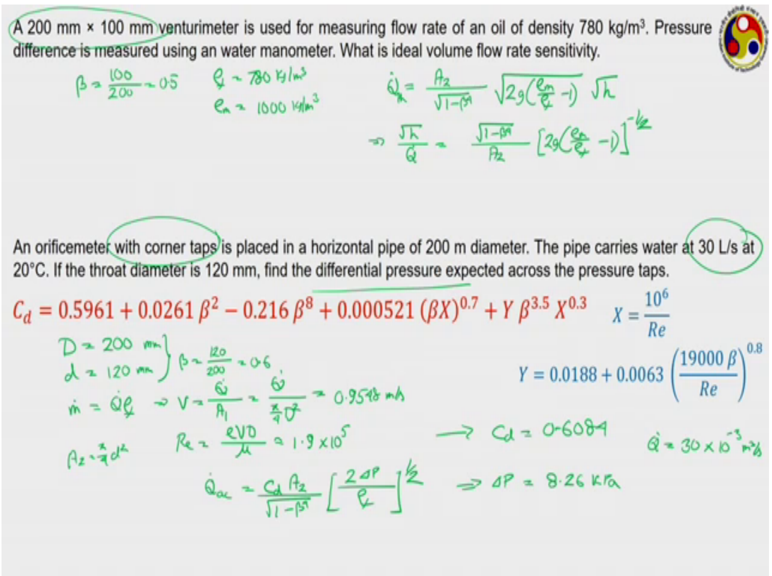

Another small problem here we are dealing with another venturi meter where the dimensions are given in a different way 200 mm by 100 mm. This is a quite standard way of representing. This actually means that 200 millimeter is the actual pipe diameter

100 millimeter is the throat diameter. So, your beta is 100 millimeter by 200 millimeter that is 0.5 in this case as well. And now we have to calculate the this venturi meter is measuring flow rate of oil of a density 780 k g per meter cube pressure differences measured using an water manometer.

So, here your working fluid density is 7 8 0 k g per meter cube. And manometric density is manometric fluid density is what that of water that is thousand kg per meter cube. And you have to calculate: what is the ideal volume flow rate sensitivity. Sensitivity you definitely know that refers to a change in output corresponding to the change in input. Now, for a venturi meter what is your input and what is your output? Your input is the flow rate and output is the pressure drop. Or actually you are measuring that in terms of the manometer.

So, your output actually is the elevation in the corresponding manometric fluid column that is h. So, if you write the expression earlier you had an expression of Q dot is a theoretical that we are talking about is equal to A 2 in by root over 1 minus beta to the power 4 into root 2 g rho m upon rho f minus 1 into root h. This word that we have just used or if we write now root h by Q dot, then what we are going to get it is root over 1 minus beta to the power 4 by A 2 into 2 g or I should write this way 2 g into rho m minus rho f minus 1 whole to the power minus half, this is the sensitivity.

Of course, ideally you should have written at the h by Q dot, but as h by Q dot does not have a direct linear relationship. So, it is quite common to represent either as root h by Q dot or h by Q dot square. You can put the values you are going to get the value of the ideal sensitivity. And if you are looking for actual sensitivity then you have to multiply this on it is C d. Fine, a third problem to finish up the thing here we are having an orifice meter to deal with. And orifice meter with corner taps. This is the important we have discussed the location that the location of taps strongly influences the corresponding pressure recovery part and the measurement particular the value of C d in practical situation.

So, we are dealing with an orifice meter with coordinate taps it is placed in a horizontal pipe of 200 millimeter diameter. The pipe carries water 30 litre per second at 20 degree Celsius throat diameter is 120 millimeter. So, we are having capital D equal to 200 millimeter small d equal to 120 millimeter. So, beta equal to 120 by 200 that is 0.6 in this particular situation now fluid properties are required rho f and it is given at 20 degree Celsius.

So, let us continue the same value of rho f that is thousand k g per meter cube. So, what is the mass flow rate m dot volume flow rate is given that is your volume flow rate is given as your Q dot a 30 litre per second into rho f will be the mass flow rate. So, and if our interest is to calculate the velocity of the fluid, then how much will the velocity the velocity will be this volume flow rate divided by the cross section area.

Let us say the pipe area that is Q dot divided by pi by 4 d square. So, you can calculate the velocity the value will be coming something like 0 0.9548 meter per second. From there you can calculate the Reynolds number. So, Reynolds number will be rho V into d by mu. The density and viscosity of water which we have used in the previous slide the same we can use here. And the value will be coming something like one point 9 into 10 to the power 5 in this case.

Now, the issue is that to calculate the pressure draw we have to calculate the delta P in this particular problem. We know the mathematical relation. We know the mathematical relation as something like your Q dot actual is equal to C d into A 2 divided by root over 1 minus beta to the power 4 into 2 delta P by rho f whole to the power half. Here b 2 is beta is given A 2 is half of pi small d square A 2 is pi by 4 small d square del and rho f is we are using a thousand k g per meter cube, but what is C d? C d is the one that we have to know.

So, for that purpose we need to use some kind of knowledge from previous experience. And this is one correlation that we are going to use. Where C d is generally found to a function of beta and there are some times capital X and capital Y if we expand them they will as functions of Reynolds number. So, if you use this then your C d just put the value of beta and Reynolds number in this expression and your C d will be coming as 0.6084 which is quite common for orifice meters.

So, if you put these values then put all the solution delta P will be coming something like 8.26 kilo Pascal. So, this is an example of how to use the different correlations to get the value of C d. One thing you have to be careful here the volume fluid is given in 30 litre per second that is your Q dot is actually 30 into 10 to the power minus 3 meter cube per second. You should convert this one to SI unit before moving forward

So, with this knowledge of orifice meters and venturi meters and their application to real life problems; let us move on to a few more discussions.

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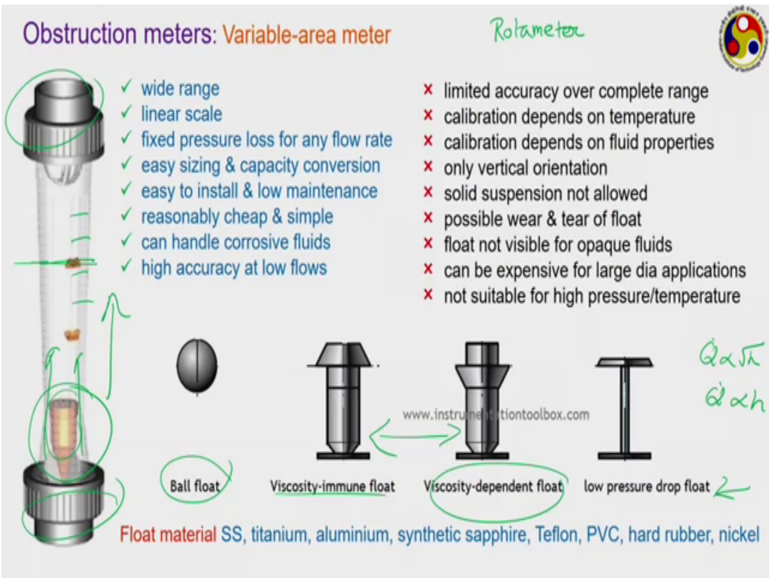

And for that we have another obstruction meter to deal with what is a different kind something known as a variable area meter. Here the fluid is allowed to flow through again between the 2 flanges we are putting on the meter, but the meter is having a variable cross section area not like the venturi meter rather it is uniformly varying it is a taper tube through which the cross section area continuously increases in the upward direction and generally fluid is allowed to flow only in the upward direction. As the fluid is falling in flow in the upward direction the area is increasing.

And inside this channel we have this float this is made of different kinds of materials your float can be of different material like the eye it can be of metal stainless steel, Tyner, titanium, aluminum, nickel or we can use Teflon we can use hard rubber we can use PVC there are several kinds of material used to make this float depending on what kind of fluid you are dealing with. As the fluid is flowing through this the float will move upward and then we will acquired an equilibrium position depending on the balance between the forces that is acting on this.

I shall be coming back this shortly, but the float can have different kind designs the idea being we have to maintain a force balance. So, that the float is able to maintain a perfect equilibrium position; then the accordingly whatever objective that we are going to look for we can have different kinds of floats. Like we can have just ball float plane ball float is the simplest possible design generally using smaller units. The viscosity immune float the second one this is the one that is generally used when we are the viscosity of the fluid is very critical. The fluid that we are using the viscosity can be quite critical in that situation we use this viscosity immune float. I do not want to go to the details of their design you can refer to the website which is shown here for more details on them.

The viscosity dependent float where actually you want to take the viscosity of the fluid into consideration then we go for this; these two are can be thought to be opposite to each other. One takes viscosity out of the equation the other takes viscosity into the equation. This one is more suitable when you are dealing with large diameter tubes whereas; this one is used for small diameter tubes.

This is the one that is generally used when we do not want large pressure drop of course, as the fluid has to make has to flow past the float within this tube there will be certain pressure drop. When you do not want any pressure drop or significant pressure drop then we go for this. So, this is the 4th one is particularly suitable when you are dealing with low pressure gas flows; when we cannot afford too much loss of pressure.

Now, have you seen this particular instrument? It is actually more popular by another name. That is why I am asking you this is more popularly called rotameter. Rotameter is very commonly used you may have already found rotameters in your university libraries or institute sorry not library university laboratories, wherever you have done some fluid flow related experiments or maybe heat transfer related experiments. This is called a rotameter which is nothing but another obstruction type meter traditionally known as the variable area meter.

Each has several advantages like it can serve a wide range of operation it has very linear scale the position of the floor generally varies linearly with Q dot the flow rate, which the big development over the previous 1s. Because in the previous case we had Q dot proportional to root h whereas, in this case Q dot is directly proportional to h. So, this is a big development or big advantage compared to the venturi meters and orifice meters. There is a fixed pressure loss for any flow rate generally as the pressure drop that the fluid suffers does not depend on the flow velocities.

We can have them in easy sizes we can also suppose we want to we are using one rotameter for a particular situation, now you want to change the range of operation. Then we can easily do this just by changing the float itself they are very easy to install just like in this diagram the flanges are shown which like in this particular case they generally are having some kind of threads, they can easily be tightened to the corresponding threads on the main pipeline and we can keep start using this immediately.

Hardly any calibration required because they always come pre calibrated and we not we do not have to go for frequent calibration very low maintenance requirement as well. They are reasonably cheap simple can handle corrosive fluids as well. And they are generally highly accurate particularly for low flow rates another big advantage over venturi meters. They are very accurate or particularly accurate at low flow rates, but their disadvantage can be over the accuracy is a much lesser compared to venturi meters, if we consider the overall range or the entire range particularly at higher flow rates they are much lesser accurate.

Calibration depends on temperature. I have just mentioned they are easy to calibrate or hardly occurs any calibration, but that is true when you are dealing with an isothermal flow situation. When the temperature changes fluid properties changes drastically accordingly we may have to recalibrate them. Calibration depends on fluid properties we shall shortly be seeing these two points in the next slide they can be used only in vertical orientation. Like orifice meter can be used only in horizontal orientation, they can be used only in vertical orientation; However, venturi meter can be used in any possible orientations.

Solid suspension is not allowed because as the float is their fluid has to find a way pass to the float. And if there is some kind of solid suspension, that may not be able to pass through the small annular gap rather that will block the flow. So, solid suspensions are not allowed. And because there can be possible wear and tear of the float itself particularly when there is some kind of dirty fluids to deal with. And if we are dealing with a fluid which is not opaque which is not or rather I should say which is not transparent their float will not be visible and if we cannot see the float then we cannot get the reading also. Because as the float keeps on moving up and down we can we generally, have a scale on this particular glass tube. And when the fluid settles in at some position somewhere here we can directly get the corresponding value from the scale, but if you are not able to visualize the float we can get the reading also.

So, we cannot use them for opaque fluids. And they can be expensive for large diameter applications; however, for smaller diameters they are very good to use. And they are not at all suitable for high pressure temperature applications. Generally, we use glass tubes. So, when you are working up to something like 200 degree Celsius and just about 2 or 3 mega Pascal pressure. If we want to use for slightly higher pressure then we can go for stainless steel tubes which can sustain up to something like 300 degree Celsius or about 70 mega Pascal pressure, but not very common to use that at such a pressure temperature ranges.

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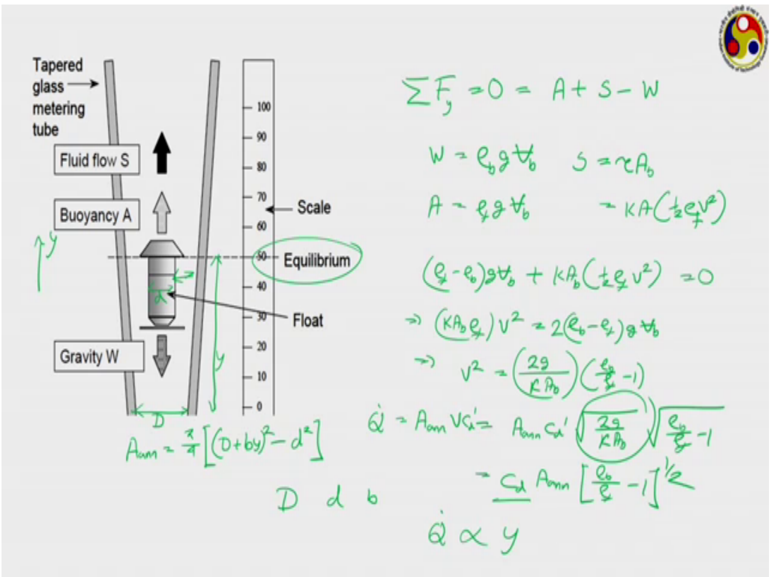

Now, let us just take a look what are the forces that is acting on the float. The float there we can see there are 3 forces one is the gravity which is acting downwards one is the buoyancy force depending upon the density difference between the flowing fluid. And, the float material we can have a buoyancy force and also as the fluid is flowing in the upward direction it will have or fluid there will be some kind of drag force which is also moving work in the upward direction.

So, when the float acquires some kind of equilibrium position, then the summation of forces acting in let us say this is a y direction that has to be equal to 0. Now what are the forces acting in this direction. Let us say this is the positive y direction. So, we are having the buoyancy force A plus the fluid flow force S minus the gravity W that is equal to 0.

Now, how much is the weight? Weight will be equal to rho b, rho b refers to the density of the float material into gravity into the volume of the float. Similarly, how much will be the buoyancy force. Buoyancy will be equal to the weight of the fluid that has been displaced by the float. So, it is equal to rho f rho f refers to a density of the fluid 2 g into Vb. And what about this S? S is the drag force. Now it will refer to the shear stress into the area of the float and how we can get the shear stress shear stress can be certain constant K times half rho V square where V is the velocity of the fluid. And of course, rho f

So, if we put all these forces together now then we can write that rho f minus rho b into g Vb plus KA into half rho f V square is equal to 0. Or Ab I should say KA b rho f into V square is equal to rho b minus rho f 2 into this to g into Vb. Or V square is equal to 2 g by k into the area of the float here Ab of course, the phosphors are confidentiality or the peripheral area over which the shear stress is acting into rho b upon rho f minus 1.; that means, if you are interest is the flow rate. What should the flow rate? Flow rate should be the A n that is the area or of the annulus like this particular annulus though is the fluid is flowing.

So, how much is the area of the annulus. A annulus can be written as pi by 4 into the channel diameter. So, channel diameter can be d plus b y whole square minus the float area, where small d is the area of the flow diameter of the float. So, this is a small d. Capital D is the smallest possible diameter of the channel, and y is the distance that has been traveled by the float, when it has reached from capital D position to the equilibrium position and be certain suitable linear constant. So, d plus b b y refers to the change in the diameter as it is V in the upward direction. So, d plus b y is the effective diameter of the channel at this equilibrium position small d is the diameter of the float. So, do we have the area of this channel we may have certain kind of coefficient of discharge also coming in,

So finally, if we put everything together so, we have A n n into Cd prime into root over 2 g by KA b into root over rho b upon rho f minus 1. That is certain discharge coefficient Cd into a area of this annular portion into rho b upon rho f minus 1 whole to the power half. So, this constant C d which actually takes care of all these terms generally is a generally comes from the manufacturer. And what we do we make the combination of this parameters capital D small d and b such that this displacement becomes a linear function or I should say Q dot becomes a linear function of y. Then only from the scale directly we can get the measurements of the flow rate. So, variable area meter or rotameters are very common devices for fluid flow measurement and this is a very simple way of getting their working principle.

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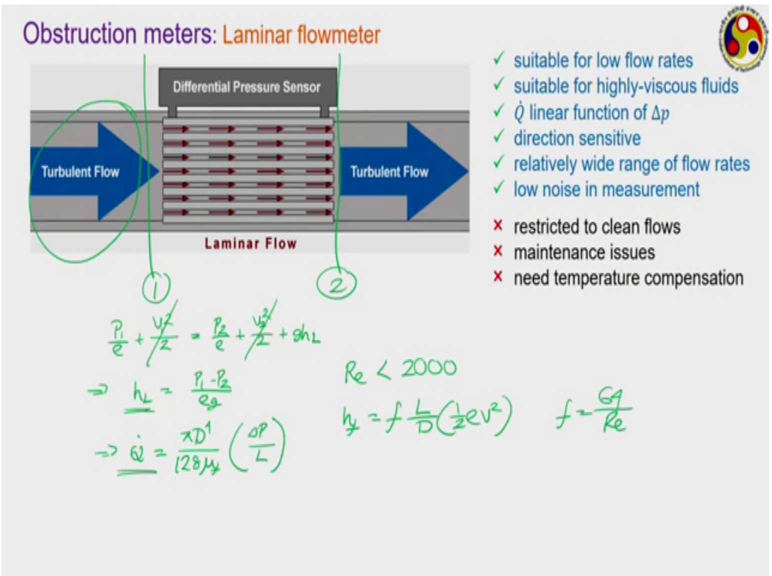

Another device, another abstraction kind of device known as a: laminar flow meter. They are generally used for high velocity fluid for turbulent flow situation. In case of turbulent flow actually this particular laminar flow meter is also known as target flow meter; so, this is another alternate name that is also very popular. Here what we are doing here in the main flow stream we are putting this particular section. In these sections there are several small capillary tubes or very small diameter tubes and we are allowing the fluid to flow through the small diameter tubes.

As the fluid is flowing through the small diameter tubes then or I should say that total fluid which is flowing through the inter cross section that gets divided into several components. And as the diameter of each of these small tubes are. So, small then each of them experience laminar flow. And we then make use of this laminar flow situation. How can we make use of the laminar flow situation? sorry I have made a mistake actually this target flow meter term we shall be using later on this is not suitable for laminar flow meters, I am very sorry for this, but let us come to this situation for laminar flow meter let us say this 1 and 2 are the cross sections. Now, 1 is before it enters the laminar flow channels 2 before once it exists the laminar flow channels. If we apply Bernoulli's equation, then P 1 by rho plus V 1 square by 2 is equal to P 2 by rho there is no change in elevation V 2 square by 2 plus g into h l where g into h l h l refers to the loss in head because of this.

Now, 1 and 2 are having same cross section areas. So, under steady state condition V 1 and V 2 are equal to this; that means, h l is equal to P 1 minus P 2 by rho g. Now h l is coming because of the loss of the fluid head loss of the fluid is flowing through this small dimension channel or small diameter channels. And as the diameters are so, small that they can easily visualized to be laminar flow. And for laminar flow we actually have a measure of this h l. Heavy heard about the Darcy Welsbach equation I am sure you have learned is influenced in fluid mechanics where for laminar flow situation that is when Reynolds number is less than 2000 we can write this h l to be equal to f into l by d half rho V square. And this f for laminar flow is equal to 64 by r e that is the Reynolds number.

So, if we put this into equation then if you put everything back here. The Q dot will be coming I am not showing the development because you can just put this expression for h l into the equation and this is also very standard you will find this as 120 pi d to the power 4 1 given mu f into delta P upon. L where l refers to the length of this portion, D is the diameter of the main tube mu f is the fluid viscosity and delta P is the pressure drop between portion 1 and 2. So, from the measurement of this pressure drop delta P we can easily get this delta P. This equation is known as the Darcy Welsbach equation. And we can easily get the measure of the flow rate using this.

So, they are very easy configuration particularly suitable for low flow rates and highly viscous fluids also again high viscosity hillocks in laminar maintaining the laminar flow situation. The Q dot that is flow rate is a linear function of delta P just like the previous situation and these they are direction sensitive. Because in which direction flow rate is happening accordingly the pressure drop direction will also change. So, we can also get an idea about this flowing from 1 to 2 or 2 to 1. They have relatively wide range of flow rates as well and very low noises measurement because as you are dealing with laminar flow during measurement hardly any disturbance in the flow stream.

However, problem is they restricted to clean flows just like orifices as we are dealing with small diameter channels there can be blockage if there is in doubt present in the flow stream. Then there can be maintenance issues temperature compensation may will be required because viscosity can vary significantly with temperature. So, we have to be careful about the fluid flow temperature or the temperature at which you are doing the experiment, but laminar flow meter can be a good one to use particularly you are dealing with highly turbulent flows.

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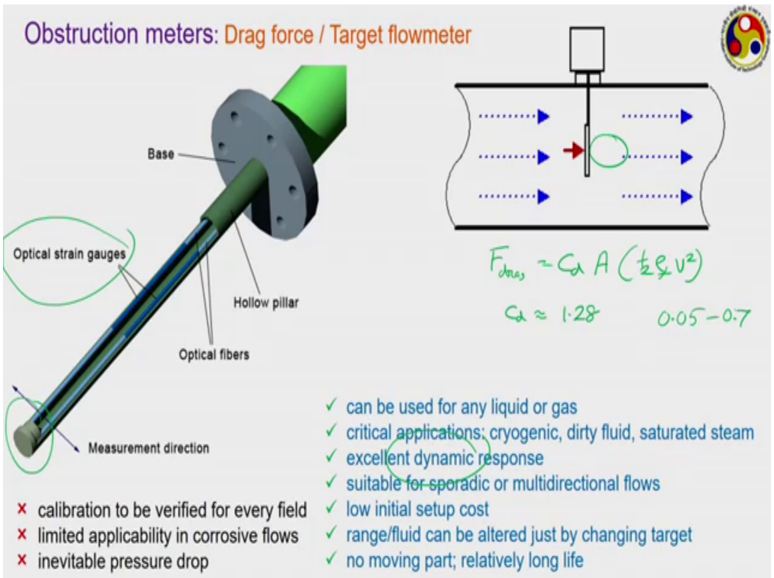

Another one often known as a drag force flow meter or where, I made the mistake that target flow meter. That is a quite interesting example not very popular, I should make it clear from the beginning and also there are doubt. So, that we should call them obstruction meter at all, but what we have here in this drag force flow meter or target flow meter we have a tube. Just like shown here we have a hollow cylindrical tube inside the tube we have the tip of this tube is immersed into the flow stream where you want to get the measurement of the flow.

As it is as the fluid is flowing over this it experience a certain kind of force on this certain kind of your drag force and that force is sensed by this pair of strain gauges which are mounted on the inner surface on the opposite inner surface of this particular cylindrical tube and this force can be seen to be a to be directly proportional to the flow. Like this is the situation your flow plate this particular head of this can be the order I should say the tip of this cylindrical pin can be like a flat plate just shown. Here if it is a flat plate then it will be oriented exactly perpendicular to the flow direction or we can also deal with spheres if like instead of a plate like it is shown a plate, but you can also have a spheres. And depending upon which configuration we have additional circuitry located inside the cylindrical hollow pin takes care of the corresponding calculation.

Now, when fluid is flowing over this corresponding drag force can be seen to be C d into area of this obstacle into half rho f into V square. The value of C d if we are dealing with a flat plate C d is something like 1.28 approximately I should say it is 1.28; however, if we are dealing with a sphere then C d can have a very wide range 0.05 2 0.7. This is significantly wide range that we may have. So, and that depends upon the Reynolds number of the flow.

So, we can have some kind of correlation to calculate C d based upon the Reynolds number and once we know the value of C d we can get the value of the velocity from this particular calculation. The big advantages they can be used for gaseous situation as well both liquid and high velocity gas flows can be measured on the flow rate I should say. They can be gone used for very critical applications like cryogenic applications very high temperature pressure streams we can also use them for dirty fluids corrosive environments.

They have excellent dynamic response all the devices that we have used earlier they are generally used for steady state response, but this is the one that is an excellent dynamic response. And so, we can usually use them for dynamic measurement they are suitable for sporadic or multi directional flows as well low initial cost is quite the initial setup cost is quite low. But, because we hardly need anything there is only a flat plate or sphere and the corresponding circuitry located inside this hollow tube, that is all.

The range of the range of flow rate or the fluid to deal with that can easily be altered just by changing the target or that flat plate. So, we can use the same meter can be used for different kinds of situations just by changing a tip of this. And there is no moving part. So, there is relatively very long life compared to a few other devices; however, calibration to be verified for every flow field because calibration can be quite tricky party, where the value of C d which is dependent on the velocity itself they are limited applicability in corrosive environment.

I have mentioned earlier they can be used for corrosive situation, but generally when you are dealing with fluids with solid suspension or limited amount of solid suspension, but if it is highly corrosive then that can corrode the plate itself or the tip itself. So, you have to be careful in such situations. And there is definitely large pressure drop which is going to happen across this. So, this is also certain kind of obstruction that is putting into the target, but they are not very popular rather a device which is you huge can be visualized to an improved version of this one is quite common in industries which is called turbine flow meter.

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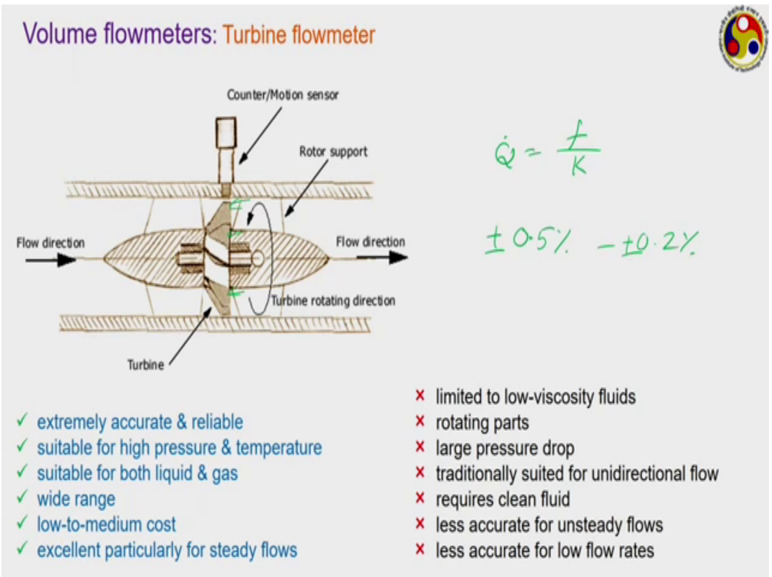

And this is no more an obstruction flow meter this is a volume flow meter the other category that we are going to deal with. Here actually we have a turbine mounted in the flow field. I shall briefly be going through them just to mentioning their operating principle here we have a turbine these are the turbine blades. As the fluid is flowing through this it drives the turbine blades therefore, the blade starts to rotate and as the blade or the rotor starts to rotate there is a permanent magnet mounted on the housing of this.

And as the permanent magnet starts to move along with the rotor then there is whenever it crosses the pole of the coil there is a change in the permeability. And that change in permeability can be sensed by any suitable instrument and that can give you an idea about the flow velocity and correspondingly the volume flow rate of the flow stream which we are going to deal with. Generally, it has been found that the flow rate can be represented as if by K. Where, f is the means as I mentioned there is a whenever it crosses the pole there is a change in permeability. And each such change in permeability gives leads to the leads to one voltage of pulse.

So, here f is first see the frequency of that voltage pulse and k is some instrument based constant. So, we can easily get the flow rate from this. They are highly accurate instrument probably the most accurate one among all the ones that we are going to deal with or we are going to talk about their accuracy can will be in the range of I should say plus minus 0.5 percent or even lesser particular in dealing with liquids. For gaseous it can be slightly higher for, but for liquids we can even go to 0.2 percent. And commercially available turbine flow meters generally comes with very good range of calibration and high accuracy.

There as I mentioned they are extremely accurate and reliable over the entire range of operation suitable for high pressure and temperature suitable for both liquids and gaseous wide range of operation. Their cost is low to medium because I should say they are much costlier compared to the obstruction meters, but can be less costly compared to the next one that we are going to talk about and they are excellent particularly when dealing with steady flow situation, but not that good in transient situation because the frequency itself will becomes difficult to measure.

They are not they are limited to low viscosity fluids for higher viscosity ranges the drag force can become significant and can significantly affect or I should say significant damp in the rotational motion the there is rotating part. So, there will be much larger wear and tear much larger maintenance requirement. The turbine generally needs to be manually lubricated also to reduce this wear and tear. They can induce significantly large pressure drop in the flow stream much larger compared to venturi meters etcetera. Traditionally suited for unidirectional flow because, the motion of the rotor is insensitive to the flow direction.

And so, it is not possible to capture the flow direction using the turbine flow meter. They requires clean field or clean flow stream because if there is solid suspension that can strike the turbine blades causing permanent erosion to the turbine blades and some clogging also. And they are less accurate for unsteady flows and also for low flow rates they are extremely high accuracy over at the upper side of the range, but not dead great on the lower side. But, the next one can be extremely accurate over the entire range true, from 0 flow to very high flow rate which is the electromagnetic flow meter.

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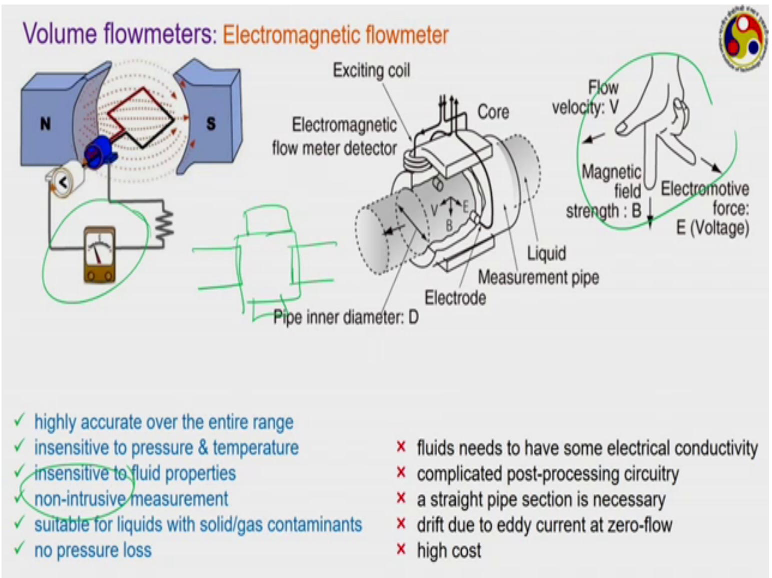

Working principle is very simple you must have heard about the Faraday's law of induction which is the principle of electric current generation or I should say AC current generation alternating current generation. That is when a conductor is moving inside a magnetic field then that produces an EMF and if we capture that EMF then we get electricity. That is the principle here. Here we have the any conducting fluid even that is flowing through a channel we put a permanent magnet field or around the channel. Basically if this is your channel in between if this is the channel in between you are going to put the flow meter and the flow meter will house a permanent magnet.

And as the conducting fluid is flowing through this because of the motion of a conductor in this magnetic field there will be a current generation which is given by this very famous the right hand rule. Where if we put these 3 fingers perpendicular to each other then the magnetic field will always be given direction of magnetic field is given by this. And the flow velocity will always be given by this then this one your index finger will give you the direction of the EMF generation; from where we can get the idea about the direction of flow as well. Only one restriction is that it is a very simple working principle and extremely accurately hardly need to go for any calculation. There are several standards electromagnetic flow meters available in the market as well, but only problem for them is that the fluid has to be conductive. Conducting is it does not need very high conductivity common tap water itself a sufficient conductivity to deal with such flow situations or such kind of magnetic flow measurement., but they are not that much suitable for gaseous flow measurement.

So, their advantage is highly accurate over the entire range. As I have mentioned starting from 0 flow to the maximum flow suitable for this magnetic flow meter insensitive to pressure and temperature insensitive to fluid properties because they are only dependent sensing the EMF that is generated. And that is the independent of the prop any property of the fluid and very important non-intrusive measurement.

Whatever measurement that we are talking about all over intrusive, but here we are not putting anything inside the flow field, whatever we are doing that is only outside these magnets are only part of the wall of the conduit that you are dealing with. So, nothing is blowing inside the flow field no pressure drop. So, this is non-intrusive measurement; suitable for liquids with solid and gas contamination because there is nothing to block the flow. So, we do not care about contaminants and no pressure loss, but problem is the fluid needs or some electrical conductivity.

So, certain liquids and gaseous cannot be used with this measurement. Complicated post processing circuitry because the corresponding EMF needs to be related to the velocity or flow rate. A straight pipe section is necessary to allow the fluid to flow through the flow meter for 0 flow situations there can be certain drift created by the eddy current losses; however, generally that is taken care of the process by the processing circuitry and they are costlier. They are more costlier compared to the turbine flow meters, but they are when we are not sure about the flow to the flow velocities to deal with this is generally a very put into option to go for.

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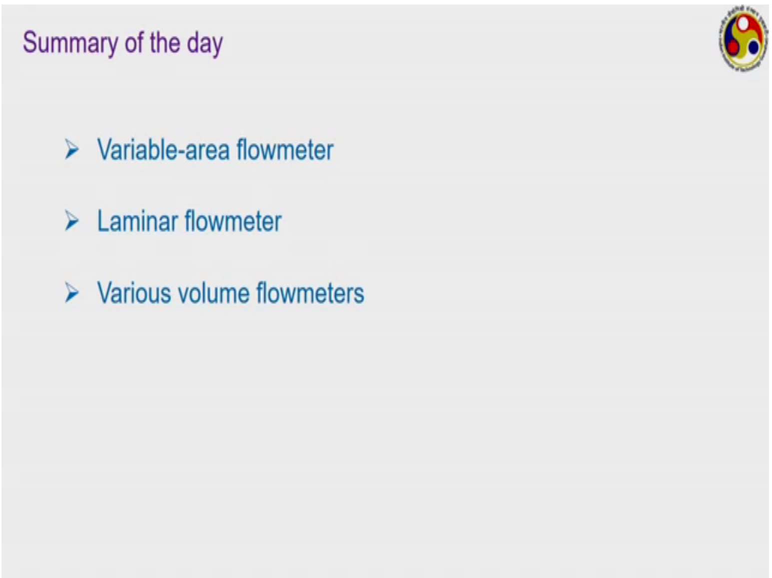

So, that takes us toward the end of today's discussion. If you other volume flow meters I have to discuss whether I shall be discussing only in the next lecture where I shall also be talking about mass flow meters. So, we have talked about the variable area flow meters and laminar flow meters today. Then we talked about the target flow meter, and then 2 different kinds of volume flow meters that is the turbine flow meter and electromagnetic flow meter we have talked about.

In the next class we shall be starting with the discussion on ultrasonic and vortex shedding flow meters. Then we shall be talking about the mass flow meters where we directly get the measurement of the mass flow like the Coriolis mass flow meter. And then certain kind of velocity based probes that we shall be talking about. So, till then I would like to take a leave from you.

Thank you very much for your attention.