Upstream LNG Technology
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Lecture – 15
Flow Measurement in Natural Gas- I

Welcome today we shall look into the various types of Flow Measuring devices which are used in the Natural Gas industries. You might have known that there are many many devices, which can be used for measuring the flows, but in case of natural gas we use a few of those measuring devices, which are used in general. So, we shall be focusing on a few types of flow measuring devices for natural gas.

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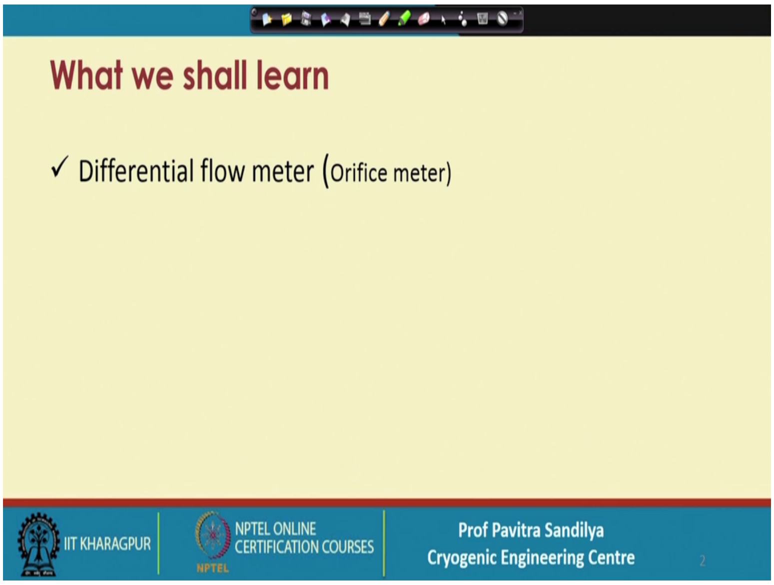

Now, in this particular lecture we shall be learning about a differential flow meter and that is orifice meter, which is the most widely used flow meter in the natural gas industry. The differential flow meter, this name signifies that it is measuring the differential pressure drop; that is caused during the flow of any fluid through a pipeline or a over a surface.

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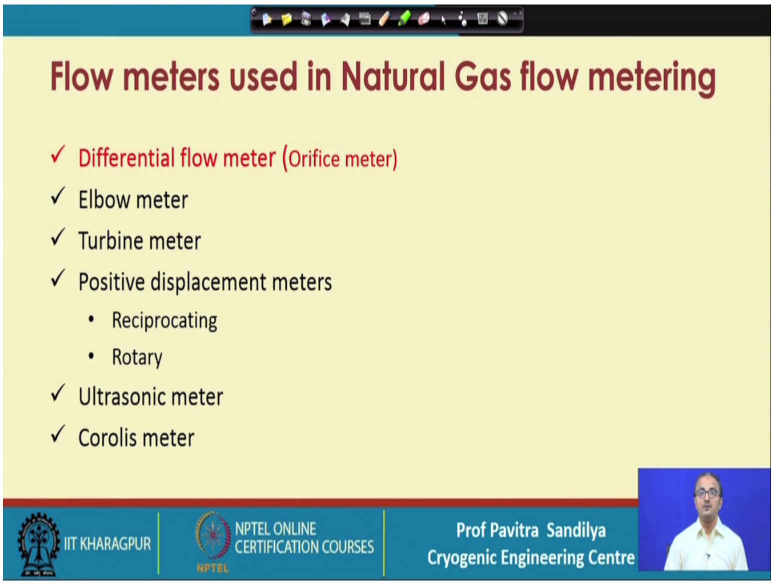

Ah as I was telling that there are many many flow meters available, but in case of natural gas a following are some of the most commonly used flow meter meters; first is the differential flow meter that is orifice meter, then there will be elbow meter, turbine meter, then positive displacement meters. Under this again we have two types; one is reciprocating and the rotary and ultrasonic meter and Corolis meter.

So, I shall be talking of all of these one by one, but I shall be going in detail on the orifice meter, which are because this is the most widely used meter and it is quite simple to use. So, in this particular lecture, we shall be looking into the orifice meter.

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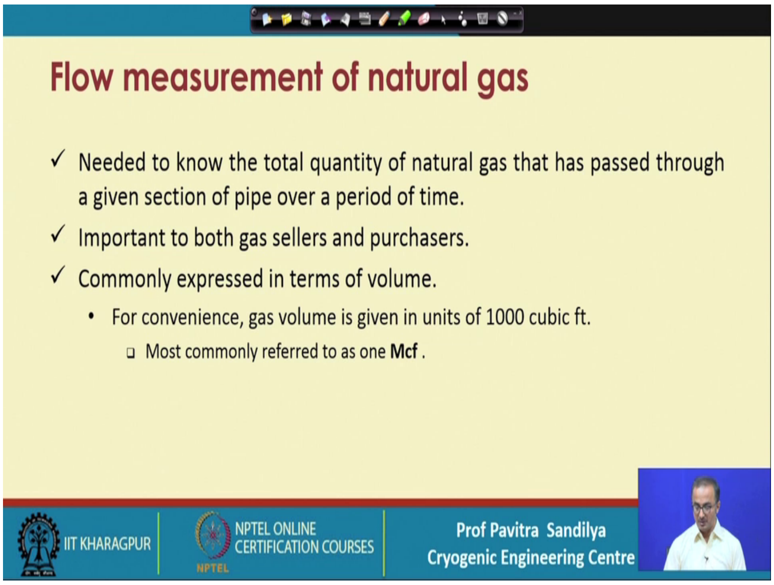

Now, why do we need to measure the flow? We need the flow rate, because whenever we want to quantify the amount of gas being supplied from the supplier to the customer over some period of time.

So, we would like to know that how much quantity, how much amount we have been given and how much amount we have been using, because based on that we shall be ah, the cost will be decided how much cost I should, we have to pay. So, that is why it is necessary for us to know the flow rate and it is important for both the customer as well as the supplier.

Generally the amount in case of gases is given in terms of the volume and conventionally these volumes are given in terms of or multiples of 1000 cubic feet and most commonly used is the Mcf a million cubic feet.

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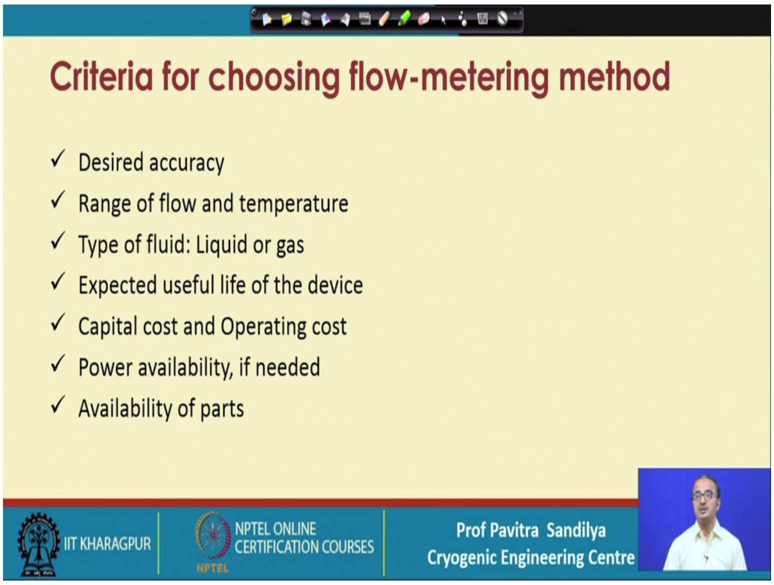

Now, what are the various criteria to choose some flow metering device. So, first is the accuracy we need, there are many many flow meters of which will give us different type of accuracies.

So, depending on the kind of use in hand we shall have to decide that how much accurate we we want to know the flow rate. Then the range of the flow and the temperature, because when we talk of gas especially, the temperature pleasure role, because it decides the density of the gas, and the density changes the volumetric flow rate for a given mass flow rate.

The type of the fluid whether we are handling liquid or whether talking of gas and the expected useful life, that how long the flow meters is intended to be used. Of course, the cost factor comes, in this case we have to look into both the capital cost that pertains to the money we have to pay to purchase it; that is the capital cost and operating cost during its operation what are the various cost involved in, including the installation, the maintenance, all these costs come under operating cost.

And if some flow meter is needing some external power for its activation, we shall find that in some of the flow meters we need external power. So, whether there is this power available at the given point of use or not;, accordingly also we have to choose the flow meter.

And next is the availability of parts whether, because this comes especially when we talk of the maintenance, because while we are using it, if there is any kind of failure, we should be able to replace it or we should be able to repair it. So, for that we need to have the spare parts available for the particular flow meter.

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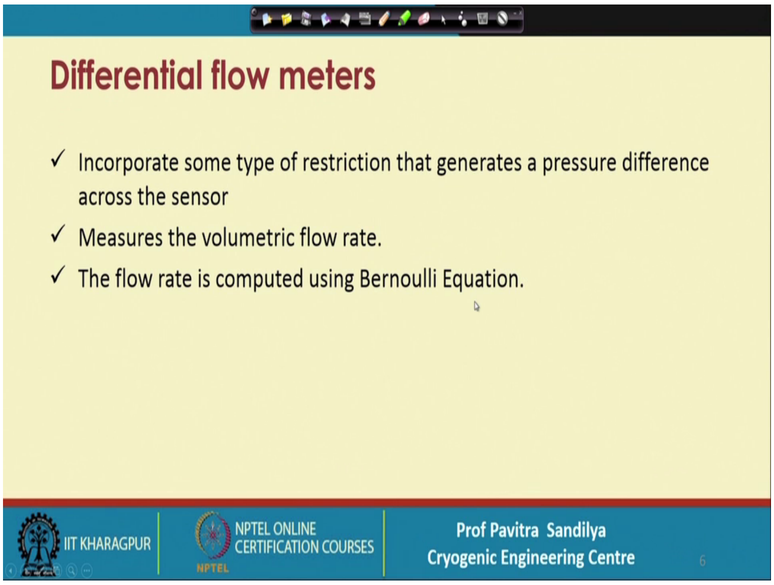

Now, coming to the differential flow meter, let us see that how it works. In this case what we do that generally any fluid, when it flows in an open channel or a closed channel due to drag there will be a pressure drop. Now drag as you know that drag is a resistance to the flow of a fluid.

Now this drag may be coming due to the skin friction ; that is the friction between the surface over which the fluid is flowing and this comes due to the, due to viscosity and it may be due to form drag. And the form that comes into picture whenever there is kind of a tortuous ; that means, non straight line part of the fluid, that is there is some kind of change in the direction of the fluid flow then we get the form drag.

So, because of the drags there will be some pressure drop along the flow path of a fluid. However, this, this pressure drop may not be substantial over a short path and we may, if I want to measure the pressure drop.

We are, I might have to use a very long linear length. So, in that case, it may be infeasible to install the flow meter over a long length of the pipeline. So, for that what we need, we need to artificially create a pressure drop. Now pressure drop on one hand is going to help us in measuring the flow, on the other hand it also means that we are losing the energy and it is necessary for us to see to it that we do not create.

So, much restriction on the flow path that the pressure drop is very substantial, and if the pressure drop increases too much, then we will find that the pumping power will also increase.

So, whenever we are talking of putting up any kind of restriction on the flow path of a fluid, we have to decide the restriction very carefully, so that we put enough restrictions we, that can give us enough pressure drop that can be measured over a finite length of the pipeline. So, that way we have to look into the provision for the restriction.

Now we put some kind of restriction on the flow path for pressure drop measurement and then this pressure drop is measured by some sensor. Now, after these days whatever that pressure drop; that is delta p is measured, based on that we develop some kind of theoretical formula to get the volumetric flow rate and this flow rate is generally computed by the Bernoulli equation.

So, Bernoulli equation perhaps all of you know that, it is an equation which is based on the energy balance and that Bernoulli's equation we use to derive an expression for the volumetric flow rate.

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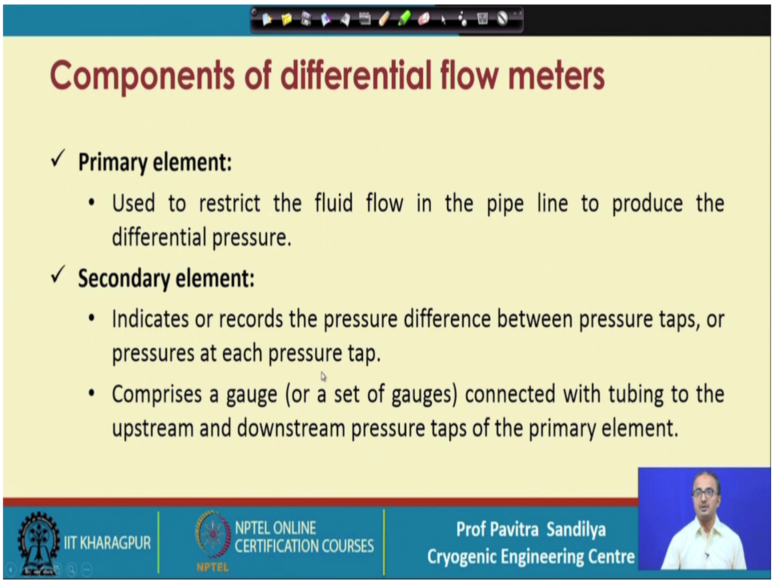

Now, first before going to our theoretical derivations, let us look into the various components of a differential flow meters. These components are same for the various types of differential flow meters ah. Please mind it, not only orifice meter we have other differential flow meters like Venturi meter, so this is applicable for that meter also.

So, we have a primary element and what we mean by primary element is this, that this is the element which restricts the fluid flow to produce the differential pressure across a finite pipe length. And then we have secondary element which means that this will be, this will record or indicate the delta p that has been caused by the restriction and this delta p is measured across some pressure taps.

We have some to pressure taps on the pipeline well, across these pressure taps the delta p is measured, and it consists of some kind of gauge or a set of gauges. Means either I can have a differential pressure measuring device or I can measure the pressure at the two pressure traps and take the difference. So, in either way I may have a single gauge or I may have a set of gauge. So, these constitute the secondary element.

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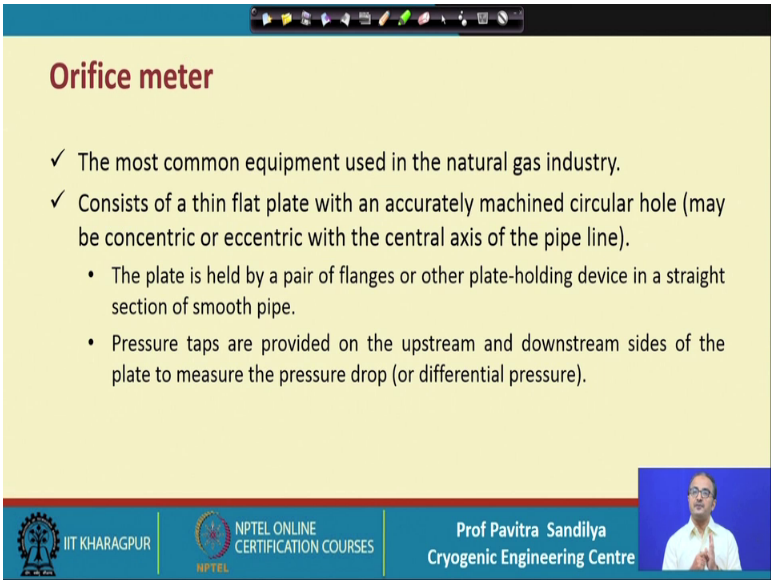

Now, coming to the orifice meter, it is the most commonly used flow meter in the industries, because of its simplicity of operation, simplicity of design and installation. So, the orifice meter is the most commonly used flow metering device.

Now, what do you, what it has, it consists of a thin plate if you have a simple a plate. Of course, this has to be machine properly with a concentric hole; that means, this is a circular plate with a concentric full generally, but sometimes we also use eccentric hole. Eccentric means the hole is not having the same axis as the axis of the plate.

So, they have two different axis. So, that we may also use eccentric holes, but generally well concentric holes orifice meters are very common. And this plate will be held by flange between the two pipelines or some kind of holding device, and then pressure drops are provided at some designated locations of stream and downstream of this orifice meter, and all these pressure taps may locations have been standardized.

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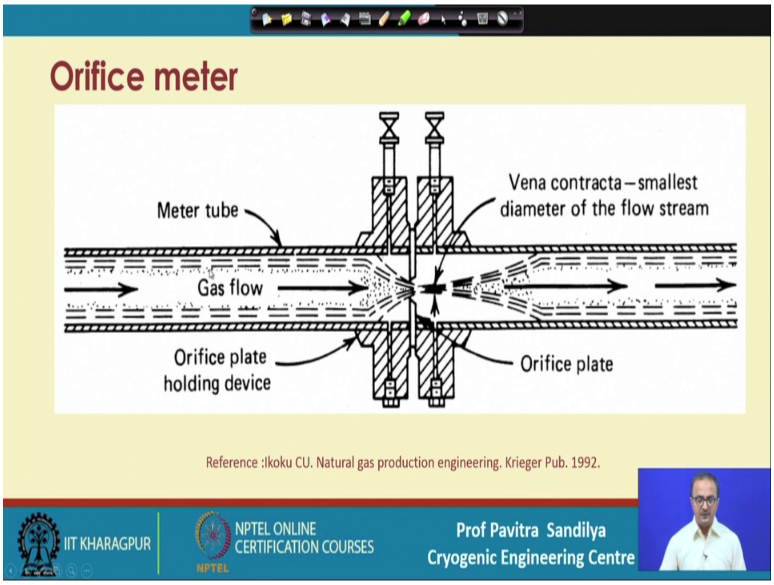

Now, let us look here that here we see that there is some flow of some gas going through pipeline, and here we have the metering tube over tube and here we see that by some flanging arrangement we are holding and, this is the orifice.

This orifice here we see and these are the two flanges and this gas is flowing through this pipeline, and what happens as it is going through the orifice the flow is converging and is converges. And here you can see this edge of the orifice is not sharp edge its what we call Beeville edge and this bevelling is done to slowly expand the gas, because if the edge is very sharp then what will happen?

There will be lot of energy loss. So, there to reduce the energy loss, we make it Beeville edge and then we will find that this flow converges here and slowly and slowly at some point it will start again expanding and again it will occupy the whole fluid.

It does not mean that a vacuum is created here, the fluid will also be here that this fluid which is here in these zones, there will be in quite turbulent way and this particular area, where this, because this area is getting constricted and after this orifice is passed this area keeps on narrowing down. The minimum area attained by this particular stream is called the Vena Contracta and it gives us the smallest diameter of the flow stream.

So, this is the way we visualize the flow of a fluid happening through an orifice meter. This is also applicable to any kind of liquid. And here we have the orifice plate holding device and as I said this is the orifice meter.

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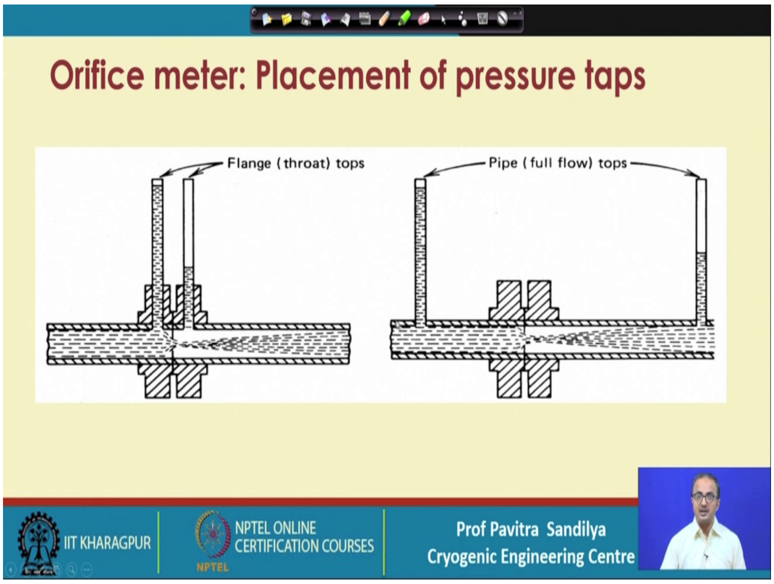

Now, now as I was telling that there are various ways of putting the pressure taps. So, one way is that, we put the pressure taps right over here in the armoured flanges and they are flange type or if flange taps, and here what we are showing here that there, we are finding that there two differ two levels, these levels are indicative of the manometric reading.

Now, as we see if the flow is taking place from the left to right as is seen here, then definitely the pressure at the downstream depth will be lower than the tread the upstream step; that is indicated by some kind of this height of the column, liquid column, you can say this kind of a barometric column you can say.

And here we have another type of tap, this is the pipe taps here you can see, these tabs are located away from the flanges and even the distance between this tap and the orifice are also prescribed in the literature.

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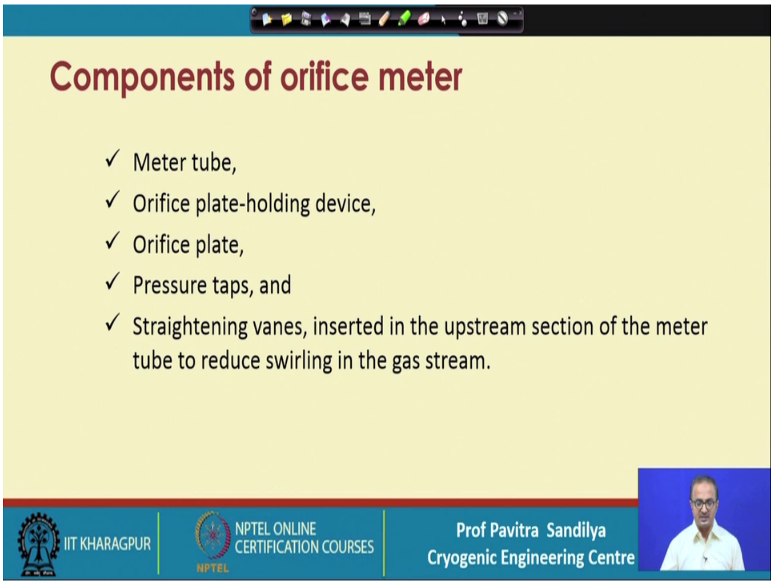

Next we come to the various components of orifice meter. In this here meter tube as shown in the figure orifice plate holding device in orifice plate, pressure traps and the straightening vanes. These straightening vanes are inserted on the upstream side of the meter to reduce the swirling action in the gas stream, because the swirls cause lot of energy loss. So, we reduce the swirls by putting some kind of straightening vanes.

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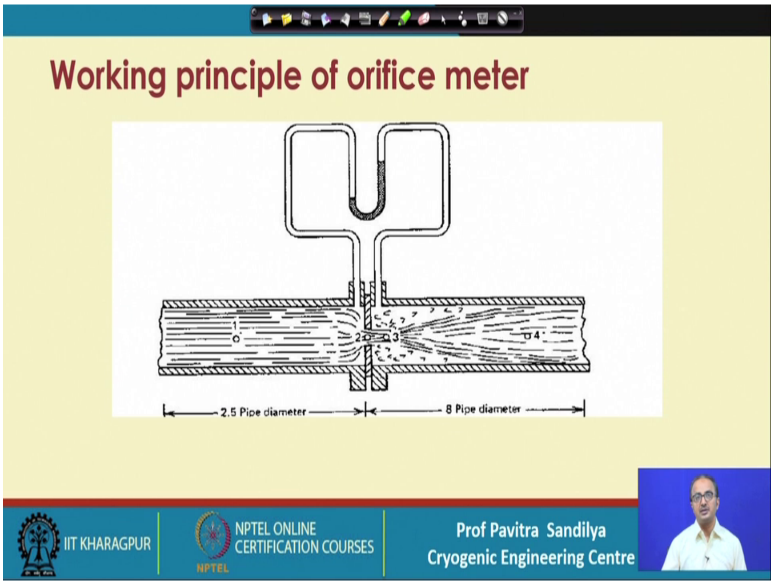

And now let us come to the working principle of the orifice meter. As I told you earlier that the gas is coming now in this two analyse it what we do. We demarcate some points like these are one; point 1 indicates some point on the upstream side and then 2, it demarcates the point right inside the orifice and then 3 at the vena contact and 2 again at a fully developed region on the downstream side of the orifice.

And here we have shown the kind of typical dimension of the pipe ok. And here we have shown some manometer, which is measuring the pressure drop across the orifice meter.

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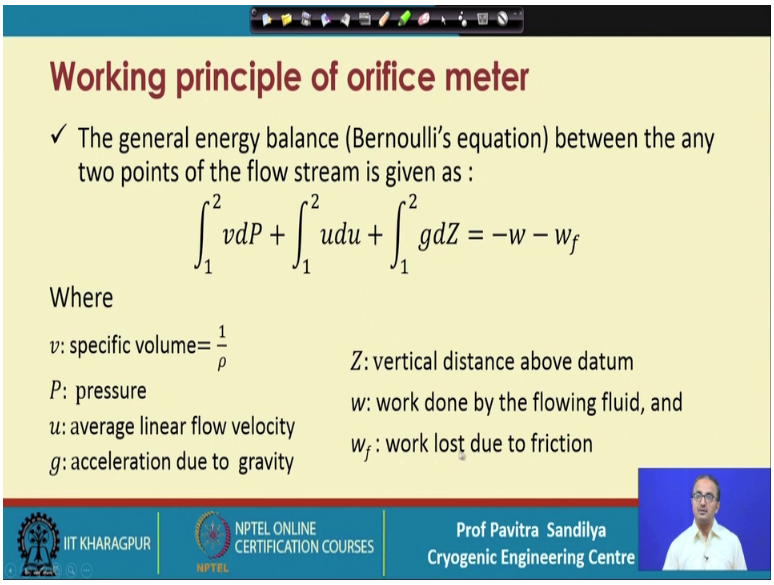

Now, coming to the analysis what we do that, we use the Bernoulli's equation between point 1 and 2 as shown in the figure. Now here we are writing the various terms in the Bernoulli's equation. First term is the, is representing the, you know that in Bernoulli's equations.

We have three terms pressure energy, then potential energy and the kinetic energy. So, first term is indicated pressure energy, second term the kinetic energy and third term is the potential energy. And in this Bernoulli's equation this is a bit modified that, from what we learned in our school, that here in this case we include two more terms in right hand side, this is not given in our school days.

Here these two terms of right hand side show the effect due to any kind of work done by or on the system. And in this the w f shows the work done due to the friction. So, this is the engineering Bernoulli's equation that is the modified from the Bernoulli equation, where we assume the or neglect the all the frictional losses and other works.

So, the, this v is the specific volume; that is the reciprocal of the density, p is the pressure, u is the average linear flow velocity at a given point over a cross section and g is the acceleration due to gravity, Z is the vertical distance from some datum and w is a work done by the flowing fluid and w f is a work lost due to friction.

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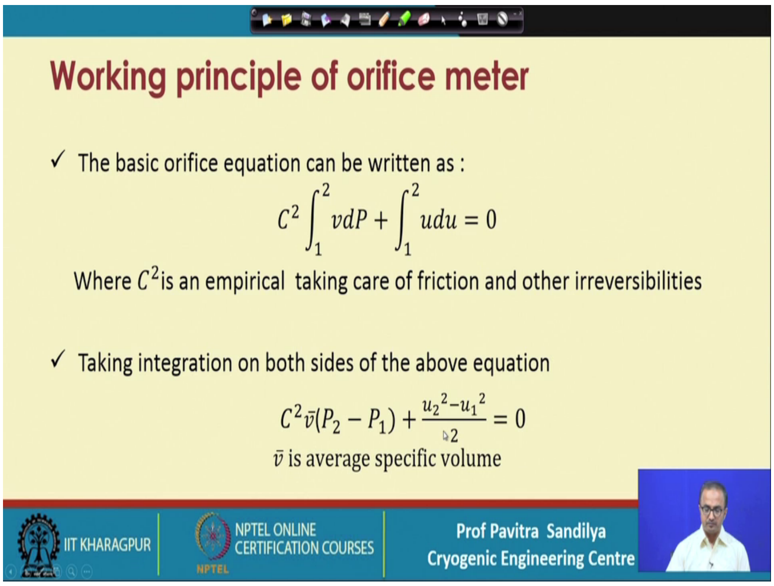

So, after writing the Bernoulli's equation what we do that, we read at is the equation and neglecting the potential energy loss politica. Potential energy really, if the flow meter is horizontal, then we can neglect the change in the potential energy by assuming that we can write this equation.

And in this case we put some kind of an parameter C, this C accounts for any kind of losses due to the turbulence or any other loss. So, this C and here we say that on the right hand side we are keeping zero; that means, this C is incorporating all the work effects during the flow of the fluid. So, this is the way we are simplifying the Bernoulli's equation.

And once we integrate, we integrate by assuming some average specific volume oh between the points 1 and 2 and this is especially necessary in case of compressible fluids; like gases. For liquids this may be assumed to be constant, but for gases we have to be careful. So, we use some kind of an average specific volume and then we integrate this kinetic energy term.

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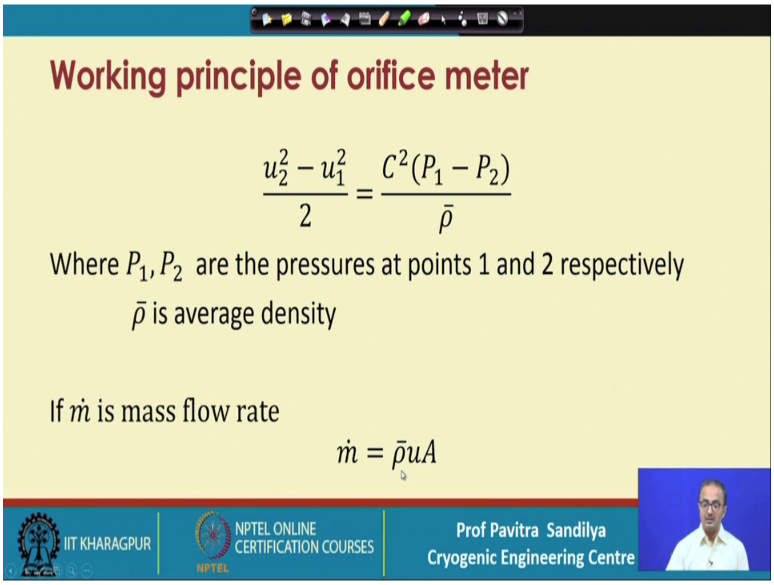

After this we rearrange the equation like this to. On the left hand side we have the change in the kinetic energy, on the right hand side, we have the change in the pressure energy, and these are the pressures people and put on the pressures which are measured by the pressure gauge.

Here we are using the row average, the density average. Now what we are doing that we are representing the mass flow rate in terms of the product of the density, the velocity and the area of cross section. This product area of cross section into the velocity is the volumetric flow rate into the density gives the mass flow rate.

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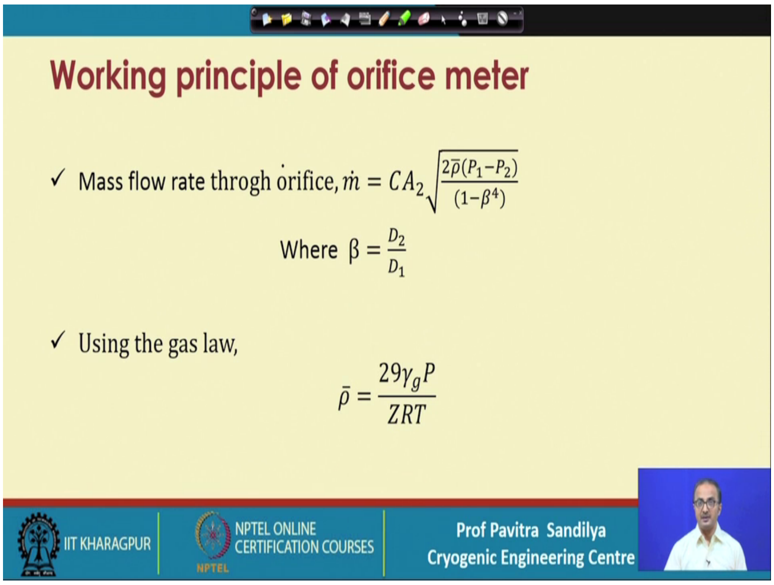

Now, after this we can rearrange the equation to obtain this equation and that are not explaining this. In this equation this beta is the ratio of the diameters at point 2 and at point 1 that and you can see that D 2 is always less than D 1, so beta will always be less than unity.

And then what we are doing that, we are again representing the average density by a some gas law. In this equation this gamma g is the specific gravity.

Z is the comfortability factor, T is the temperature and P is the pressure, R is the universal gas constant and 29 is the molecular weight of air, because this gamma g is defined as the density of the gas to the density of the air.

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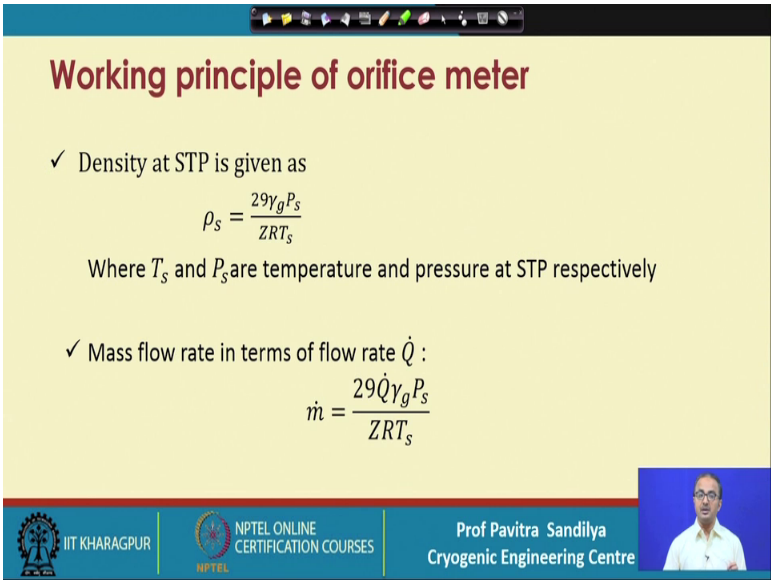

Then what we do that, because in case of gases we have always referred to some standard condition. So, we again define the density as some standard condition, and like this that in this case we write the same gas flow, but now we put the standard pressure and standard temperature. And now we put the mass flow rate in terms of the standard conditions.

We must remember the mass flow rate will remain the same irrespective of pressure temperature, but the volumetric flow rate will change depending on the pressure and temperature.

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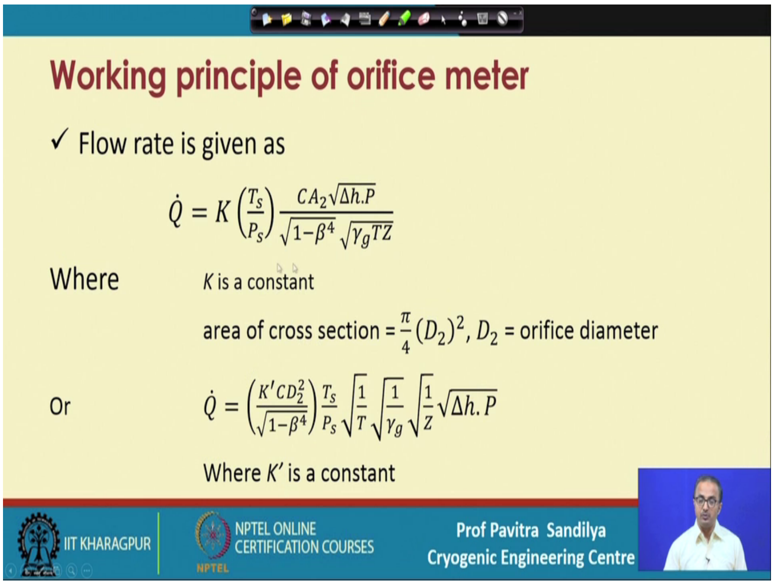

So, after this rearrangement now what we see that, we write the volumetric flow rate and my considering the above equations and here we put that if you manipulate the equation you will find some constant K will come and then the delta h. In this delta h is the differential pressure in terms of the head, head of the fluid.

Now, this fluid may be water, this may be mercury. So, it can be something appropriate liquid it will be. So, this delta h is representing the differential head and then we have all the other parameters here. And ultimately we get put the area of cross section A 2 in terms of the diameter and this is a pi by 2 D 2 square and then we incorporate this D 2 over here; that is the orifice, orifice diameter and then we obtain this particular equation. Again we can get some another parameter K prime 1, once we are manipulating this equation.

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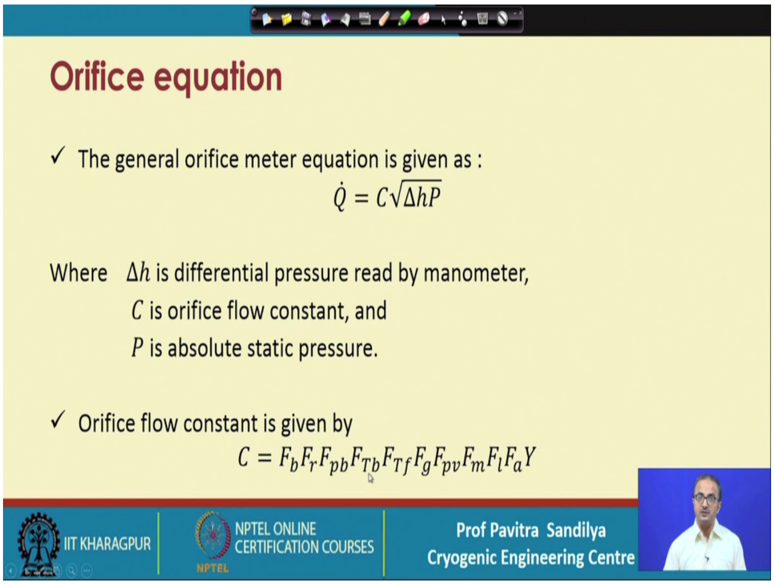

Now, in case of natural gas industry what would equations we have shown, this is given in terms of this particular equations C under root delta h into P, and this delta h is the differential pressure measured by the manometer, C is some orifice flow constant and P is the absolute static pressure and orifice flow constant has been given in terms of mainly, many correction factors about which we shall see now, that in this case these values will be given in terms of some table or some formulas.

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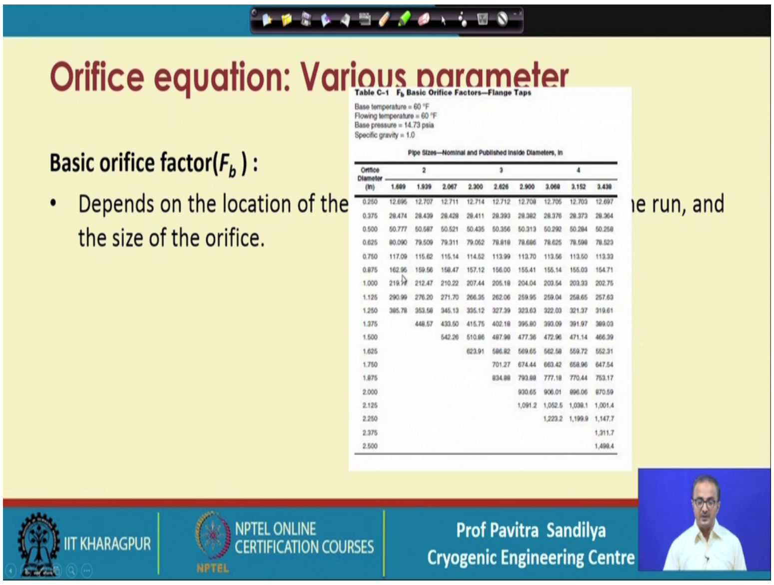

Table C-1 F_b Basic Orifice Factors—Flange Taps

Base temperature = 60 °F
Flowing temperature = 60 °F
Base pressure = 14.73 psia
Specific gravity = 1.0

Pipe Sizes—Nominal and Published Inside Diameters, in

Orifice Diameter (in)	2			3			4		
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438
0.250	12.695	12.707	12.711	12.714	12.712	12.708	12.705	12.703	12.697
0.375	28.474	28.439	28.428	28.411	28.393	28.382	28.376	28.373	28.364
0.500	50.777	50.587	50.521	50.435	50.356	50.313	50.292	50.284	50.258
0.625	80.090	79.509	79.311	79.052	78.818	78.686	78.625	78.598	78.523
0.750	117.09	115.62	115.14	114.52	113.99	113.70	113.56	113.50	113.33
0.875	162.95	159.56	158.47	157.12	156.00	155.41	155.14	155.03	154.71
1.000	219.[illegible]	212.47	210.22	207.44	205.18	204.04	203.54	203.33	202.75
1.125	290.99	276.20	271.70	266.35	262.06	259.95	259.04	258.65	257.63
1.250	385.78	353.58	345.13	335.12	327.39	323.63	322.03	321.37	319.61
1.375		448.57	433.50	415.75	402.18	395.80	393.09	391.97	389.03
1.500			542.26	510.86	487.98	477.36	472.96	471.14	466.39
1.625				623.91	586.82	569.65	562.58	559.72	552.31
1.750					701.27	674.44	663.42	658.96	647.54
1.875					834.88	793.88	777.18	770.44	753.17
2.000						930.65	906.01	896.06	870.59
2.125						1,091.2	1,052.5	1,038.1	1,001.4
2.250							1,223.2	1,199.9	1,147.7
2.375									1,311.7
2.500									1,498.4

So, we just see the significance of them, the basic orifice factor, it depends on the locations of tabs and the internal diameter and the size of the orifice and this is given by some table in the literature.

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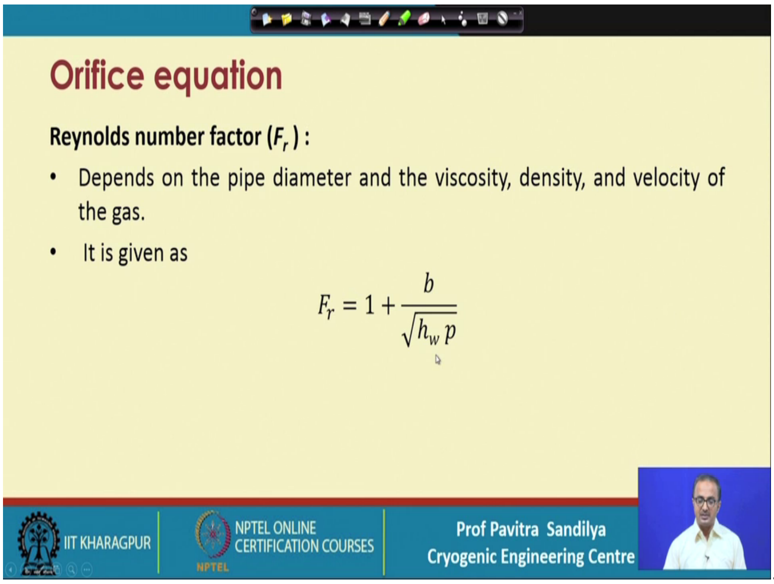

Similarly, we have another correction factor Reynolds number correction factor, it depends on the pipe diameter, viscosity, density and the gas velocity and is given by this particular term.

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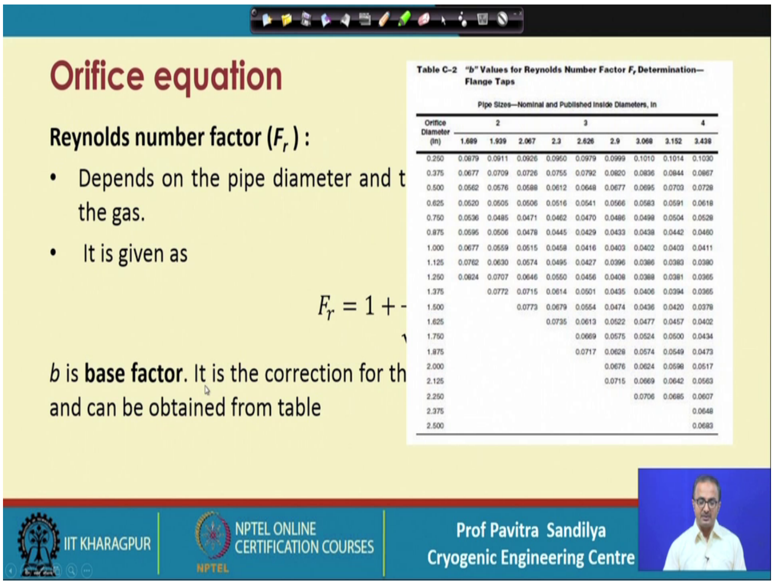

Table C-2 "b" Values for Reynolds Number Factor F_r Determination—Flange Taps

Pipe Sizes—Nominal and Published Inside Diameters, in

Orifice Diameter (in)	2				3				4
	1.689	1.939	2.067	2.3	2.626	2.9	3.068	3.152	3.438
0.250	0.0879	0.0911	0.0926	0.0950	0.0979	0.0999	0.1010	0.1014	0.1030
0.375	0.0677	0.0709	0.0726	0.0755	0.0792	0.0820	0.0836	0.0844	0.0867
0.500	0.0562	0.0576	0.0588	0.0612	0.0648	0.0677	0.0695	0.0703	0.0728
0.625	0.0520	0.0505	0.0506	0.0516	0.0541	0.0566	0.0583	0.0591	0.0618
0.750	0.0536	0.0485	0.0471	0.0462	0.0470	0.0486	0.0498	0.0504	0.0528
0.875	0.0595	0.0506	0.0478	0.0445	0.0429	0.0433	0.0438	0.0442	0.0460
1.000	0.0677	0.0559	0.0515	0.0458	0.0416	0.0403	0.0402	0.0403	0.0411
1.125	0.0762	0.0630	0.0574	0.0495	0.0427	0.0396	0.0386	0.0383	0.0380
1.250	0.0824	0.0707	0.0646	0.0550	0.0456	0.0408	0.0388	0.0381	0.0365
1.375		0.0772	0.0715	0.0614	0.0501	0.0435	0.0406	0.0394	0.0365
1.500			0.0773	0.0679	0.0554	0.0474	0.0436	0.0420	0.0378
1.625				0.0735	0.0613	0.0522	0.0477	0.0457	0.0402
1.750					0.0669	0.0575	0.0524	0.0500	0.0434
1.875					0.0717	0.0628	0.0574	0.0549	0.0473
2.000						0.0676	0.0624	0.0598	0.0517
2.125						0.0715	0.0669	0.0642	0.0563
2.250							0.0706	0.0685	0.0607
2.375									0.0648
2.500									0.0683

In this case b is some base factor and is also obtained from some table given in the literature.

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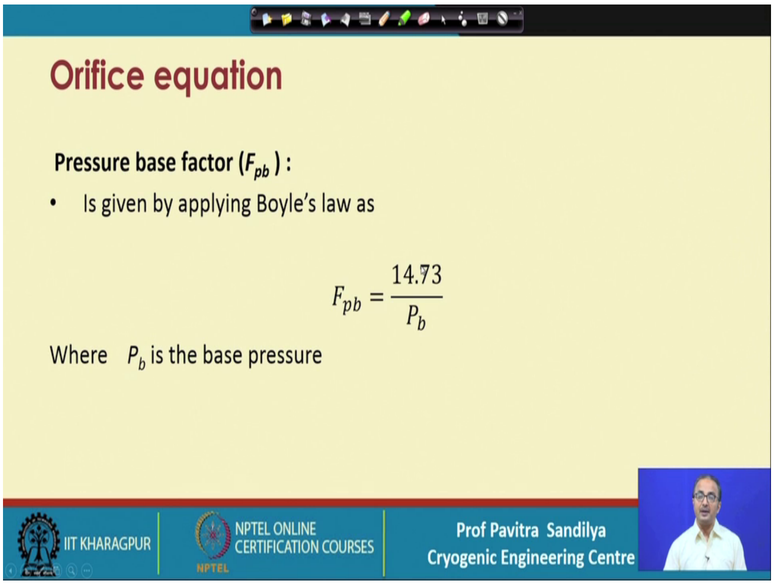

Then we have the pressure base factor. This applies to the change in the volume due to the pressure change and this is the that factor, pressure base factored these P is the base pressure, some base pressure.

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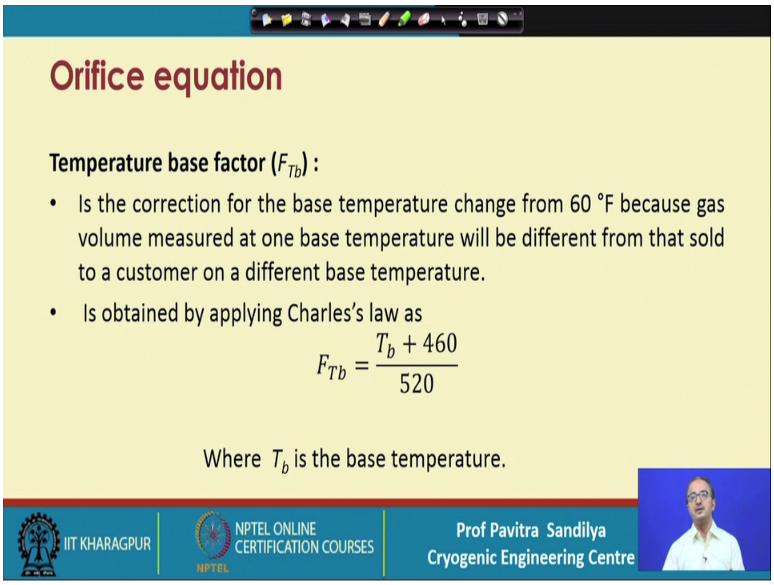

Then we have temperature base factor, is a correction for the base temperature, if it is change, it is different from 60 degree Fahrenheit about 50 degree centigrade, because the because of reason that gas volume changes with the temperature.

So, we have to put this correction and it is obtained by putting some Charles Law, this is the Rankine. So, in this case 5 20 Rankine and this is this T b is in terms of Rankine. So, if we can also put it in terms of Kelvin on other things. So, it will be either that means, but it is the ratio of the absolute temperature, either Rankine or Kelvin.

In literature we will find that the values are given in terms of FPS system, so that is why you will find all the tables are also given in fps system, it does not matter we can later on convert the, convert the units.

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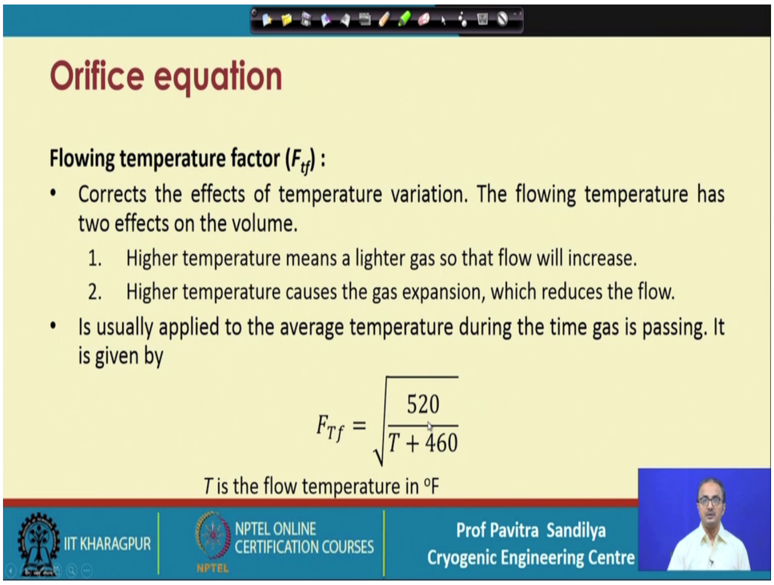

Then we have the flow temperature factor, this corrects for the temperature variation and this flow temperature has two effects; one is that, if it is high temperature then the gas becomes lighter and the flow will tend to increase and if the, this high temperature also causes gas expansion and, then by expansion, it was reduced the flow. So, this ah, this is applied to the average temperature during the time gas is passing and is given by this particular factor.

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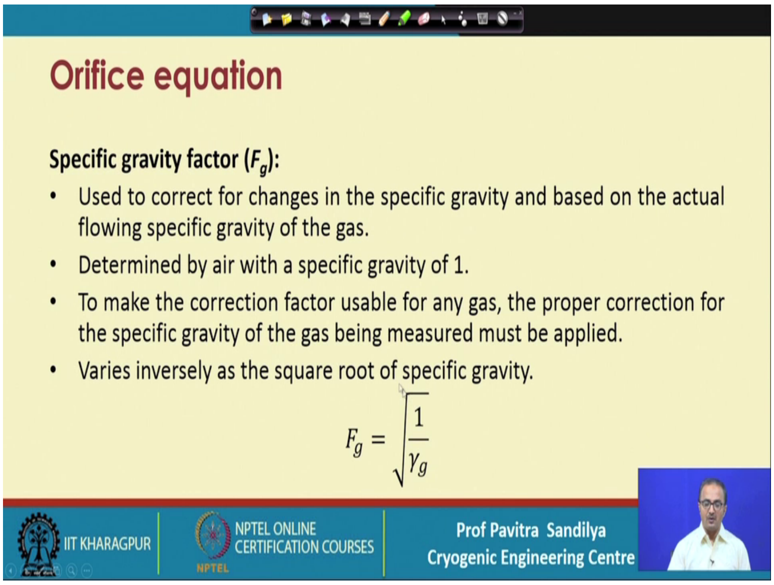

Now, we have the specific gravity factor, what is used for? It is used to collect for the changes in a specific gravity and because it can change due to change in the density and which is a function of the temperature pressure.

So, during the flow it this temperature pressure may change, due to which the specific gravity factor will also take change and determine by the air with specific gravity of one. And we have to have the proper correction for the specific gravity of gas and this is given in terms of the square root of the inverse of the specific gravity.

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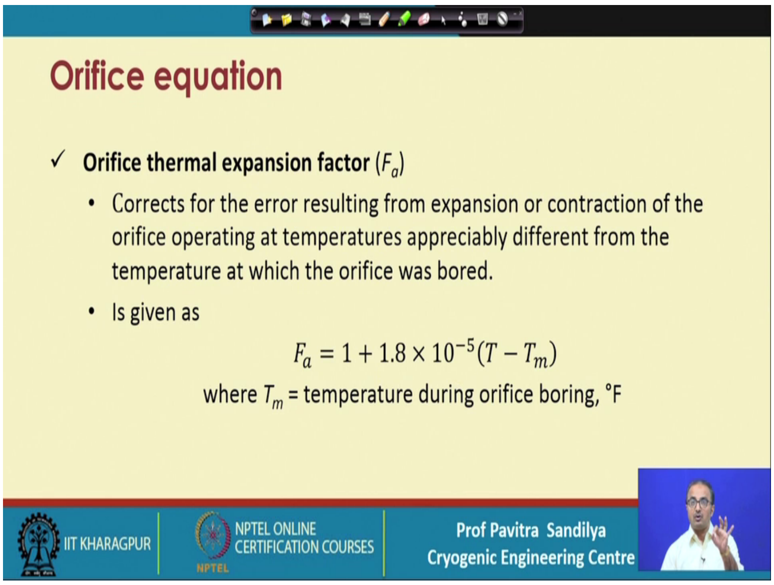

Next we have the thermal expansion factor and this corrects for the any kind of expansion or contraction of the orifice, because of the change in temperature if it is very high temperature the orifice will itself expand or some tempted slow it will be contract. So, this contraction and expansion of the orifice with the temperature of the gas is corrected by this particular formula F a and these formulas have been given empirically, so there is no theory behind this kind of things

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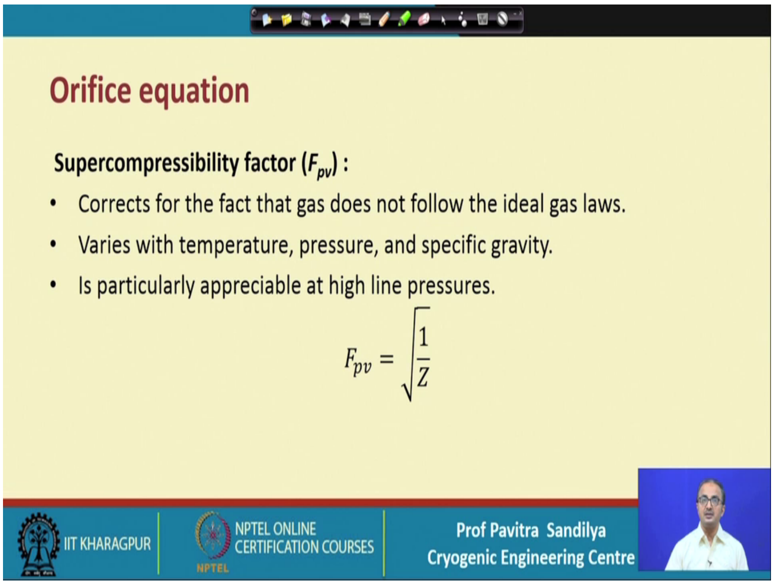

And then we have the super compressibility factor; that is the compressibility factor, this we have to. Again we use this kind of an equation to account for the changes in the pressure temperature and specific gravity.

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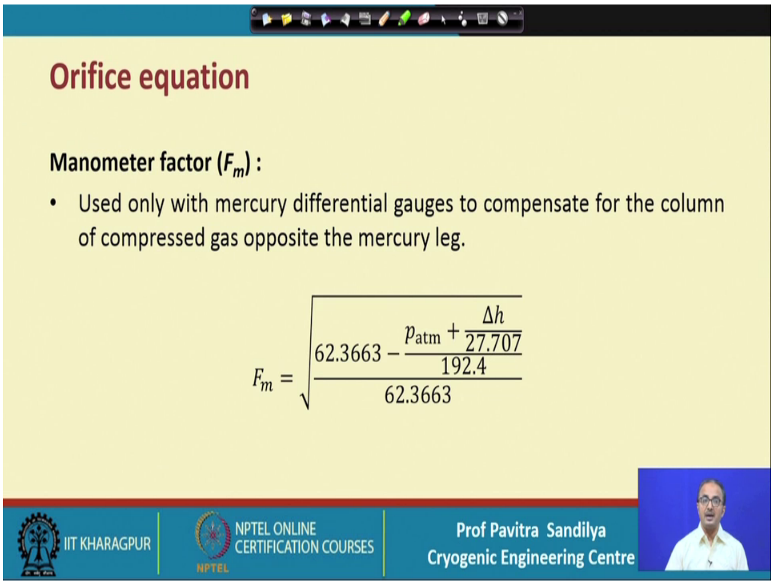

Lastly, we have the manometer factor due to the, this compensates for the column of the compressed gas, because whenever we have this; as I told you that the manometer contains some kind of liquid, either water or mercury.

So, if this mercury is existing and the degree compression for the, of the gas due to the prints of mercury. So, due to this there may be a change in the delta p and this correction has to be given and this is the way the correction is provided for the presence of the mercury, mercury.

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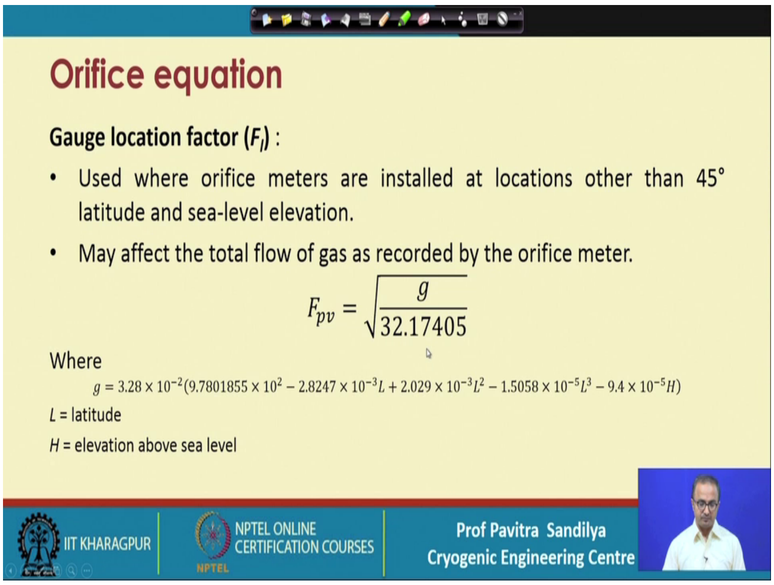

And then depending on the how the gauges are located in what, at the, what latitude and sealable that also have a effect on the metering, so for that we give this particular correction. And this here this g is not, is the correction for the gravitational acceleration and this is given by this equation. In this equation we have L is the latitude and H is the elevation above the sea level.

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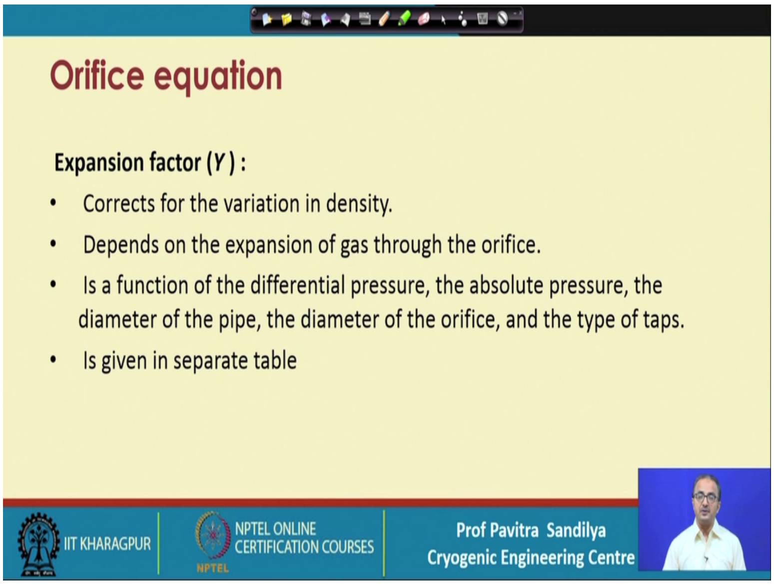

And next we have the expansion factor, it is used to correct for the density variation, and it depends on the way the gas expands through the orifice and is a function of the differential pressure, absolute pressure, diameter of the orifice, diameter of the pipe and the type of taps.

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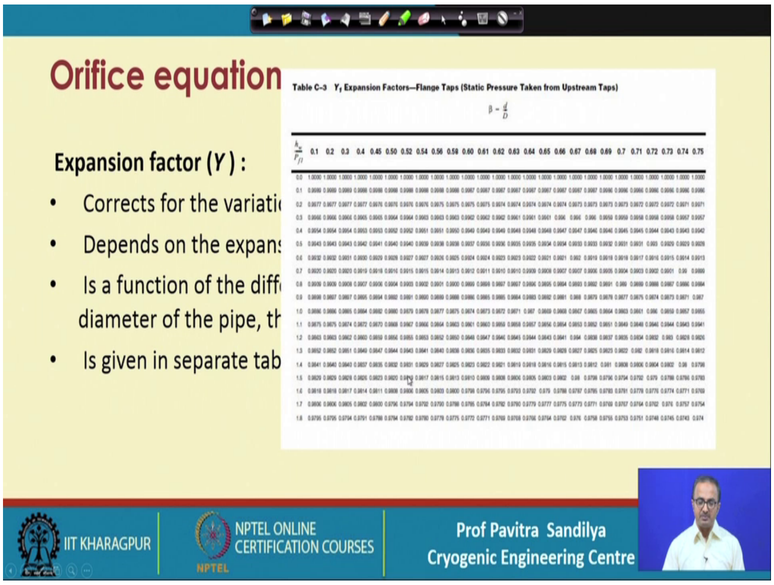

And it is given in some table and these are table in which this particular correction factor can be obtained.

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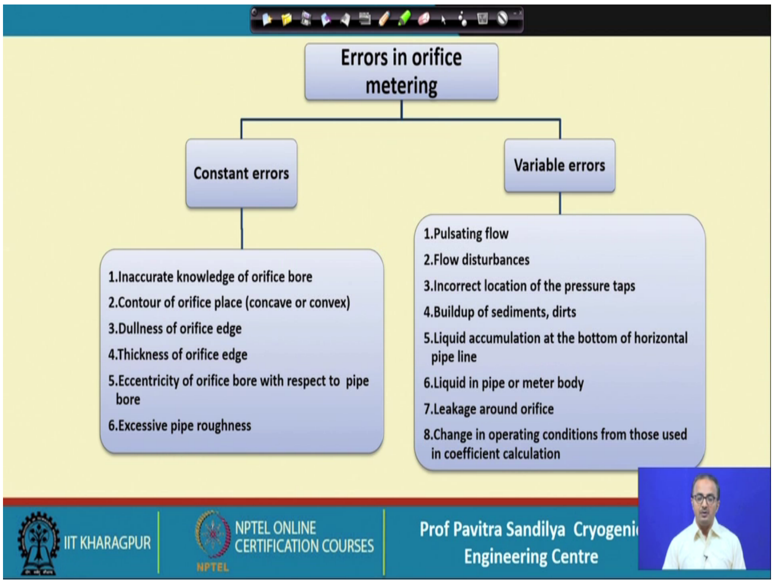

Now, there are many errors in measuring, we should be aware of the errors like a constant errors, due to the inaccurate knowledge of the orifice board, then the contour of the orifice is not put properly concave or convex, the dullness of the orifice edge. It may be the thickness of the orifice edge, the eccentricity of the orifice, whether they have the same axis with the orifice plate or not, the excessive pipe roughness, there are constant errors and variable errors are like this.

There be pulse the flow may be pulsating, there may be flow disturbances, then the pressure taps may not be located properly, then there could be with time, there will be some deposition of the sediments, dirt's etcetera.

There could be liquid accumulation due to the condensation at the bottom of some horizontal pipe, then liquid in the pipe or the metering devices, then leakage around the orifice and change in the operating conditions from those, from the base conditions which have been used for in to derive the coefficient values. So, these are the some variable errors.

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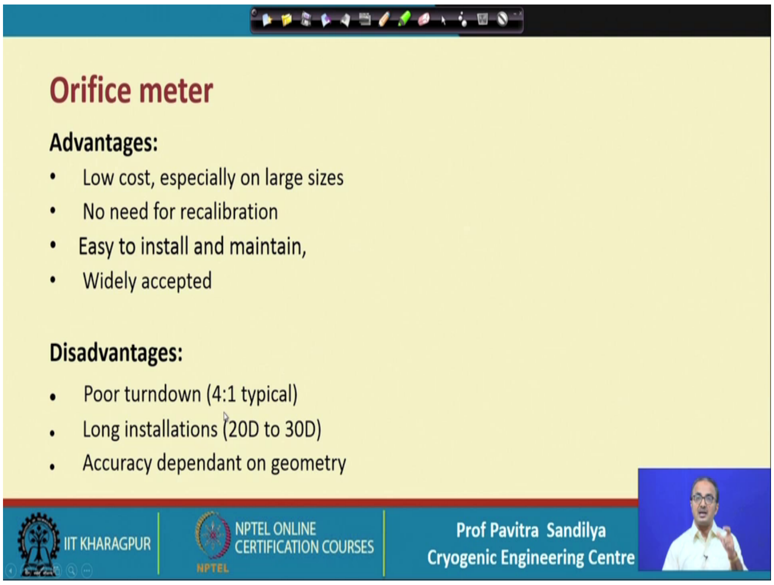

And then advantages is this that orifice meter is low cost, especially for large sizes it, but there is no need of calibration then easy to install and maintain and widely accepted. Disadvantage is this, it causes poor turndown that is a change between the maximum and minimum should accept maximum and minimum flow rates, there is turn down ratio, then installations about 20 D to 30 D, D is the pipe diameter, it needs that kind of a length and the accuracy of the orifice meter depends on the geometry.

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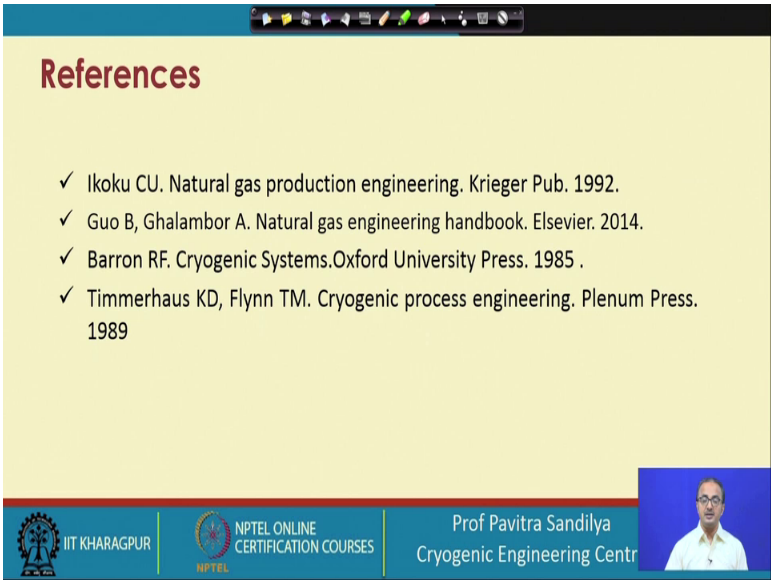

So, this information can be obtained in more detail from these references.

Thank you.