Upstream LNG Technology
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Lecture – 22
Tutorial on flow and pressure measurement in natural gas systems

Welcome after learning about how to measure the flow rates and the pressure using various types of devices; especially in case of flow rate we found that we were using a orifice meter which is very common in the natural gas industries and in case of pressure we also learnt about the manometer which is very common. So, today we shall be looking into two problems on the estimation of the flow rate using orifice meter and some pressure measurement the pressure drop.

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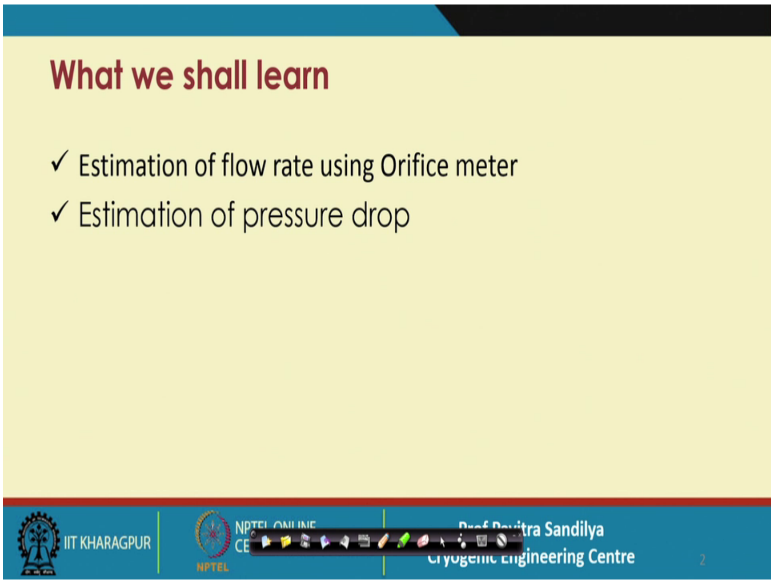

So, what we shall learn today is estimation of flow rate using orifice meter and estimation of pressure drop.

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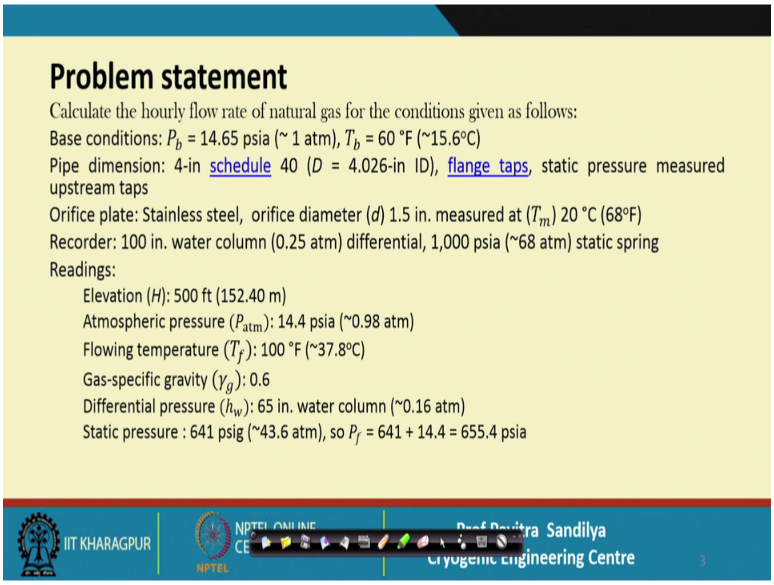

So, first let us take up a problem on the flow measurement here we are given that to calculate the hourly flow rate of natural gas for the given conditions. Here there are various conditions are given as we will find in the equation for the orifice meter which we saw earlier. First is the base condition here the things are given in fps units because the equations we learned they were having the fps units.

So, here we find out base pressure is 14.65 psia that is pound per square inch absolute. Then the base temperature is 60 degree Fahrenheit that is about 15.6 degree centigrade. Then the natural gas is flowing through a pipeline of 4 inch schedule. Now, 4 inch schedule 40; now generally what happens that whenever you talk of the pipelines these pipelines the dimensions are given in terms of the nominal diameters and the schedule numbers signifies the thickness of the pipeline.

So, whenever we want to know the exact inner diameter and outer diameter; we have to go to some standard charts from which we can get the inner diameter or the outer diameter and the thickness.

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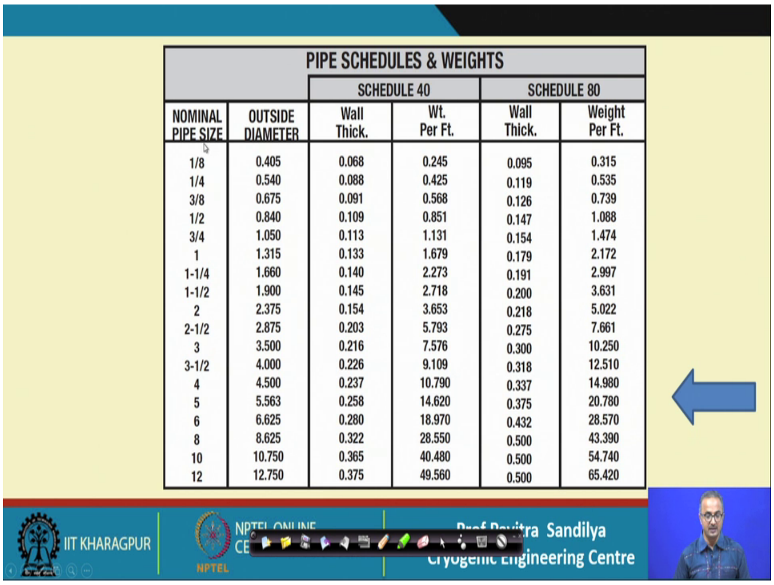

So, let us see that how a typical charts looks like here; we have a chart it on the first column in the chart you find that we have a nominal pipe size one eighth, one fourth, three eighth all these are inches. And corresponding to each of the nominal size we have the outside diameter like for example, for a one eighth inch nominal pipe size we have 0.405 inches of outside diameter. And then on the next column we find we have the schedule number 40 and schedule number 80.

And you if you see that the wall thickness is given in the schedule number; so, for one eighth nominal size for 40 schedule number the wall thickness is 0.068 inches. And similarly for the schedule number 80 the wall thickness is 0.095 inches and the, these columns are signifying the weight per feet of that particular pipe. So, with this we shall see that we have in our problem we have been given 4 inch schedule number 40.

So, what we will do? We will go to the 4 inch here and correspondingly we will find the outer diameter has 4.5 inches and for a schedule 40, the thickness of the pipe is 0.237 inches. So, these are the data we would need from this particular table. So, here we have the outer diameter as 4.5 and from that we subtract twice the thickness to get the inner diameter that is 4.026 inches is the inner diameter of the pipeline, then the that the flange tab.

As we learnt earlier that for whenever we are putting the pressure taps to measure the pressure difference across the orifice meter; we can have the pressure tap as various positions.

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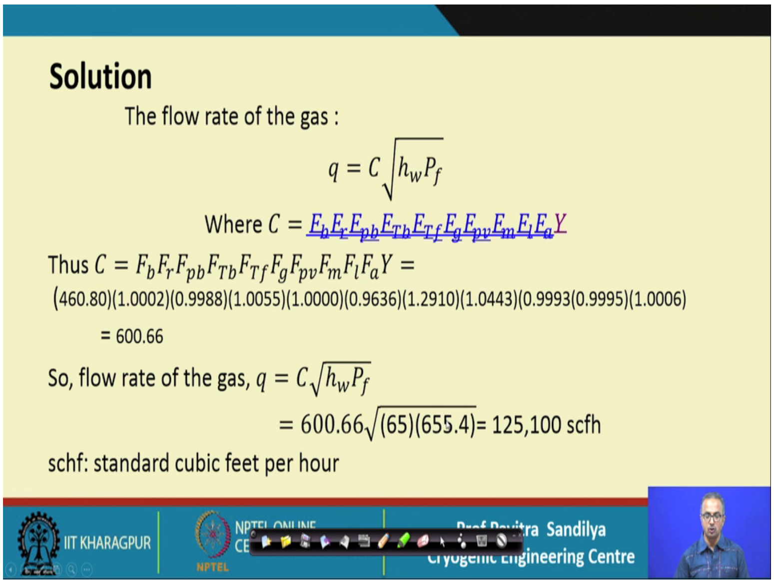

So, in this case it is specified that we have flange taps and if you recall we can see that how these taps were looking; that these taps were given in terms of the their distances from the flange. So, in case of flange taps the taps are just on the flanges.

Then we have the static pressure measured upstream taps; then the orifice plate is stainless steel orifice diameter is 1.5 inches and the it is measured at 20 degree centigrade then we have a recorder that is having a 100 inches of water column it is measuring the pressure difference across the orifice meter. And then this is the 1000 psia is the static spring that is a 68 atmosphere. And here we have some ordered data like elevation; that means, elevation from the sea level about 500 feet; this is important because the gravitational force changes with the sea level.

So, naturally it will also depends on the potential energy will change with the sea level; then you have the atmospheric pressure as 14.4 psia, the temperature of the flow is 100 degree Fahrenheit, gas specific gravity is 0.6, differential pressure is 65 inches water column and static pressure is 645 psig that is about 43.6 atmosphere. And this is the gauge pressure with the gauge pressure we add the atmospheric pressure to get the absolute pressure as 655.4 psia.

Now, we go to the solution the solution is this we this is the equation which we use to solve for the flow rate. Here the C is the discharge coefficient which is a function of various other factors about which we learnt in our lecture. So, in this problem we shall be evaluating each of these factors one by one.

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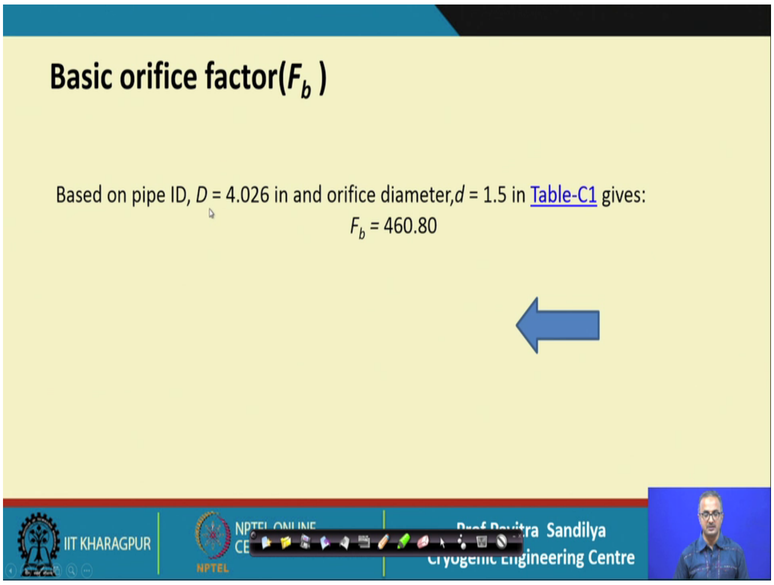

So, let us first look at this basic orifice factor and this basic orifice factor is based on the inner pipe diameter and the orifice diameter.

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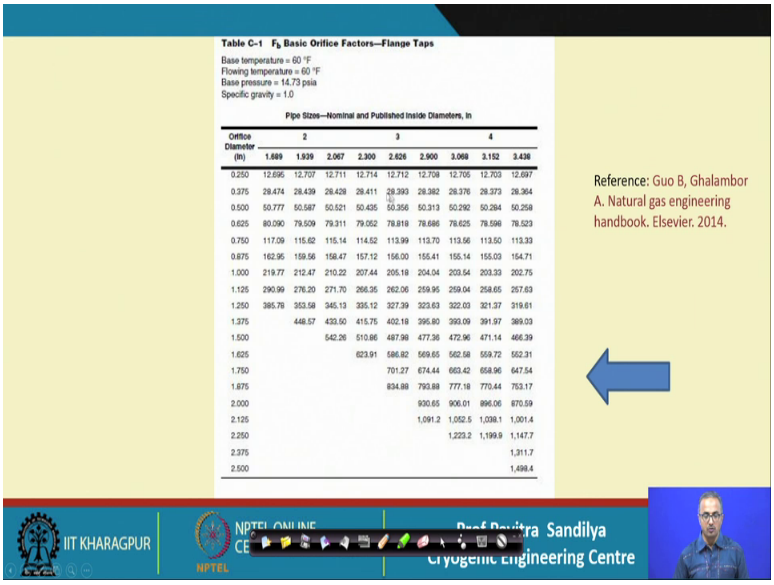

Table C-1 F_b Basic Orifice Factors—Flange Taps

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		2			3			4	
(in)	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	219.77	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

And this table we have to refer to get the value of the C 1 here in this thing you find that we have the orifice diameter. And we have the various nominal diameters from this table and this is also given the base table 60 degree Fahrenheit flowing temperature 60 degree Fahrenheit. So, all these things are given here; so, based on this table we shall be obtaining the value of the F b and that is obtained at 460.80.

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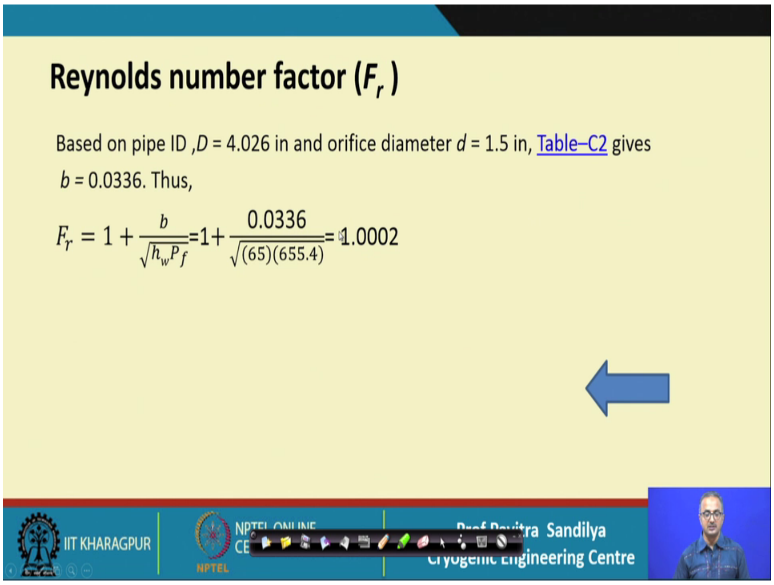

Next we go to find out the Reynolds number factor even for this we shall be using another table. So, this is also based on the inner diameter and the orifice diameter.

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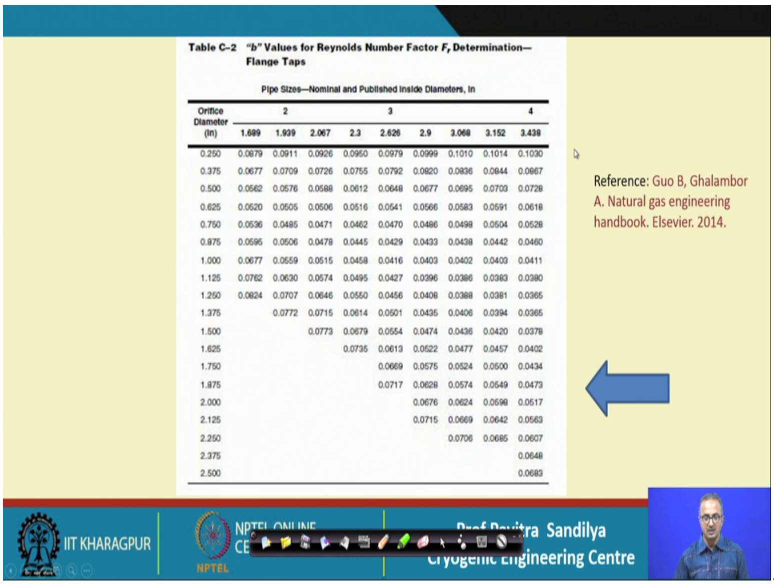

Table C–2 "b" Values for Reynolds Number Factor F_r Determination—Flange Taps

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

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So, here we have the value of the Fr for the various types of orifice diameter and we find the value of this Fr from this particular formula 1 plus b by under root h w P f. Here we put the value of b which is obtained from this table and then we have the h w that is the water column height that is 65 and this is the pressure absolute pressure and from this we get the value of the F r.

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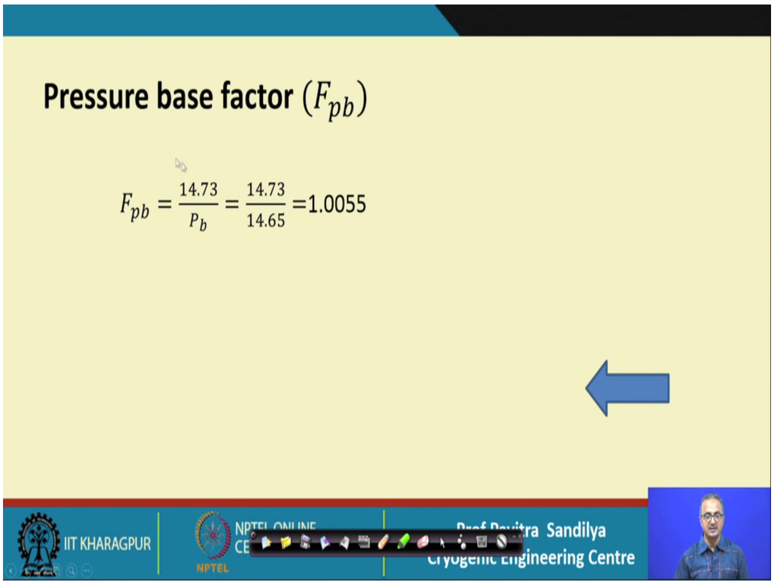

Next we come to the another correction factor that is the pressure base factor; here we are using this particular formula; please note that in this formula the pressure has to be in terms of psia. So, we are putting this pressure value here and we are getting this value of the pressure base factor.

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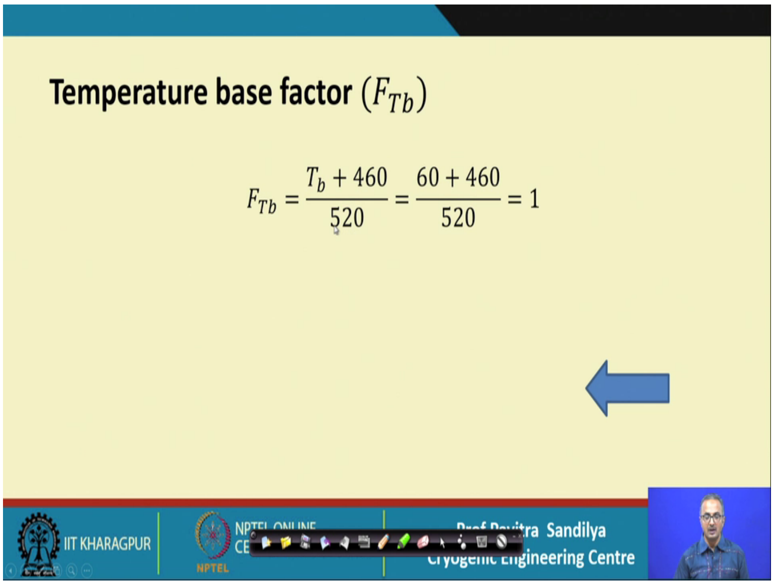

Next we come to the temperature base factor; in this case the temperature has to be in terms of the Rankine. So, here we put the Rankine pressure and temperature and we get it as 1; next we come to now just for recalling that temperature pressure are needed because they change the density of the gas and the density of the gas changes means that the volumetric flow rate for a given mass flow rate will also change that is why we apply the pressure and temperature correction factors.

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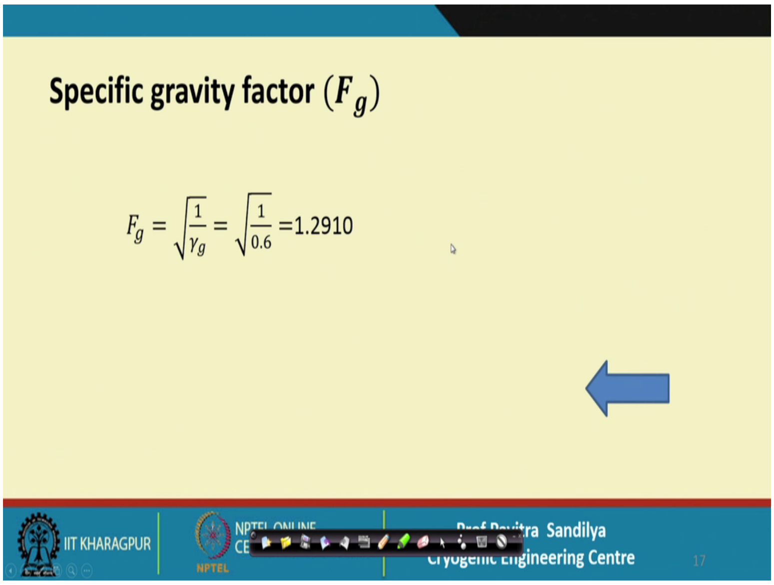

Next we come to the gravity factor; the gravity factor is taking care of the specific gravity of the gas which is given as 0.6 and this is the value.

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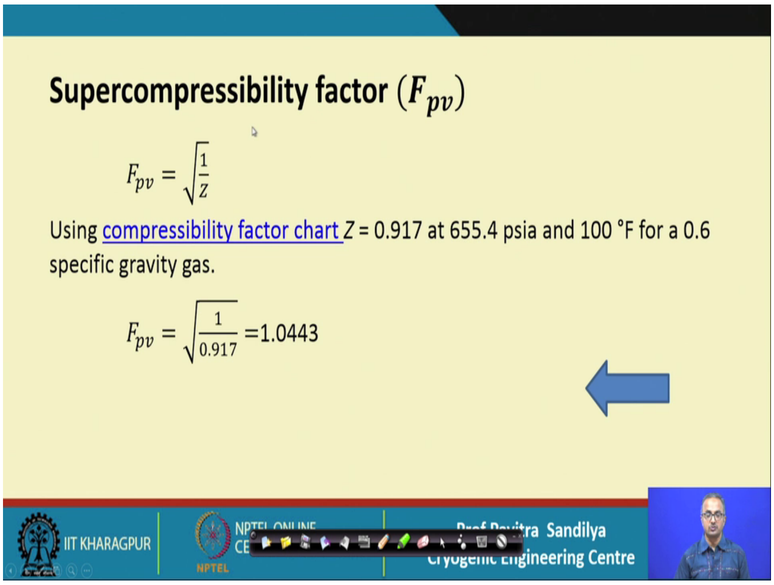

Next we go to the super compressibility factor this is given by under root 1 by Z and this Z value can be found out from the compressibility chart about which we learnt earlier.

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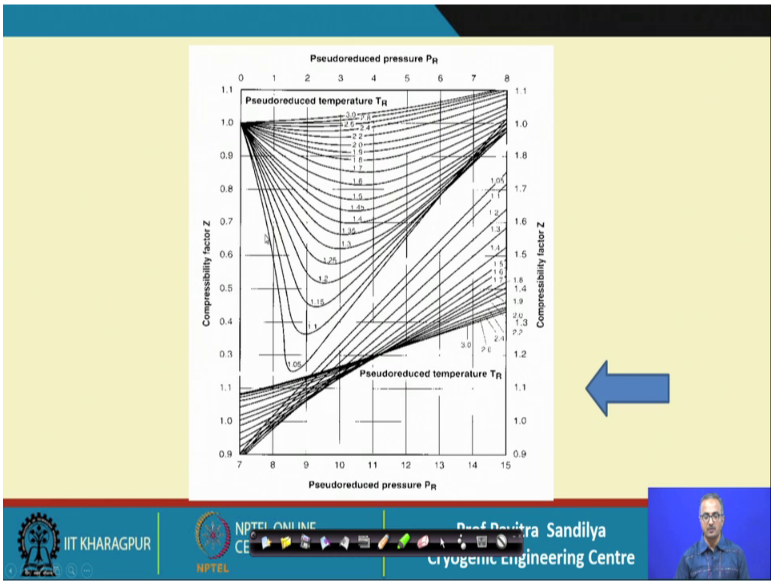

Here we have the P R that pseudo reduced pressure and on this here the reduced temperature and accordingly we can find out the value of the Z. So, knowing the P R and the T R, we can find the value of the Z; so, here we have the value of the Z as this and this is the formula with which we get the super compressibility factor.

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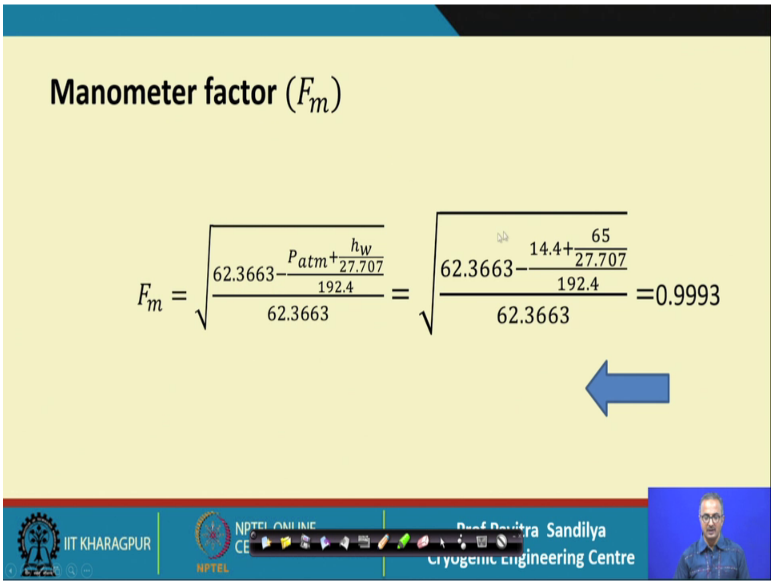

Next we go to this value of the manometer factor here we have the manometer factor with this particular formula it does not need any kind of charts, simply we put the atmospheric pressure the water column height and with this particular formula we get the manometer factor as 0.9993.

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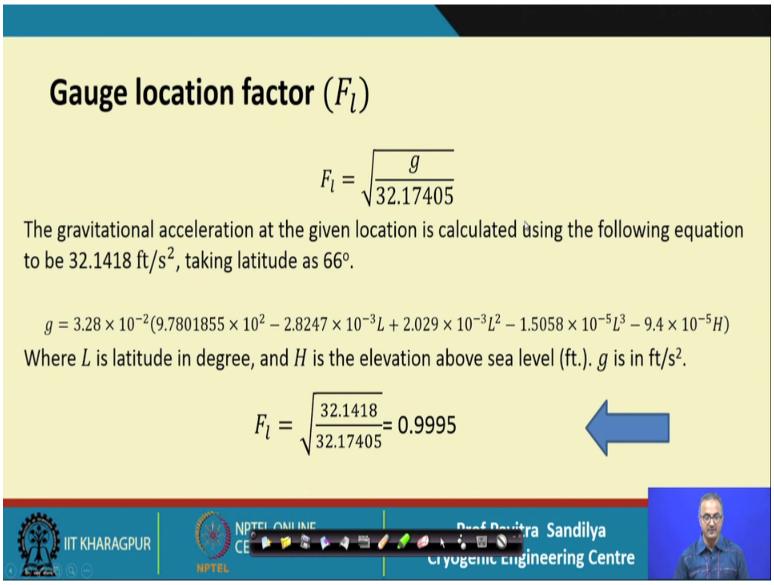

And next we have the gauge location factor this takes care of the gauge location depending on the latitude and the elevation from the sea level.

Now, the latitude is taken to be 66 degree and the sea level is term in taken in feet. So, these 2 factors are incorporated in this particular formula of g. So, you see that this g depends on the latitude and the elevation from the sea level. So, we calculate g using this 66 degree and the elevation which is given in the problem and we get the value of g as 32.1418. Now with this using this formula we get the gauge location factor.

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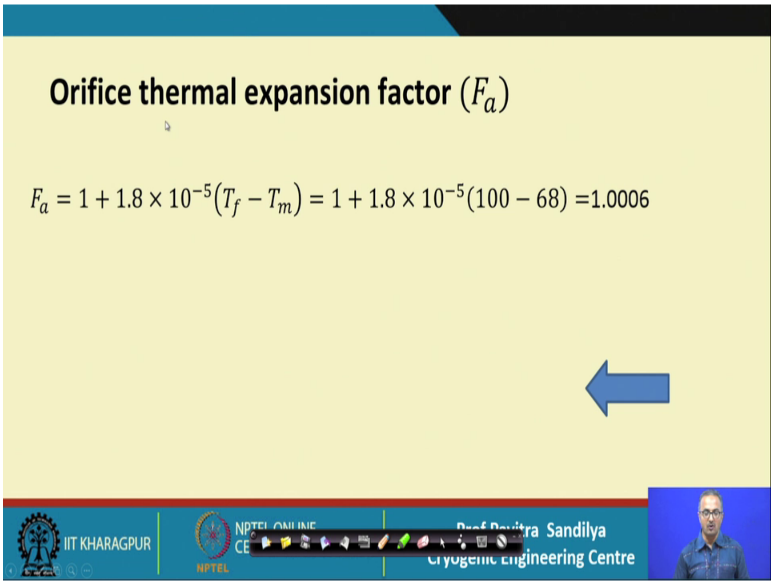

And then we have the orifice thermal expansion factor using this formula this is the fluid temperature 100 and this is the manometric this temperature that is 68 and with this we get the value of 1.0006.

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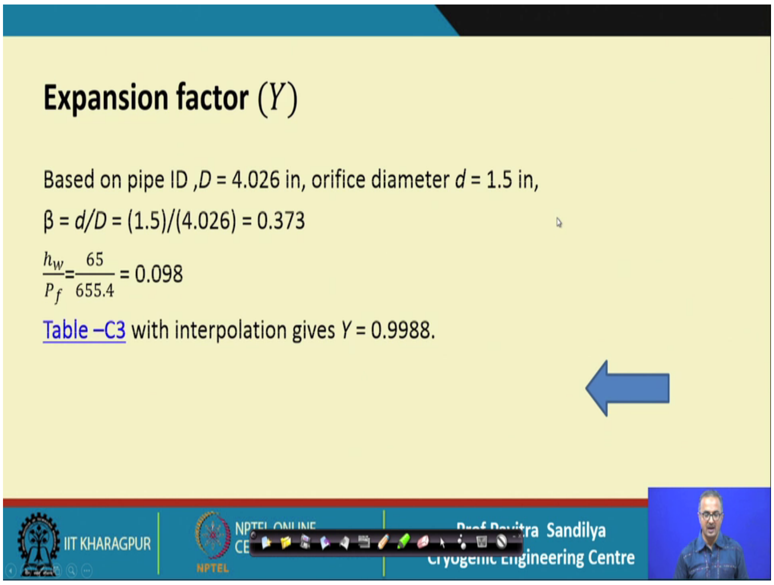

And lastly we have the expansion factor and this expansion factor is obtained from table C 3, but before that we have to find some parameter value like beta beta is the ratio of the orifice diameter to the inner diameter of the pipeline. With this we get the value of beta and then we find the value of this ratio h w by P f from the given data and we get this value.

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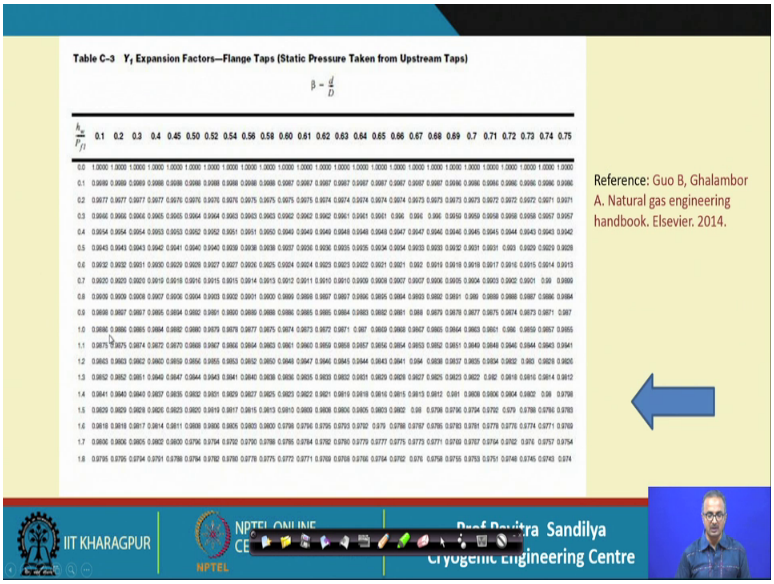

Now, we go to table 6.3; here we have the beta value d by D and this is the value of the h w by P f. So, with this 2 values we locate the value of the Y and this value we take and we find that this value is almost 0.9988. Now with all the values calculated now we use the expression for C which is given like this and we put all the values here and we get the value of C as 600.66.

Now, once we get the value of C we shall put this value in this equation and with; in this equation once we put it; we find that this is the value of the flow rate. And please mind it that the unit of the flow rate is also specified that is scfh which is nothing, but the standard cubic feet per hour perhaps you know that the whenever we are reporting the volumetric flow rate of any gas which is a function of the temperature pressure, the v generally report in terms of some datum pressure temperature.

And in this case we are using the standard temperature pressure that is stp. So, this that this is how we are getting the value of the flow rate in terms of the standard cubic feet per hour. So, this is how we have solved a problem to estimate the flow rate of a gas in this case natural gas through a orifice meter applying various types of corrections.

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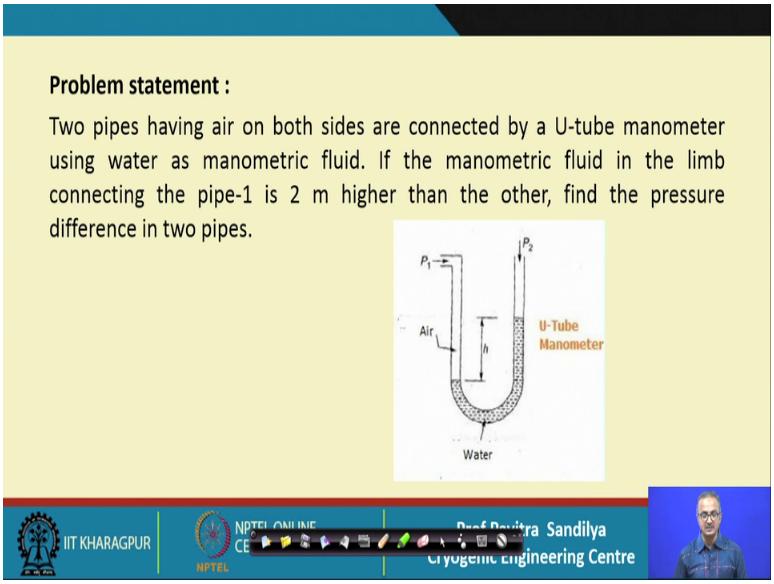

After this we shall move on to the pressure measurement; the pressure measurement as we learnt earlier that manometer is a very common device with which we measure the pressure difference; it can also be used to measure the absolute pressure by exposing one of its limbs to the atmosphere.

So in this problem we have a situation like this that 2 pipes having air on both sides are connected by a U-tube manometer. So, here we find that is a U-tube manometer and the pipe is having the air is flowing through the pipe line. So, we find that the 2 ends of the manometer, we have 2 pressures P 1 and P 2 and looking at the figure we can find out that pressure P 1 is more than pressure P 2; that is why the this manometric fluid has been depressed more on the P 1 side than in the P 2 side.

And here we find that difference in the levels of the manometric liquid in the 2 limbs is given by h. So, here in this problem we have told that if the manometric fluid in the limb connecting the pipe is 2 meter height; that means, this is the 2 meter this h here is our 2 meter we have to find the pressure difference between the 2 limbs that is we have to find out the P 1 minus P 2.

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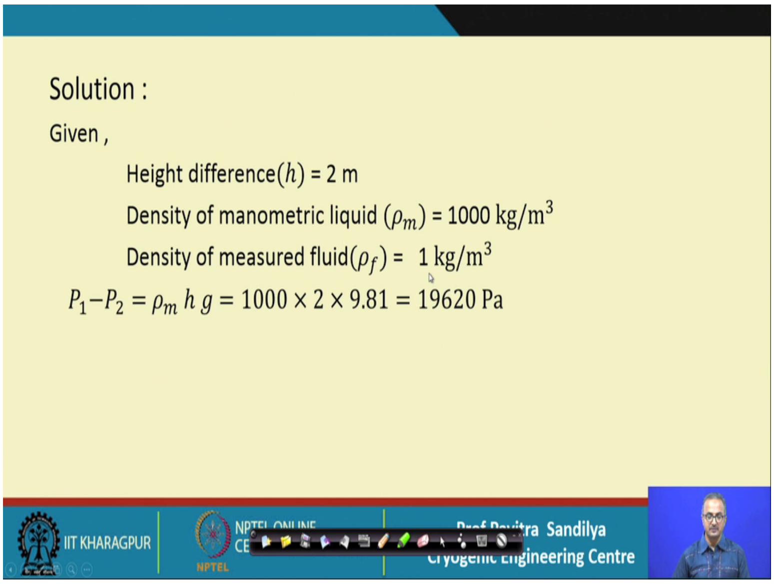

So, for this we see that these are the things given to us the manometric liquid is water. This is a water we take the density of water generally as 1000 kg per meter cube and the density of manometric fluid is air; it is approximately about 1 kg per meter cube; And because with this we find that the delta P is found out to be this by rho m h and g. Now please note that in this case we are neglecting the density of the air with respect to the density of the water; that is why we are taking only the density of the water here. And by incorporating the various values we find that the pressure drop between the 2 limbs of the manometer is coming out to be 19620 or about 19.6 kilo Pascal.

Now, please understand that this is how we are finding the delta P and this kind of method may also be incorporated to find out the flow rate. Like in the previous problem of the orifice meter, we can we can say that we are using a manometer across the orifice meter and this is how we can get the pressure difference across the manometer and with this information, we can solve for the flow through a manometer.

Thank you.