Heat Exchangers: Fundamentals and Design Analysis
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Lecture - 65
Heat Exchanger Testing

Welcome to this lecture, today we will try to understand and important aspect of the Heat Exchanger Design and Simulation that is the Heat Exchanger Testing. So, what is Heat Exchanger Testing? It is, we have understand that or we have used different kind of heat exchanger test surfaces right from the finite tube, ordinary tube. Then you have talked about the plate fin type of heat exchangers. Then we have also talked about the perforated plate, we have talked about the metal foam and other surfaces.

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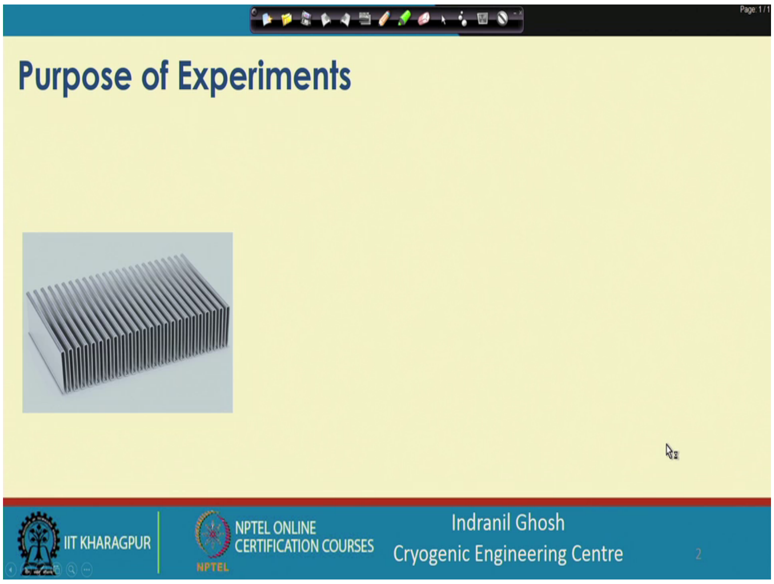

And one of the important aspects for this surface is basically to understand say these are different type of the plate fin type of surfaces.

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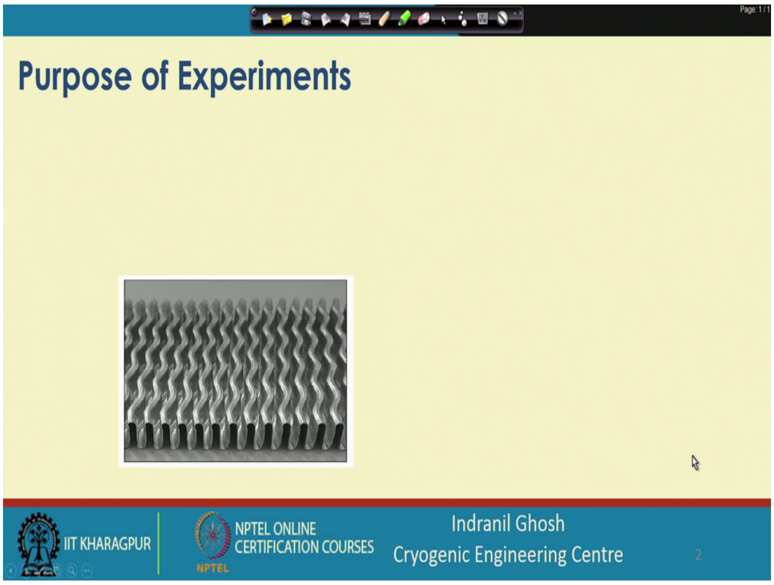

This is weigh between, then we have earlier shown that plain rectangular fin.

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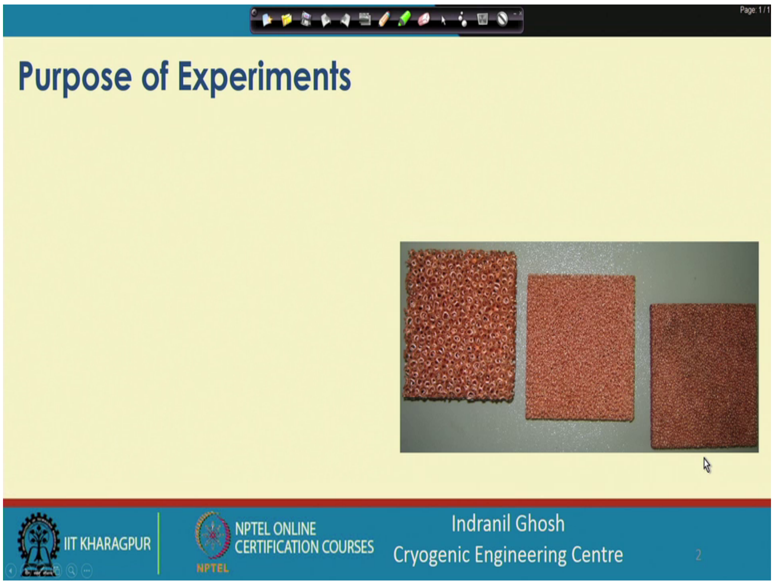

This is metal foam.

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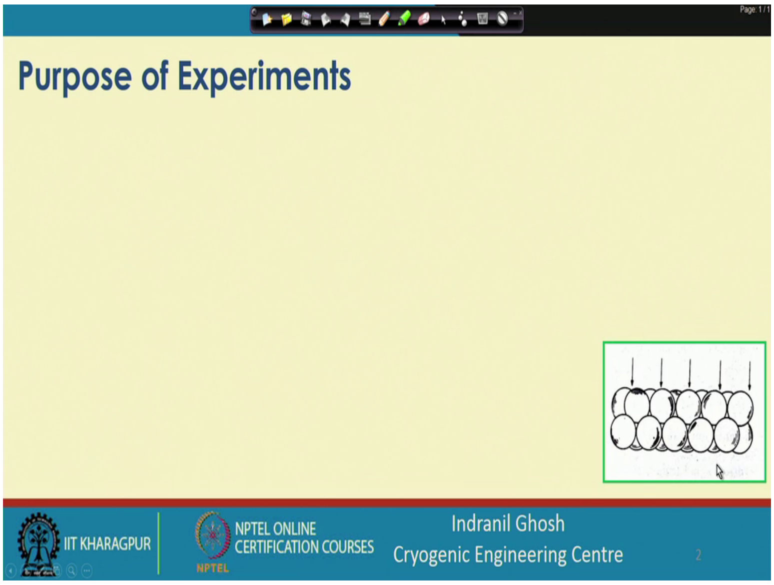

Then we have also talked about the packed but regenerators.

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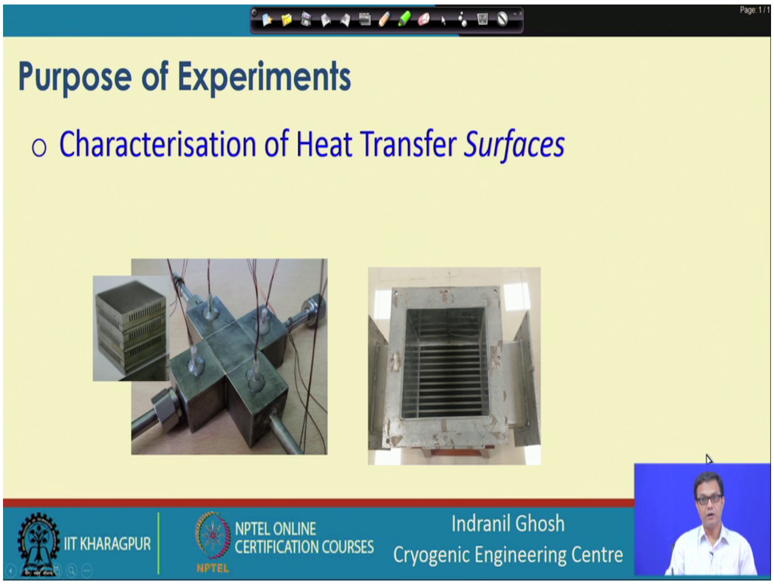

So, for all this surfaces what we need is the characterization of the surfaces. And when we characterize the surfaces those surface characterization properties will be used to generate or will be used to design or simulate the heat exchangers.

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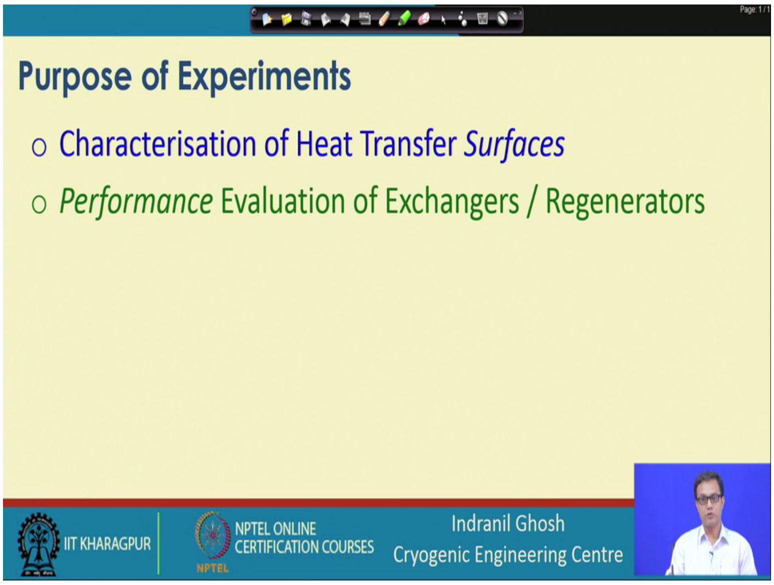

So, these are basically some of the heat exchangers. And where do it design or simulate the heat exchangers we also need to make a performance evaluation of those exchanges or like basically we want to find how the is the effectiveness of these exchangers or the regenerators.

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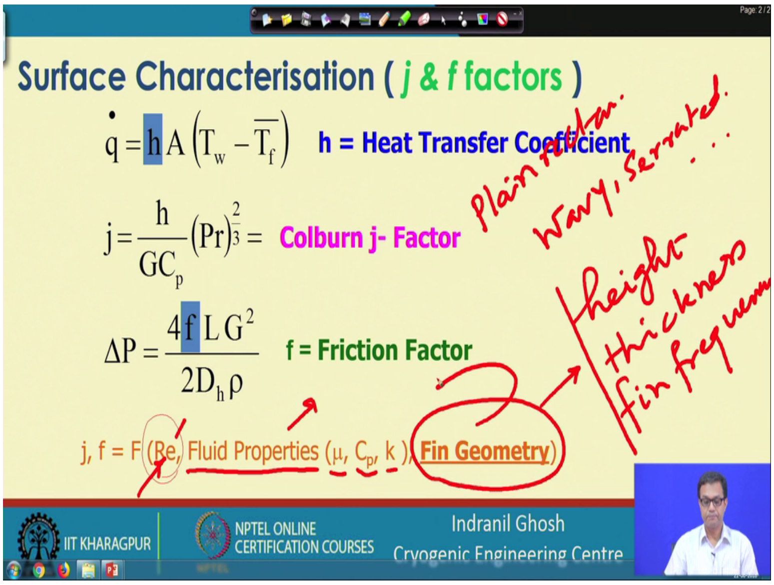

So, basically this two are the primary aspects of any heat exchanger testing; basically the heat exchanger surface characterization and the performance evaluation of the heat exchangers or the regenerator. So, what we mean by the surface characterization of the heat transfer surfaces first of all. So, we have already learned about the heat transfer coefficient and the pressure drop characteristics. So, here we find that this heat transfer rate is basically we have a parameter called Heat Transfer Coefficient. And that is generally expressed dimensionally in the form of Colburn j-factor. And within that Colburn j-factor we have that the parameter inbuilt embedded in it that is equals to the heat transfer coefficient.

So, this is what we intend to find. And we know that this will be useful very much useful for many heat transfer calculations. And we also want to find out what is the pressure drop and there we find that the friction factor the f or the fanning friction factor is very important parameter. So, basically we find that these two parameters the j and f; the heat transfer coefficient the dimensionless heat transfer coefficient and the friction factor are the parameters to characterize any heat transfer surfaces. So now, we find that this two parameters heat transfer coefficient and the friction factor will be a function of the Reynolds number. And it is not only the function of Reynolds number it is also a function of the fluid properties.

So, that is generally taken care through the different I mean parameters which are useful like mu, C p and thermal conductivity. And more importantly particularly for the plate fin type of exchangers we will be discussing in details about this plate pin type exchanges in this lecture. And there the fin geometry they will be of very much importance. By fin geometry what we mean is the height of the fin, then the thickness of the fin, then the fin frequency.

So, this are the parameters which will be different for different type of fins, say we have the wavy fin, we have the serrated fin, and we have other fin types, we have said are shown you just light just say in the previous slides at the plain rectangular plain rectangular fin and so forth. So, we have design a factories we find that it is the function of the Reynolds number, we find it is a function of the fluid properties, and it is a you know function of the fin geometry. So, as we can understand that different fin geometry will have the different heat transfer coefficient and the friction factor.

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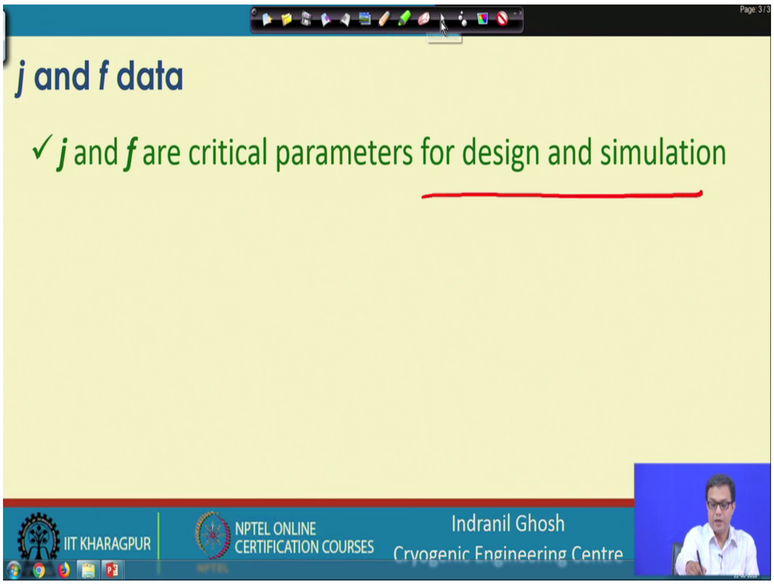

So, now in principle we would able generate this data; I mean which is necessary for the design and simulation of the heat exchangers. So here, you may be remembering that in all the cases whenever we have talked about the design or the simulation of the exchanger. This heat transfer coefficient and the friction factor become important parameter for the design process or the simulation process.

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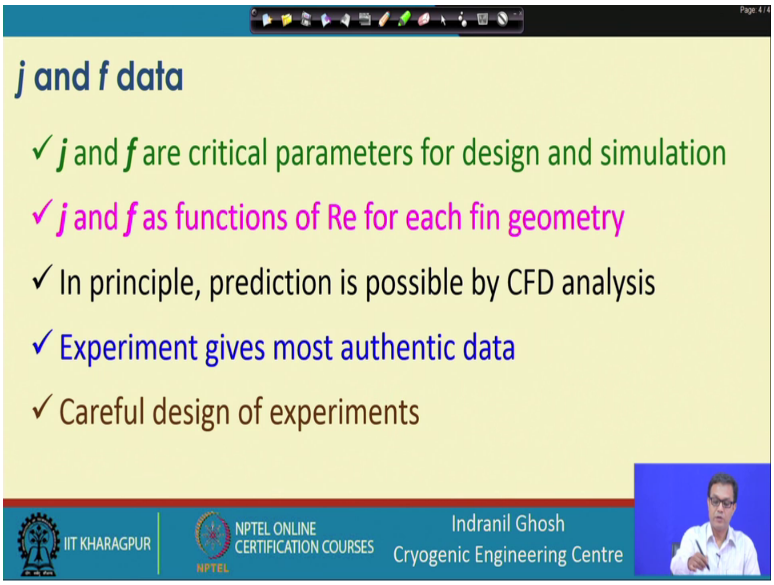

But, in case of this j and f as we have understand that they are function of the Reynolds number and for each particular geometry if we choose it will be a function of the

Reynolds number. Now this in principle this j and f the friction factor or the heat transfer coefficient the dimensionless form or in it is dimensional form. We should be able to predict it from the computational fluid dynamics from the velocity and the temperature profile, but it may not always gives you the most accurate data or reliable data.

So, to generate the authentic or reliable data most of the time we I mean we go for the experimental determination of the heat transfer coefficient and the pressure drop. And when we try to generate experimental data we always keep it in mind that the experiments being costly. So, we have to minimise the number of experiments. So, always we try to design the heat exchangers setup in such a way that it gives us; I mean the desired output, but in a cost effective manner. And we always try to link this experimental data in the form of some correlations and sometimes it is empirical correlations; we tried to correlate the experimental data to minimise the number of experiments.

So, what we understand that careful design of the experiment is always very much necessary. So, we will try to understand it in the next slides.

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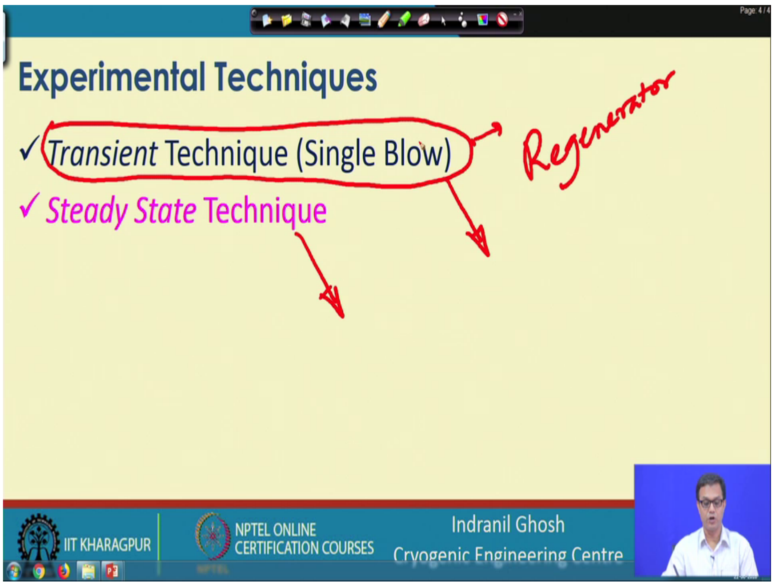

So, what are the experiments those are possible or generally used for the determination of the heat transfer coefficient and the pressure drop the particularly we are talking about the surface characterization. So, we have the transient technique or often we call it as single blow technique and then we have the steady state technique. As you can understand that the transient technique we will have the temperature time dependent component of the temperature and the pressure, but in steady state obviously it will be coming to a steady state the temperature will not change with time and we measure on the basis of that steady state temperature and pressure.

But also it is that is a kind of something like we always do not go for this the transient technique for the heat exchanger. I mean this is more for like the regenerator test surface or the test surface where we have. In this particular test when we talk about this will understand; that we need only one type of test surfaces. Particularly which is suitable for regenerator or very high (refer time: 09:46) heat exchangers we go for this single blow technique. But this steady state technique we need a kind of heat exchanger test surface. And for this one we do not really need heat exchanger, but it needs of a kind of arranged these surfaces plates or the surfaces to be arranged sequentially to test it in a single blow condition.

So, we will go in details about these two processes in the next slide.

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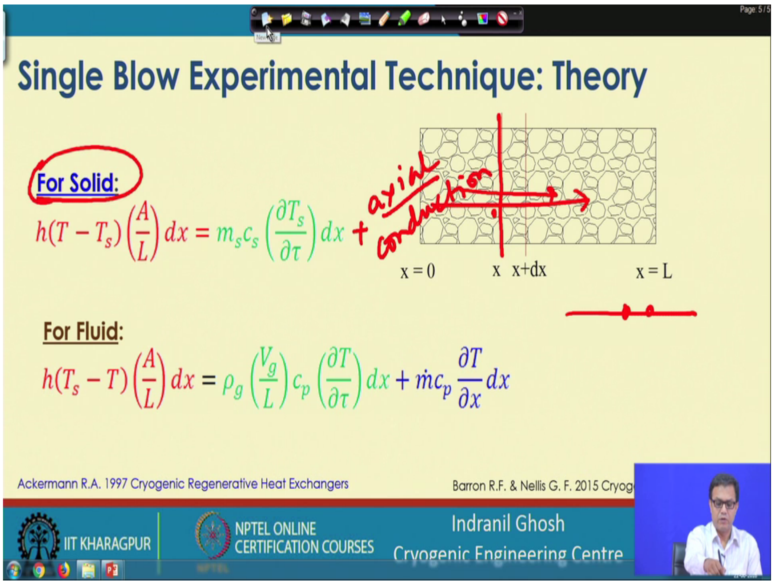

So, you may be remembering this theory while, when we talked about the regenerator design and simulation part that we have a packed bed filled with either say packed spheres or some other webs I mean oven screens and copper shorts or lead shorts. And sequentially the hot and cold fluid stream flow from each side. And we have written separately the equation for the solid part and we have also written the equation for the fluid part. And in addition to this we have also another term particularly for the solid part which we have not included in this one is the actual conduction of heat.

That means when we have two surfaces or I mean two metals and we have a temperature gradient along this. So, there would be an added term which will take care of the axial conduction in this equation. And of course we have not included in this particular equation.

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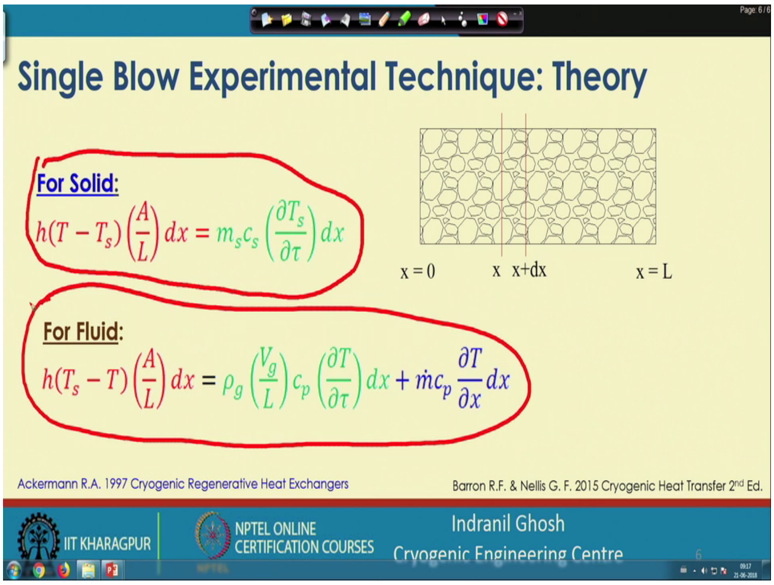

But, these are the type of equations we solve for this single blow technique. And we have different type of numerical models or techniques to solve these equations. And now coming back to our single blow technique one important aspect of it is or the most accurate prediction of the temperature or the heat transfer coefficient from this experiment is obtained from this outlet temperature prediction.

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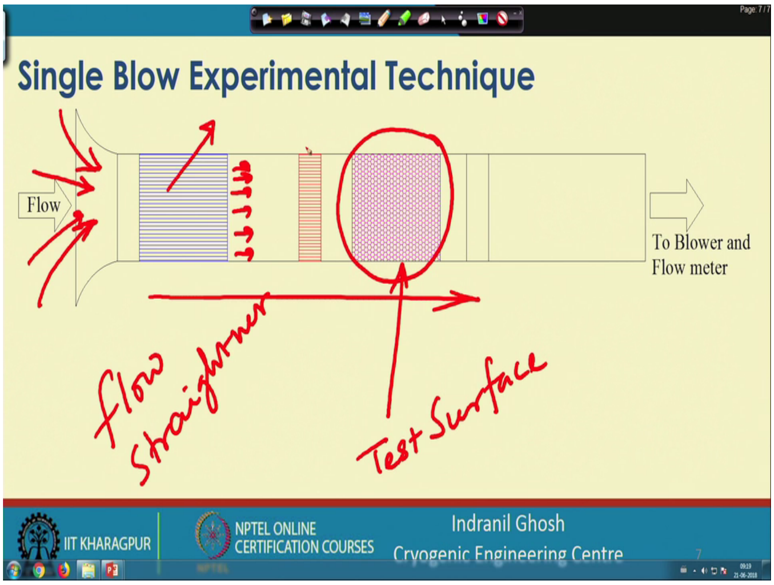

Say here, this is the typical experimental setup, where the flow takes place from this end we have the bell mouth type, of this is the flow convict through which the flow will take place this is the float straightner, this is well straight in the flow because where do with the flow is taking place from this one through this bell with this bell mouth is to the make smooth entry of the air most of the time. We use air as the fluid and here we have the flow straightner.

So, this will make the velocity of this fluid mostly uniform across the section. So, mostly it is a depending on the geometry of the surface this is the test surface and depending on the geometry of the test surface it may be a circular cross section or it may be this test section may be of circular cross section or it may a rectangular cross section.

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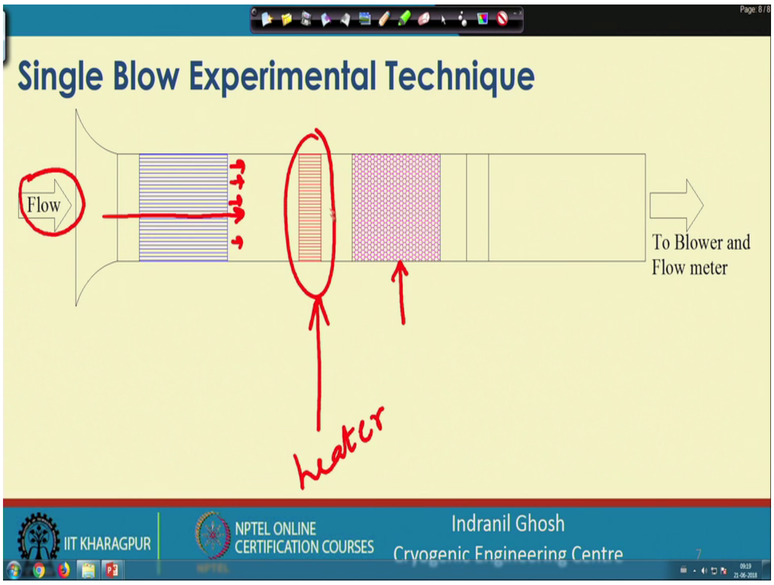

So, here we have one heater this is the heater and the when this heater is switched on. This will heat up the say if this flow is air. The air is getting streamlined and uniform with the uniform velocity, it is approaching this heater and before entering to this test section, it will get uniformly heated up.

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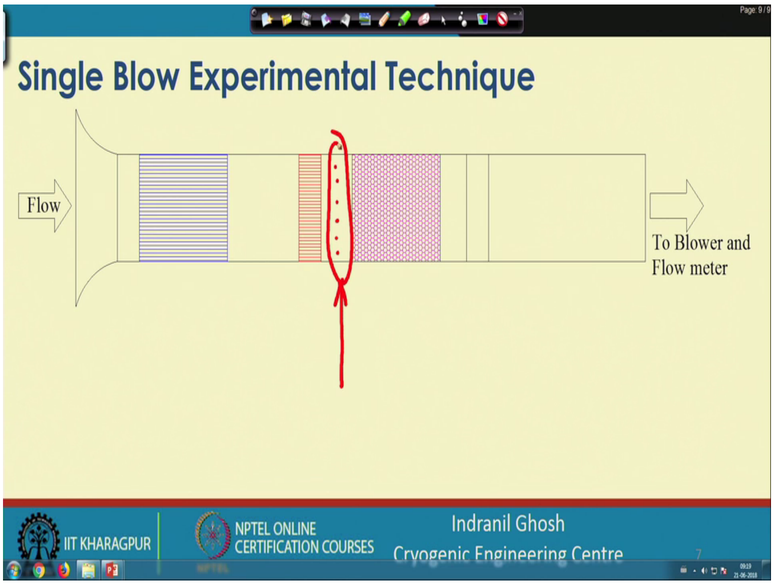

And what we do is that we have some thermocouples or the p r t, platinum resistance thermometers or some heat temperature measurement at this point. So, we measure the inlet temperature.

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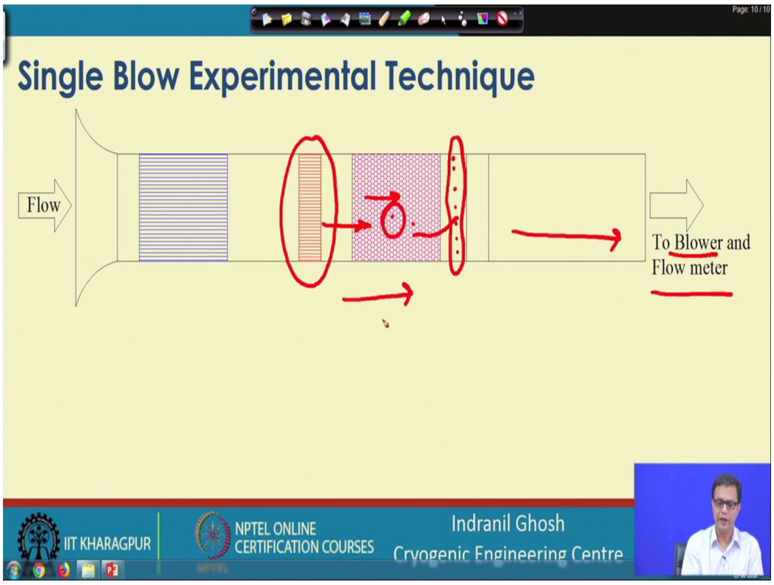

And when it comes out you know when this heated flow or the air will be passing through this test section. And when it comes out from this end it will also get heated up. I mean it is it will be earlier when it was not getting heated up it was coming with the same temperature same inlet temperature and the outlet temperature was same. But now this air which is you know which has already been heated up it will pick up some heat or it will reject some heat to this metal. And then it will follow this temperature profile will be following this one.

So, afterwards it will go to the flow measurement device and there is a blower to have you know this induced kind of flow through this test section. Now what is the kind of temperature profile that we expect at the inlet and what we do, what we expect at the exit.

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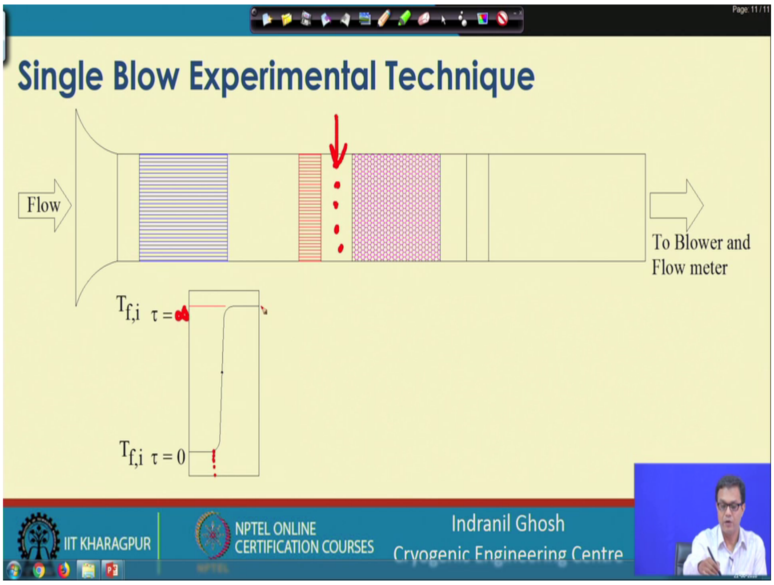

So, here you can understand that this is at T equals to 0 or tau equals to 0 this is the temperature of the air and at this point we have started the heater switched on the heater and the temperature of this fluid which is being measured at this point at this point before the entry to the test section.

So, here this temperature is keep on rising and at some you know T tau equals to infinity it will reach a steady temperature at this point. So, when this is you know after sometime it is reaching this temperature; we will note what is the kind of temperature that is being observed at the exit.

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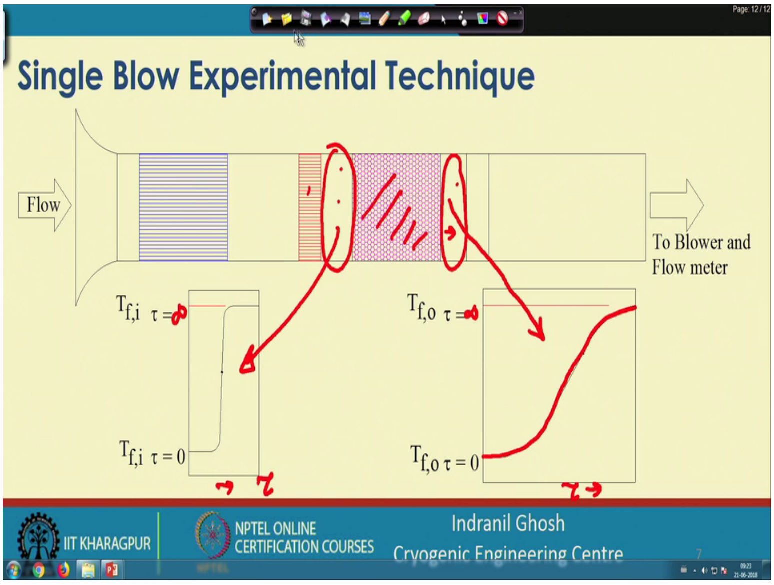

Here this is the temperature profile at the exit; I mean if we measure the temperature here we will have a record like this. And this is the temperature which will be this is on this side we have the time top this is tau with time it is following this kind of temperature profile. And obviously as you can understand that this transient phenomenon between this time limit it will finally, you know approach this temperature. So, this is the inlet temperature where it is you know heating it up the heating is complete it will reach to the or this air or the fluid that is coming out will have the same temperature as that of the destruction or that of the fluid which was coming in.

So, this is at it goes to infinity and this is tau goes to infinity. So, we have for this the exit temperature the temperature will be increasing like this. So, now, as we have understand from the earlier theory that we are able to predict the exit temperature depending on the inlet temperature.

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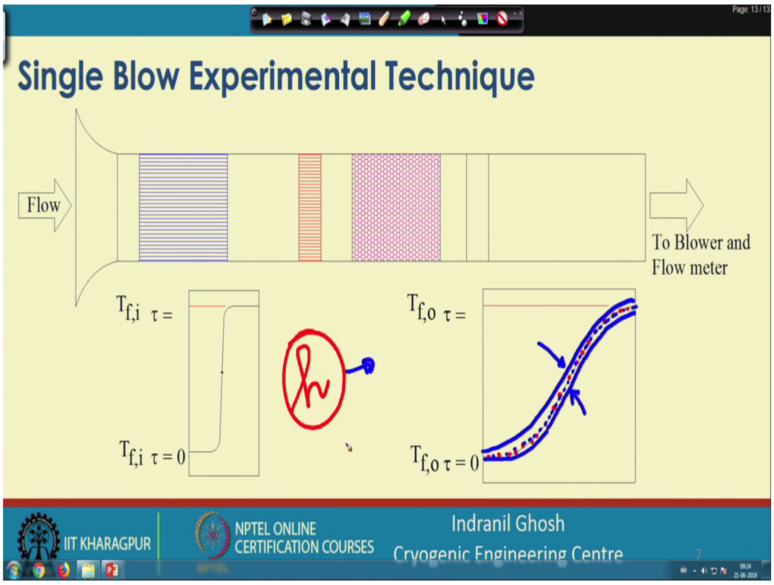

So, what we will try now that we have this data point for the exit temperature. So, we have measured these exit temperatures, and theoretically as you have noted that this theoretical prediction of the temperature profile will have a parameter called h. Now we will put different value of the h to find out which value is giving a good prediction of the heat transfer coefficient or the temperature profile. So, depending on that value say we will be this is corresponding to some h, this is some other h value and the one which is giving a good prediction we will accept that value of the h for this measurement.

So, like that you can understand that this is basically a kind of iterative process to find out the heat transfer coefficient in a single blow measurement technique. So, this is how we measure the heat transfer coefficient and mostly it is meant for regenerative type or a very high n t u heat exchanger type.

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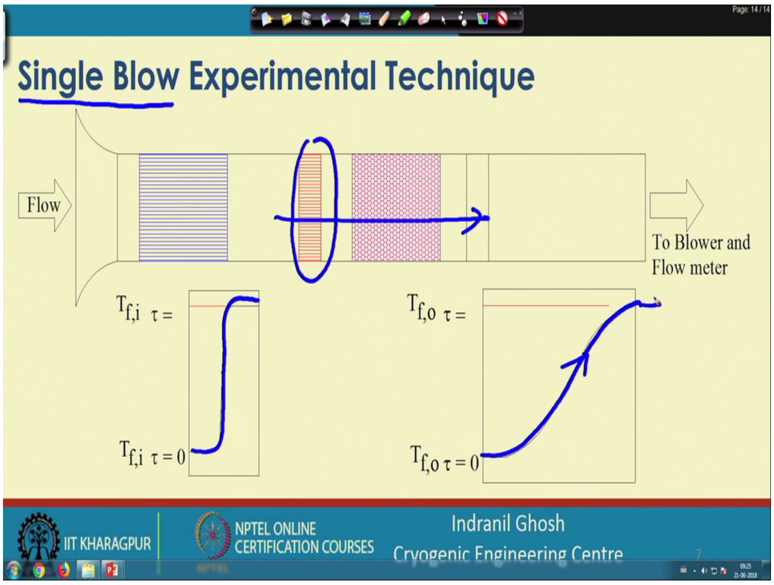

As you can understand that only one fluid is passing through this exchanger and it is not the; like in a heat exchanger where at least two fluid stream has to exchange heat with each other it is not so. It is only single fluid and that is why we call it as a single blow or technique the same fluid will be flowing through. But, as we have said that we have switched on the heater and it is temperature is on the rise and the temperature on this side is also going to be you know or it will be increasing with time before it becomes saturated or reach a steady state.

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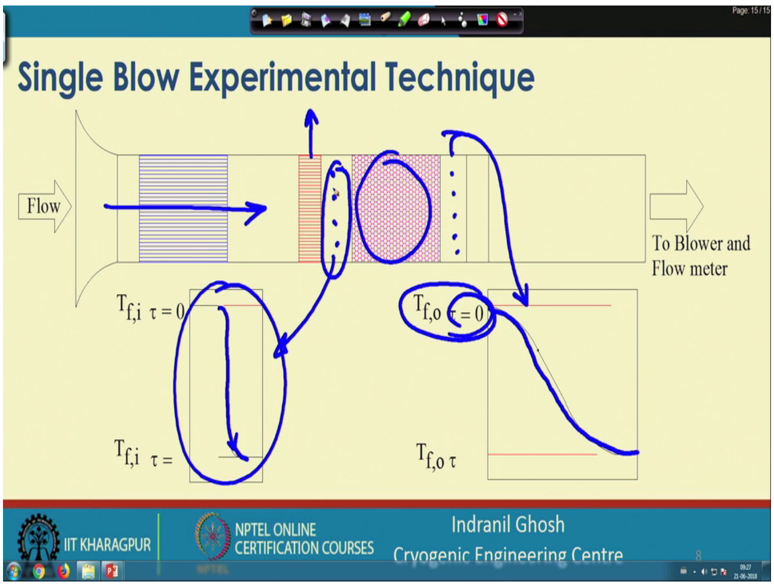

Now, if we the suddenly the switch off this heater we will; if we suddenly switch off this heater we will find that this temperature of this at the inlet condition it will start decreasing. So, this is in the cooling mode and this is the temperature profile which we record when we switch off the heater, and this is the temperature corresponding to the exit or the outlet. So, the temperature at initially this is at the exit T f o at tau equals to 0 at initially when you have just switch off slowly it is temperature will be gradually drop it will be dropping and the decreasing.

And here also in the inlet condition as we have switched off the heater that air is flowing on top of this one. So, gradually it will try to reduce and it will follow this kind of temperature profile. So, here also this will follow the exit temperature will also follow the pattern of the inlet one. But this is being in a heated up condition it is temperature drop will be much you know at a slow at a whereas, this temperature drop at the inlet will be much fast.

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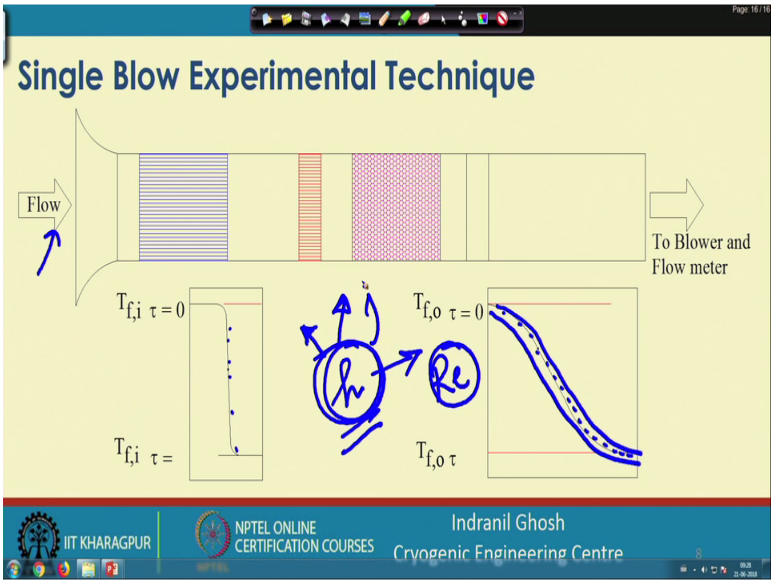

So, here also we have a set of data points we will obtained a for the temperature profile at the exit. And depending on the temperature profile given you know as a input to that theoretical calculation and here also for different h, we will have different type of you know prediction of the temperature profile. The temperature profile corresponding to the h which gives the best fitting of this curve will be the heat transfer coefficient. So, this has to be followed for different flow rate.

And accordingly we will have the heat transfer coefficient for different velocity of the air and corresponding to different Re. And we would be able to calculate the h, and if this is the dimensional form of the heat transfer coefficient then we need to calculate it is the non dimensional form of it or in the form of j. So, this is how we estimate the heat transfer coefficient a particularly in a transient technique or the single blow technique.

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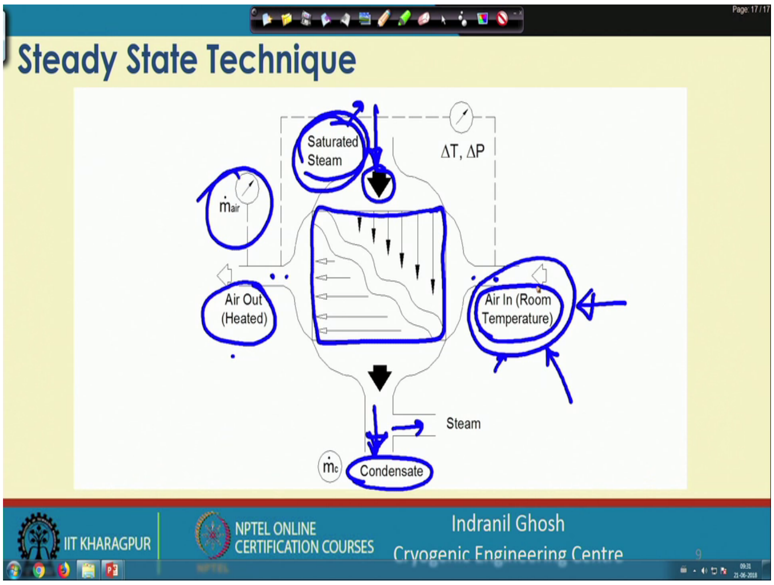

Now, we will go to the steady state technique. In a steady state technique most of the time what we do is that we use the heat exchanger. And most of the time it is a type of cross flow heat exchanger, where we have the air mostly used as the fluid. And this air will be passing through the exchanger in one of the flow channels, whereas on the other side we will have condensing fluid most of the time we use a saturated steam. So, that we have you know the steam this is the access steam and this is the condensate which will be coming out.

So, here we have the saturated steam condensing fluid on one side of the other side is a air. So, the air is getting heated up and the saturated steam is getting condensed. So, from this heat transfer we would be able to find out the heat transfer coefficient and the pressure drop. Pressure drop of course, we measure it at the inlet and the exit. And now as we have said that this is the heat exchanger which is the test session what I mean is that what is the test surfaces where did we put the test surfaces. The test surfaces are there on the air site, whereas the steam side is slightly having you know a virus channels or you know where we have the known heat transfer coefficient. And for the easy drainage of this condensate and we have a known heat transfer coefficient for that side.

And usually the saturated steam or the condensing steam or the condensing fluid is having a much higher heat transfer coefficient compared to the air side or the gas side. So, this is how we do I mean in the steady state technique we allow the air to reach to a steady state condition and the steam will be continuously flowing through this heat exchanger. And we will measure the condensate, we will measure the flow rate of air, we will measure the delta t across the heat exchangers and then we will be able to predict the heat transfer coefficient. And finally we have to calculate the dimensional fond or dimensionless fond of the heat transfer coefficient.

Now if we go into the theoretical part of this study state technique we will find that this is based on certain assumption.

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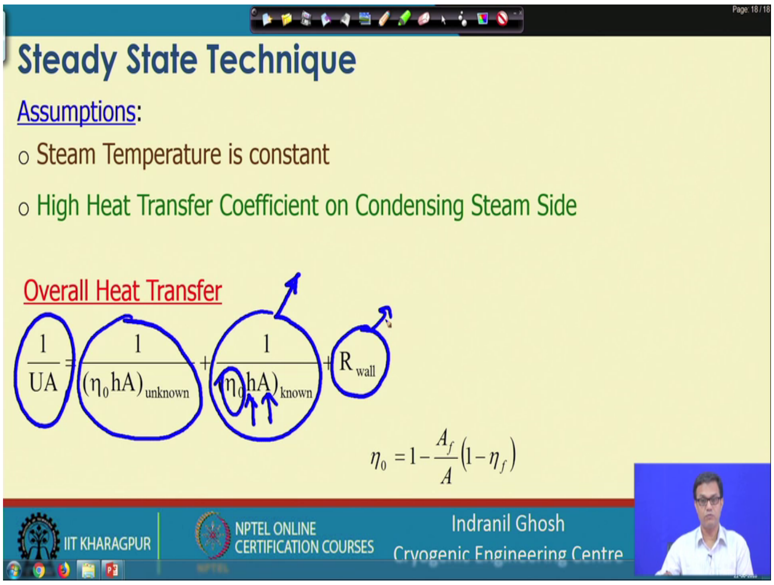

The assumption being that the steam temperature is constant and there is the high heat transfer coefficient on the condensing steam side. So, these are the two basic assumptions we made while in the steady state technique. And in the steady state technique when we make this assumption we find that the overall heat transfer resistance is 1 by UA; it is given as it is given by 1 by UA and it is the comprising of three factors. One is obviously the air side which where we have put the tests surfaces, where we need to find out the heat transfer coefficient this is the steam side where do we need to find out the or it is already known the heat transfer coefficient is known the area is known and eta 0 that is also known the overall heat transfer I mean the free in efficiency.

And this is also it may be substantial or it may be you know for a very accurate measurement of the heat transfer coefficient. We should not neglect this wall resistance though it will be of smaller you know magnitude.

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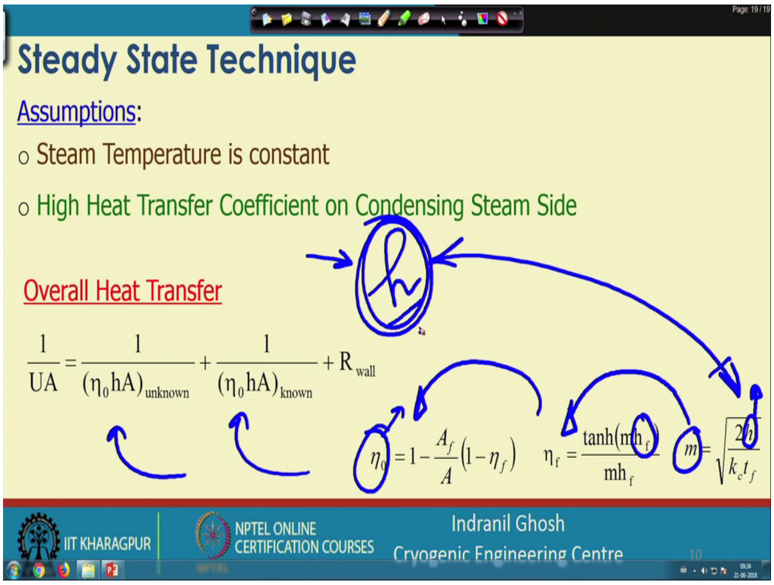

So, now here we find that; so this is eta 0 is overall heat transfer coefficient and eta f is basically the fin efficiency and where this m is parameter as you know that it is 2 h by ktc. This is the thin fin approximation and this is quite legitimate for plate fin type of heat exchangers. And here as you can understand that this m is containing some h; this hf is basically the fin height do not be confused with the heat transfer coefficient that we are trying to find out is h, but it is contents the parameter h in this m parameter. So, this is basically if you want to find out this overall heat transfer coefficient we need a parameter the heat transfer coefficient knowledge is necessary, but we want to also calculate this or basically our intention is to get this heat transfer coefficient.

So, you can understand that we may have to use iterative technique finally to get this heat transfer coefficient. And this eta 0 is generally it is a very high for plate fin type of heat exchangers, but still we initially assume this eta 0 to be 1 and later on you know when we have estimate some estimate of h. Then we calculate this eta sorry m and from there we calculate the eta f and from there we calculate the eta 0 and then we put those values on this side to get an corrected value of the h. So that is the usual technique. But as such we have this equation where we know that one of the heat transfer one side of the heat transfer coefficient is known the other side sorry the other side is not known.

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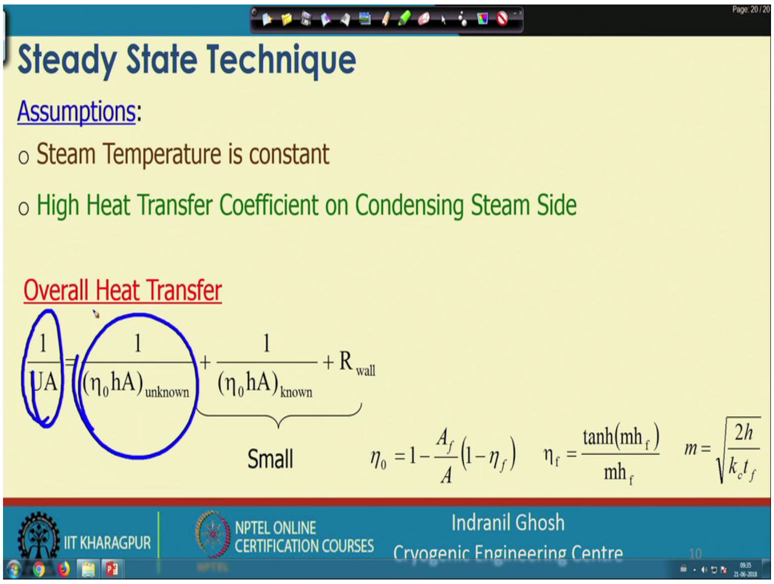

And we try to calculate this 1 by UA experimentally and then we try to find out what is the heat transfer coefficient on the unknown side.

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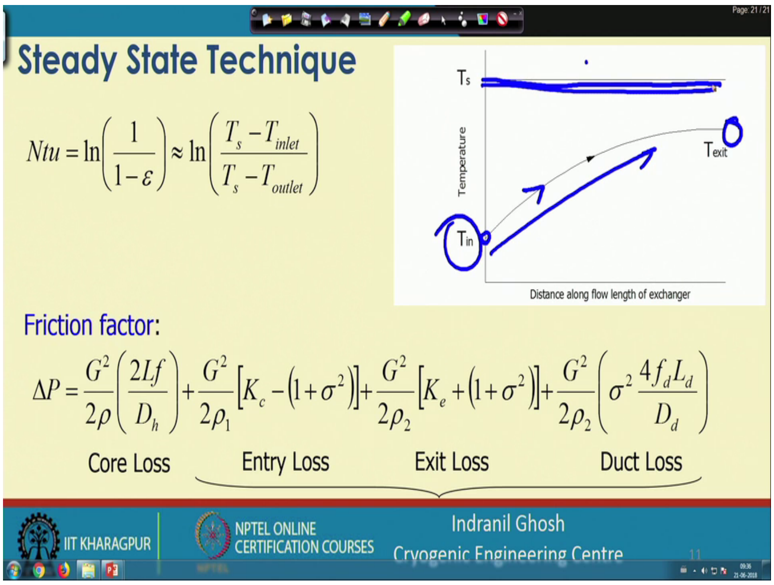

So, along with that we also have this relation a h to; this Ntu is basically related particularly when we have a temperature profile like this; I mean this is a condenser in steam we are using. And the temperature is we are assuming it to be constant as per our previous assumption, and the temperature of the fluid is going from this inlet temperature to this exit temperature. So, this air is picking up heat from the condensing steam and the condensing steam is maintained at a particular temperature.

So from that, based on that equation we will be having this Ntu epsilon relation and from there we will be able to predict the UA. So, we will come to that in the next slide.

Thank you for your attention.