Heat Exchangers: Fundamentals and Design Analysis

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Lecture - 66
Heat Exchanger Testing (Contd.)

Welcome to this lecture. In the previous class we have we were talking about the steady state technique for measuring the heat transfer coefficient or the GNF coefficient for the plate fin type of heat exchangers. And there we have seen that the steady state technique in the steady state technique we have the condensing steam, and the air is getting heated up and there is a heat transfer between the fluid and this condensing steam. And air gets heated up and it picks up the heat from the condensing steam and the condensing steam gets condensed.

And we have made 2 assumptions that the heat transfer coefficient sorry, the heat the temperature on the steam side will have a constant wall temperature, it will be maintained at the condensing steam temperature whereas, the air will be getting heated up from it is inlet temperature to the exact temperature.

So, depending on this relation of the basically we assume that here the C r or the heat capacity rate ratio is 0 because the condensing steam is having a very high heat transfer coefficient.

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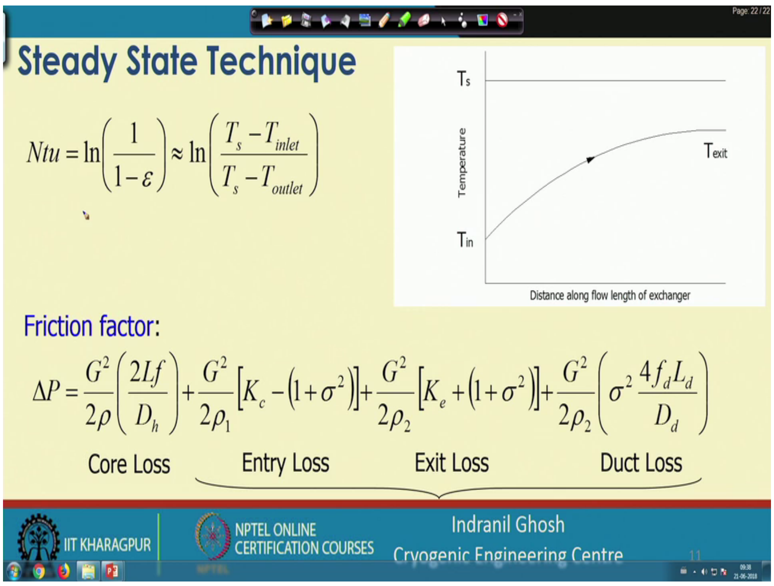

And we have this C r equals to 0, and the heat capacity basically is very high for the condensing steam. So, we have this high you know this because of that one we have this C r equals to 0 and we have a constant temperature for the on the steam side.

Now, the air is getting heated up from the T in to the T exit. So now, we in this condition what we do is we measure the inlet temperature we measure the exit temperature of air, we measure the flow rate of air and we would be able to calculate the condensing steam temperature we that is already known depending on the pressure of the saturated steam. And exit and inlet and the exit of the air temperature is measured. So, we have an idea about the Ntu, and once we know the Ntu basically this is UA by C min.

This C min is nothing but the air heat capacity. So, this C min is known and we know that Ntu that is equals to Ntu. This Ntu is basically this you know from this relation we have already calculated from the measured value of the inlet and exit temperature and the temperature saturated steam temperature.

So, we can understand that we have the knowledge of UA. So, once we know the UA as we have seen in the previous slides; that you know because of this I am sorry, this is in the previous slides we have seen that we have seen that.

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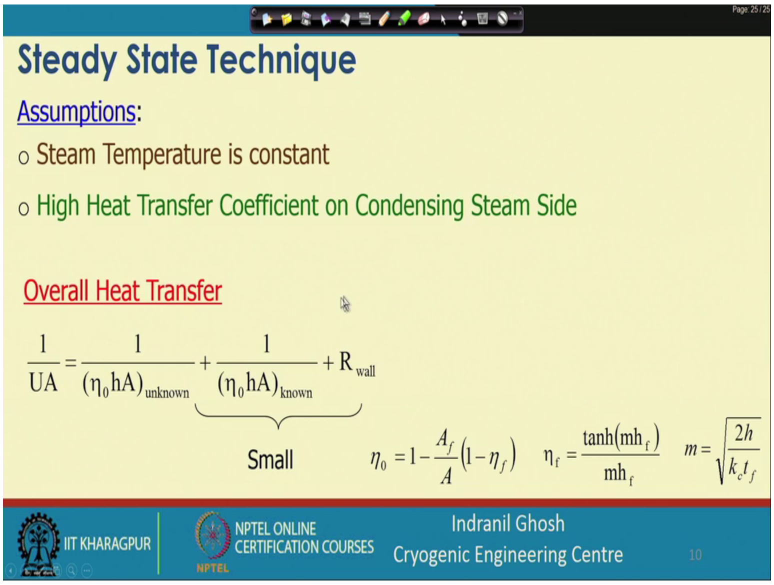

This the 1 by UA part this 1 by UA part is related to the known heat transfer coefficient. It is also you know known wall resistance, but already we have an estimate of this UA.

And now we would be able to calculate this unknown heat transfer coefficient where we have put the test surfaces on this side.

So, this is how we measure the heat transfer coefficient in the plate fin type of heat exchangers, in the form of the heat exchanger. And moreover in the same way we also calculate the from the inlet and the exit pressure, drop we measure and the from this differential pressure measurement we can correlate it to the different losses. Here we have the core, this is the core friction part and then we have the entry and the exit loss as we have discussed earlier during this plate fin type of heat exchanger pressure drop calculation.

And this is the duct loss this is the air we will find that it is flowing through a duct, and that is also giving some kind of a heat pressure loss and that is also you know taken, but this parameters will be generally very small as compared to this you know core pressure drop.

So, this parameters are generally known we have the known value of the K e and K c and we know how to estimate that. And we have the duct size known and the friction factor of the rectangular duct or a you know square duct that will be known. And from there we would be able to estimate all this parameters and we can now calculate this friction factor corresponding to the pressure drop, I mean the where we have the test surfaces.

So, basically we measure the pressure drop and then from there we calculate the friction factors using this relation. If someone wants that you know we do not need that much accuracy you know we can easily neglect this term. We one can just concentrate on this part, and one can find out the friction factor from the pressure drop calculation. But if someone is looking for an accurate measurement of the friction factor, then one has to take care of all these the parameters given in the equation.

So now these are the 2 parameters we will be calculating from the heat exchanger I mean from the test set up, and we have already talked about this part and this is the steady state test set up.

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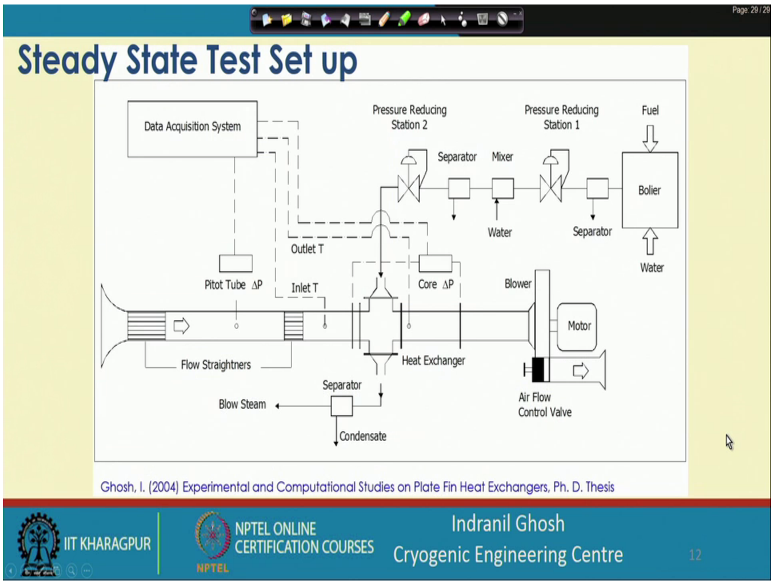

It looks bit complicated bit we will be trying to we will be you know separate it out. Here we find that we have a heat exchanger I mean this is the heat exchanger, and this is where we have the heat exchanger which we want to test. And the test surfaces are there on the air side and on the steam side. So, we can understand that we have 2 circuits here one is generating the steam and the other part is the air. And this is the air flow path, and we have a blower on this side and we have a flow control valve here and this is a data acquisition system to monitor the temperature and pressure at the different point.

So, here we will first of all separate it up out into 3 components one is the air side, one is the steam side and separately we need to look into this particular design of this heat exchanger, for this to understand this steady state heat transfer technique.

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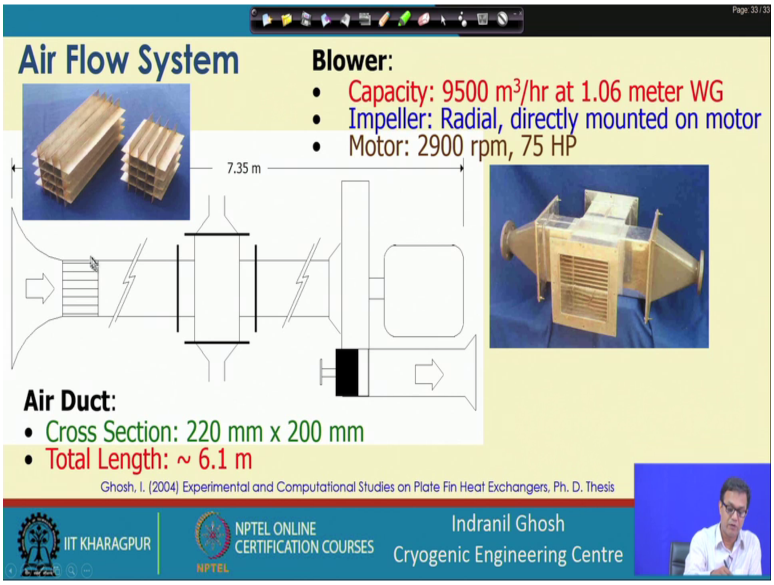

So, this is a what is the air flow system. So, here we have the again a bell mouth you know air entry, then this is the test section, here we have the flow straighteners, this is the heat exchanger. This is generally in case of plate fin type exchanger depending on the geometry most of the time you will find that this test section is a rectangular cross section. And here this is the blower and this transition you know from rectangular to circular is generally done at the entry of the blower. This is the motor of the blower and here we have at the exit of the blower we have a flow control to you know test it at the different Reynolds number.

So, this is what is about the air flow system in general, and this is the air duct that has been used in this test set up is typically of this dimension. And the total length is 6.1 whereas, the blower capacity is something like 9500-meter cube per hour, and for a 1.06 water kg of pressure drop or the pressure head; available with this blower and it is a motor rpm and the power is 75 HP.

So, basically this blower capacity and this what is called this air duct configuration depending on the test set up and the R e values that you need. That will dictate this terms or the size of the blower will be basically governed by the type of heat exchanger test surfaces you were, you know you are going to test them. So, here we have taken this kind of a dimensions overall dimensions for this the air flow system. So, here some of the pictures so this is the heat exchanger that has been tested in this test section. This is the flow straightener that has been used in this particular sorry.

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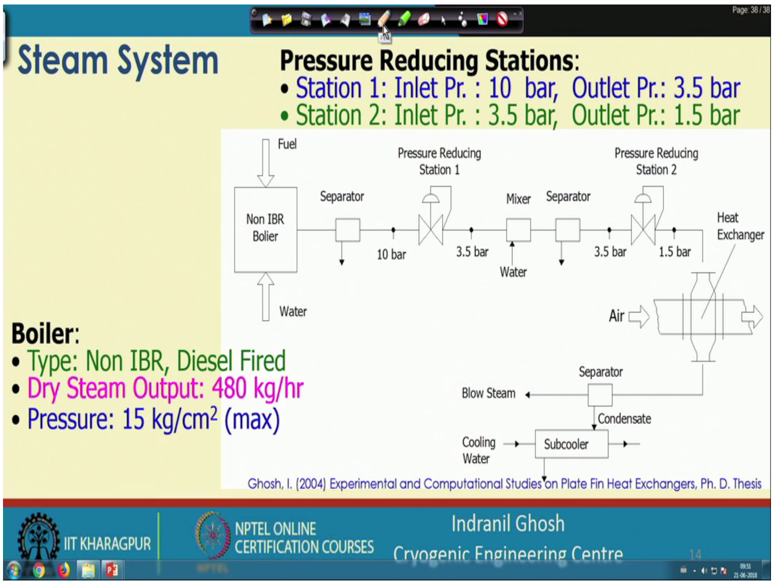

So, this is the flow straightener section, this is the exchanger what is the here and this is this the flow control valve, which has been placed in this position.

So, now we go to the steam system. The steam system is basically a we use in the laboratory system we have used a non IBR, diesel fired boiler; it is a package type of boiler which gives a nearly about 480 kg of dry stream and at a pressure of 15 kg per centimetre square. So, this is the you know when we want to take it to the heat exchanger, we want it at a saturated condition, but it is very difficult to maintain it at a saturated condition. And moreover when it is the air is flowing through this you know some of the steam will get condensed, and it may you know create some kind of 2 phase flow in this region on the steam side.

So, that is why we it is allowed basically this is I forgotten to tell you; that this is the method used by Kays and London. And we have adopted that technique sometime this steady state technique is also called the Kays and London technique. And here we maintain the steam at nearly about 4-degree super heat is maintained at this point, and it is the nearly about 1.4 to 1.5 bar.

So, here we have the steam at 15 bar pressure nearly and you know from there we will be reducing it to 1.5 bar, but if we want to do it in a single stage we you know that there would be very large degree of super heat, we will not be able to control it at this point. So, what we do is that, we reduce it into stages one you know by the time it comes from this boiler to this point, you know through the phase separators and all it will be available at a pressure of 10 bar.

So, from 10 bar we reduce it to 3.5 bar and that will give you some degree of super heat. And that super heat is you know removed in order to remove the super heat we mix it with the water. So, this water will the mixing with this super-heated steam, and this excess water will be again separate it out and finally, we have the saturated steam at 3.5 bar. Once we have this saturated steam at 3.5 bar we reduce it to 1.5 bar and with this degree of super heat of about 4-degree centigrade, we send it through this heat exchanger.

So, when it comes out from this exchanger you know this steam at 4-degree centigrade super heat will be lost, and you know along with that there will be this condensation of this steam. So, mostly we can assume this will be prevailing at a temperature of T s corresponding to the saturation temperature saturation pressure of 1.5 bar.

So, the steam that is the used in this process is about 3 to 6 time of the you know part that is getting condensed. And this is excess steam is used because we do not want any accumulation of the steam or the condensate on the steam side. Because any condensation process on that one will reduce the I mean if it is getting accumulated the steam you know getting condensed, and that condensed if it condensate if it is accumulating on the steam side surface that will reduced the heat transfer coefficient.

So, we want a drainage of that excess condensate or the condensate and that is why we use the excess steam and that excess steam will take care or remove the condensate from that heat exchanger or from the test channels or the on the steam side. So, this condensate is again collected and then we measure it and then we subcool it and then we you know collect this condensate. So, that gives you basically an idea about the energy balance and this excess steam will be blown out.

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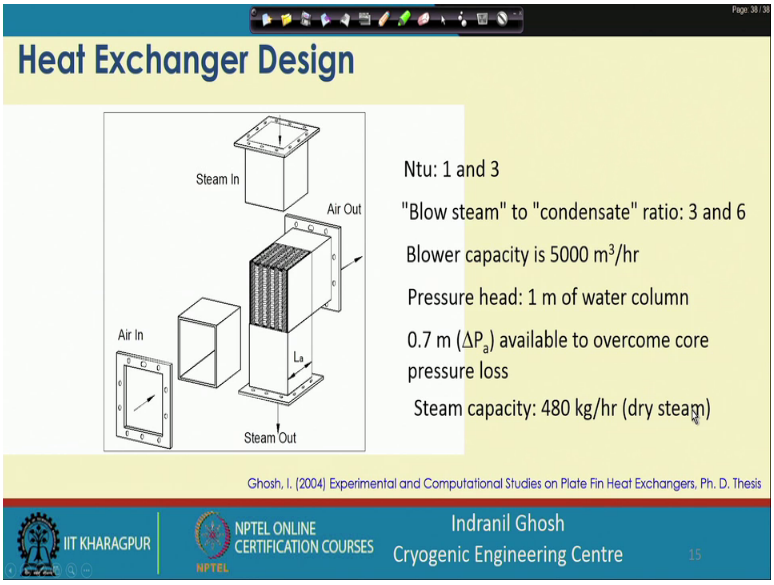

So, this is about the test section or the steam system and we have the heat exchanger this needs a special attention because this exchanges are to be designed carefully, otherwise that is going to give you erroneous results. And the recommendation is that the Ntu is it should be nearly about 1 to 3. And there is a reason for that if we are going to use a very high Ntu exchangers we can expect that you know that Ntu relation we have shown as the 1 by 1 minus epsilon. And that you know that it is like that T it is at T s and the inlet temperature is this is T in and this is T out.

So, this is coming at T in and it is moving out at T out and this the steam side temperatures are remaining constant. So now, if it is such that the heat exchanger Ntu is very high, we will end up with the case that you know this the T s minus T out will be very small. And then the probability of error will be you know it can be shown that this error estimation will be much more. So, we design the exchangers so that the Ntu remains within 1 to 3, and the blow steam to condensate ratio is as I told you that it has to be nearly about 3 to 6.

So, the blower capacity it has already been decided depending on the Reynolds number and the pressure head available with that kind of blower. And out of that you know available pressure head. Only a part of this one will be available for this heat exchanger core, this is the only heat exchanger core, this is the length of the exchanger core. The these are the sides you know this is the fin, these are the fin which we are going to test these are the fins we which we will be testing.

And the pressure drop for that heat exchanger core of length L a we have all the allocated points 0.7, or 70 percent of that one meter of the water column. Or 70 percent of the pressure head available with this blower will be allocated for the core pressure drop. And rest of it will be you know to that what is the flow strightener and (Refer Time: 17:45) etcetera etcetera, that will be consumed by that remaining part.

And we have assumed that 480 kg of dry steam and depending on this assumption we have calculated the heat exchanger I mean design has been done.

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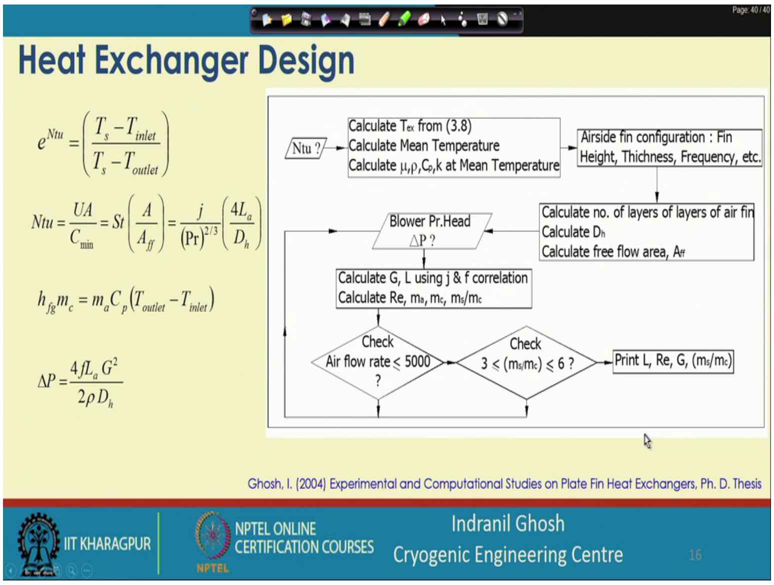

So, starting with the Ntu we first calculate you know from this relation we calculate the exit temperature. And from there we calculate the mean values and the you know based on the mean temperature. From that we already know the fin details. So, from there we can calculate the hydraulic diameter etcetera and we can estimate the pressure drop.

So, once we know the pressure drop we calculate the other j and f correlations we use here. We need to have a rough estimate of the heat transfer coefficient and the pressure drop for the test surfaces. And from there we can check whether this it is you know within that Reynolds number region or whether you know it is conforming to our flow rate or you know whether it is that maintaining that steam to condensate ratio within 3 to 6. And accordingly we will be finalizing that length of the heat exchanger.

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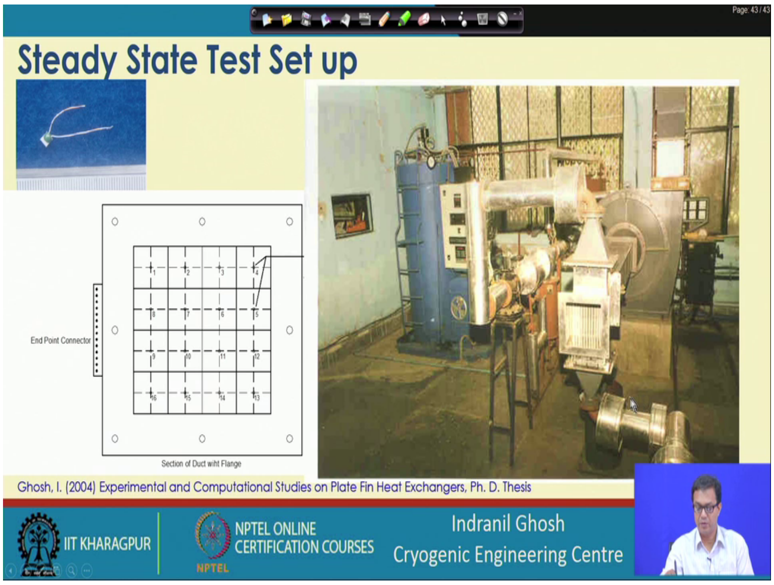

So, once we know the heat exchanger length, we can test it I mean put it in the test section this is the pictorial view of the test set up this is the boiler. And then we have this is the boiler these are the different pressure I mean reducing station, pressure reducing station 1 2. And then we have the steam coming like this, this is that heat exchanger the steam is flowing like this and getting condensed and then it will be following this one. There is another test section this is here removed that part this is a where we have that bell mouth, this has been removed and to show it you know the heat exchanger inside.

So, we have another rectangular test section like this on this side. And then you know the air will be flowing this is an induced type one. So, we have this is blower and this is the valve and the motor is on the backside. So, this is the pictorial view of the test set up. So, here is some of the instrument part I mean this is basically a PRT single PRT Platinum Resistance Thermometer. And we have measured the inlet temperature at a particular point, but for the measurement of the exit temperature we have to measure it at different locations, because we expected non uniformity in the temperature region in the exit of this heat exchanger.

So, that is about the measurement part, then we have also measured the flow rate at different locations I mean at the entry of the air flow.

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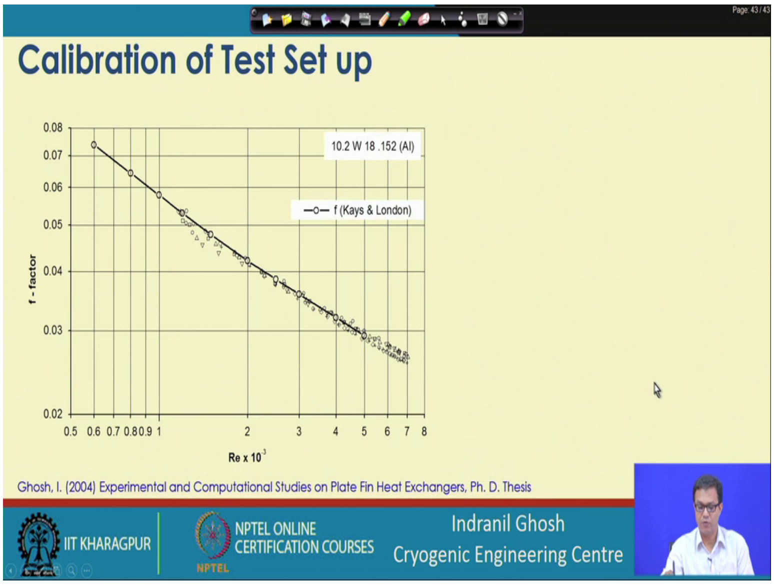

And then once we develop the test setup it is very important to calibrate the test setup. So, for calibration of the test setup what we need a test surface for which the heat transfer coefficient or the pressure drop is known. So, initially what we did is the we calculated the friction factor, and this is the test surface which has been tested by Kays and London. And we have the data for the Kays and London, and to test that we have our test setup correctly build we have measured the pressure drop at different time. And what is important for any test or the measurement or thermal measurement thermo hydraulic measurement is the repeatability test.

So, we have done this experiments time and again and we have calculated or we have seen that it is conforming to the values given by the Kays and London. So, this is basically the cold test or this is where we did not use the steam only the air was flown through the heat exchanger test surface.

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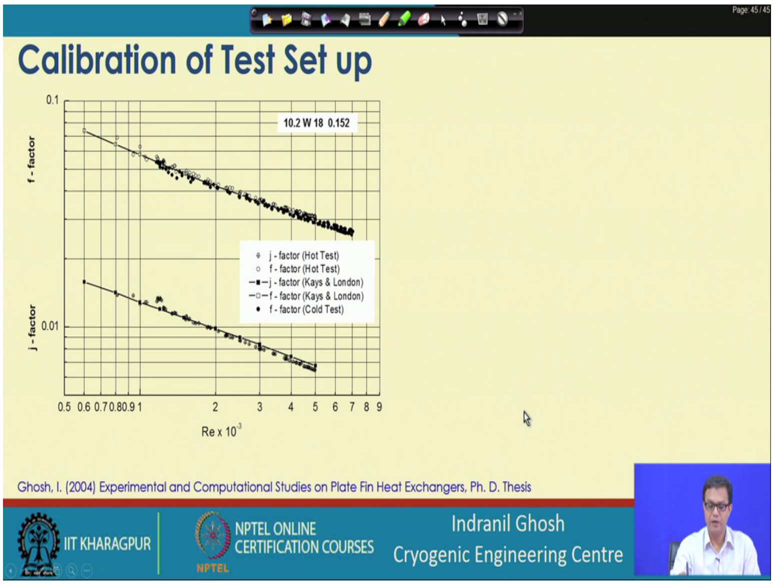

So, this is how we have measured the friction factor, and then in presence of the steam we have generated the friction factor and the also the heat transfer coefficient or the j factor. So, here we can understand that the j factor and the friction factor are very you know closely related or they are very I mean they are almost following the results given by the Kays and London. So, this calibration will be able to eliminate what is called the systematic error or the while any, any experiment if we are performing it contains 2 type errors. You maybe knowing the one of them is the systematic error another one is the random errors.

So, basically what we try to understand or try to calculate is the random error associated with the different measurement whereas, the systematic errors are eliminated by this type of calibration of the test setup. So, that has been done first and then subsequently you have tested the different heat exchanger surfaces.

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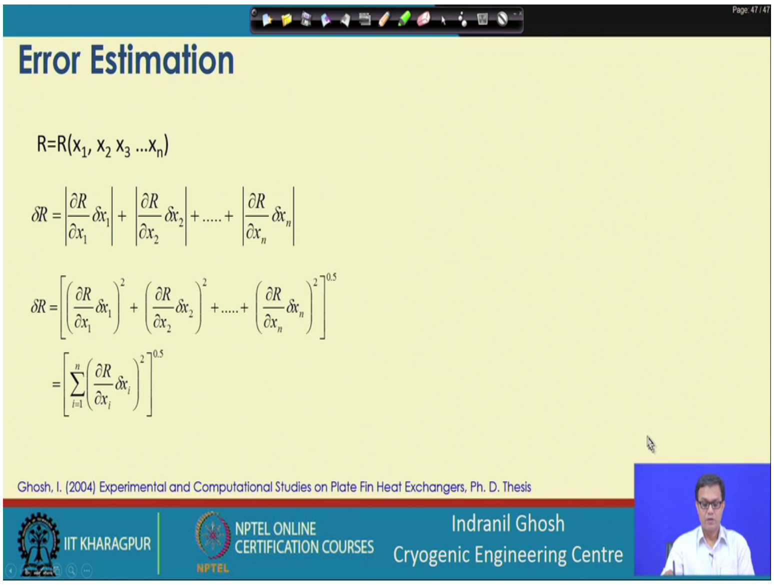

So, this is the random error estimation and these are the type of expression that we use for calculation of the random errors. This is if there are x number of say n number of parameters X 1 X 2 X n, then we have the error associated with that measurement will be say delta R. And delta R will have component I mean this is the delta x 1 associated; the error associated with the x 1. And this is delta x 2 associated with x 2 and so on, and it keeps on adding and the errors are additive. So, the total error associated with this measurement will be delta R comprising of all the individual errors of measurement.

But another estimate of this I mean error is given by this relation by (Refer Time: 24:50). So, this is how we estimate the error the random error associated with any kind of measurement.

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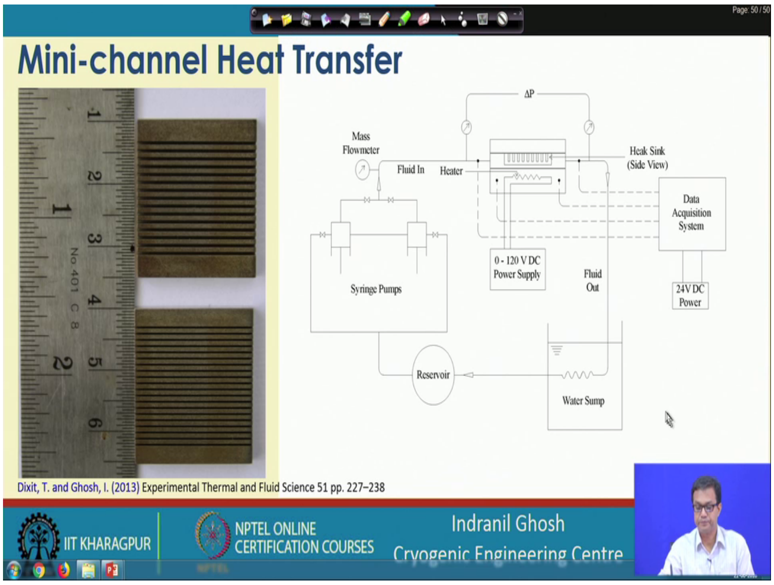

So, when we talk about the mini channel, it is slightly different you maybe you know expecting a similar kind of test setup, but here we go for a power supply and we heat it up from the bottom. And it is unlike you know we send the steam in this one because this you can understand the dimension of this surfaces. And this surfaces are very small in size this is about 0.25 mm channel. And here we do a different type of you know test where we calculate, the flow rate or we simulate the flow using syringe pump.

And it is through which the syringe pump will allow the water to flow in through this small channels and we measure the pressure drop across this you know channel. And then we also put some known amount of heat through the power supply and then we estimate the heat transfer. And accordingly we calculate the heat transfer and the pressure drop for these channels.

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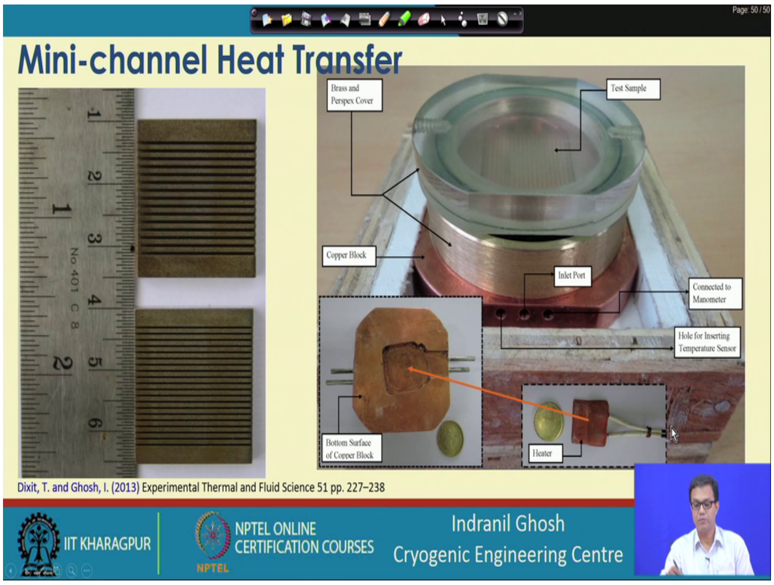

So, this is the kind of test setup you know we use for the sample holders.

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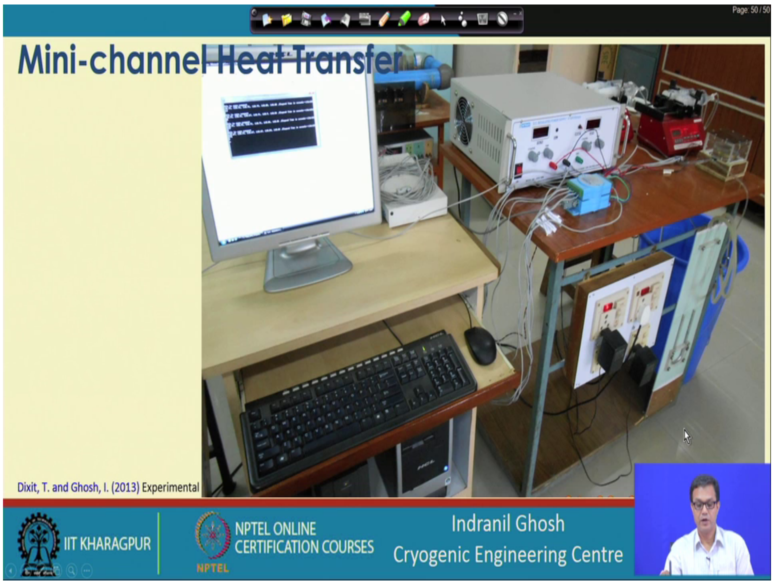

And this is the type of experimental setup where we have the syringe pumps, data acquisition system, then this is the power supply and like that.

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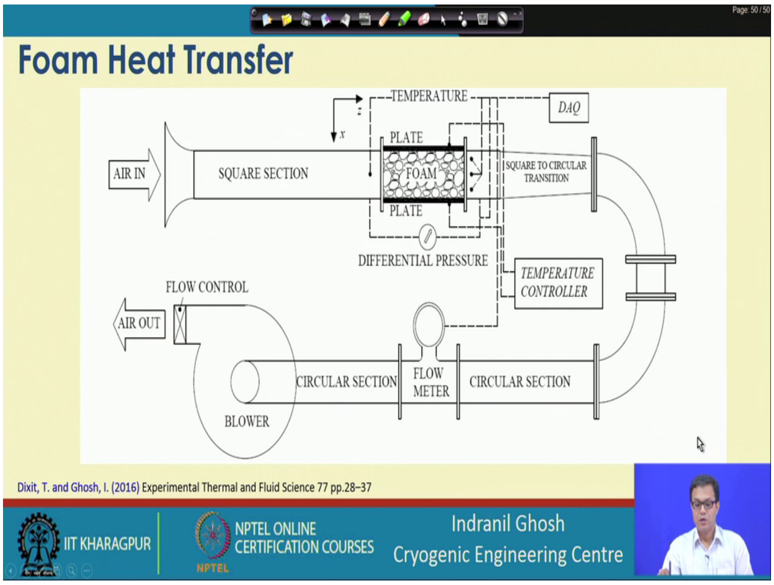

So, in case of foam heat transfer a similar type of experimental setup is used.

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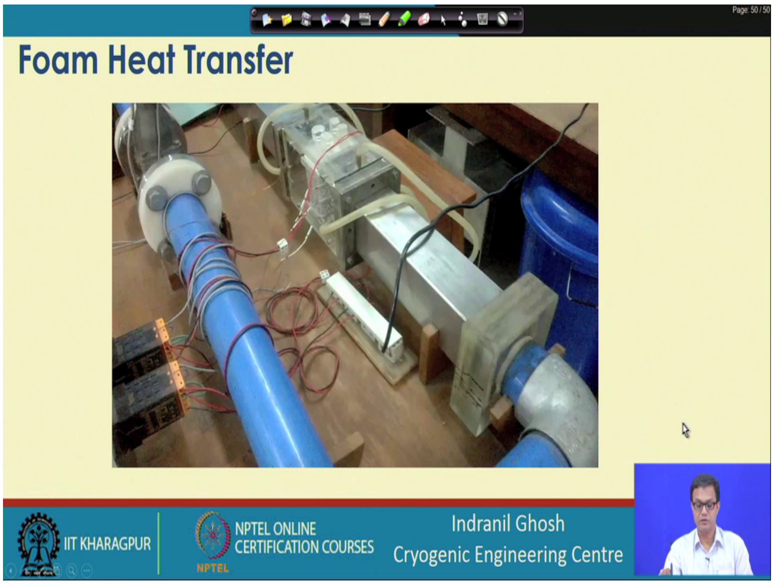

But again this will vary from time to time, and here just we will have a glimpse of this test setup. This is the regulator test session, so here it is heated up from the top and the bottom. And this is where we have the aluminium metal foam within it. And we measure the it is supposed to be covered up when it is in the heated condition, but for you know the video recording we have removed that this cover.

And they are maintained at particular temperature they are electrically heated up and this is the flow measurement device or it is an inline flow metre. And it is a measuring the floor rate and you will find we will be showing you this is the air entry, and this is the blower. The air enters from this end and then it flows through this section this the test section and then it finally, comes out like this. So, this is the data acquisition and then we calculate the heat transfer coefficient and the pressure drop.

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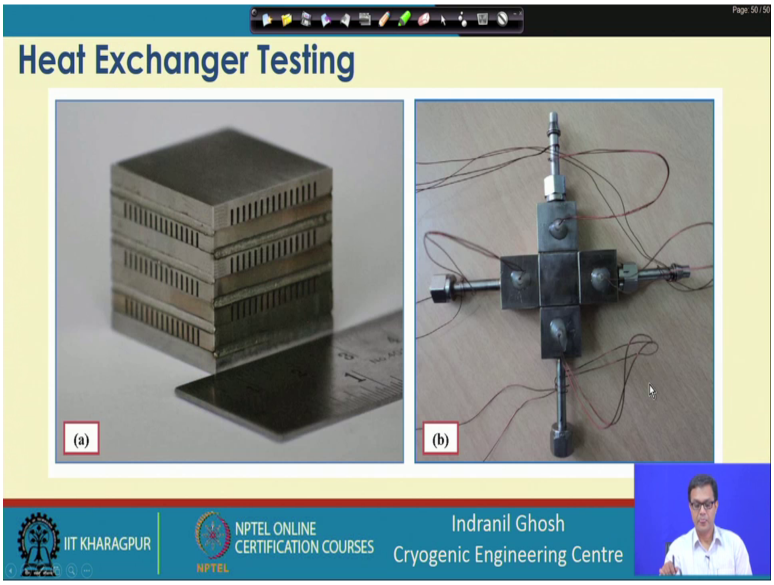

So, when we make the heat exchangers finally, out of this test surfaces we have a different type of I meantest setup for measuring the performance.

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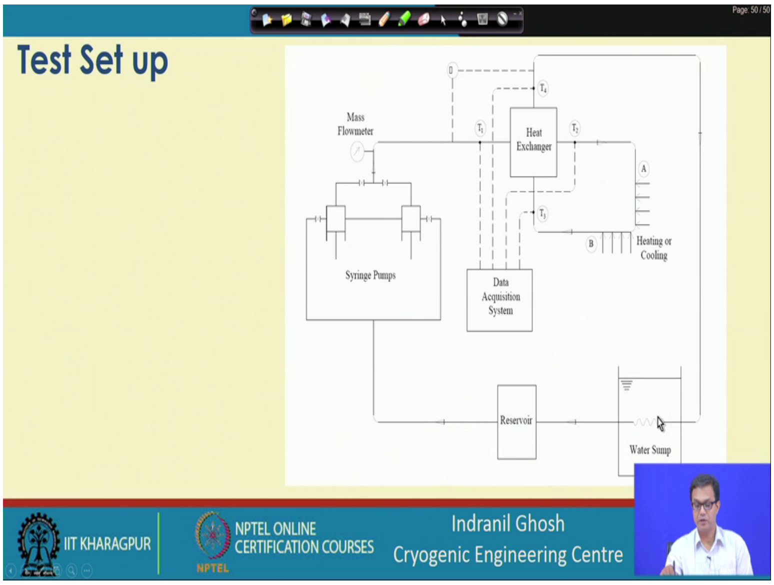

So, this is one of the test setup where we measure the heat transfer performance or the heat exchanger effectiveness. So, here also we put the air sorry, this water flowing through this one. We allow the water to flow through this channel then we put either heat in it and then you know this is the other fluid or the same fluid, but with a different temperature. And then you know it is flowing like this in a closed loop.

So, this is the cold fluid and this is the hot fluid exchanging heat with each other. So, here we are putting heat and from measurement of all this temperatures we would be able to calculate the efficiency overall efficiency of this heat exchanger. So, this is about the test setup of a the heat exchanger.

Thank you for your attention.