Heat Exchangers: Fundamentals and Design Analysis
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Lecture - 56
Fixed Bed Regenerator (Numerical) (Contd.)

You are welcome to this lecture, today we are going to talk about the design of a Fixed Bed type Regenerator. So, here we will try to solve a numerical problem already we have discussed about the design procedure, what are the type of I mean how we will go about the design of a regenerator, what are the parameters that is to be fixed or finalized from a design problem of a regenerator, that we have already discussed in the previous lecture classes. And in this particular lecture as you can understand that the design of any regenerator is quite similar to the design of a heat exchanger like where we intend to find out the length or other parameters or the design parameters of the heat exchangers.

Similar to that here we want to decide what are the parameters which will be necessary like what would be the length of the regenerator? What would be the material or the amount of material to be used particularly for that regenerator under the condition that the flow rate of the this process is already known or the temperature of the fluid flowing inside or flowing in the hot stream during the hot period or during the cold period the temperature of the fluid streams are given.

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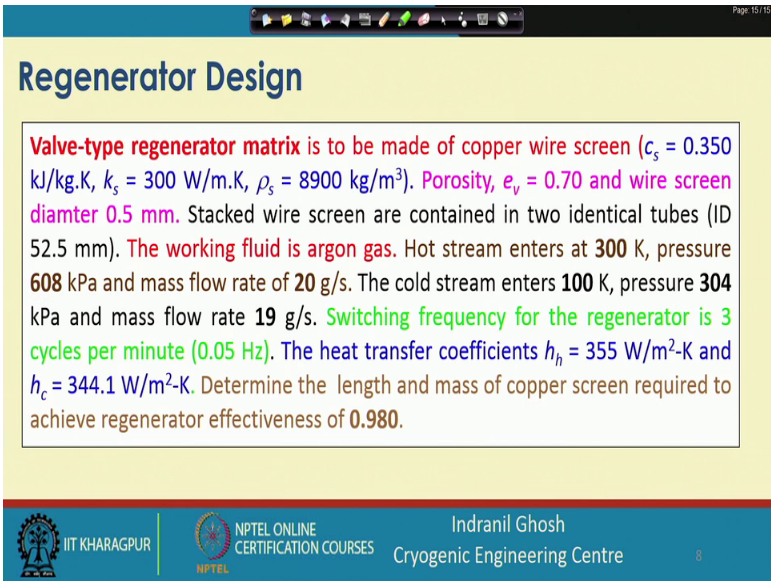

So, first of all if it is the valve type as we have said again that this is the valve type matrix, and it is made of say copper wire screen. So, this is something new to us already we have talked about the packed bed spheres, but this is about the copper wire screen, and this is used as the matrix for the regenerator.

And here once we have said about the matrix I mean material, we know its specific heat particularly at the temperature if it is specified. So, and its thermal conductivity and the density of the material is also given. So, here for this copper wire screen we have a porosity of about 0.7 and its wire screen diameter is 0.5 millimetre. So, it is the woven screen and this wire diameter is told, it is given. So, we have to find out the equivalent diameter and its expression we will remember in the previous class we have talked about it, and if it is not we will today we will discuss about that part. That stacked wire screen are contained in two identical I mean tubes so, its id is 52.5 millimetre and the working gas is argon.

So, it is already as I have told that we need to know certain more parameters like the flow rate of the fluid streams and its temperature and pressure. So, that we would be able to find out the fluid properties and here for this hot stream we know that the temperature of the hot stream is 300 Kelvin it is entering at a pressure of 608 kilopascal and its flow rate is 20 gram per second. Whereas, the cold stream is entering at a temperature of 100 Kelvin at a reduced pressure of 304 kilopascal, but its flow rate is not equal to the hot flow rate and its flow rate is reduced slightly by 19, it is 19 gram per second.

The switching frequency of the regenerator is three cycles per minute so; that means, in every you know after 3 cycles per minute the there I mean hot fluid and the cold fluid stream will change, and for this particular problem we have already specified the heat transfer coefficient, otherwise this is generally it is not known and we are supposed to find out once we have told about the wire screen and its flow rates are known. So, the heat transfer coefficient and the pressure drop or the friction factors can be obtained from the correlations corresponding to the copper screen and, but; however, for this problem we have already evaluated it and its the hot and the cold fluid heat transfer coefficients are given as h and h c.

And what we are supposed to find out is the length and the mass of the copper screen required to achieve and effectiveness regenerator effectiveness of 0.98. So, if you have to achieve 98 percent efficient regenerator effectiveness, what would be the mass of the copper screen to be used and what would be the mass or what would be the length of the regenerator that we have to specify or we have to calculate. So, these are the parameters that has been given and the procedure that we have to follow we will first look into that and then we will go about the solution of this problem.

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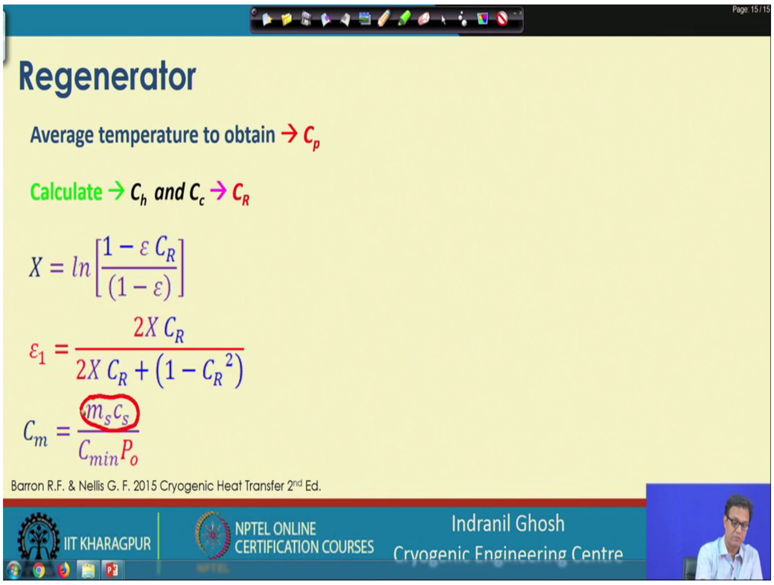

So, first of all we will try to find out what is the average fluid temperature to find out the specific heat or the fluid properties, then we try to calculate since we know mass flow rate of the fluids, hot fluid stream and the cold fluid stream. So, we would be able to find out the hot fluid capacity and the cold fluid capacity, and from there we would be able to calculate the capacity ratios here, because we know that depending on the C R value whether it is C R equals to 1 or not then our calculation will change. So, once we know the C R value and we will be if it is not C R equals to 1, then we will go for this calculation of this X parameter and given by this relation l n into one minus epsilon C R multiplied divided by 1 minus epsilon

So, from that we would go to the calculation of epsilon 1 and this epsilon 1 is again this correlation is given already we have talked about it. So, we will try to find out this epsilon 1. So now, we had an effectiveness corresponding to this C R value based on that x and this epsilon is what we are looking for? Epsilon is 0.98 we are looking for an effectiveness of 98 percent. So, from there we will be able to calculate X and we will be able to find out an equivalent epsilon 1. So, that is equals to given by this correlation.

So, once we know that we will try to now find out the C m; C m the matrix capacity rate ratio. So, this, but please note that we have for sorry we have for this parameter we need to know the mass flow rate mass of the regenerator and the specific heat of the regenerator, but unfortunately this is one of the parameter that is what we are trying to find out. So, we have no idea about this C m.

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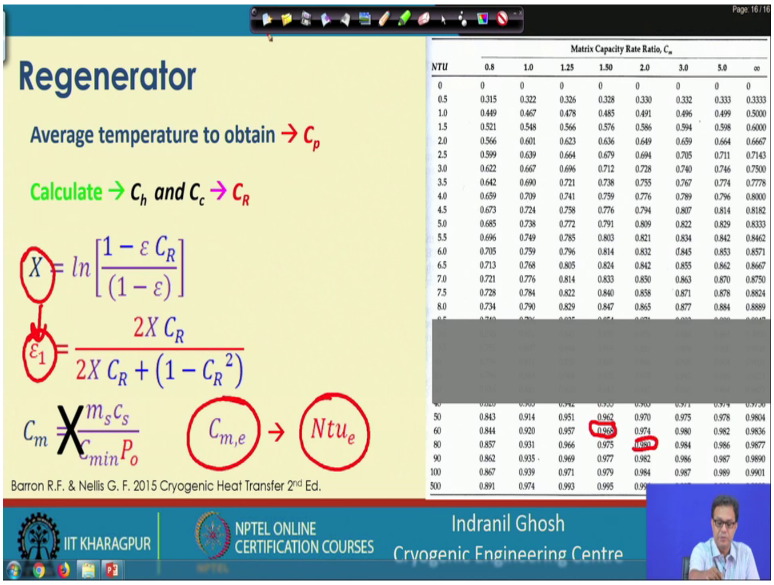

So, if we do not know what we have to do is that, we have to say we do not know about it. So, we will assume some equivalent value this one.

And from there we will you know already we have the value of this epsilon because we have already epsilon 1 we have calculated based on this parameter X we have calculated our epsilon 1, and we have assumed some value of C m e. So, once we have that C m e and equivalent matrix capacity rate ratio and then we have the value of epsilon. So, we would be able to find out the equivalent N t u. So, like you know if we have find some value of this epsilon 1 corresponding to say 0.98 or something like 0.968 for example, if we have obtained say 0.968.

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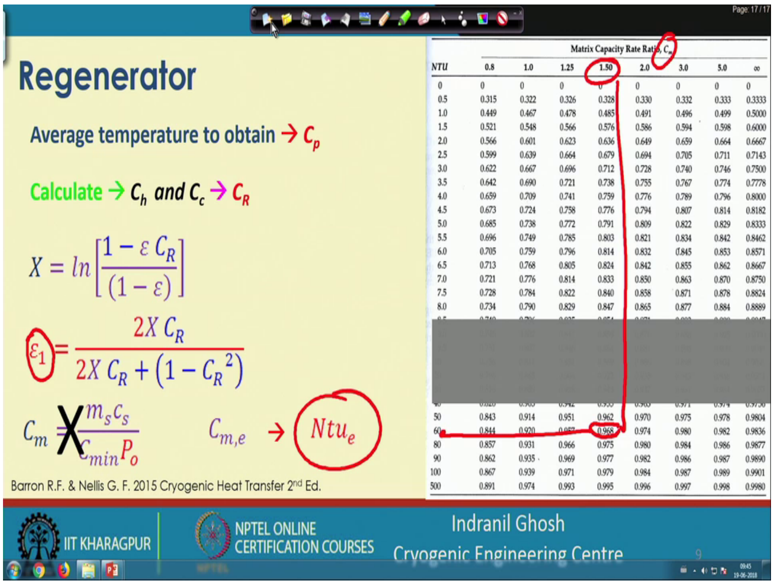

And we have assumed say value of C m e equals to 1.5. So, the corresponding N t u is 60. So, that is what is the I mean depending on the value of this epsilon 1 that has been obtained and the approximation or the assumption of C m we would be able to get some equivalent N t u. So, once we know that equivalent N t u value we would be able to calculate the N t u based on this relation.

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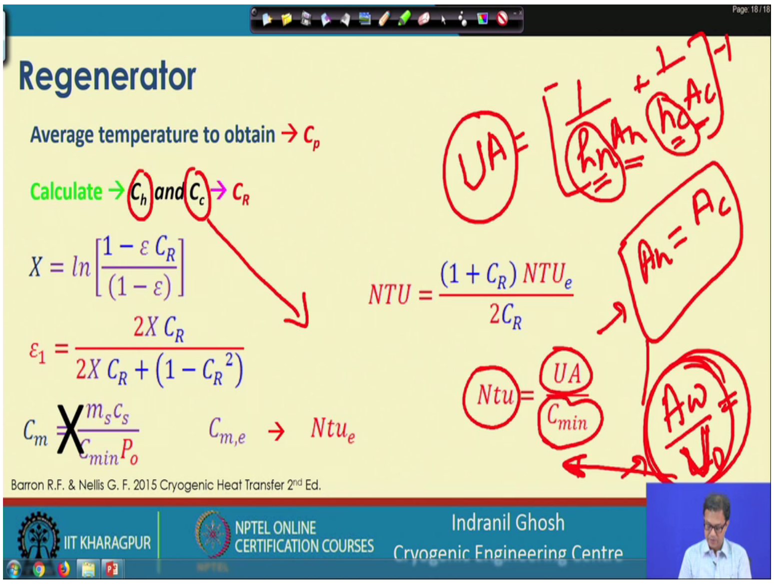

So, once we know that N t u value then we have, you know we can put it in terms of N t u equals to U A by C min and you know that this C min part is already known to us, because already we have a calculated C h and C. So, out of these two we would be able to find out or distinguish which one is the C min.

So, once we know the C min this N t u part is already known the C min part is known we would be able to calculate the U A. Now you note that this U A is basically nothing, but one by h h and a h plus 1 by h c A c whole to the power minus 1. Here most of the cases we will find that the regenerator are fixed bed regenerators in case of fixed bed regenerator this A h is equals to A c, and we can you know take out it from this outside this one and also we need to have an estimate of this h c and A h, h h and a c the heat transfer coefficient for the hot fluid stream and the cold fluid condition.

And so, accordingly as we can understand that we have already have an estimate of this U A. Since we know this U A and you know we have already knowledge about the h c and h h and h c we have the, you know we can calculate the heat transfer surface area corresponding to the hot fluid or the cold fluid stream. So, once we know this surface area we know what is the ratio of heat transfer area per length and or generally it is in terms of the A w by V 0 corresponding to the packed beds sphere or corresponding to the wire screen mesh woven screen.

So, from there we would be able to find out this is A w by V 0 is already known in terms of its porosity and etcetera and then we would be able to correlate with this V 0 will be correlated with that length and from there we would be able to calculate the length of the regenerator. Particularly for this problem we know that this a 0 by l or A w by l is given by for a wire screen type process.

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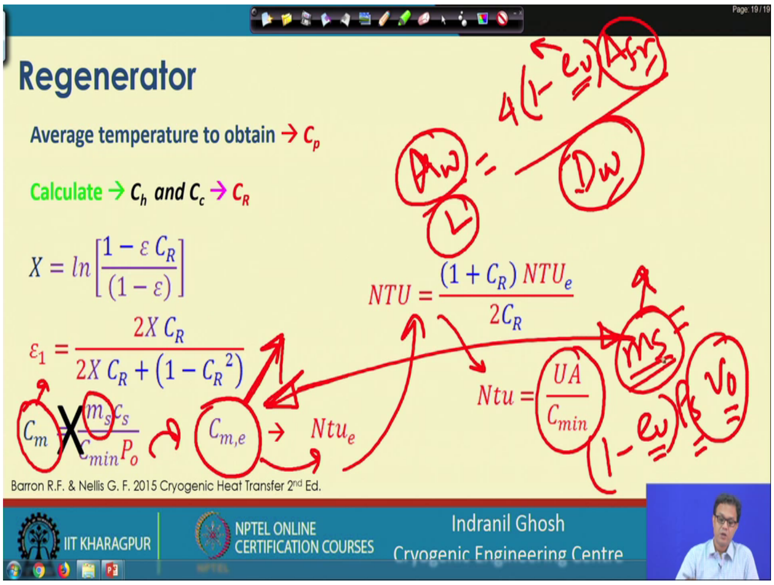

A w by L is equals to four times 1 minus e v multiplied by a frontal area divided by D w, what is this D w? D w is the diameter of the wire screen e v is the porosity or the void inside this bed and this A frontal is the frontal area of that bed. So, accordingly as we have obtained the A w and we know the frontal area we know the wire screen diameter the porosity. So, we would be able to find out the length of the regenerator. And now once we know the regenerator length we would be able to find out the m s the amount of the element or say the wire screen the copper wire screen that will be necessary. So, this is given by 1 minus e v into rho s into v 0. So, this is e v is known rho s is already been given and v 0 is the volume of the of the regenerator.

And so, accordingly we would be able to calculate the mass of the copper screen that would be necessary, but please mind that it was based on an assumption that we have assumed some value of C m e or the matrix capacity rate ratio and because we did not have an idea about this m s. So, we have done all these calculation based on some value of the m s and now we are getting some value of this m s at the end. Now obviously, we can understand that this you know depending on our initial guess, this may not be the same.

We have the based on this m s you know we will now be able to calculate a new value of the C m, and that value of the C m will give us a new value of the C m e and from there again you know we will get N t u effective and from there we have to calculate the N t u, from that N t u we will be able to calculate that U A by C min and the procedure will be repeated.

So; that means, here this process becomes an iterative process. So, based on our initial assumption of that C m our next calculation or the number of iterations that are to be done will depend. So, if we make a good estimation of that C m the number of iterations will be less otherwise, if we are making a bad estimate of this regenerator capacity C m we will land up with the different mass and we have to I mean do number of iterations to get the actual value. So, as you can understand this is the procedure for doing the calculation or the regenerator design.

So, now we will go to the slight, I mean we will try to calculate for this particular problem which we have defined in this case. So, here we have been told that we are going to use a valve screen a valve type regenerator, and this regenerator is made of this copper wire screen, its porosity is given.

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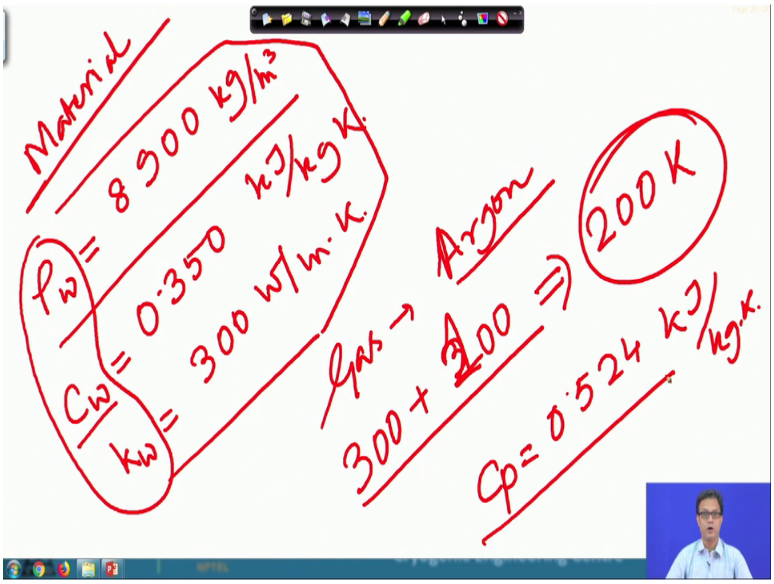

And the other parameters like say rho w that is the density is coming to be 8900 kg per metre cube this is we are talking about the copper and then specific heat C w it is also 0.350 and it is kilo joule per kg Kelvin this is the specific heat and then we have the thermal conductivity k w or k s I mean this is equals to 300 watt per metre Kelvin

So, these are the values we have for the material and once we know this material, we have to now look for as we have said that we need to look for this is for the material part or this is for the copper. And we need to look for the gas part the gas is argon and this gas is we have already said that this gas is argon, and it is entering at some temperature and pressure and it is moving out with at some different temperature and pressure. So, its inlet temperature was 300 for the hot and 200 for the cold streams. So, we will take it sorry the 100 as the for the cold one. So, it is at an average temperature of 200 Kelvin we will try to estimate its property.

And the C p corresponding to this value is 0.524 kilo joule per kg Kelvin. So, that is what is the C p value of this argon gas. So, this gaseous argon C p once we know we would be able to calculate the heat capacity of the hot fluid and that of the cold fluid.

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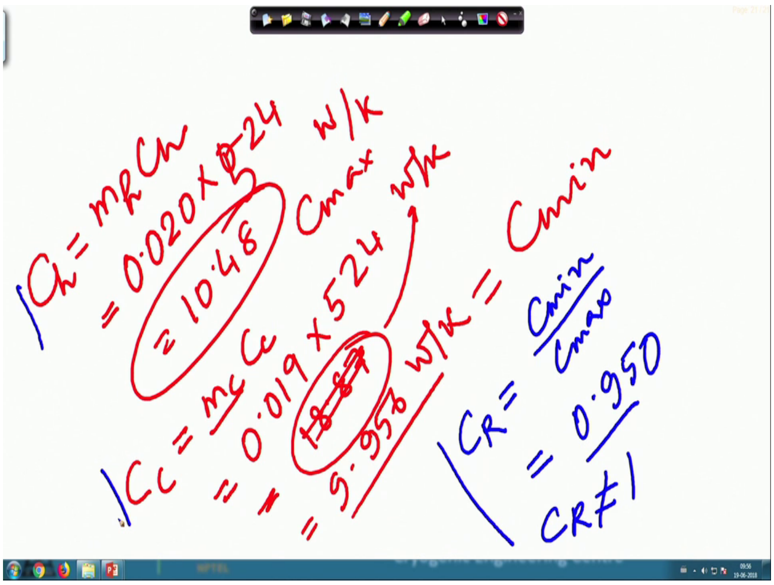

So, now we see the C h equals to m h and that will come out to be 0.02 multiplied by 524 and this comes out to be 10.48 watt per Kelvin. Similarly the C c is m C c and the mass product of this one is slightly less as we have seen this is 0.019 multiplied by 524 and this many watt per Kelvin and this comes out to be 18.87 watt per Kelvin.

So, as you can understand that this is the sorry I am sorry this is 9.956 watt per Kelvin. So, it the C min and this is the C max. So, this value is the c max value and this value is the C min value. So, we have the C min and C max and then we would be able to calculate the C R. So, this is C min by C max and from there we would be able to find out that this is nothing, but 0950. So, we have an idea about C R and C R not equals to 1. So, already we have an idea about the C. So, we have the idea of C h C c and now we would be able to calculate the X factor that parameter.

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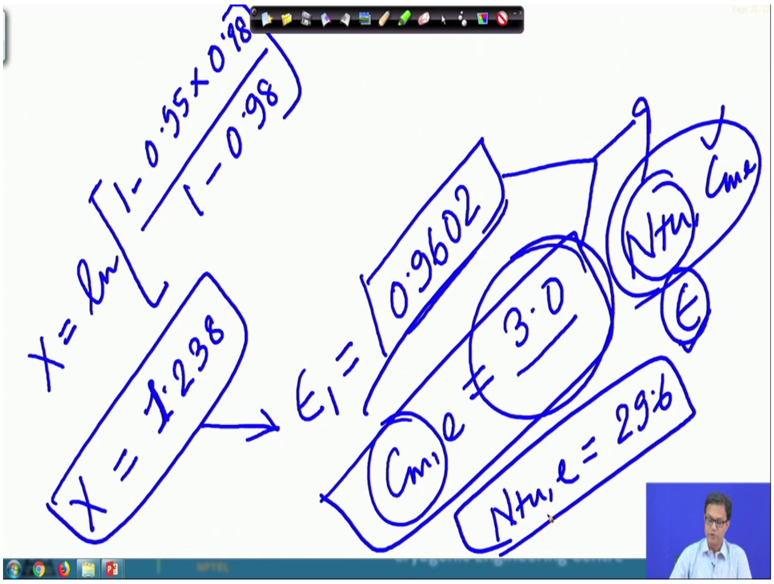

And that will come out to be we have already told about the expression of this one. So, 1minus 0.695 multiplied by this is C R multiplied by the epsilon 0.68 divided by 1 minus 1.98 that is the effectiveness. So, this X comes out to be 1.238 is the value of this X.

So, corresponding to that value if we put it in that value of the epsilon so, we get this epsilon 1 to be 0.9602. So, this is the value of epsilon 1 and at this point what we need to do is that, we need to calculate the matrix capacity rate ratio and which is not known C m as we have said that it is we have no idea about the mass of the regenerator material that will be necessary. So, will make an assumption about this C m equivalent e m e and that has been chosen as 3 for this particular problem. So, once we know that C m equals to 3 and we have an idea about this regenerator effectiveness. So, 0.960 is the regenerator effectiveness and the equivalent this capacity rate ratio is 3. So, corresponding to this two values is we will go back to that N t u and C m e relation particularly for the epsilon.

And so, we have this value we have this value we will go for this value. So, accordingly we will find that N t u if you use that chart you will find the this comes out to be 29.6. So, once this is known as 29.6 we would be able to calculate the value of the N t u.

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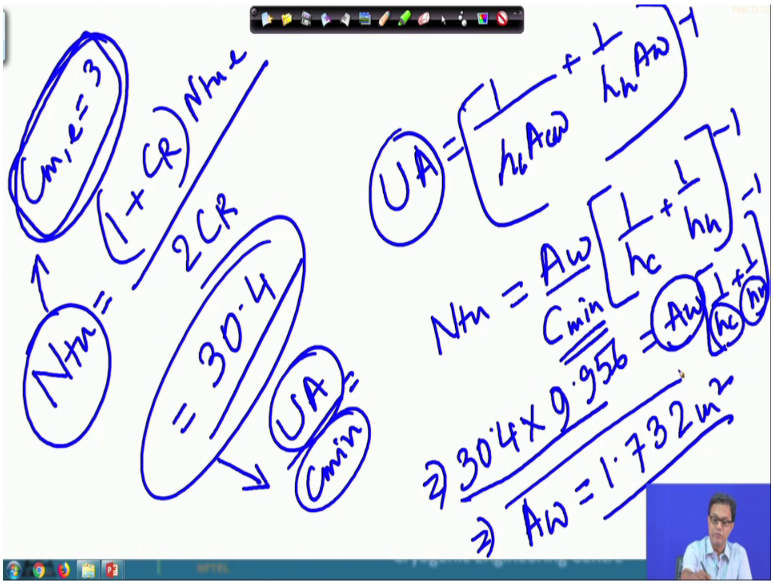

So, this N t u comes you know N t u and N t u equivalent they are related by this relation N t u effective divided by 2 C R. So, we have this N t u coming to be 30. So, 30.4 actually this is 30.4 and. So, this is the N t u value based on our assumption of C m e equals to 3. So, we are getting a value of N t u equals to 30.4.

So, once we know the N t u we would be able to calculate the it is just nothing, but U A by C min we have the idea about C min and this is you know U A would become 1 by h c A c we are calling it say w plus 1 by h h A w and this whole to the power minus1. So, already this is known. So, U A by C min C min is already known this part is known this is this will come out to be say A w divided by 1 by h c plus 1 by h h whole to the power minus 1. And if we put this value or divide this value by C min then it comes to be U A by C min that is equals to the N t u that is equals to 30.4 multiplied by C min value was point 9.956 So, that is equals to A w into 1 by h c plus 1 by h h whole to the power minus 1.

So, here if you look at you will find that already we have talked about this h h and h c. So, we can find out the A w or and from there we would be able to calculate this A w to be 1.73 meter square. So, this is what is the area needed for this particular regenerator to achieve you know 98 percent porosity. But please mind that we have made an assumption that the C m e equivalent is 3.

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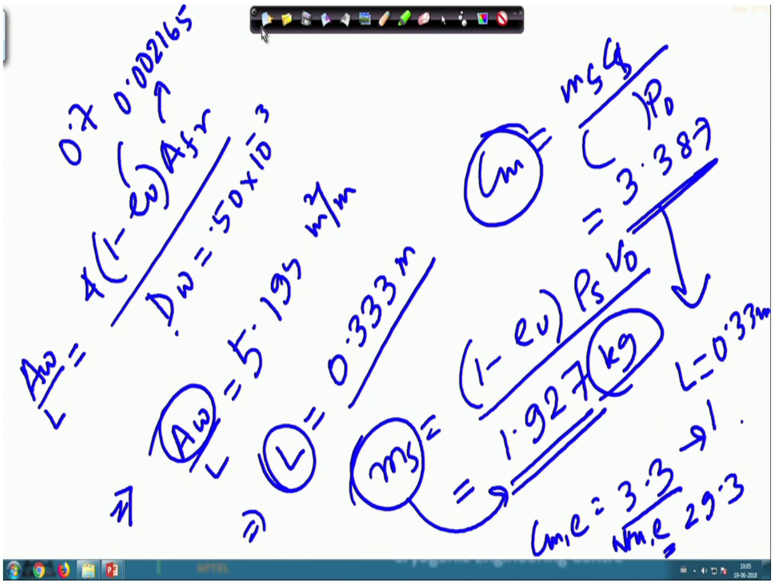

So, now, once we know the area we would be able to as we have said that we will be able to calculate the length. So, A w by L is 4 into 1 minus e v and multiplied by a frontal area divided by d w is the wire diameter.

And from there if we put all these values e v is 0.7, then we have the frontal area that also is about 0.0021635 and the wire screen diameter this is equals to 50 point sorry 0.50 multiplied by minus 10 to the power minus 3 and from that we get A w by L is equals to 5.19 5.195 metre square per metre. So, already we have the value of A w we would be able to calculate the length and it will come out to be 0.333 meter. So, this is the length of the regenerator.

So, now we have the mass that is equals to 1 minus e v multiplied by rho s into v 0 and then you know if we put this values that comes out to 1.927kg of copper screen the now this is we have an idea about the m s. So, once we have the idea about the m, we can now you can see that we would be able to calculate the C m because we know the C m equals to m s c s divided by that p zero and that other parameters. So, once we have that one we would be able to calculate the matrix capacity rate ratio, and from there we get you know the second estimate this will come out to be 3.387.

So, we have you know a quite a good estimate of this C m and accordingly you will find that C m e is coming to be 0.3 and from there you will be able to calculate the mass and. So, and there you will have this N t u equivalent to be 29.3 and finally, this length will converge to nearly about 0.33 metre or 330 mm. So, here that will correspond to a mass of about 1 point.

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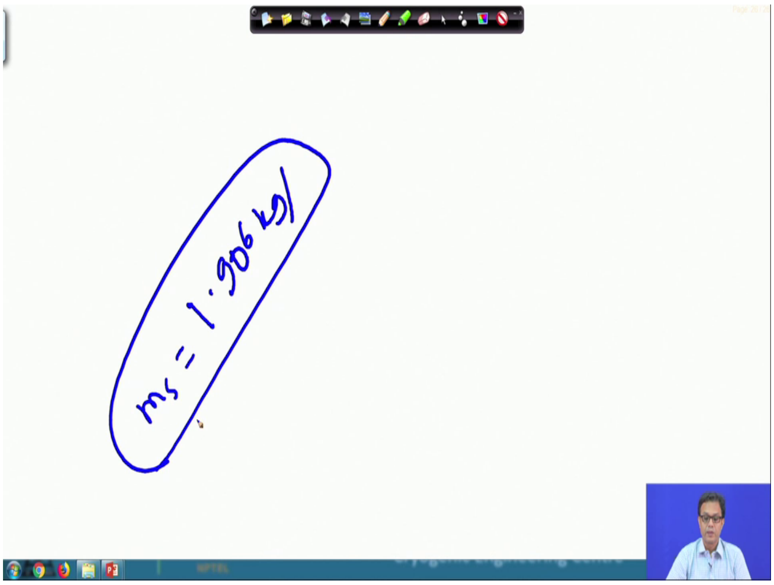

The total mass will come out to be about 1.906 kg of copper screen. So, this is a in inertial about the design of this regenerator and, but please mind that in many of the cases we will not have this idea about the this heat transfer coefficient. And we have to depend on the correlation existing correlations or we have to depend on the experimental value of the heat transfer coefficient to design this kind of regenerators.

Thank you for your attention.