Heat Exchangers: Fundamentals and Design Analysis
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Lecture – 38
Surface Condenser

So, if you recall we were discussing regarding condensers and initially I have shown you in our last lecture I have shown you a power plan condenser, which is also known as a Surface Condenser and we like to continue with surface condenser. But, but before doing so, what I like to do, I like to go back to my previous lecture because, the last slide I have told very important, I have supplied very important information to you I like to stress upon it. So, if I go to back to my previous lecture; this was the last slide of the previous lecture.

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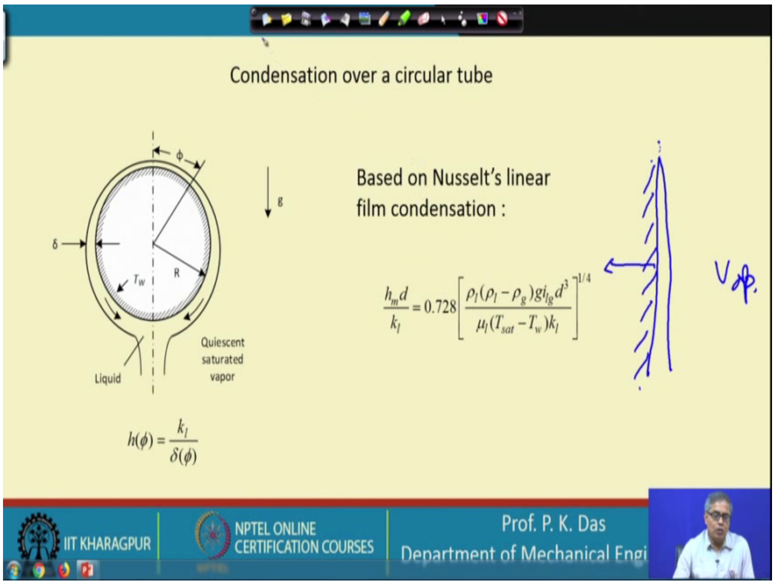

So, here you see that Nusselt film condensation; I have we have used so, let me tell a few things regarding this and then again we will go back to the current lecture. So, you see the Nusselt film condensation theory is very unique theory in heat transfer sorry so, what Nusselt did? Nusselt first did this theory for a vertical flat plate.

So, let us say this is a vertical flat plate and this is a vertical flat plate and heat is being taken from this vertical flat plate and this side there is vapor so, vapor is getting condensed. So, we will get a film of condensation like this, I have shown and exaggerated view, but this film will be really thin and then he has made quite a few assumptions and based on that assumptions he has determined what could be the heat transfer co efficient and Nusselt number and also average Nusselt number.

So, these analysis we have he has again extended for a circular tube. So, the assumptions I like to tell certain thing regarding, the assumption the assumptions are the film is really very thin. So, that there is no conviction within the thin film and it is heat transfer is only due to conduction, from the wall to vapor heat transfer is taking place only due to only due to conduction that is one thing.

Another thing that there is no seer at the outer at the interface of the vapor and liquid; that means, the vapor is almost at the stationary condition or with a very low velocity. Why I am telling these because these are all important when we will try to analyze a surface condenser. And other assumptions which he has made that the vapor is in saturated condition and the liquid film that is also not getting are cooled, these assumptions are not always quickly applicable and people have devised methods by which they can take care of these assumptions.

So, basically what you see that the film which forms on the outside of the tube is very thin, then it thickens out because all the films are collected and film is become film become thicker and thicker and ultimately as a thick stream it falls from the bottom of the tube. And you know as I have told that heat transfer is due to conduction so, this liquid film that is the conduction resistance and that goes on increasing; that goes on increasing as we move from the top most point to the bottom most point of the tube.

So, obviously, the tube will be most effective in condensing vapor at the top most point and where almost no condensation of vapor will take place at the bottom most point. So, this is important and; obviously, that for an engineer it is not good that we have got a thick field. So, I mean in there are many methods for reducing the film thickness and this is a simple formula from all the properties and geometrical parameter it has come and it is easy to use.

So, people can use this thing, with this few; word I can go back to the next slide or next lecture so, this is my current lecture which is surface condenser and if we go to the surface condenser.

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So, I am showing some sort of a typical surface condenser of a steam power plant and there are quite a few points I like to have your attention, you see this diagram which is taken from the net very carefully. So, this is showing the tube layout, first you see the tubes are laid in a very dense; configuration and the arrangement is not in line, but staggered arrangement these are all important.

So, tubes are laid out in a staggered arrangement so, this is very important and in a surface condenser of a steam power plant how the tubes will be laid out they are at different patterns. So, some of the patterns I have shown here again taking from published literature I have shown here. But, what is important and what I like you to give some more attention please it is like this that in a steam power plant steam is condensing in the condenser and steam is condensing in a condenser with the help of water which is taken from the ambient atmosphere.

So, the temperature of the cooling water could be 30 degree, could be 25 degree and in cold country it could be 10 15 degree even lesser than that. So, near that temperature if this steam has to condense then, the steam pressure is sub atmospheric pressure. So, in part of these; circulating fluid loop of a steam power plant the fluid is at a pressure higher than the atmospheric pressure and at part of the loop the pressure is below atmospheric pressure so, what will happen? Air leakage will take place inside the circulating loop; that means, when the steam will come to the condenser for condensation it will have air along with it air is a non condensing.

So, what will happen schematically again taking some sort of a figure from the published figure I have shown, this is the cooling water; what is the cooling with, green color is the cooling water, red color is the tube wall outside we can see the condensed film. But, outside there will be a layer of air; that means, the air quite dense collection of air will be there and obviously, then we do not have any vapor mass or any vapor molecule steam molecule nearby.

So, after some time the condensation will get hinder more and more air will collect inside the condenser which is not getting condensed, which is not going out of the condenser and inside air quantity content will increase. So, that will increase the pressure of the condenser so, there are quite a few things, first thing it will reduce the rate of heat transfer, some sort of a snow balling effect is there, more it reduces the rate of heat transfer, more air accumulates and there will be pressure rise.

So, if there is pressure rise then the steam is not able to expand fully. So, work done will be less and this is what we get to see in summer situation that the power plant capacity of producing work that reduces partially this phenomena is responsible for this.

Then, what is the way out? Way out is that we have to take this air out. So, there are air extraction pumps suppose this could be the location of the air extraction pump and from there air has to be continuously extracted from the condenser to maintain the back warm. And this is a typical thing, this is a typical feature and the heat exchanger designer has to take care of this when he is concerned with the design of a condenser for a steam power plant application.

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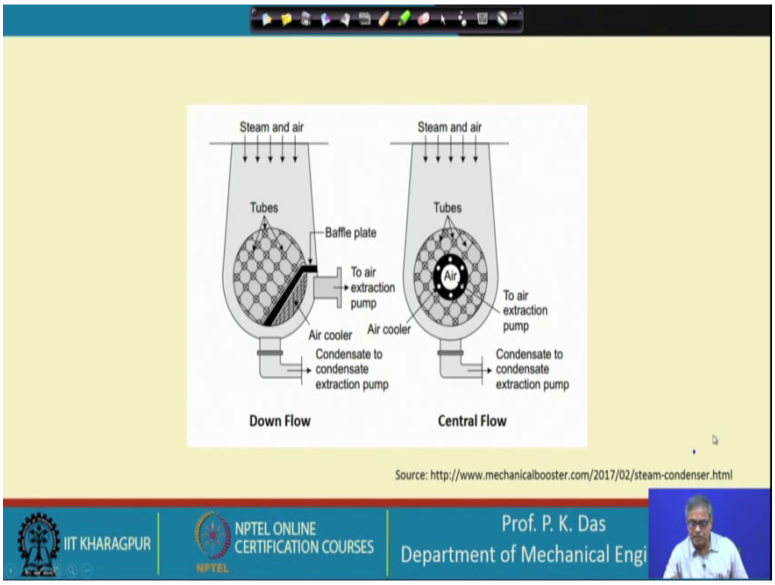

So, let us proceed here I have shown two very common situation of steam condensers and these are basically tube layout and here you see here you see, there will be some sort of some sort of greater density of cool antives. So, here we will have more cooling capacity, more vapor will be cooled and air can get separated from vapor very easily and then it will be taken out by some air extraction pump.

So, it can be taken out from this bottom portion or it can be taken out from the central portion. The main issue here is that we have to have good cooling where air extraction point is kept so, that we are not taking out vapor we are only taking out air. And also so, if you cool the air density will increase so, we have to handle lesser amount of air volume. So, that is also a secondary point so, this is one of the very unique design feature of our surface condensers.

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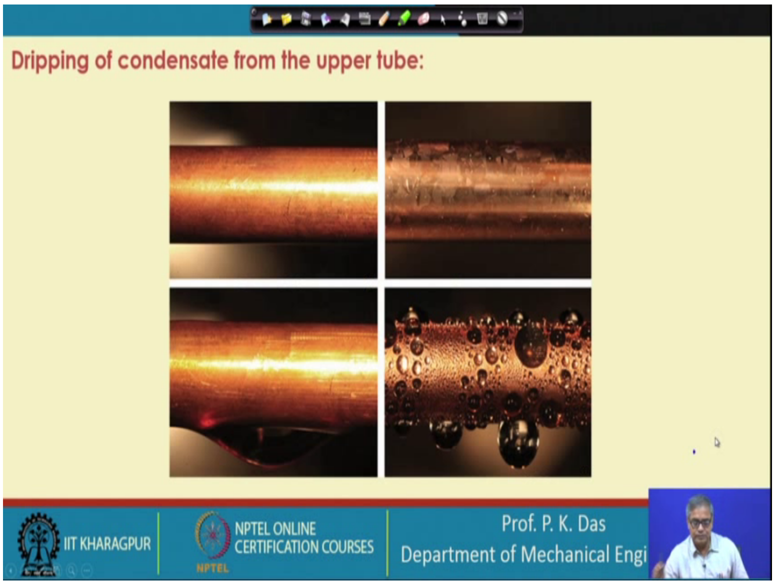

So, let us with this let us here I am showing this figure once again, I have shown it in my earlier lecture here I am showing it once again. So, as I have told that though we like to have drop wise condensation for obvious reason of very high rate of heat transfer, we are unfortunate that we cannot sustain drop wise condensation on commercial tube surfaces. There are certain tubes which are costly clean environment they can be used and they can sustain drop wise condensation for longer period lot of research is going on, but that is not for your steam condensers, steam power plant steel we have film wise condensation.

So, if we have got film wise condensation water film or condensed film is forming. Then where that condensed film will go? Due to gravity it has to drain that is what is has been shown here. Now, if it drains what happens, where it will fall? It will fall in the hot well of the condenser ultimately which I have shown in our earlier lecture, but before that it will fall on the tube which is right below it what is the effect so, let us see what is the effect of it.

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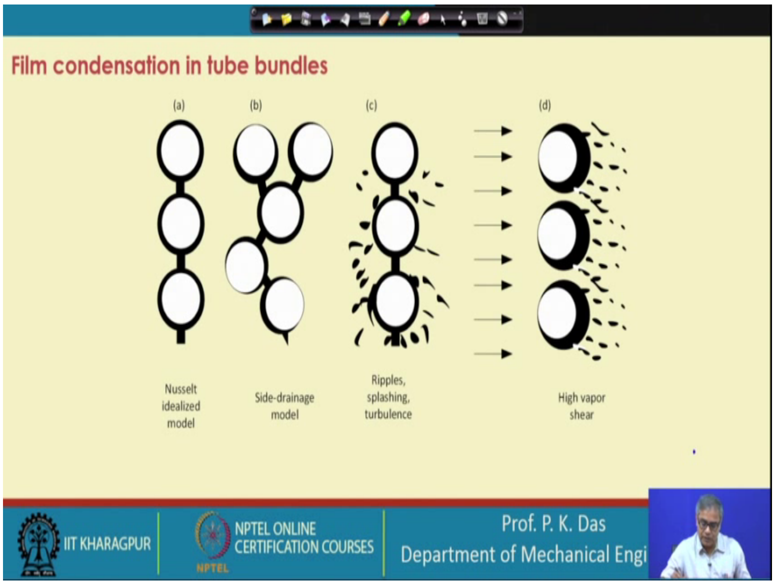

So, the effect has been shown here this is a tube row you will appreciate I have shown you the cross section of a power plant heat sorry, condenser that how many tubes are there? Very large number of tubes are there, one tube below another tube below another tube like there. So, many tubes are there.

So, if so, many tubes are there let us say this is the first tube of a particular tube column. Then here the condensate grows that condensate will fall on the top of the next tube, what I have told at this point the tube has got the maximum capacity of condensing steam here the film is thinnest. For the next tube I am killing this opportunity because, the film from the tube above is falling on it and the film is already thicker here not only that everywhere the film will be thicker.

So, whatever heat transfer I will get from the top tube I will not get from the second tube. Whatever heat transfer I will get from the second tube, I will not get from the third tube like this, this is called film condensation I mean this is film condensation in tube bundles and this is what happens. Now slight; belief from this situation one can have, if we have this kind of a tube layout which is staggered layout, but in staggered layout also we cannot solve the problem fully.

If there is lot of vapor activity and if this film falls with a high velocity then there will be ripple, splashing, turbulence, etcetera so, probably the situation will be something different. And if there is a vapor flow across the tubes then it can take care of the liquid condensate, but even then on the backside there will be some accumulation of condenser.

So, this is one thing which deteriorate the rate of heat transfer of a condenser tube, this diminishes the rate of heat transfer of a condenser tube and we are not concerned with one tube or see if we see again I will take you back to some figure earlier. So, here if you see how many tubes are there from top to bottom very large number of tubes are there so; obviously, what is happening to a particular tube we should not be bothered what is happening the overall heat transfer considering all the tubes that should be our consideration.

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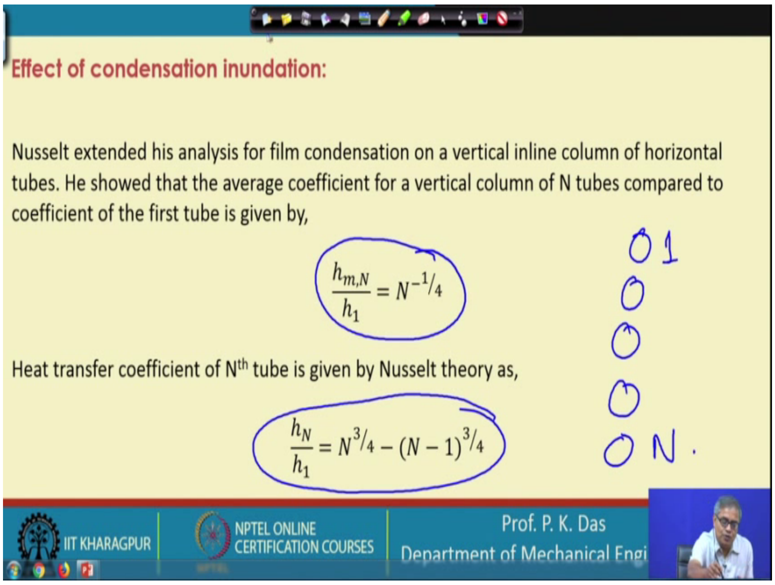

And for that what we have to do the plain analysis of Nusselt which we have done that is inadequate. So, there is one phenomena called effect of condensation in inundation, what is that? That from the top tube film is falling on the tube below it and changing it is heat transfer capability.

Again Nusselt analysis we if we proceed with let us look into the; let us look into the last diagram sorry last equation second equation of this let us say the first tube has got heat transfer co efficient h 1 and Nth tube has got a heat transfer co efficient of h N. So, h N by h 1 is given by this particular formula, it is dependent depending on the which number of tube we are considering from the first tube.

And then considering all such tubes the average heat transfer co efficient for N number of tubes vertically one after another vertically one after another, we are considering N number of tubes vertically one after another this is our number 1 and this is our Nth tube. Then for all the Nth tube taken together the mean heat transfer co efficient is given by my given by the formula this one, this is from Nusselt analysis. So, you see our heat transfer co efficient will reduce and these we have to take into cognition otherwise our heat exchanger design will not be proper.

So, why I am telling all these things because when we will try to design or rather we will try to see the design, see of a heat exchanger taking an example we will consider all these kind of things. Here let me tell you that in this kind of a class or other in the classroom any class the heat exchanger design cannot be taken to it is fullest extent. You can understand the complexity we will take some example to analysis method towards design that is what is the solid purpose of the course that can be explained to some extent, you can be familiarized with different issues. Otherwise in a practical design of a condenser it will be really difficult and; I mean it is quite a few activities iterative procedures which cannot be taken care of in a classroom teaching.

But we will try to supply the critical issues crucial points and the physiques which goes behind it particularly from the heat transfer and from the fluid flow point of view. So, continuing with the inundation of condensation if we go to the next slide.

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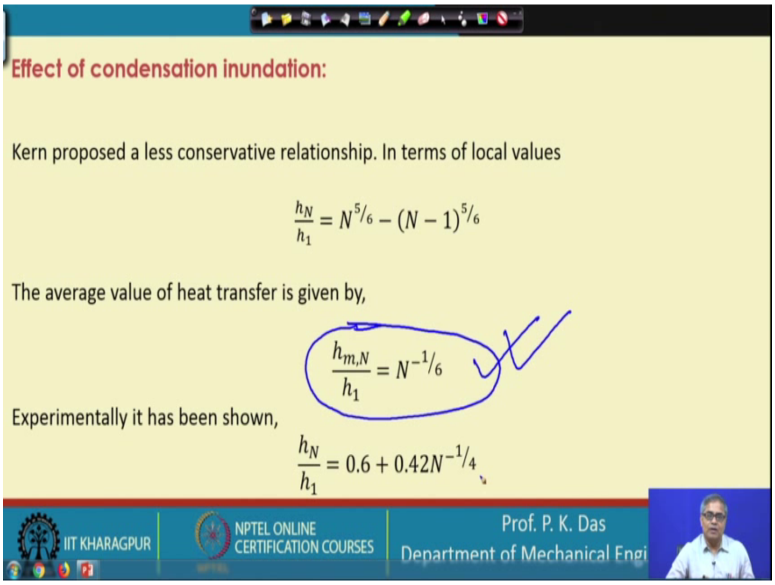

So, Kern has proposed actually Kern d q Kern he has got one very he is a stalwart in the field of process equipment and he has got one book which you may refer also that is process heat transfer and heat transfer equipment designs are discussed there. So, he have given a less conservative relationship, where the first relationship gives that Nth tube what will be the heat transfer co efficient and the second relationship that gives that how the average heat transfer co efficient for all the tubes if there are N number of tubes we can determine.

So, that means, the first tube analysis will be done by Nusselt analysis and then for average heat transfer co efficient we have to reduce the heat transfer co efficient obtained from Nusselt analysis. And the factor by which it has to be reduced is given by the formula show in the last slide and it can also be from the formula it is shown here and then experimentally people have got some value.

So, the experimental value is like this and you see experimental value is having some sort of a constant plus some sort of a power of N, where N is the number of tubes in a particular column. So, this is regarding inundation of the condensed film and which is very important when we will consider the condensed design so, we will keep it in mind and let us cross it.

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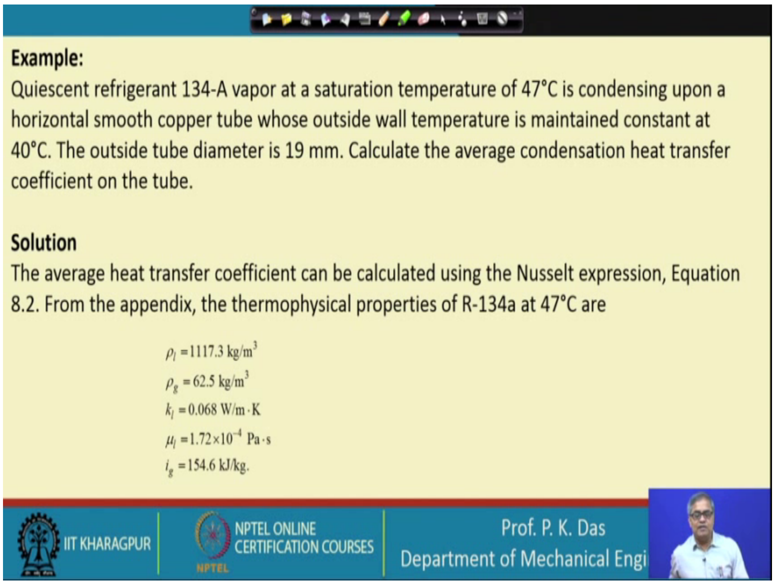

So, next slide I like to give one problem for practice, this is a very simple problem we do not have any complexity in it, but even then; there should be some sort of a there should be some sort of a; practice of what we have learnt. So, that is why I have picked up this problem so, it says quiescent refrigerant 134 A vapor at a saturation temperature of 47 degree Celsius is condensing upon a horizontal smooth copper tube whose outside wall temperature is maintained constant at 40 degree Celsius. The outside tube diameter is 19 millimeter. Calculate the average condensation heat transfer co efficient of the on the tube.

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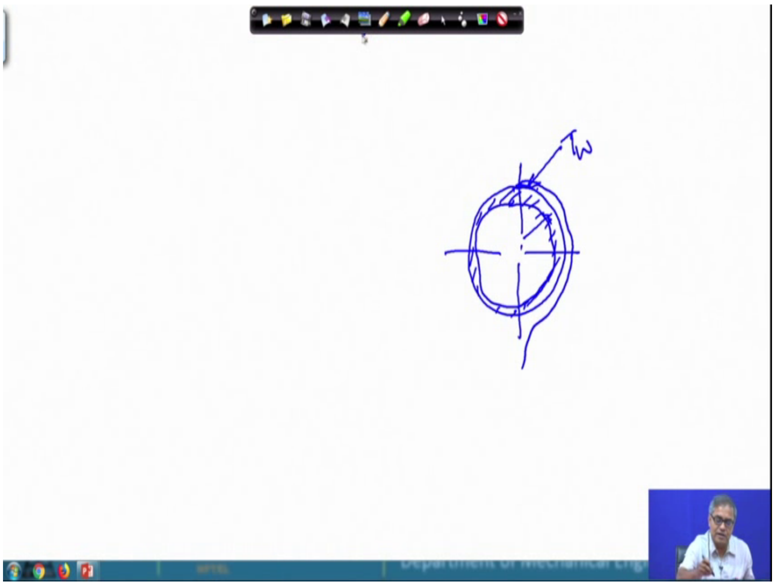

So, basically if we try to look into this problem so, basically what we are looking into let us say we have got one tube. So, this is our tube let us say some coolant is passing through the tube and the coolant is passing with sufficient velocity etcetera. So, that the outer wall temperature is kept constant this is T W so, that is kept constant this is actually TW wall so, that is kept constant.

So, this is also one assumption of Nusselt condensation theory so, Nusselt condensation theory that assumes that condensation takes place over a over an isothermal surface. So, this is also another assumption so, as we have shown earlier the condensed film will be something like this and this. So, condensed film will grow and Nusselt analysis has given us the value of average film thickness over the surface over the tube surface so, directly we can use this.

And then if we go back to our previous the average heat transfer co efficient can be calculated using Nusselt expression equation some equation number we have given which is irrelevant, but the equation which I have told you. This is from some source we have taken this data the thermo physical property of R 134-A at 47 degree Celsius are given here this is from some source.

So, basically this problem has been taken from the book of Kakac the heat exchanger book whose reference I have given. So, from there this has been taken I showed the properties that has been taken from that book. So, what are the property? Liquid refrigerant density, refrigerant vapor density thermal conductivity of the liquid refrigerant viscosity of the liquid refrigerant and the, I mean the enthalpy that is also given that should be the latent heat of the vaporization that that is also given.

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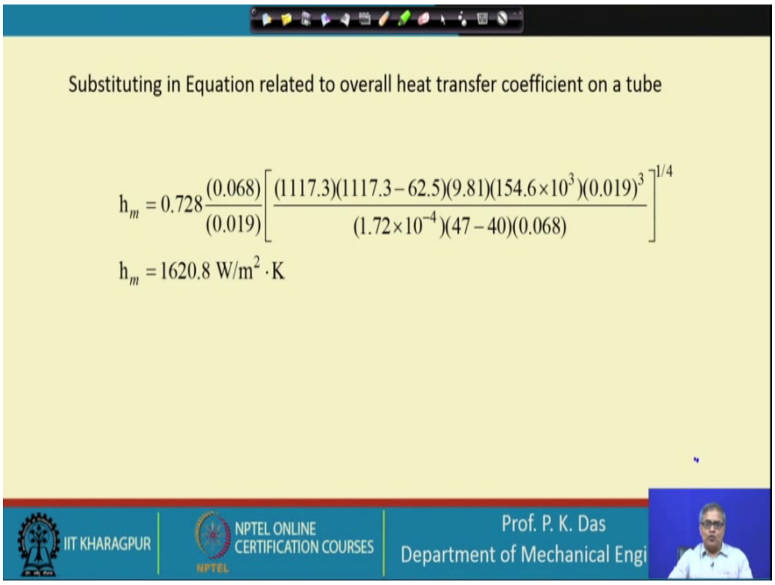

Then substituting the equation related to overall heat transfer co efficient this is just one line. So, we will substitute this one and we will get the mean heat transfer co efficient like 1620.8 watt per meter square Kelvin. So, this is simple guess to show how to use this thing which properties are relevant and this is what we have done and probably this kind of problem you have done already in your heat transfer course, but before going to a really difficult example we like to solve this problem.

With this we will come to an end of today's lecture and then we will proceed we have seen condensation on a single tube then we will see on multiple tube and probably we will go to a heat exchanger particularly the thermal aspects of heat. So, some of the points which I have told are very important please have a look into that inundation of condensation inundation in condensation particularly when there is a column of tube that is very important. Because, that has got it is effect on entire condenser design and particularly relevant for steam condenser design. So, this is one point I would like you to give an attention and probably you can also; look into literature from internet to know more about it.

Thank you.