Heat Exchangers: Fundamentals and Design Analysis

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Lecture - 37
Phase change heat exchangers (Contd.)

Hello everyone. So, we were discussing heat exchangers involving phase change. So, at least one fluid of a two fluid heat exchanger or multi fluid heat exchanger will change its phase within the heat exchanger. So, those kind of heat exchangers are called heat exchanger phase change heat exchanger or two phase heat exchangers. Now, this also we have told that our concern or focus is for liquid to vapour or vapour to liquid phase change that means the two mechanisms boiling and condensation, and for that matter in some cases it could be evaporation also. So, these are the mechanism which we will consider for phase change and which are prime importance for phase change heat exchangers.

So, what we will do in this lecture we will start with boilers and condensers that means, what are the classification, what are different types of boilers and condensers available in the industry used in practice so, those we will discuss at the beginning. And then gradually, we will go how the heat transfer takes place may be we will touch upon little bit of fundamentals regarding boiling and condensation. And then of course, take examples to see with these fundamentals, how one can build up the design principle for this kind of heat exchangers. We will take up condensers first and then we will go to boilers or evaporators.

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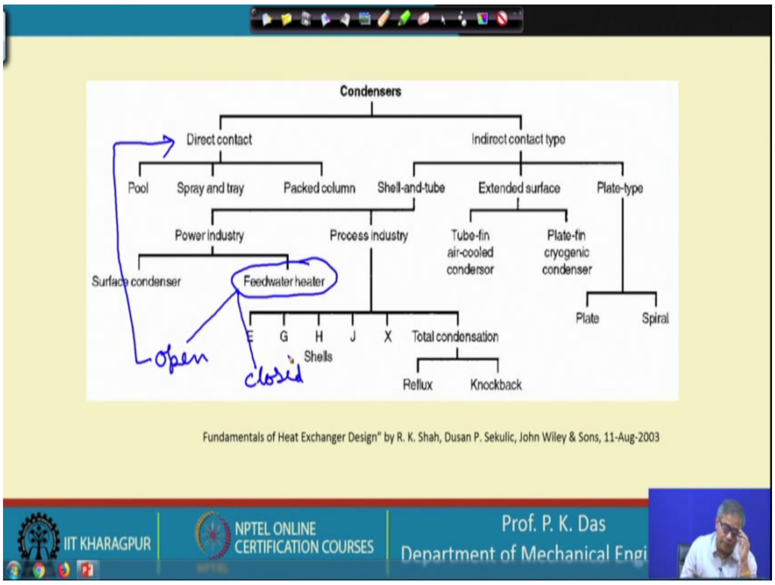

So, let us first start with some sort of a classification of this phase change heat exchangers. So, first we see the condensers, so condensers the classification the way the classification has been shown that it is direct contact, you see this is two main classifications are direct contact condensation and indirect contact type. Again let me tell you in direct contact condensation the coolant and the vapour they will come in direct contact. That means, you see condensation during condensation, if you recall our earlier lecture in condensation the fluid stream, which will be condensing that will give up heat, it will give up latent heat from vapour phase, it will come to the liquid phase. And to take up this heat given up by the condensing phase another fluid is needed that is the cooling fluid.

So, now, if the cooling fluid and the vapour, they are in direct contact then those kind of condensers are called direct contacted condenses. So, there could be pool type condenser, there could be spay, spray and tray, type condenser and there will be packed column type condensers. We will come back to these things sometimes afterwards to give some over view of different kind of condensers, probably once again; we will refer to this diagram also. But now before we start the process of condensation one should have some idea regarding condensers, so that is why I am giving the classification.

Then as I have told during my introductory lectures that direct contact heat exchangers are not many in number, rather indirect contact heat exchangers are quite often seen and used in industry. What is indirect contact? Let me recapitulate once again here between the two fluid stream there will be some sort of a solid wall. So, in case of condensers also vapour and the cooling fluid they will be separated by a solid wall. So, direct contact, indirect contact type condenser as we can expect there could be many variation. One of the main variation of indirect contact type condenser is shell and tube type condenser.

So, shell and tube type geometry we know already, we have studied it in introductory lecture I have told. So, shell and tube type condenser, sorry shell and tube type heat exchanger there will be number of tubes and these tubes through this tube one stream of fluid will passed and then this tubes will be exchanging with another fluid stream, which will be contained within the shell.

Now, the question is very pertinent question one may ask that whether the condensing fluid will be on the shell side or the or the cooling fluid will be on the shell side now these depends on this depends on application. So, in some cases we will find that the condensing fluid will be in the shells shell side and in some cases of course, it is possible to have the condensing fluid in the tube side. So, both are possible and when specific examples will come I will again refer to this point now shell and tube type of heat exchangers generally they are these are big heat exchanger they are not.

So, compact, but for big capacity where space etcetera are not restricted large amount of heat load has to be taken care of so shell and tube heat exchangers are used. So, in power industry we have surface condensers and we have feed water heater. So, let me explain these two things we know in a stream power cycle in a stream power cycle. So, in the boiler the water is heated to produce stream this stream condense says in the turbine to produce work, and then the exhausting from the turbine, which is at a low pressure and low temperature is to be taken into a condenser and these condensers are called surface condensers. So, this see surface condenser very often they are used for condensing stream in a stream power plant.

As we proceed the I will show you a schematic diagram of a surface condenser we will solve problem pertaining to this kind of condensers. So, you will get to know more about it. But at this moment let me tell you this is very important for steam power condenser where steam is getting condensed. We used in most of the cases water as the coolant. So, basically one side there will be a condensing vapour in the heat exchanger, and another side there will be a single phase liquid that is nothing but water. In certain odd cases suppose arid zone, desert zone we have got the earth of water. So, in some odd cases what we can have, even we can have very large air cool condensers, but that is that is very rare kind of application.

So, we are having condensers where steam is the condensing fluid, and water is the coolant for power plant condensers. Now, this is important that water will be passing through the tube side, and steam will be passing over the tube. Again I will try to show you different diagrams etcetera photographs etcetera take I mean taken from the net, so that you can get a good idea how the process take place. And this condenser where condensation is taking place on outer surface of the coolant tubes is called surface condenser. So, specifically this name is used for steam power plant condensers, but any type of condenser were condensation is taking place outside the tube then we call it surface condenser.

So, when I tell this thing it is clear to you that condensation can take place outside the tube condensation can take place inside the tube also. We will see both the cases as we proceed. Then we are having feed water heater. So, you should have most of you must have gone through some course of power plant or you have got some basic idea of power plant. So, in the power plant in large power plant particularly for utility power plant which is generating electricity, so we go for feed water heating.

From the condenser whatever feed water we get that is raised to a high pressure with the help of a pump, but the temperature saturation temperature corresponding to that high pressure is I mean really large and that temperature we do not get at the outlet of the condenser. So, the liquid water has to be heated to the saturation temperature. So, this can be done by different method by the flue gas can be done, but it can also be done with the help of steam taken from the turbine and this kind of heaters are called feed water heaters.

So, feed water heaters basically then we are taking steam that steam is condensing and heating the feed water. So, basically this is also kind of a condenser construction wise it may not be identical to the main condenser of the steam power plant, but many of the features are similar to what we are having in our main condenser of the steam power plant. But at this point let me tell you the feed water heater there could be two types of feed water heater open feed water heater and close feed water heater.

In open feed water heater steam and feed water they come in direct contact and then that becomes some sort of a direct contact condenser which I have described just at the beginning. So, the feed water heater here let us say this is having two types one is your what, one is your, open and another is your closed, so when it is closed it is your indirect type heat exchanger and when it is open, so it is nothing but your direct type direct contact type heat exchanger. So, to some extend I will try to touch upon this points.

But at the beginning, let us have some, let us have some basic idea then we are going to process industry in process industry lot of shell and tube heat exchangers are used for your condensation, and you see if we see the history of the development of heat exchanger, we will see from the very early days shell and tube heat exchangers are being used as condensers. So, here you see in the classification there are E, G, H, J, X etcetera these are different kind of shell designed in a shell and tube heat exchanger.

There are tubes and there are there is a shell and in the shell we have got different kind of features internal features. So, that we can have different kind of flow arrangement and E, G, H, J, X these are actually different kind of shell arrangement. So, let me tell one thing here from where they come.

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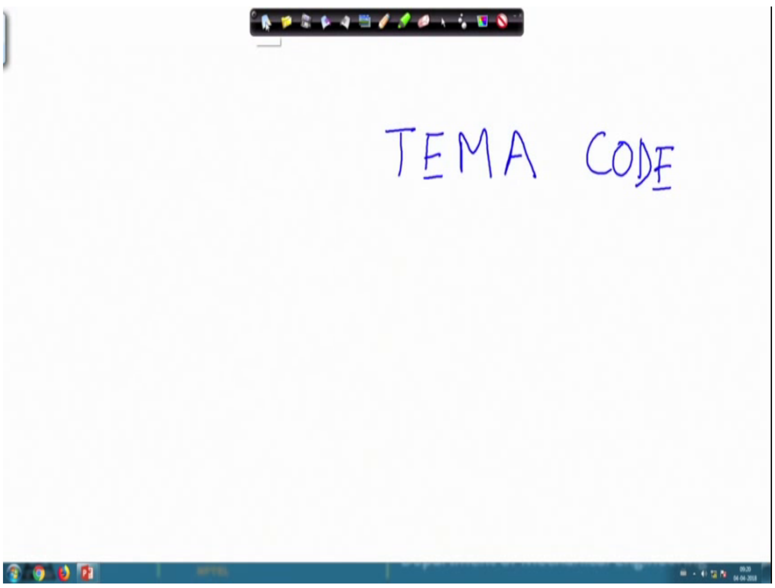

So, there is a standard which is known as TEMA standard TEMA code or TEMA standard. What TEMA stands for, TEMA stands for please I mean note it carefully tubular exchangers manu Tubular Exchanger Manufacturers Association. So, basically this is an association which has developed lot of codes and standards for heat exchangers particularly tubular, and very particularly for shell and tube heat exchangers and there are design codes etcetera.

There are I mean suppose somebody is a practitioner in heat exchanger somebody is a design engineer heat exchanger engineer, he should be very thorough with the TEMA code TEMA standard and particularly, which we will not cover in this in this course that is the mechanical design some, some sort of manufacturing aspects mechanical arrangements seals gaskets etcetera supports. So, everything, if somebody wants to find some sort of a single solution or a entire solution of the heat exchanger design one cannot, but to consult the TEMA code.

So, in the TEMA they have got different standard shell configurations and these are these are indicated by capital numbers what I have mention earlier. So, so those are different kind of shell structures and, and E, G, H, J, X etcetera some of them I will not all of them, but at least some of them I will we will see later on. And then total condensation.

So, one is called reflux and another is called knockback again for the time being I like you to know only the name probably reflux condenser, we will touch upon to show what is a reflux condenser. So, what we can see shell and tube heat exchangers are one use is your power plant and another use there are in different, they are used in different chemical and process industries petroleum refineries etcetera. And different kind of designs are possible.

Now, let me tell you in case of large air conditioning plant particularly for chillers etcetera shell and tube heat exchangers are also used. Then we have got other design, design other than shell and tube design. So, we have got extended surface that means, fin tube fin tube fin heat exchangers are very widely used in air conditioning and refrigeration application very widely used. So, already we have taken some sort of a fin tube heat exchanger example where condensation is taking place and we have solved that problem. So, you can remember from there, so tube fin is one kind of example.

And they plate fin is another kind of example air liquid (Refer Time: 17:00) cycle etcetera in cryogenic lot of application of plate fin heat exchangers are there. Then plate type heat exchanger and both we have got gasketed plate and spiral plate kind of heat exchangers are used for as condensers. So, we can see there is a very large variety of condensers; all the condensers I will not be able to discuss in details, but let me at the beginning you should have some idea that what are the different condensers, some of them I will take up in detail and some of them I will cursorily discuss.

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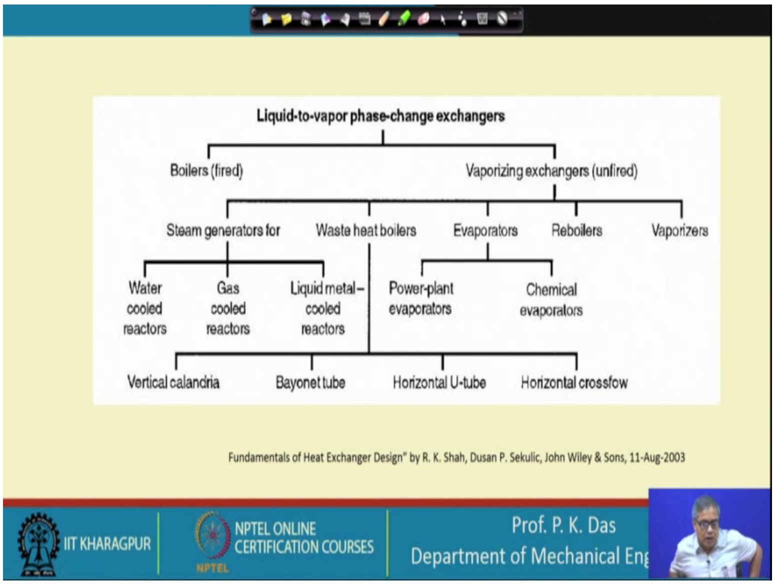

Now, let us go back to the next slide as we are doing discussion some for condensers, you should be curious to know what could be different kind of classification for boilers and evaporators. So, I will be very brief here, because probably I will refer to this diagram once again when some of the boilers etcetera I will teach in detail. But for the sake of completeness when we hive discuss different classification of condensers; let us have a look into different types of boilers.

Let me tell a word of question which I will use number of times that the classification etcetera are we are showing this classification just like the previous classification is taken from the book of R. K. Shah and Sekulic. These classifications are not exhaustive one may have a different type of classification this classification may not contain a particular type of condenser and evaporator. Because the varieties of heat exchangers are so many that whatever way we try to classify them, we may miss one or two very very unique kind of heat exchangers.

So, here what we see that boilers when we talk about boilers or evaporator the first thing we the that comes in our mind is the boiler of a power plant. And boiler of a power plant is a fired heat exchanger. So, this you have to remember that in side we have got some sort of a firing arrangement or in other words what I can tell that in most of the cases the furnace and the heat exchanger they are combined into a single component design, very intimately combined very intimately combined, so that is why its stands apart from other heat exchangers.

Probably I will show you some figures etcetera, but I will not discuss in details the design or analysis aspect of boiler, for that there cloud be some sort of a different forum or different course, because this is completely, I mean design principle is many way different from the design of the other heat exchangers.

So, that makes our life simple, if we separate it out then vaporizing exchangers unfired, so we have got steam generator even without the fire boiler we can generate steam. Then particularly nuclear reactor, so water cooled nuclear reactor, gas cooled nuclear reactor, liquid metal cooled nuclear reactor. And then waste heat boiler from the industry we get waste heat boiler. So, there could be different kind of design some of them I will show. And nowadays another kind of boiler which is coming which is not there in this list that if we have combine cycle power plant than we can have HRSG heat recovery steam generator, so that is not there in this particular list, so I may be some of the coming lecture I will spend some time on that.

Then there could be evaporator, then power plant evaporators are there, and then chemical evaporators chemical process plant evaporators are there. Then reboilers are there and vaporizers are there falling film evaporators are there. So, this is kind of a classification which is not I should say very complete, but it gives an over view of the different kind of vaporizers and boilers.

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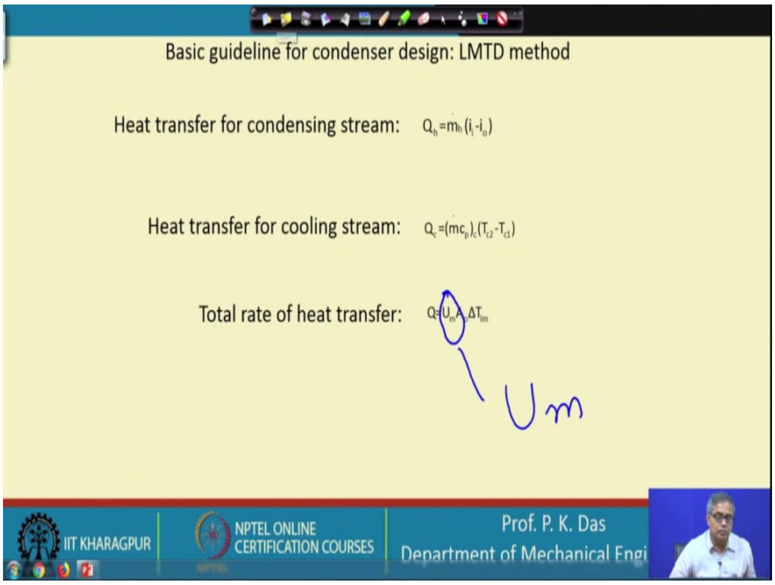

With this the basic guideline for now as I have told that we will spend some time on analysis of condenser. And first what we take is shell, and tube type condenser shell, and tube type heat exchangers are quite common, we have done its design the analysis for shell and tube type condenser is not different from that, not very much different from that. And they as this is the mostly used condenser configuration. So, we will spend some time on it.

So, this is just a recapitulation, you will find that I am telling nothing new, I want to impress upon you the basic design principle for any shell and tube heat exchanger is same. For condensation some unique issues will come which will take care of. Suppose the first equation itself is slightly different heat transfer of the condensing steam, so that is the mass flow rate of the condensing steam will be hot steam.

So, m dot h into the enthalpy difference, because if it is condensing over the entire heat exchanger throughout the length of the heat exchanger, then its temperature will not change, but definitely its enthalpy, enthalpy of per unit mass that will change, because the vapour content will change. Initially there will be more vapour content in 1 kg of the condensing fluid, later on there will be less vapour content in 1 kg of the condensing fluid. So, the vapour content will change and that is why it is by enthalpy.

Heat transfer equation for the cooling fluid stream that will not be much different, because it is not changing its phase. The total rate of heat transfer will be given by mean over all heat transfer coefficient. Why mean, because the overall heat transfer coefficient may change along the may change U m, because it may change over the length of the heat exchanger, so that is one thing we have to take care of.

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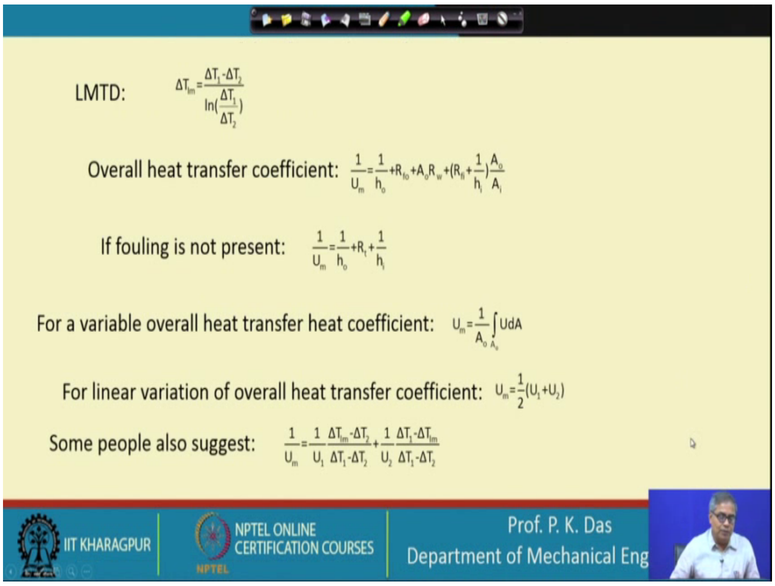

Then if we go to the next page, LMTD we will get overall heat transfer coefficient this is the standard formula. And, if the fouling is not present, then this standard formula can be can be simplified. For a variable overall heat transfer coefficient, we have to determined U m by this particular thing I am giving two formula which are not very unique, but one can used, if there is a variation of the overall heat transfer coefficient. If there is a linear variation of overall heat transfer coefficient; obviously, knowing the U at the inlet and outlet and averaging we can get; if 1 by U m and delta T they are linear, so then one can use this kind of a formula. All these are good, if U does not very drastically over the length, if it varies very largely over the length. Then of course, we cannot do anything.

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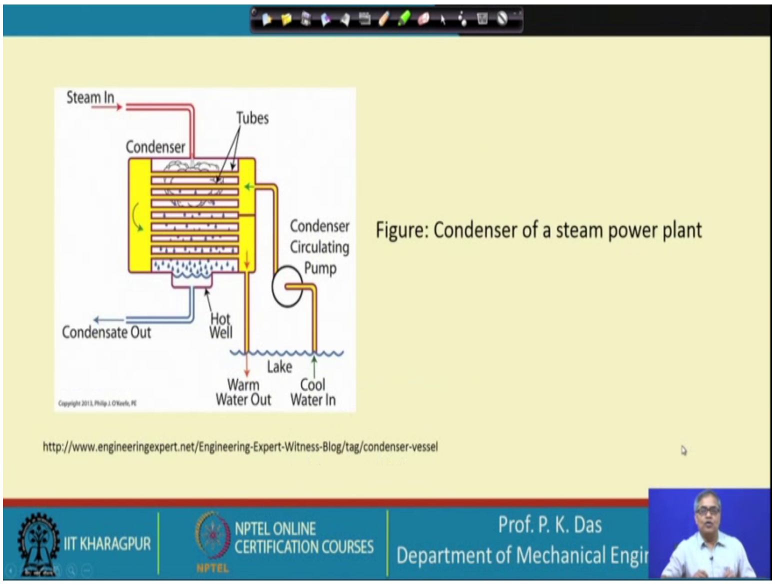

So, first we taken example of a steam power plant condenser. So, this is a surface condenser of a steam power plant. So, here you see the vapour is passing through the shell side over the tube and liquid is passing through the tubes. So, let us say this is the liquid water is being pumped, it is passing through this tubes coming back and here, and then it is going out. And vapour is coming from the top, and on the tube there is condensation, and then the condensate is getting collected in some sort of a it is part of the heat exchanger, but some sort of a well which is called hot well, and from there condensate is being taken out ok.

Because here it is in the droplet form, so there should be some sort of a height of the condensate before it is pumped out. So, this is pumped out like this. So, condenser of a steam power plant this is called a surface condenser. Here, what, what is important to note that the condensation is taking place outside the tube, what has been shown is a schematic diagram generally this steam inlet is much larger to reduce the velocity it is not like this, but it is a schematic representation. So, let us go to the next slide.

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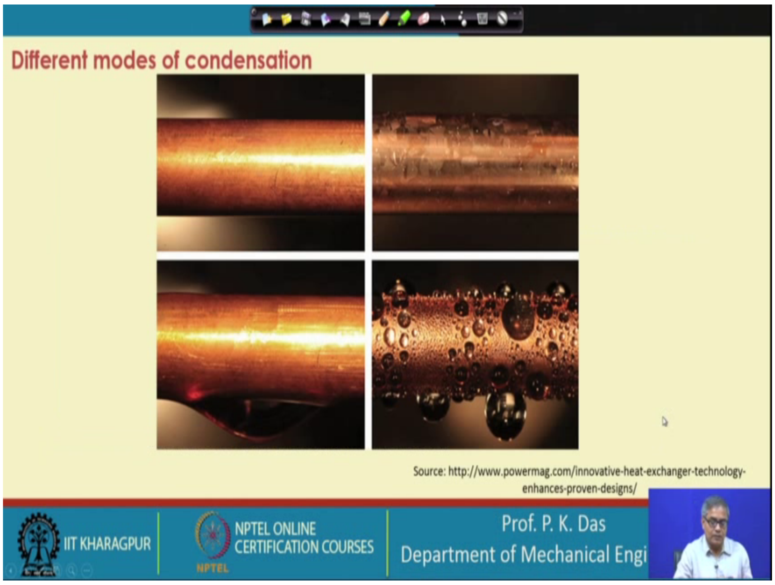

Here I am showing condensation on outside of the tube. You see this particular diagram here you cannot see anything but here condensation is taking place. These tubes are of course, may not be your condenser tubes these are copper tubes for laboratory experiment or for maybe refrigerant application. But here what you find you cannot find anything here actually there is a thin film of liquid over the tube, and film condensation is taking place. Condensation are of two type one is film condensation, so here we can see film condensation.

So, film is getting collected that is why you can see this liquid drop here. Here you can see that there is it is not uniformly covered by film. So, there are some patches where there is no film and here it is drop wise condensation, which we are also familiar we have seen our day to day life. So, these are the drops formed over the tube this is drop wise condensation. So, what I want to show you that outside a tube how condensation take place drop wise condensation is very good high heat transfer coefficient, but we do not get we get film wise condensation. So, we will consider film wise condensation.

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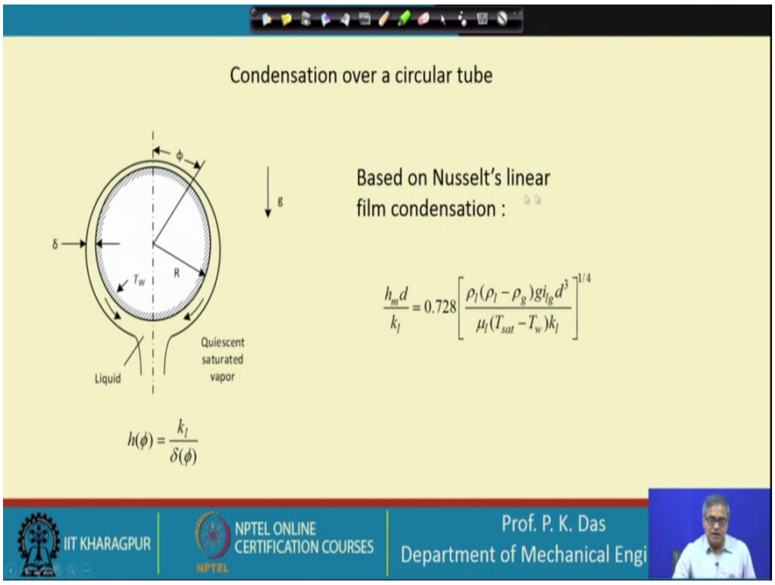

Based on Nusselt's linear film condensation theory we get, if there is a tube and the film will be like this and we get the overall heat transfer coefficient h m h m d by k l this is liquid this is the Nusselt number. So, Nusselt's number we get by this formula rho l is the liquid rho l is the liquid density, rho g is the gas density i l g is the latent heat of vaporization, g is the gravity gravitational constant, d is the diameter, mu is the viscosity, k is the k is the thermal conductivity, one is the subscript for liquid. So, this is the formula for Nusselt number we get.

h varies along the periphery; that means, with the angle phi and by integrating we get this kind of a formula. So, this is what we get for outside heat transfer coefficient how to determined, the how to determined the outside heat transfer coefficient, maybe we will refer to this refer back to this formula once again. So, with this I like to end this particular part of the lecture, and then we like to like to continue with this in our next lecture.

Thank you.