Conduction and Convection Heat Transfer

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Lecture 61

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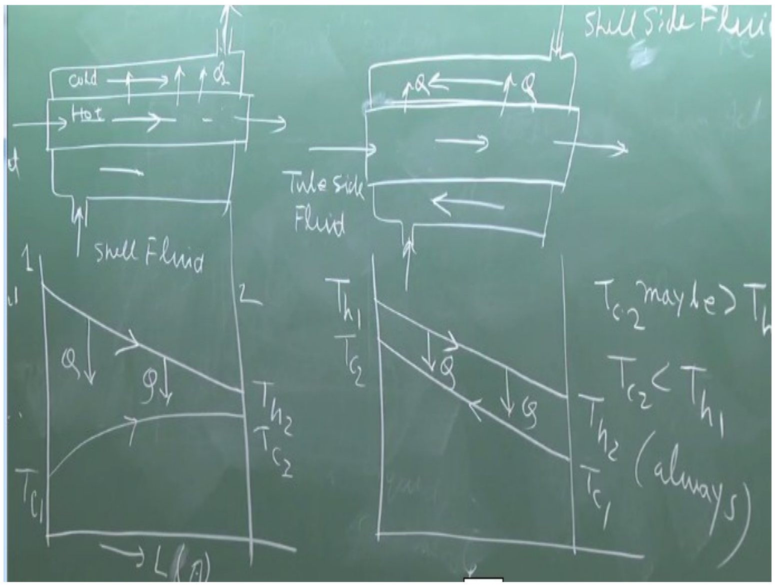

Now, I will go to the heat exchanger. Now this is Tube Fluid. And this is Shell Fluid. Now this is a Parallel flow arrangement and this is a Counter flow arrangement. This is the Tube Side fluid flow. And this is the Shell Side Fluid. Now this is a parallel flow, as I told that flows in the same direction; this is a counter flow. Now we will go for analysis for which we take a very simple configuration of one tube.

And one shell flowing either in parallel that means co-flow or in counter flow opposite direction, so that we can understand our analysis more intensive. Now if we draw the temperature diagram along the length of the heat exchanger or the surface area whatever you tell in bracket I am writing. Length or surface area; if you go this direction. Now this Tube Side Fluid enters with some temperature.

Let us consider the Tube Side Fluid is the hot fluid and this fluid is the cold fluid. Now one assumption we will make that the fluid temperature is uniform across section. There is no variation, this varies only in this direction because of the heat transfer. If you consider this is hot and this is cold, then the heat is flowing in this direction Q. Similarly, heat is flowing in this direction from the hot to the cold fluid.

Now if we make a qualitative picture how do the hot fluid changes its temperature, at any temperature hot fluid temperature is represented by a uniform temperature you consider the temperature is uniform across a section. Then, if this is the outlet section we can qualitatively show this is the hot fluid temperature curve. We use the suffix h as the hot fluid and 1 as the inlet section. And T_{h2} as the outlet section, two outlets one inlet.

Similarly, the cold fluid temperature will be like this which enters at a lower temperature Tc1 and gain heat and comes out at a temperature Tc2 which is greater than Tc1 and heat is flowing in this direction and via this tube wall which may be thin or thick. Now here, one thing that to make the heat transfer Q there should be always a temperature gradient so therefore the outlet temperature Tc2 in this case is always less than Th2. Tc2 cannot be higher than Th2.

Tc2 is always less than Th2 always otherwise heat transfer will not take place. As the difference goes on increasing the rate of heat transfer is decrease, so that if you have—in fined long heat exchanger you can expect that these two things will be meeting or converging one value. Because the heat transfer will go on decreasing as this difference decreases, so that the change will be again less.

That means always in a fined heat exchanger T_{c2} that cold fluid outlet temperature will be less than to the hot fluid outlet temperature. What happens in this counter flow exchanger, counter flow exchanger the hot fluid temperature is like this it is flowing in this direction. That is Th1 and Th2 which comes out here, but the cold fluid it is flowing in the opposite direction and the cold fluid temperature will be going like this.

And here you observe the heat transfer takes place in this direction from hot to cold fluid and this temperature gradient at any temperature difference rather at any section is responsible for the heat transfer. So therefore, Tc2 has to be less than Th1. But Tc2 may under certain condition maybe greater than Th2 that means here Tc2 maybe greater Th2 under certain condition. But Tc2 is less than Th1 always.

That means in a counter flow it is possible that the outlet temperature maybe heated more than the temperature of the hot fluid outlet temperature more than the hot fluid outlet temperature. It is possible only in the counter flow not in the parallel flow. Under certain cases where one of the fluid changes face that means condensation and boiling.

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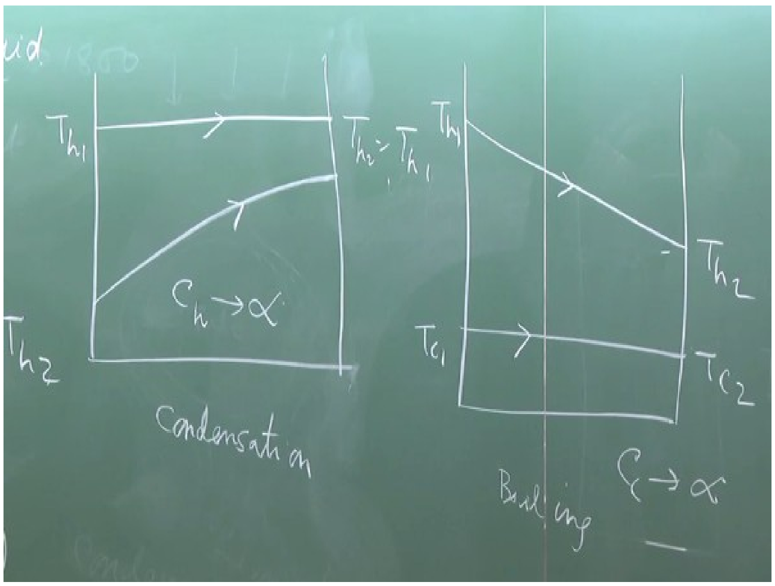

We can draw the diagram like this for condensation. For condensation, the hot fluid does not changes temperature. That means if the hot fluid is Th1, so Th2 is Th1 we can show and the cold fluid is for example, water and this is T for the hot fluid, it does not change its temperature so it looks like that, this is expressed as the specific heat of hot fluid tending to infinity. Just like Prandtl number zero, Prandtl zero infinity, molt and metallic, heavy oil, a thermal boundary layer hydrodynamic boundary layer, like this.

In case of boiling, if you are told that draw the figure in case of boiling, in case of boiling, I am not drawing here heat exchanger thing, assume this is the inlet, this is the outlet plane, in case of boiling hot fluid which is the gas, high temperature gas that changes its temperature but the cold fluid does not change its temperature, that means Tc2, Tc1. That means here we write that Cc tends to infinity.

And the beauty is that for boiling and condensation the qualitative picture is such it is immaterial whether the flow is parallel or counter, the picture is same. But for other cases when there is no face change, picture it is not same. Now after this I will go hurriedly to the concept of overall heat transfer—overall heat transfer coefficient. This is very important for the analysis.

Now, Overall Heat Transfer Coefficient, just have a recapitulation, Overall Heat Transfer Coefficient. Now what is overall heat transfer coefficient? (Refer Slide Time: 25:31) One thing is true that we know that the heat transfer takes places from hot fluid to cold fluid. If we consider the hot fluid in the pipe inner insider it is in this direction otherwise it is in this direction, that at every section heat is flowing in the direction from one tube to another tube – tube to shell or shell to tube via this wall.

And the responsible temperature difference is this one which is changing along the length. So, we recapitulate a heat transfer coefficient definition.

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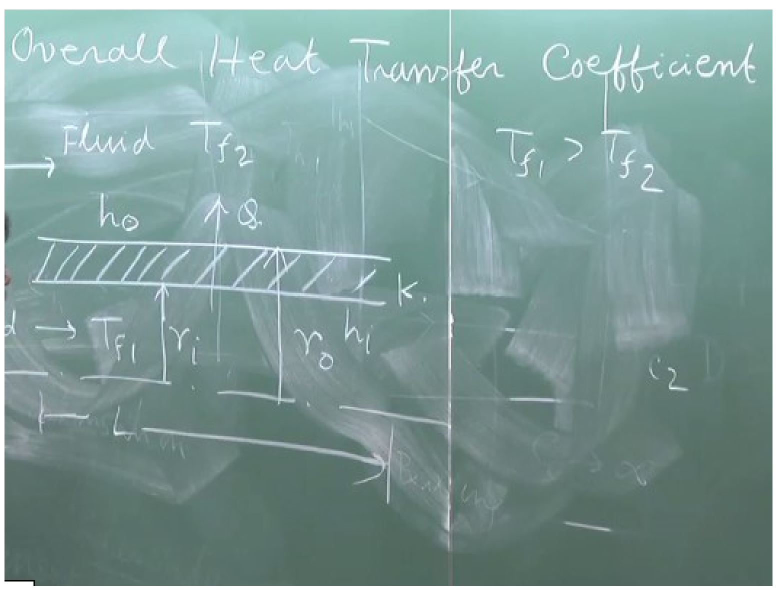

Let us consider this case again what we read earlier that there is a pipe I am drawing the symmetric part from the axis which has a fluid flowing through this pipe simply going back to the first few lectures, introductory lecture of heat transfer which I taught you. Fluid at a temperature of Tf1 and there is another fluid flowing through outside fluid which is at Tf2 that means the ambient fluid.

And if we consider that Tf1 is greater than Tf2 and the heat is—therefore flowing in this direction Q. Now this is inner radius ri and if this is the outer radius ro that means ro – ri is the thickness. And if the thermal conductivity of this solid material is k. And if the insider heat transfer coefficient of fluid is hi, if you remember very initial days, very simple expression which his constant throughout the length.

Similarly, the outside heat transfer coefficient of the fluid. This coefficient initially we use to tell film coefficient this is because we are now learned details convective heat transfer the entire resistance comes through a thin film adhering to the surface either in force or free convection that is why it is known as film heat transfer coefficient. And if the length of the pipe is L this length.

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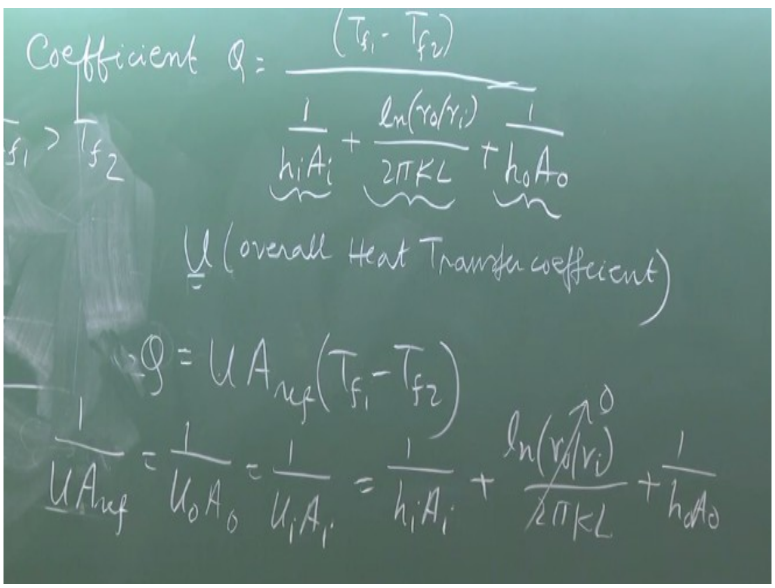

Then if you remember correctly than Q is equal to Tf1 – Tf2 that is overall temperature difference potential difference divided by 1 upon hiAi, if Ai is the inner surface area that means twice pie rl into L. I am not writing in this fashion, inner surface area plus if you remember ln(ro/ri) divided twice Pie kL plus 1 by hoAo which is twice pie ro into L that is outer surface area.

So, this is nothing but the total resistance, this is convective resistance the inner fluid, this is the conductive resistance due to thickness of the tube that means after the film conduction which we consider convection it goes through solid conduction and then again film conduction and the liquid conduction under flow which is the convective flow, so the convective resistance again. So, this is the overall resistance, this is the thermal network.

Now if we define Overall Heat Transfer coefficient u in a manner that total heat transfer, total heat that is transferred that the same Q is given by this overall heat transfer some reference area into $T_{f1} - T_{f2}$. One has to tell that based on what reference area heat transfer property is defined. For example, based on one characteristic geometrical dimension we have to tell for internal flow this dimension is a hydraulic diameter, in a pipe it is simply the diameter of the pipe.

Similarly, for a flat plate the hydraulic the characteristic geometrical dimension is the length of the plate. So therefore, you have to tell that, that u based on what reference area. So, if you consider a general reference area then if we define in this then one can write 1 by uAref, sometimes this reference area maybe either outside surface area or inside surface area. And accordingly, u is defined as uo or ui.

That means based on outside reference area or inside reference area. One can write by comparing this two 1 by uoAo is equal to uiAi all these things has the total resistance that means 1 by hiAi plus ln (ro/ri) twice pie kL plus 1 by h0A0. So therefore, we get a concept of overall heat transfer coefficient that means if I know that convective heat transfer coefficient at two sides and now the thermal conductivity and the thickness of the pipe or r0, ri explicitly I have to thickness will not work.

Then I can find out overall heat transfer coefficient based on some reference area and if I know it I can find out the rate of heat transfer under this situation. Usually the pipe is thin and its thermal conductivity is so high made of material which has a high thermal conductivity and the thickness is not that high because the flow is less. So, thickness has to be there to sustain the upstairs because of the pressure created by the flow.

So therefore, if the flow is less, so ro, ri, so this part maybe neglected then this becomes like this. And this is the concept of overall heat transfer coefficient which holds goods yet. Here also the heat transfer takes place from one fluid to inner side, let us consider the hot fluid to the outer cold fluid via the tube material – solid tube. Now another thing is there which is known as Fouling factor.

After a long operation of heat-- these are all practical things but we have to know as information there is nothing grade at all. After a long operation in industries usually what happens the impurity in the liquid which is flowing both the side either tube side and shell side gets slowly deposited and make a coating in the form of a film over the two surfaces. These are known as scales, not our geometric or dynamic scales of our theoretical analysis.

The scale means a formation of thin coating the impurity is gets coated and makes a scale formation. And what happens physically that puts an additional thermal resistance to the heat flow both inner side and outer side because of the scale formation due to impurities.

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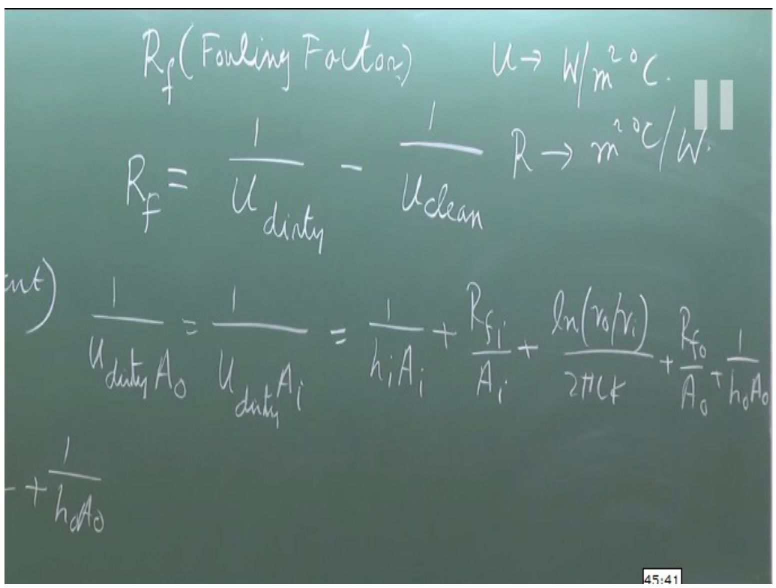

And that is expressed by a fouling factor denoted by R comes from the resistance this fouling factor expressed in terms of a resistance R and which his defined as—and because of that what happens thermal resistance enhances therefore the overall heat transfer coefficient gets reduced. Because thermal resistance is 1/u tens a reference area and therefore it is the heat transfer terminology in the practice that define the u dirty.

This is the definition of fouling factor in terms of a resistance minus u clean that means the 1/u dirty is more than 1/u clean that means the resistance of the dirty tube is more than the resistance of the clean tube by this factor R. This is a fouling factor. Sometimes people may ask, what is the fouling factor? This is an additional resistance due to the scale formation because of the impurities, and this is defined as u dirty.

So therefore, one can write 1/u dirty, I can write now, 1/udirtyA0 or is equal to 1/u dirty again I express in Ai is equal to 1/hiAi and this dirty, inner surface maybe dirty, outer surface maybe dirty. So therefore, this fouling factor is Rf, so this is for inner Rfi/Ai plus if you do not neglect the conduction resistance this is r0/ri by twice pie Lk plus Rfo/Ao plus its convective resistance. So therefore, one can take care of the fouling factor in this way.

Because fouling factor is expressed as a resistance inverse of this u. So, u unit is W/m2oC, whereas the thermal resistance unit is m2oC/W and fouling factor is expressed in terms of meter square degree Celsius per Watt. So, if it expressed like that you can take care of – if it is told fouling factor is inside the tube, outside the tube accordingly you can take care of AiAo and use this overall heat transfer coefficient.

Clear? Now the major problem comes after knowing all these things. The major problem comes here I rub all these things the major problem comes here that all these expressions a overall heat transfer coefficient was defined so that I can express this Tf1 – Tf2. Here one assumption I took that Tf1 and Tf2 constant. That means the potential for heat transfer is constant throughout. In our very preliminary heat transfer problems we took it a constant fluid temperature, a constant – that means the potential, constant. But here what happens Delta T for heat transfer changes.

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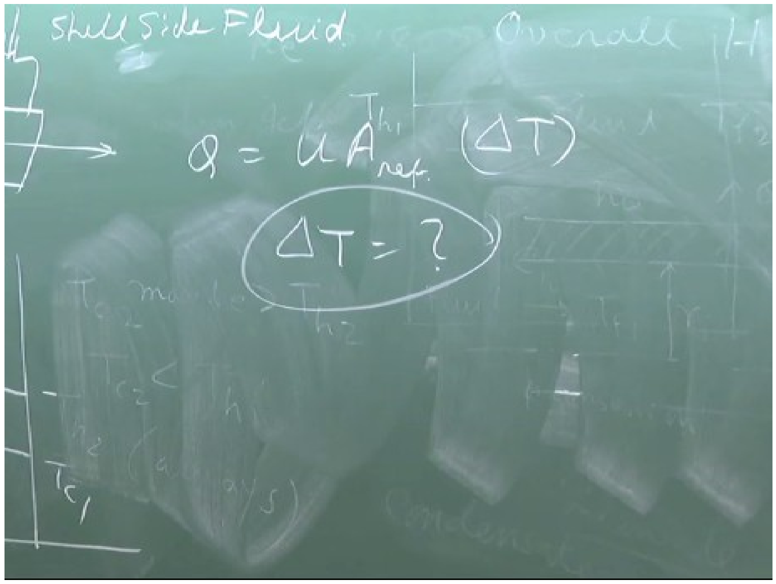

So, if I write this here for heat exchanger Q is equal to u -- let us take overall outer surface area uA or inner surface area, reference area A0 or Ai does not matter Delta T, what Delta T? This is a big question this Delta T changing. For example, in a parallel flow it is Th1 – Tc2 and not Th2 – Tc2, so Delta T is maximum at the inlet. In case of parallel flow this goes on decreasing which Delta T. Which I will take?

Heat transfer takes place at each and every section following that rule but with a varying Tf1 – Tf2. So which Tf1 – Tf2 we will take. So therefore, the question comes we should define a overall heat transfer in such a way that the Q is expressed in terms of this with a suitable mean temperature difference which is some mean of the inlet temperature and outlet temperature difference. What is that?

So, a simple deduction will tell you that the total heat transfer is related to a mean temperature. Total heat transfer is known for us. Why? Because if I know the duty for example flow rate, and the specifically Th1, Th2, Tc2, Tc1 I know the heat transfer, flow rate specifically time, the temperature change in any one of the fluid and that have to be balanced because heat loss by one fluid will be heat gain by other fluid. But, how to now this u?

The problem is posed like this. Now I will tell you what exactly the problem is.

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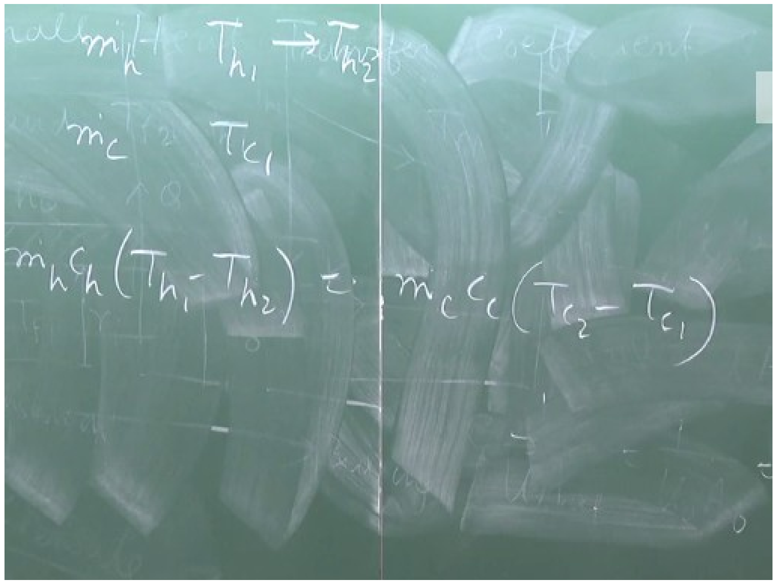

Now let us consider a situation like this, you have a duty fixed that means you have cool a hot fluid from Th1 to Th2 known. And you know that your cold fluid flow rate requirement available is this. And the cold fluid temperature available is this Tc1 which is usually the ambient temperature. So immediately a boy of class 8th will write mhch (Th1 – Th2) is equal to mcCc (Tc2 – Tc1) because entire heat exchange is insulated so from energy balance you will write and find out Tc2.

Okay Tc2 you can find out; you cannot find out of this four temperature three are independent. They are related. I know the duty that means the heat to be transfer to this. Now I have to find out the area. This is known as sizing of the heat transfer. I will design the heat transfer. First step is to find out the size of the heat transfer area then I will use this equation. Here I know u, u is given to me.

From a chart, I know that this type of exchanger, I am going to use u as know. I have to find out A reference. What is this? I only know the terminal temperatures. What is this Delta T? It is not Th1 – Tc1, neither it is Th2 – Tc2, so I cannot find out A. How can I use this equation with what Delta T? Q I know. u, I know. So, the next task is to find out this Delta T. That means this mean temperature through which we can find out the heat transfer. Clear?

So next class, I will do that it is very important and this is known as log mean temperature difference. Thank you.