Conduction and Convection Heat Transfer

Prof. S.K. Som
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology – Kharagpur

Lecture - 39
Heat Exchanger - I

Now we will discuss Heat Exchanger. This is a very important topic in the field of heat transfer. Now it is true that so far, we have studied the mechanism of heat transfer from one fluid to another fluid, from fluid to solid. We have not learned one fluid to another fluid, we have learned from solid to fluid within solid conduction. But in practice what happens in almost all industrial processes we have to exchange heat from one fluid to other fluid.

And the device in which it is done is known as Heat Exchanger which allows the heat to be exchange. For an example, just in Condensation boiling I gave the examples like that steam power plant condenser where the steam is condensed, it is an example for condensation at the same time heat exchanger, this condenser itself where the cooling water flows to the tube and the steam condenses at the outer surface as a whole heat exchanger where the heat exchange takes place between water and steam.

Similarly, in case of refrigeration condenser that the heat transfer takes place between refrigerant that is a working fluid in the refrigerating cycles. And similar is the case for boiling in boiler that in the water tube the water is heated where the combustion products flows buzz the tube, this is also a heat exchanger. Apart from these there are various processes where face change may not take place, here face change takes place.

One liquid has to be heated from some temperature, lower temperature to higher temperature. One liquid maybe requires to be cooled from some high temperature to low temperature. This is accomplished in a device known as Heat Exchanger. So therefore, we will discuss heat exchanger. Now heat exchangers are of two types basically. One is Direct contact another is Indirect contact.

Now the indirect contact is the exchanger where the two fluids which exchanges heat does not get an opportunity to have contact between one another. That means they are not mixed they are separated by a solid wall and via the solid wall the heat transfer takes places. The condenser of a steam power plant, the boiler tube and many other are such examples. And this is mostly use in industry because the two fluids cannot be mixed together.

Otherwise the fluid property will change and we will not be able to regain the fluid which is require for the subsequent process. But in some cases where it is not needed a direct contact heat exchanger takes places where both the fluids where directly contacted. For example, in a cooling tower. You know in a cooling tower the hot water which comes out from the circulating or the tube – cooling water tube circulating water tube in the condenser that takes the heat from the steam which is condensed so that water has to be cooled again to re-circulate through the condenser tube.

So, to do that we have to cool that water and that is done in a device known as cooling tower that is also heat exchanger because the heat is exchange. So, this is cool with the help of air, atmospheric air. And there what is happen a water is spread in the form of atomized—fine atomized spray through difference noses use for this purpose and air is allowed to flow which flows in the opposite direction of the spray and both of them are mixed together.

And the air takes the heat of the water and some of the water also evaporates make a evaporative cooling of the bulk of the water. I am not going into that deep. This is one example of direct contact type exchanger in a Jet Condenser. So, this is known as surface condenser, earlier I told Jet Condenser the steam is ejected in the form of Jet, sorry, water is ejected in the form of Jet in this steam which is condensed.

So therefore, the condenser is a mixture of steam condensed plus the water Jet which is spray. So therefore, direct and indirect heat exchanger, we will discuss the indirect heat exchanger just which are largely used in practice. And another type of heat exchanger is used which is known as regenerator. The difference between regenerator and this type of indirect and direct heat exchanger these are known as recuperated.

The difference is that is recuperated type of heat exchanger where there maybe two types direct and indirect the both fluids flow simultaneously and the heat exchange takes place either via a solid material or by the direct mixing. But in a regenerator what happens, the cold and hot fluids are allowed to flow alternatively through a solid body which has a high heat storage capacity with high specific they take the heat from the hot water and store it.

And when the hot fluid and when the cold fluid is allowed to pass through it they exchange that heat. And that solid metrics is made of either pebbles, powders, wire mesh which produces large surface area for heat transfer and at the same time the high specific heat capacity to store maximum heat. And alternately the hot and cold fluid are pass through it and there is a switch which changes the hot and cold fluid cycle.

That means that operates in such way the hot fluid is allow to flow and another time cold fluid is allowed to flow. This is known as regenerator. This is also of two types. One is static regenerator where the solid metrics is fixed and alternatively hot and cold fluid is allowed to flow. Another case is there which is used in the air preheater of a steam power plant, these are for your information where a metrics moves, it is a form of (()) (07:16), which rotates.

And one side continuously the hot fluid flow that is the combustion products, hot gas and another side here which is been preheated before going to the Furness is allowed to flow. That means the solid metrics by its dynamic nature rotation captures heat- stores heat from one side when it is in contact with the hot fluid and when it comes in turn other side with the cold fluid it transfers heat to the cold fluid. That is the dynamic regenerator. This is for your information.

But we will learn mostly that is used in industry is the recuperated type of heat exchanger with indirect contact that means heat transfer takes place between hot and cold fluid by via a solid partition.

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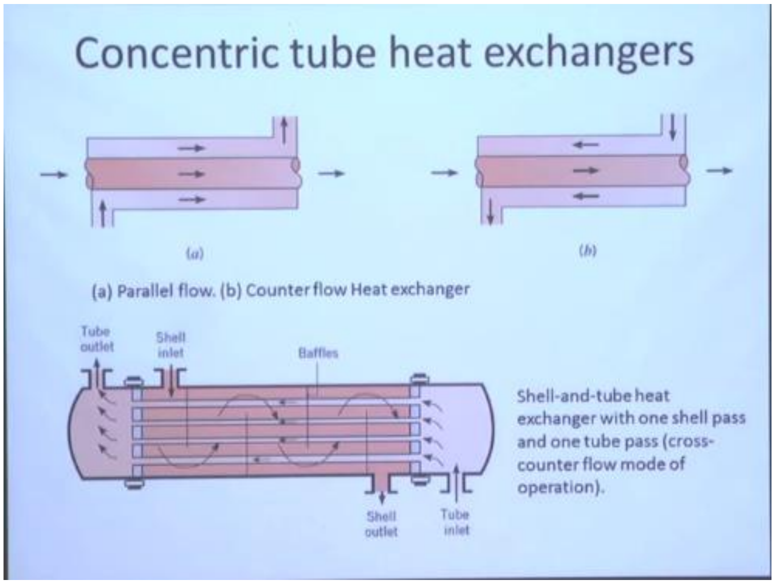

Now, I show you the most simple type heat exchanger is like this a concentric tube heat exchanger. This is the most simple-type we can conceive that there are a two concentric pipes one is the inner one and another is the outer one. So, one fluid flows through inner tube another fluid flows through the outer tube. Usually the hot fluid is flow-- allowed to flow through the inner one and the cold one is outer, but not necessarily.

In a steam power plant, it is other way. And ultimately the entire thing is insulated. Now the difference between this two is that in this left-hand figure the flow of both the fluids are in the same direction where as the flow of both the fluids are in the opposite direction. Now here this inner tube is known as the tube where there the outer tube which creates this annular passage for the flow of the other fluid is known as the shell.

That is why this type of heat exchanger is known as Shell-and-tube heat exchanger which is very, very common at every industry peoples tell, Shell-and-tube heat exchanger. If you do not know what is Shell-and-tube heat exchanger as it, you do not know what I will tell the name of your parents like that. So, this is known as Shell-and-tube, the outer is known as Shell. And this arrangement is known as parallel fluid and this is Counter flow.

And from my student, I tell you, I found that this is a (()) (09:51) because when I though from the fluid mechanics point of you both the parallel fluid in a sense the flow streamlines are parallel to each other, it should be co-flow and it should be counter flow. And when I asked my teacher he told no I cannot change the definition this is going for years and decades together it is parallel flow and counter flow, you cannot define it has a co-flow and counter flow.

However, in my mind always it was that parallel flow is a co-flow and is counter flow. Now sometimes this direction may not be parallel that is why I am telling because next time when will define their maybe be perpendicular direction that one fluid may flow perpendicular to the another flow direction that is known as crossed flow. And usually to enhance the heat transfer this is done like this.

This is a type of modified type of Shell-and-tube heat exchanger with one shell pass and one tube pass cross-counter flow mode of operation, what is the meaning this I am telling you, here the difference from the very simple one conceived here, is the number of tubes are there. And one fluid flows through this tube on one direction and goes out from the other direction. So, this one direction flow of a fluid is known as one pass. These are all industrial language.

Again, I am telling so you see, our case is like that starting from boundary layer thickness and all these things. Now we come down to industrial terminology that pass that pass that is known as one pass, one tube pass. But there are multiple tubes but single pass. Now the shell side fluid which is entered like this and going, sorry this inlet and this tube inlet, sorry correct shell inlet and shell outlet that means this must have a counter flow type.

Because the tube inlet that is the tube fluid flows in this direction whereas the shell tube flows in this direction, this should be counter flow. But at the same time this is a cross flow, cross-counter flow. Why? Baffles walls are placed like this so that shell side tube after flowing like this, it does not flow like this, it does not flow like this, it goes like this that means that creates more residence time by changing its flow direction and makes more heat transfer with this fluid.

And this way if you divide the flow, make the hurdles like that by putting these walls, these are known as Baffle- Baffle walls are Baffle, you can have a cross flow and the counter flow type.

When it flows in this direction for example here in this direction through this Baffle it is a cross flow, again it is a counter flow. So therefore, it is a mix of cross-counter flow mode of operation. Here is a one shell pass, one tube passes but multiple tube.

And use a baffles to increase the flow residence time for the shell side fluid and to cover a larger part like this and it to make a cross and counter flow mode of heat exchanger.

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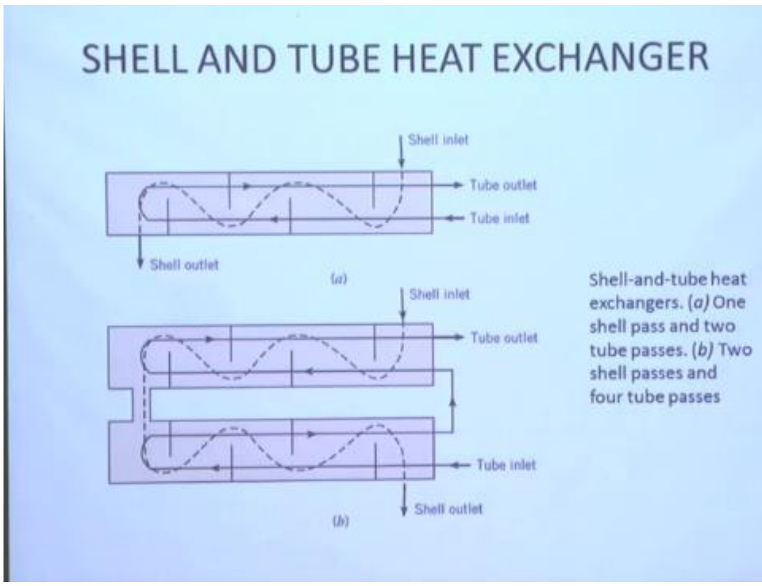

Now next I show you Shell-and-tube heat exchanger again for your practical information industry people will be very happy, this is what shell-and-tube type. Number one is one shell pass and two tube pass, that mean Tube inlet one direction again it comes out is a U tube type. Tube outlet that means in a U shape U comes here that means this is one pass and it comes likes that. That means inlet and outlet in the same side.

And this is the shell side inlet with the baffle wall. So, this is a two tube-- one shell pass and two tube pass with the baffles. Both cross counter and parallel mode. Similarly, number two is the two shell passes and one tube pass. There are two shells that mean this is one shell in series another shell. These are all done to enhance the heat transfer rate to meet the required service that means the amount of heating or cooling of the fluid desired.

“Professor – Student conversation starts” This you can see in any book there is nothing great to take any note out of this, this is just for your information. “Professor – Student conversation ends”

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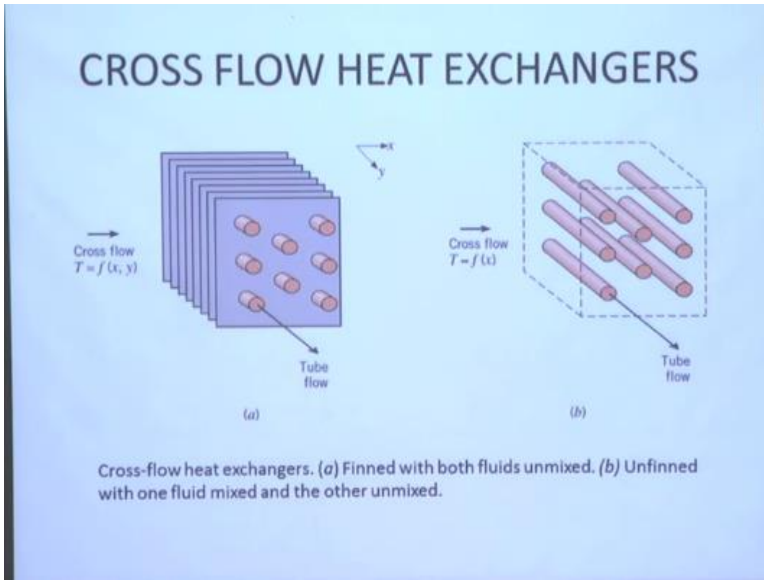

Now another type of cross flow heat exchangers is used, this before going to this I think well Compact heat exchanger, this also comes in the category of compact heat exchanger. First of all, I will explain this, this is another type of heat exchanger where the tubes side fluids are flowing through a number of tubes and where there are number of plates attach to these which acts as finned surface. Finned doing both fluids unmixed.

What is the minimum this? I will tell you. The arrangement is like that, this plate acts as fins to all these tubes. So, through tube one fluid flow and heat exchange from this fluid to the outer fluid is enhanced by finned whereas another fluid that is outer fluid which flows through the finned passage is a cross flow type through this finned passage. That means this passage in between the fins.

This is a typical cross flow heat exchanger finned which both fluids unmixed means these are unmixed not that with that the physical mixing but this unmixed what is used in heat exchanger that means this fluid is guided through this finned passage and is not allowed to move in the transverse direction. This direction of this direction. This is restricted. This flows only in this direction through the passage.

But here what happens there is an open space and there is a shell-type of thing and cross-flow takes place, there is no such restriction about the fluid to moves in both transverse directions that is why this is known as unfinned with one fluid mixed and the other fluid unmixed. That means there is no finned to guide the flow of the other fluids in cross flow direction. That is the only difference in the unmixed and mixed.

So therefore, with one fluid mixed and the other unmixed that means this is unmixed, this is guided through the tube, this is not very important just a practical thing.

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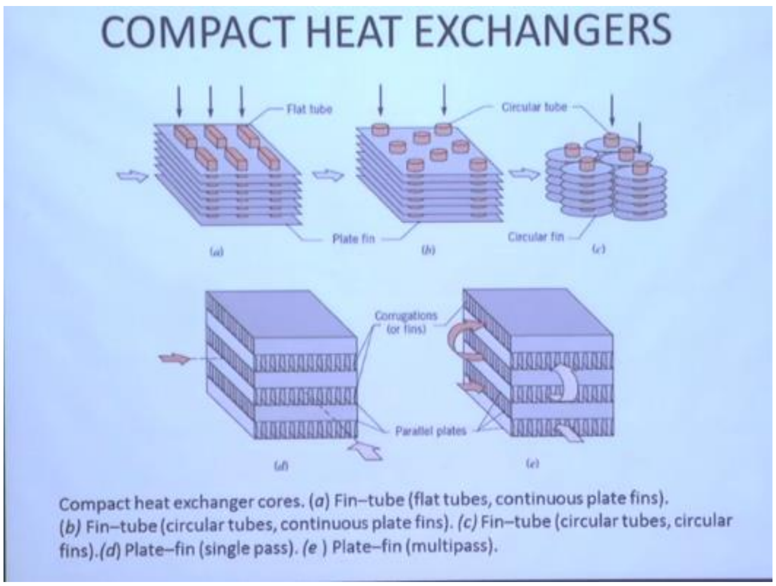

Now which is important little bit but still practical is Compact Heat Exchangers. This is very important. Employer asks, what is a compact heat exchanger? We want a heat exchanger which must have a very high heat transfer rate so that it mix the service require, huge service, we have to cool a hot fluid by a very high degree of cooling. That means the temperature difference is very large or the other way heating.

So that it will meet the desired service of high heat transfer rate but it should be compact the small. How it is done? We know the rate of heat transfer for an imposed temperature fields depends upon the surface area. So, if you can make the surface area more heat transfer rate is more for which you know that the liquid is ejected for heat transfer purpose in the form of spray. This is because if you split the liquid into spray of various minute drop then the ratio of surface area to volume increases which enhances for the same flow of liquid the heat transfer rate by enhancing the surface area.

Similarly, if we can design a heat exchanger, which provides a high surface area but in less volume, because the size is very important. If you tell I have a big heat exchanger which has a big surface area but it is so big that is size is big volume is big so that how can I accommodate this; question of accommodation, the space requirement. So therefore, the compact heat exchanger is an exchanger which is very small but high heat transfer rate.

That means whose surface area to volume ratio is very high, that is the index that is known as surface area density. So that surface area to volume ratio has to be very high so that in a small size we have high heat transfer rate. There is a criteria not very much strict but we usually have this convention when the surface area per unit exceeds 700 meter square, this you can write, 700-meter square per minute cube.

You usually refer a heat exchanger is the compact heat exchanger. So, everybody wants for a compact, it is a simple example I am telling you that if you have a big long rod of diameter D and heat exchange takes place between the two fluids that is shell-and-tube heat exchanger and shell. So, you know that if you go on increasing the length you have the more surface area, piDL, piDL is more so for example here you have the more length and more the surface area piDL.

But the same length if you make a helical, that coil tube, helical coiler, if you make a coil tube within a small space you have more surface area, sometimes while changing the flow field we create a more surface area virtually by creating residence time. So anyway, you have to provide something either by geometrical surface area by enhancing the heat transfer by providing extended surface area so that we have a or the flow field itself so that we have a compact heat exchangers.

Next is, this compact heat exchanger is of different type just I show you certain compact heat exchanger. This is Flat tube type of thing and the Fin plates. These are also Circular tubes with circumferential thin film a fins. This is with rectangular fins which already I showed you and this is very interesting-- this is parallel plates with fins and this passages we have the fluid flowing. And another fluid flows through this alternate passage.

One fluid flows through this passage another fluid flows through this passage from this direction, this is a cross flow and also with a corrugated this surface which acts as a fin which provides a more surface area like this, these are the fins. This circumferential fins, this the flat fins that means extended surface area that means somehow you have to make a geometric which provides more surface area and if I have to make the flow in such a way that provides more heat transfer.

Because you know from our basic heat transfer knowledge that rate of heat transfer is enhanced by the temperature gradient which depends upon the flow field and also by the surface area. Because, finally the heat transfer is –K* gradient of temperature. "Professor – Student conversation starts" Now next, I will go for the analysis but before that sometimes a question I ask, use to ask nowadays there is no scope.

Some 20 years back, if you go some of your teacher face this questions when they were my student. Because this question cannot be answered it is an informative thing. If you do not know what is the largest means from the compact, the most compact heat exchanger heat and mass exchanger. Sometimes, heat and mass transfer coupled in certain devices, that is a chemical engineering domain not in your domain in the earth.

Can you tell me which is the most compact heat exchanger? Heat and mass exchanger in the earth? Somebody tries to things, sir something was used in that industry in USA some radiator of general motors in the Harrison radiator division, my elder brother went there and he told they have developed a most compact heat exchanger like that, but what is the answer do you know? Then next question is that who is the creator of this heat exchanger?

The most – you know the scientist so far have only exploited the nature, we could not create a nature. Somu, you know the answer? Sohail. No…no. This question answer you know? Sohail. Sohail? Scientist only exploit the nature cannot concur the nature. Nature gives all clues to the scientist for solving the problems and to know the nature more and more. So, the creator is God. With this thing also difficult to answer this, creator is God through us.

We are implemented there. (()) (23:58) but God is the designer, this is our lung. I cannot tell you the exact figure of the surface area of the lung that the heat exchanges heat and mass transfer you will be astonished to know. One day, you know what is the biological system you can ask Prof. Suman Chakroborty who is one of our bright and young colleagues who work in the interface of engineering and bioscience.

He knows some quantitative figures; you will be astonished to know the surface area of the lung. However, this is just one tip I give that the most compact heat and mass exchanger designed by God through us in the earth, so we cannot reach anyway near to that whatever exceptional engineers you are to design (()) (24:43) forget about your general Motors, Harrison Radiator Division. Okay.

So medical people are astonished and that is the reason for which medical people never thing of doing any research so they are very happy with their entire skill to maintain the thing, because their maintenance is huge, because a medical doctor tells me that what do you do beyond that, the creation is so complex and such amazing to maintain it we spend our entire skill of the lifetime that is enough for us, you people thing of designing, thinks, okay.

Many of your fathers maybe medical officer, you can ask them. “Professor – Student conversation ends”

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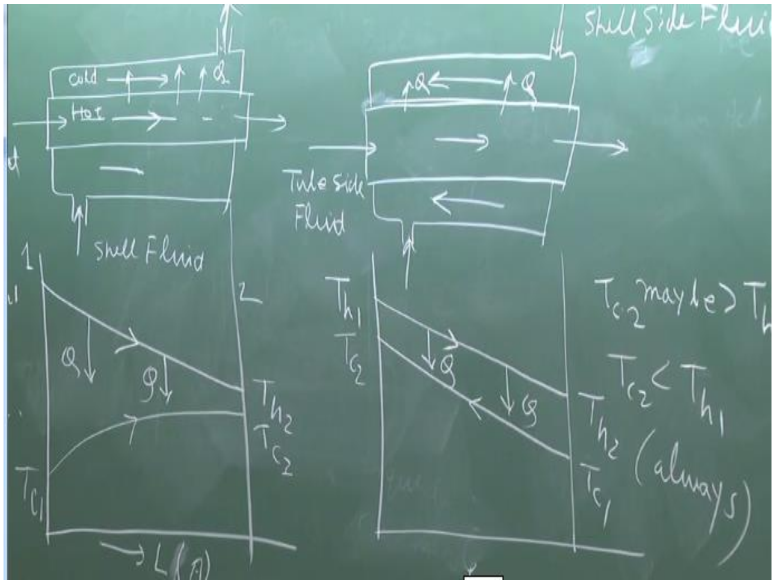

Now, I will go to the heat exchanger. Now this is Tube Fluid. And this is Shell Fluid. Now this is a Parallel flow arrangement and this is a Counter flow arrangement. This is the Tube Side fluid flow. And this is the Shell Side Fluid. Now this is a parallel flow, as I told that flows in the same direction; 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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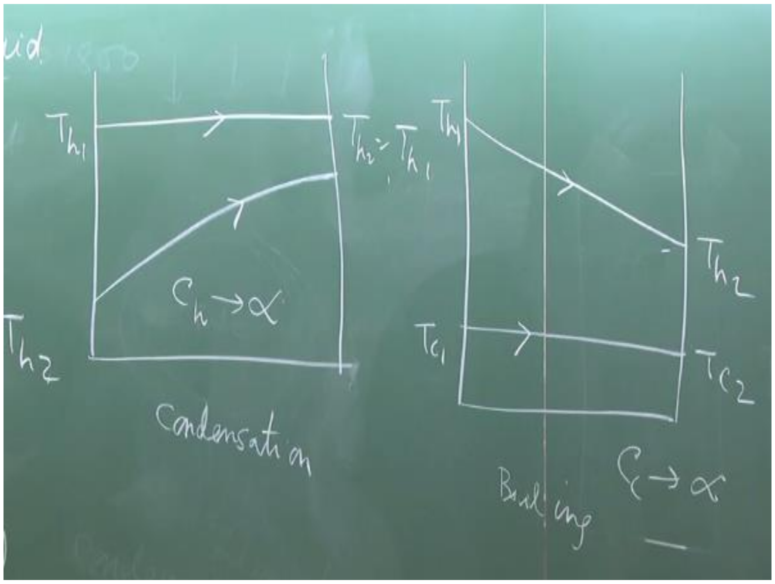

We can draw the diagram like this for condensation. For condensation, the hot fluid does not changes temperature. That means if the hot fluid is Th1, so Th2 is Th1 we can show and the cold fluid is for example, water and this is T for the hot fluid, it does not change its temperature so it looks like 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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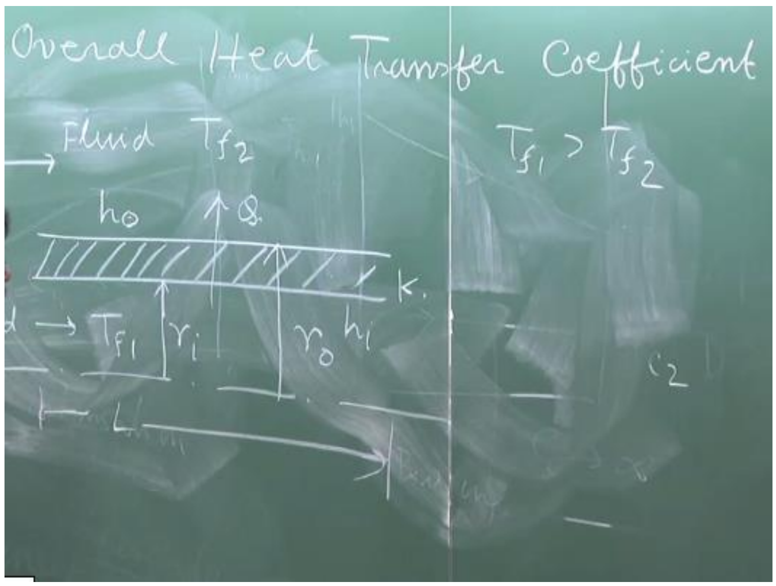

Let us consider this case again what we read earlier that there is a pipe I am drawing the symmetric part from the axis which has a fluid flowing through this pipe simply going back to the first few lectures, introductory lecture of heat transfer which I taught you. Fluid at a temperature of Tf1 and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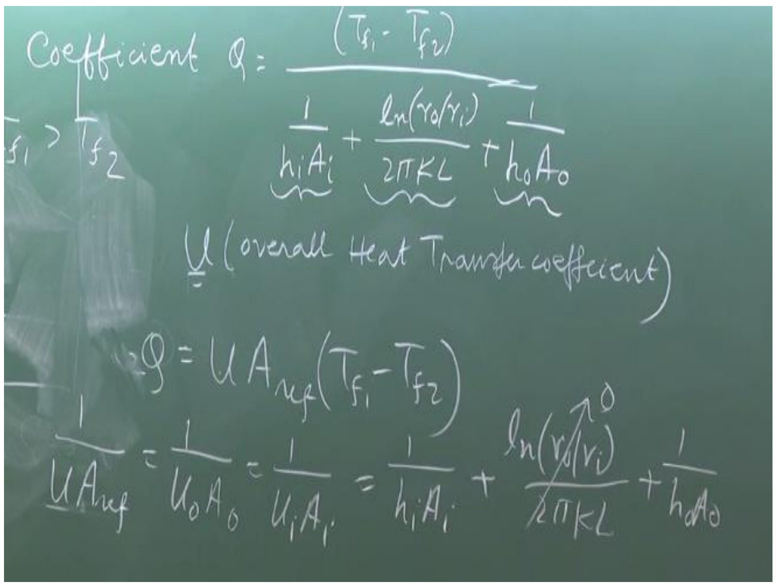

Then if you remember correctly than Q is equal to Tf1 – Tf2 that is overall temperature difference potential difference divided by 1 upon hiAi, if Ai is the inner surface area that means twice pie rl into L. I am not writing in this fashion, inner surface area plus if you remember ln(ro/ri) divided twice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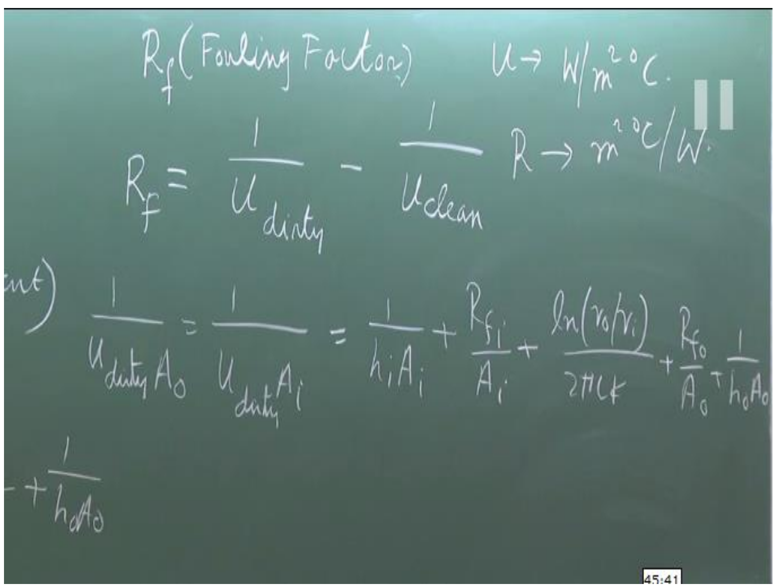

And that is expressed by a fouling factor denoted by R comes from the resistance this fouling factor expressed in terms of a resistance R and which his defined as—and because of that what happens thermal resistance enhances therefore the overall heat transfer coefficient gets reduced. Because thermal 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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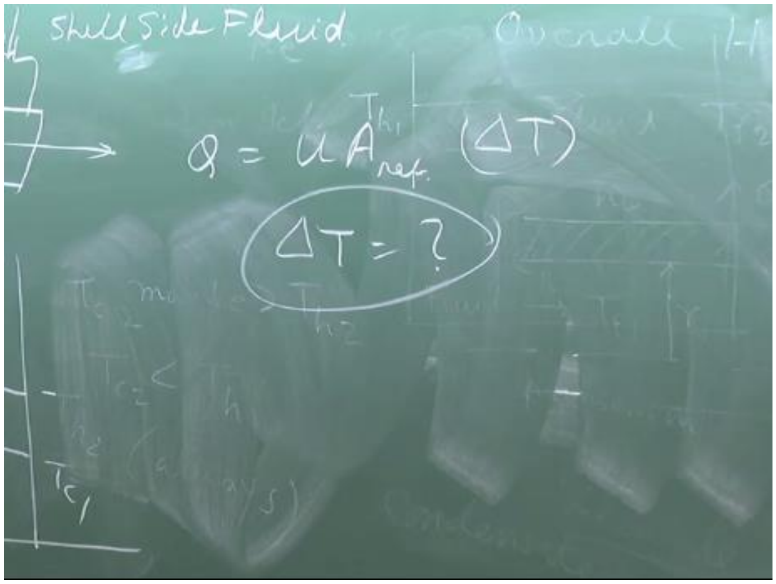

So, if I write this here for heat exchanger Q is equal to u -- let us take overall outer surface area uA or inner surface area, reference area A0 or Ai does not matter Delta T, what Delta T? This is a big question this Delta T changing. For example, in a parallel flow it is Th1 – Tc2 and not Th2 – Tc2, 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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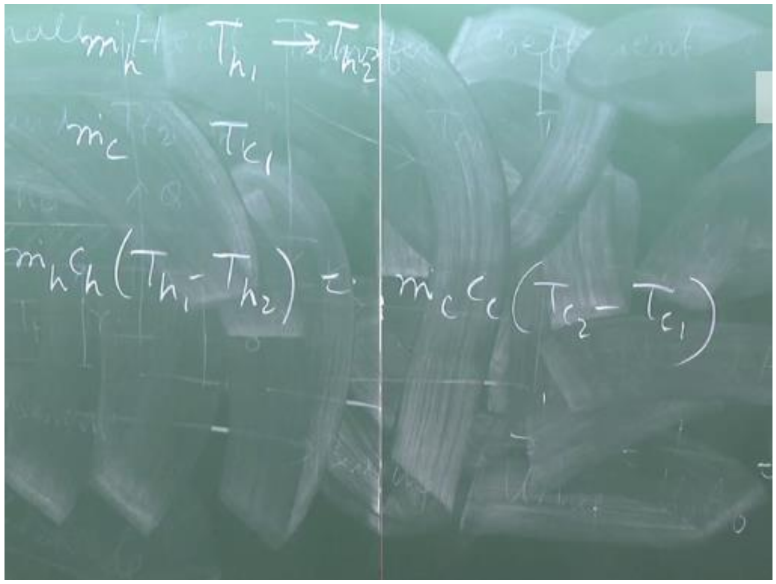

Now let us consider a situation like this, you have a duty fixed that means you have cool a hot fluid from Th1 to Th2 known. And you know that your cold fluid flow rate requirement available is this. And the cold fluid temperature available is this Tc1 which is usually the ambient temperature. So immediately 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.