

Conduction and Convection Heat Transfer
Prof. S. K. Som
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology- Kharagpur
Lecture 60

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 through the tube, this is also a heat exchanger. Apart from these there are various processes where phase change may not take place, here phase 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 place. 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.

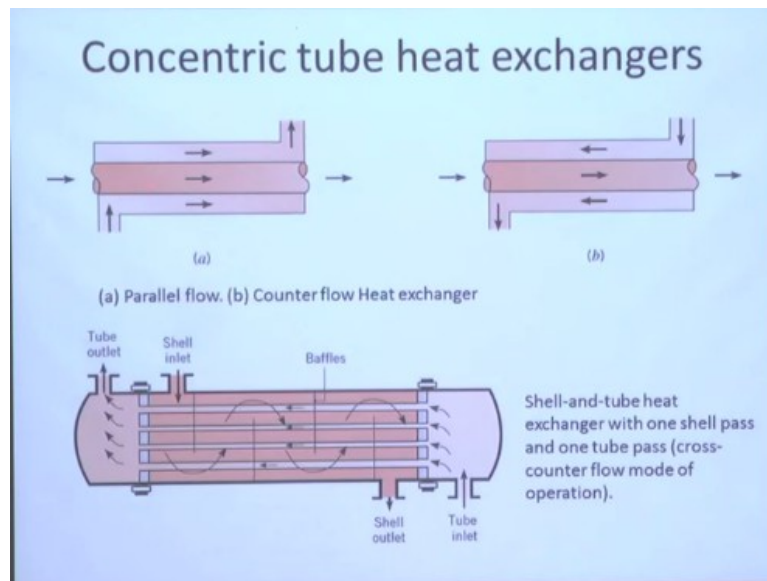
And when the hot fluid and when the cold fluid is allowed to pass through it they exchange that heat. And that solid metrics is made of either pebbles, powders, wire mesh which produces large surface area for heat transfer and at the same time the high specific heat capacity to store maximum heat. And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

(Refer Slide Time: 08:23)



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.

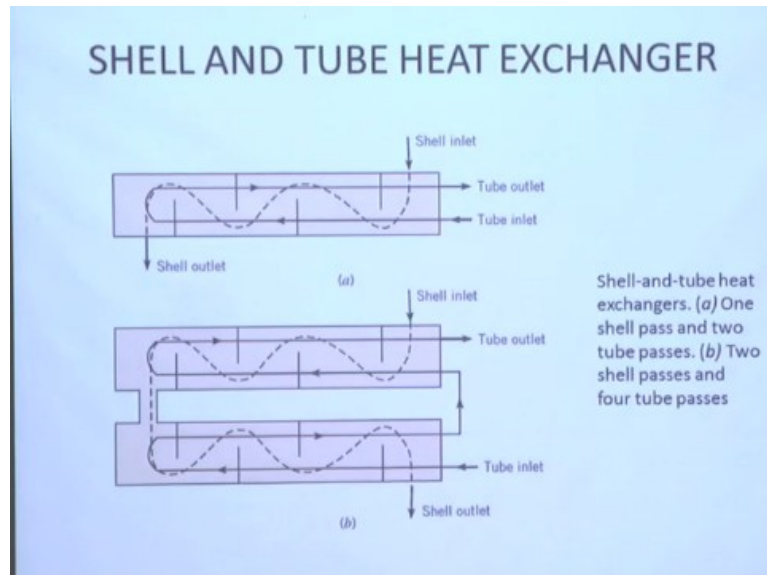
Because the tube inlet that is the tube fluid flows in this direction whereas the shell tube flows in this direction, this should be counter flow. But at the same time this is a cross flow, cross-counter flow. Why? Baffles walls are placed like this so that shell side tube after flowing like this, it 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.

(Refer Slide Time: 13:04)

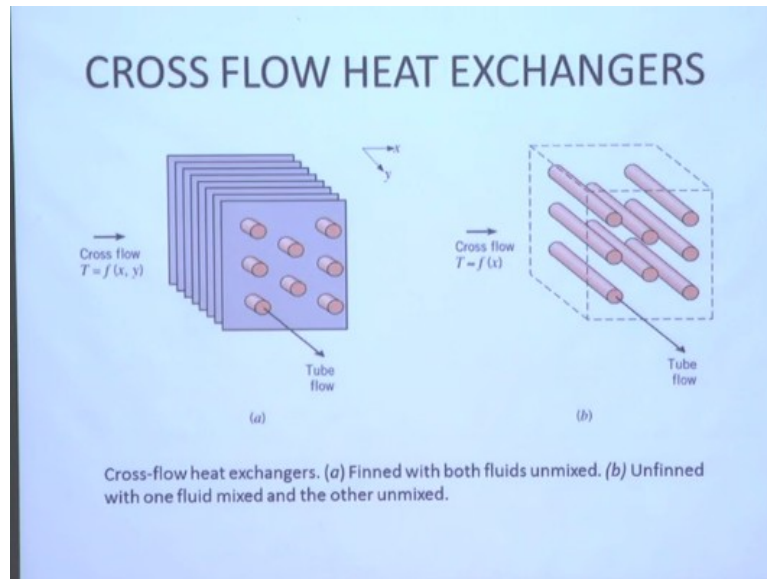


Now next I show you Shell-and-tube heat exchanger again for your practical information industry people will be very happy, this is what shell-and-tube type. Number one is one shell pass and two tube pass, that mean Tube inlet one direction again it comes out is a U tube type. Tube outlet that means in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

(Refer Slide Time: 14:10)



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.

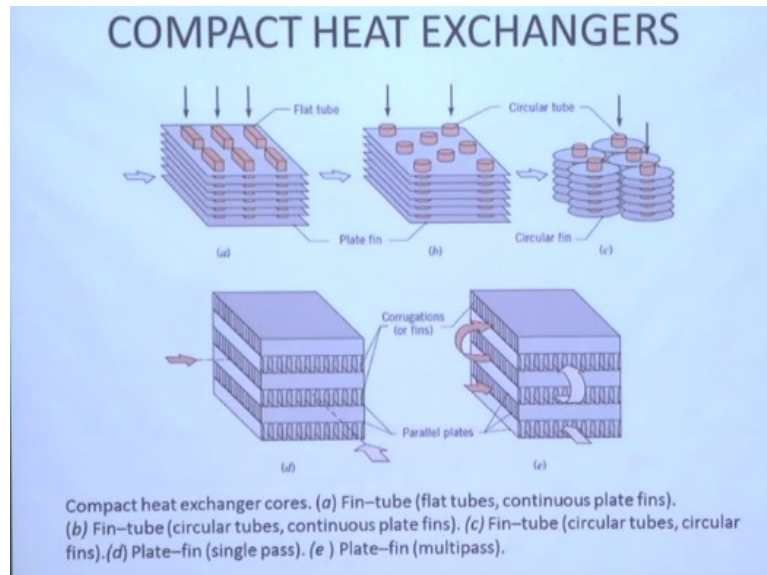
What is the minimum this? I will tell you. The arrangement is like that, this plate acts as fins to all these tubes. So, through tube one fluid flow and heat exchange from this fluid to the outer fluid is enhanced by finned whereas another fluid that is outer fluid which flows through the finned passage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

(Refer Slide Time: 16:31)



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, πDL , πDL is more so for example here you have the more length and more the surface area πDL .

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 $-K \cdot \text{gradient of temperature}$. “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.