Process Equipment Design
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Lecture – 2
Classification of Exchangers - I

Hello everyone, I welcome you all in this course and here I am having lecture 2 of week 1. The course is on process equipment design and in this lecture we will cover classification of exchangers. Now if you remember the last lecture, we have discussed different equipment which we are going to cover in this course as far as design is concerned. So, these equipment if you consider these are basically heat transfer equipment and mass transfer equipment.

So, first of all we will focus on heat transfer equipment where exchangers are very important. So, before going to start the design of exchangers, we will first focus on classification of exchangers and before starting that classification, let me define the exchanger. So, what is an exchanger?

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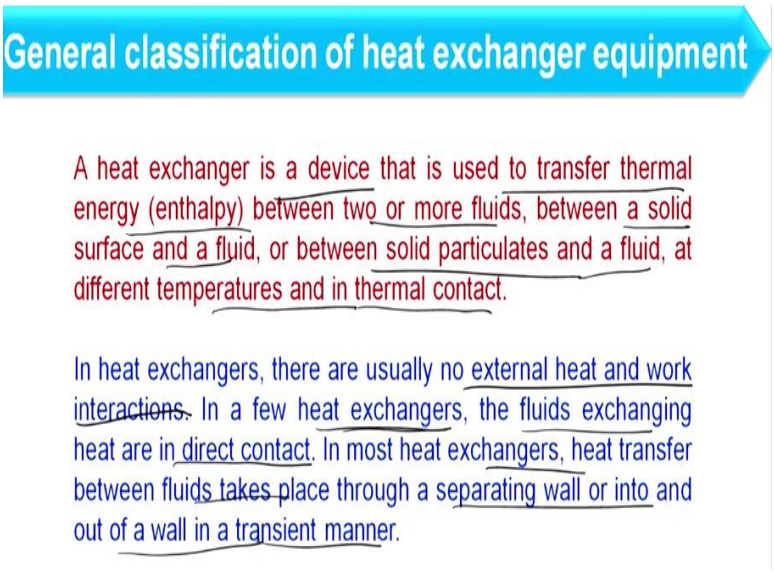

A heat exchanger is a device that is used to transfer thermal energy enthalpy between two or more fluids between a solid surface and a fluid or between solid particulates and a fluid at different temperatures and in thermal contact. So if you consider the heat exchanger, what is that? It is basically equipment basically a unit where we transfer the energy and what is the natural movement of energy from high temperature to low temperature.

So, wherever it is possible, wherever the two things occur at high temperature and at low temperature the heat transfer is possible either that is with fluids, if two fluids are available one at higher one at lower heat transfer is possible, heat exchange is possible. Between solid surface and a fluid, let us say if one hot plate is there and over that I have put some liquid or some pan so that pan is further heated up and from that to the material which is available in that pan.

So, surface to the pan and from that pan to the fluid which is available inside the pan, so you see it is basically solid surface to fluid. Between solid particulates and fluid, let us say if you have heat is available in some solid material like sand or something and when you pass air through it the heat can be transferred from sand particle to the air. At different temperatures and in thermal contact, so there must be a contact between them and that contact we call as a thermal contact.

So, whatever transferring or exchanging of heat occur in a unit that unit we call as heat exchanger. So, in heat exchanger there are usually no external heat and work interaction as I have told you that heat is transferred from high temperature to low temperature which is not required any external heat because heat is already available with the fluid with the solid whatever you say.

It means the heating media must be there and wherever it has to transfer the heat that should also be available near to that. In a few heat exchangers, fluids exchanging heat are in direct contact. We will see in subsequent slides that there are direct contact or indirect contact, what these are that we will discuss in detail there. So, in most heat exchanger, heat transfer between fluids takes place through a separating wall or into and out of the wall in a transient manner.

So, sometimes it is with direct contact means two fluids are in direct contact as I have already told you that if sand is heated up it can transfer heat to the air near to that, so there we are not providing any media between them, any separation between them, so they are in direct contact. In the similar line if I am putting a separating wall between two fluids it is called as indirect heat transfer. So, heat exchangers work on both principal, direct contact as well as indirect contact.

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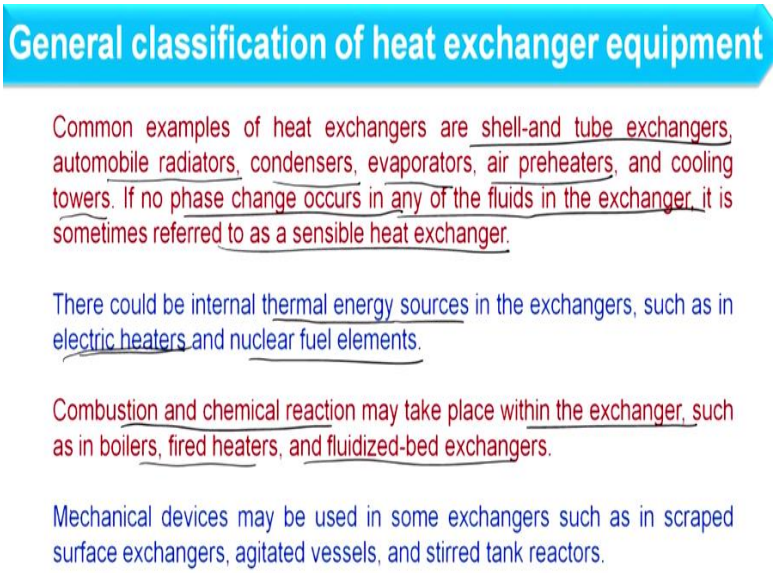

So, before going into detailed classification of heat exchanger, we will see some common examples of the heat exchangers and the most important or most common example of heat exchangers are shell and tube heat exchanger and others are automobile radiators, condensers, evaporators, air preheaters and cooling towers. All these are important heat exchanger or common heat exchangers.

And you can understand that if no phase change occurs in any of the fluid in the exchanger, it is sometimes referred as sensible heat exchanger. When I am dealing with liquid and liquid, when I am dealing with air and liquid, where phase change is not occurring there we can say that only sensible heat transfer occur. So, such heat exchangers are called as sensible heat exchangers.

So, if you will see the classification in subsequent slide, you can say that the classification is based on phase also, sometime it is single phase and sometimes it is multiple phase. So, these are some common example of heat exchangers and further there could be an internal thermal energy sources in an exchanger such as electric heater and nuclear fuel elements. You must have seen the water heater in your houses.

So, what happens over there we are not providing any fluid to heat the water, any hot fluid to heat the water. So, how water is heated up? Using some coiling inside the unit or some hot plate will be there. So, sometimes we also use internal thermal energy sources to transfer the heat. Combustion and chemical reactions may take place within the exchanger such as boilers, fire heaters and fluidized-bed exchangers.

So, you understand the function of the boiler where we insert the coal and at the periphery of the boiler we have tubes. Inside these tubes, water flows and in between we have coal which burn and due to combustion of coal significant amount of heat is generated and using that heat water which is flowing inside the tubes it gets heated up and then further converted into steam, saturated steam and then the superheated steam.

So, you can see along with heat transfer we have combustion and chemical reactions in some of the heat exchangers, and similarly in fluidized-bed heat exchanger what will happen? In fluidized-bed exchanger usually we have let us say if this is a fluidized bed, inside this we have the coiling and in this coiling water enters and exits and here I am having the bed of solid material. Bed of solid material means let us say bed of coal and from bottom we have air.

So, air when come in contact with the coal, it does two work. First is it fluidized with this bed and second is it helps in combustion of the coal because that will occur only in the presence of air. So, when this combustion will occur and that coal particle fluidized, it covers the complete coiling in which water is flowing and then water gets heated up inside this, so that is basically fluidized-bed exchangers.

And in some of the heat exchanger, we can install mechanical devices also such as a scraped surface exchangers, agitated vessels and stirred tank reactors. So, in this lecture, we are focusing on a scraped surface exchanger. So, what will happen in one side, this is basically double pipe heat exchanger, so inside the inner pipe we have fluid and this inner pipe basically rotates and over that inner pipe the outer surface of the inner pipe consists some blades, so that blades basically scrap the material.

So in annular side, usually we have some solid material and inside the inner pipe we have another fluid. So along with heat transfer we have the scrap action also so that solid will not be accumulated at one place. So, some mechanical devices we can use in heat exchangers.

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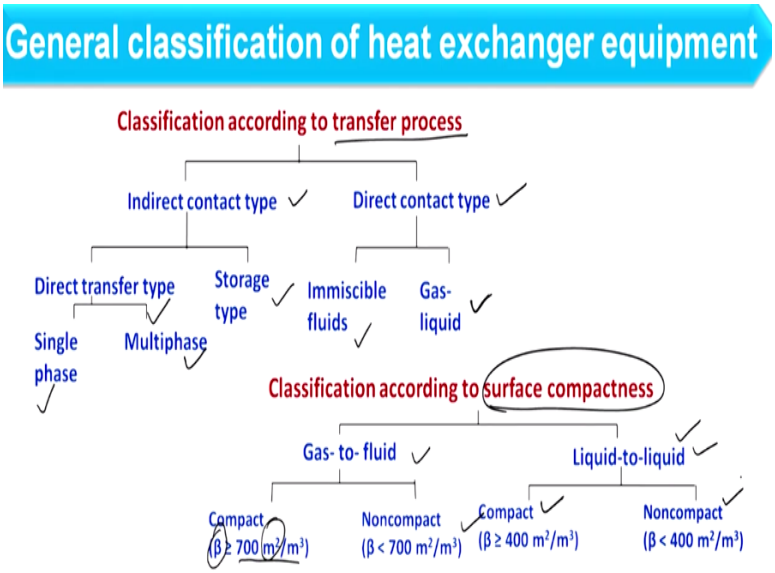

Now, we will focus on classification of heat exchangers and these classification depends on different factors. So, the first factor is we are going to classify the heat exchanger based on transfer process, how heat is transferring from one fluid to another fluid based on that we are going to classify. So, if you focus on this when I am considering transfer processes based on that, we have indirect contact type and we have direct contact type.

Now, what is indirect contact type? We also have discussed previously that when I am having a separating wall between two fluids, I am saying that the heat transfer is basically indirect. Indirect means what? There is no mixing between two fluids, no direct contact between two fluids. So, first of all heat will transfer from hot fluid to the wall and then from wall to the cold fluid.

So, obviously in that case that separating wall will work as a resistance between the two and therefore it puts extra resistance while transferring the heat from high temperature fluid to low temperature fluid. So, that is the indirect contact type. Similarly, I can focus on direct contact type that you can understand when the fluids are in direct contact, we do not have any separating wall between these two. So, let me further classify this indirect contact type.

So, if you see here we have two options, we have two category, first is direct transfer type and second is a storage type. Direct transfer type means as I have told you that heat is transferred from high temperature to low temperature but through a separating wall. Heat is first transferred from high temperature to wall, then from wall to low temperature fluid that is direct transfer type, fine.

Heat is continuously transferring to wall and then continuously it is transferring to cold fluid. So, continuous transfer is possible in direct transfer type. Now, what is a storage type? Storage type means we are storing heat which we can obtain from hot fluid to some media and then that media comes in contact with another fluid where heat is required. So, there again we have direct indirect contact type because media is available between two fluids.

To give an example let us say if I have to transfer the heat between two solids, you must have read about liquid-liquid exchanger, air-liquid exchanger, but it is very difficult to transfer the heat between solid to solid. To give an example, let us say if I am focusing on a sponge iron plant. A sponge iron plant, what is the raw material over there? Raw material is iron ore and coal, both are solids, and what is the product?

Product is basically sponge iron and we also call it metallic iron Fe. Iron ore Fe2O3 converts to Fe, so Fe2O3 is the raw material and Fe is basically the product or sponge iron or we call as a metallic iron, fine. Now what will happen? When the solid exits the equipment, I am not going into detail of the equipment, when the solid exits the equipment it is available at sufficiently high temperature. So that heat we can use to preheat the feed as well.

Feed means iron ore and coal. Now how it is done because both are solids. So what we can do, we can first of all take the heat from sponge iron to air, heat will be transferred to air, air will work as a medium to contain the heat and then that air further transfer to the or travels to the raw material that is iron ore and coal and transfer its heat to the solid. So, obviously some heat loss will be there because first air will take heat from the sponge iron and then it will travel to the raw material site.

Then it will heat raw material there, but obviously we can transfer the heat in such a manner. So, in this case air will work as a storage for heat. So, it is one example of a storage type. In subsequent slide, we will discuss the commercial exchangers available for the storage type heat transfer. So, further let me focus on direct transfer type exchanger. In this case, we can have single phase as well as multiple phase.

Single phase when I am having liquid to liquid heat transfer, when I am having air to liquid heat transfer, so these are basically single phase. Multiphase you understand where I am

having change in the phase of the fluid, fine. Let u say if I am using the steam. Steam first condense, it converts into the liquid form and then some sensible heat transfer may occur in that case.

So, in that case vapor and liquid both phase will occur in the same exchanger or in the same side of heat exchanger because it is indirect contact type. Because it is indirect contact type, so whatever would be the site, at that site both phase will occur together. So, that you can understand. Next let me classify the direct contact type exchanger. So, in this case we have immiscible fluids when I am considering two fluids which are not mixed together, let us say if I am considering oil and water.

So immiscible that fluid are there, so heat transfer can be occured without any separating wall. So, direct heat transfer is possible in that case. Gas liquid, so as far as gas liquid heat exchanger is concerned you know the example of this and that is very common in our life and that is basically the air coolers which we usually use in summers. So, there we have direct contact of air and liquid, so that is one of the example of gas liquid exchanger.

So, that is about the classification based on transfer process. Now, further we will consider the classification based on surface compactness. Now, what is surface compactness? Surface compactness means how compact the heat transfer surface is or how small the heat transfer surface is. It does not mean that heat transfer is less. It means we are increasing the heat transfer, but we are decreasing the volume, so that we call as the surface compactness.

So, it is basically defined as the heat transfer area per unit volume. So, as this heat transfer area increases in a unit volume, we consider that more and more compact exchanger. In that category, we further have gas to fluid and liquid to liquid. When I am focusing on gas to fluid, we can have compactness as more than 700. So, surface compactness we are representing with the factor beta and if it is more than 700 meter square per meter cube, meter square means what heat transfer area.

So, if it is more than 700 meter squared per meter cube, we consider that unit as compact unit, otherwise it is non compact. So, that beta value you can obtain very easily because you know the heat transfer, you know the total volume of the unit. So, in that way you can

calculate the compactness. For liquid to liquid case, compactness is smaller in comparison to gas because movement of gas becomes easier in any unit.

However, that is slightly difficult for liquid to move and therefore compactness is less when I am considering liquid to liquid heat transfer and in that case compactness should be more than 400 meter square per meter cube we consider that as compact unit otherwise non compact unit. Now what is the application of this compact exchangers? As you have already understood that it is basically in a small volume we have to increase the heat transfer.

How we increase the heat transfer? We increase the heat transfer by putting fins. Secondly, because its size is very small, utility should be there where size really matters. For example aerospace. If we are considering the equipment related to aerospace, there we consider compact heat exchangers and their material of compact heat exchanger is another important parameter.

We usually consider aluminium instead of steel or copper because that aluminum is lighter in weight. So, compact means a smaller volume, however, it should have the lighter weight also. So in that way, we consider the application of the compact heat exchangers.

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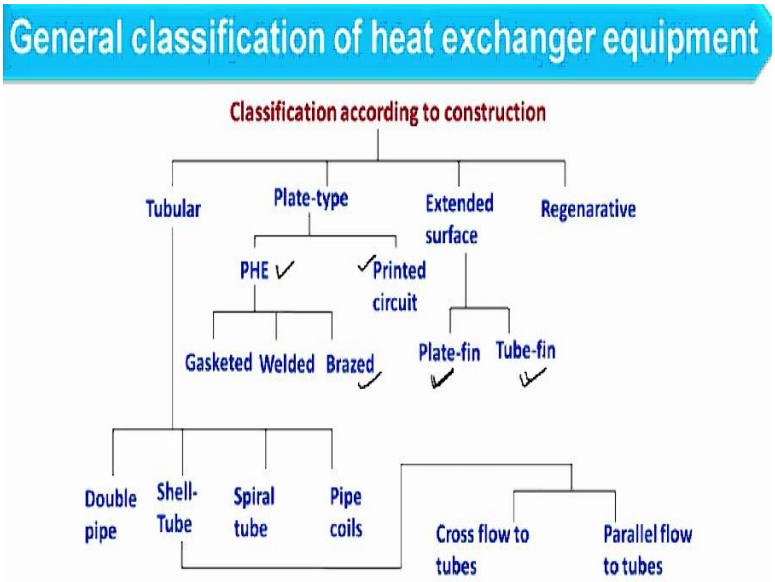

Further we are considering the classification according to the construction of heat exchanger. First one in this category is the tubular exchanger, plate heat exchanger, extended surface exchanger and regenerative type exchanger, fine. So, let me first focus on tubular exchangers.

So, very common heat exchanger in tubular category is the double pipe heat exchanger which is the simplest type of heat exchanger you can understand.

Next we have shell and tube heat exchanger which is also very common in chemical industries and spiral tube type and pipe coils. So, as far as double pipe heat exchanger is concerned, I think construction you know it already we have two pipes and one pipe is inside another pipe. So, that we call as the double pipe heat exchanger, fine. Second we have the shell and tube heat exchanger we have a big shell and inside this we have number of tubes.

So, these number of tubes are available in a definite pattern in this shell and tube heat exchanger or inside the shell and it has a definite structure. It is not only shell and tube, there are different assemblies which are installed in this exchanger which we will discuss in detail. Now next is a spiral tube. What is the spiral tube? Spiral tube is basically the heat exchanger which is available on a surface only.

Usually when I am considering the shell and tube heat exchanger, it has a particular diameter and length. The spiral tube means we have the coil over the surface. So, if I put the coil over the surface, it is basically called as a spiral tube. So, if I consider that a spiral tube its structure is like this, on the floor we have tubing. So, it is basically the spiral tube heat exchanger where two tubes move together.

If I am considering coiling, so two tubes coiling will move simultaneously, in one coiling we have one fluid, another coiling contains another fluid, but the structure will be like on a surface and it is basically available horizontally, not vertically. Similarly if I am considering pipe coil, pipe coil is like this helical structure if I am considering. So in this case, again the two pipe will move together in helical way.

Or its application will be like you can consider a reactor where if I have an endothermic and exothermic reaction inside this, I have to provide the heat or I have to take out the heat from the reactants. So what will happen? Inside the container we have the reactants and over it at the periphery we half pipe, which is basically is attached in a helical manner over the container. So, this half pipe contains basically the heating media or the cooling media as per the requirement.

So, it is basically the pipe coils heat exchanger. Further let us elaborate shell and tube heat exchangers. So these are basically cross flow to tubes and parallel flow to tubes, so it will depend on the flow type. So, that is the classification of shell and tube heat exchanger. Now, we will further classify plate type heat exchanger. Plate type heat exchanger is PHE that is plate heat exchanger and printed circuit.

Plate heat exchanger where instead of tubes we are using plates. So, plate is basically the separating wall between the two fluids, one side of the tube one fluid is there, another side another fluid is there, so that is plate heat exchanger. This we will also discuss in detail in subsequent slides. And then we have the printed circuit. Printed circuit means you must have seen the motherboards of the computer.

So, there we have the copper wiring, so that copper wiring is basically in very small heat exchangers or when we consider the printed circuit or like chip, over that we have copper coiling and inside this coiling we have different fluid which is moving for heat transfer, so that is like motherboard structure. Let me further classify plate heat exchanger. So, these are basically gasketed type, welded type and brazed type.

Gasketed type means we use gasket over the plate. How we use this? It will be discussed in a subsequent slide. So, in some plates we consider gasket and that gasket is used to separate the fluids, and in some cases where gasket is not feasible we consider welding to separate the fluid and welding you understand that at very high temperature we melt the iron and that iron fills the gap, so that is the welding and in some cases we also carry out brazing.

So, what is the difference between welding and brazing? Welding we do with the iron bar and brazing we do with the brass like if you have observed the utensils at your house, in the kitchen utensils, so all steel utensils if it has the handle if it is the pan and handle is attached to that, so either handle is attached through the screw or it will be simply pasted, so that basting is done through brazing, I hope it is clear.

Next we will further classify extended surface heat exchanger, Extended surface heat exchangers are like plate heat exchanger and plate-fin heat exchanger and tube-fin heat exchanger. So, plate-fin heat exchanger means heat exchangers is attached with a plate. So,

that plate works as a fin, and if I am considering tubes as a fin that will be considered as tube-fin heat exchangers.

All these heat exchanger plate fin and tube fin we will consider, we will discuss these in detail in subsequent slides. So, you please understand for now that it is plate type as well as tube type, plate fin and tube fin. Regenerative as we have already discussed is storage type, so based on construction we consider that as a regenerative type heat exchanger. So, what is the main point over here?

If you consider this classification, though we classify at different category at different factors, but some of the heat exchangers will definitely occur in other factors also. Like we consider that as overlapping, like if you consider based on transfer process we have indirect heat transfer equipment and that also occur in tubular exchanger, plate type exchanger. So, you consider all these heat exchangers are overlapped between different factors. I hope it is clear.

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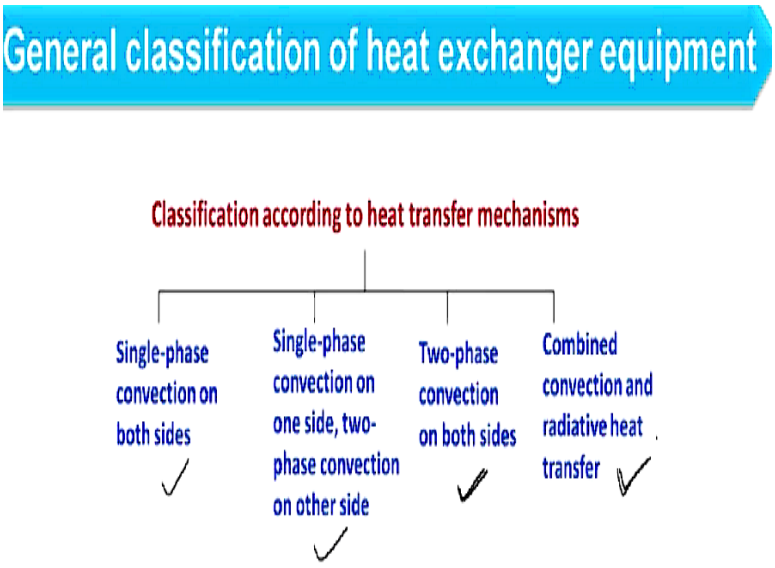

And now we will have the classification based on heat transfer mechanism. Here we have 4 classifications. First phase single-phase convection on both sides. When I am transferring heat transfer between liquid to liquid, convection occur in one fluid and second fluid also convection will occur. So, single phase will remain there, however heat transfer will occur through convection.

So, that is you can consider normal shell and tube heat exchanger when I am transferring sensible heat, so this type of heat transfer mechanism will be followed there. Single-phase

convection on one side and two-phase convection on other side. To give an example let us say we can have condenser. So what will happen in condenser? We have vapor which is to be converted into liquid.

So, phase transfer or phase exchange or phase conversion occur in one side of the exchanger and in second side of the exchanger we usually have water or the cold fluid. So, this is the example of single-phase convection on one side and two-phase convection on other side. Third we have two-phase convection on both sides. To give an example if I consider reboilers, what will happen in reboiler?

We have liquid which is available at more or less close to boiling point and when it takes heat from high temperature medium it is vaporized and that high temperature medium is what? Usually that high temperature media is a steam. So, when I am considering a steam, it will be condensed and then it will transfer latent heat to another fluid and another fluid because it is available at boiling temperature vaporization will occur.

So, both sides we can have the phase change. And fourth category in this classification is combined convection and radiative heat transfer. So, what will be the example of that? The example is boiler. In boiler what will happen? Initially we have the coal and while combustion of coal heat is generated. So, how that heat is transferred into the vapor side? That is done through the radiation.

So, radiative heat transfer occurs as well as convection will occur, in both way it will be transferred because some convection will also occur at the surface of the tube and from surface to the fire side the transfer will occur through radiation. So, usually it is done on boiler heat exchanger, fluidized-bed heat exchanger which we have discussed in previous slides and fire heaters.

So, these are some examples of different exchangers which are falling under category of different heat transfer mechanisms. So, in this lecture we have discussed the classification based on different factors and in the next lecture we will focus on details of some important heat exchangers. So, that is all for now. Thank you.