Process Equipment Design
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Lecture – 3
Classification of Exchangers - II

Hello everyone, I welcome you in the third lecture of week 1 of the course process equipment design and here we are discussing the classification of heat exchangers. Actually, this topic we have started in lecture 2 where we have classified the heat exchangers in different categories depending upon different factors, and in this lecture we are going to discuss the important heat exchangers and they are working in detail. So, let us start this.

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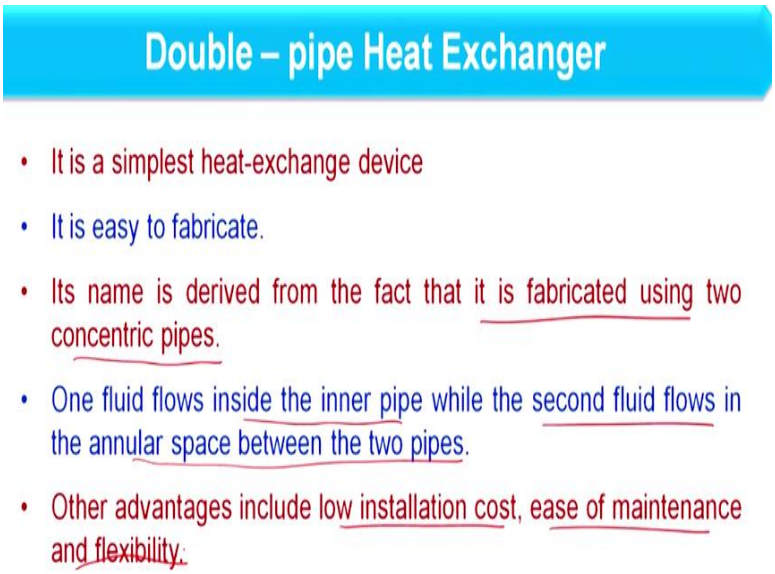

So, first heat exchanger I am considering as double-pipe heat exchanger. So, this you all know that it is the simplest heat transfer unit or heat exchange device. The structure is simplest and as it is simplest it is very easy to fabricate because we need only 2 pipes which we can insert one over another and the exchanger is made. So, as the name says it is fabricated using two concentric pipes.

So, therefore, it is called as double-pipe heat exchanger. One fluid flows inside the inner pipe while second fluid flows in annular space between two pipes. So, that I think functioning you all understand very well because you also have done experiments on double-pipe heat exchangers maybe in your second year chemical engineering course. So, this heat exchanger

is known to you very well and it has other advantages along with ease of fabrication and simple design.

The other advantages are it has low installation cost, ease of maintenance and flexibility because design is not much complicated. So you can consider ease of maintenance and flexibility in such heat exchangers.

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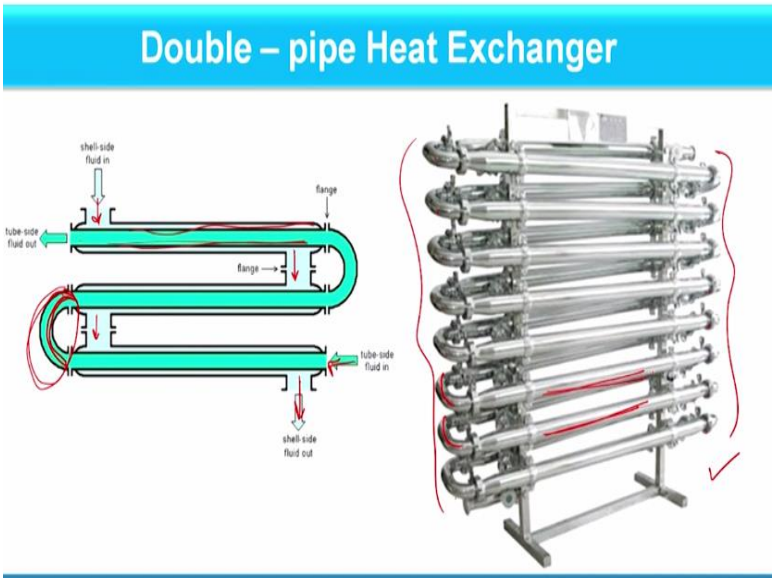

So, here you see we have this heat exchanger, double-pipe heat exchanger. This is inner side and this is annular side. This is annular side. So one fluid is moving in annular side and then a transfer from here to here and then exit from here. Another fluid is inside the tube and and move in serpentine manner. Now, if you consider this particular section of double-pipe heat exchanger, this section is basically called as hairpin, as usually we use a hairpin, it is this U shape.

Hairpins usually have U shape and that shape is available over here also and therefore this section is called as hairpin. Now, if you see any commercial heat exchanger, it looks like this. Details are available on this site that you can go through. So if you see here I am having this commercial double-pipe heat exchanger where we have hairpins like 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 15, 16.

So if I consider both sides we have double-pipe heat exchanger with 16 hairpins and inside this one fluid is moving and another fluid is in annular side So, why I am putting this hairpin or why I am putting the U turn in double-pipe heat exchanger? The reason is very simple that

it should occupy less space on the floor. Because double-pipe heat exchanger if you are considering the two concentrate pipe, right.

So as we increase the area, the length of the pipe will increase significantly and therefore it will occupy more and more space on the floor. To reduce that we can consider the same heat transfer area with less space while providing this hairpin type of structure. So because of that this hairpins and number of hairpins along with the length is very important criteria while designing double-pipe heat exchanger that point we will discuss when we will consider its designing.

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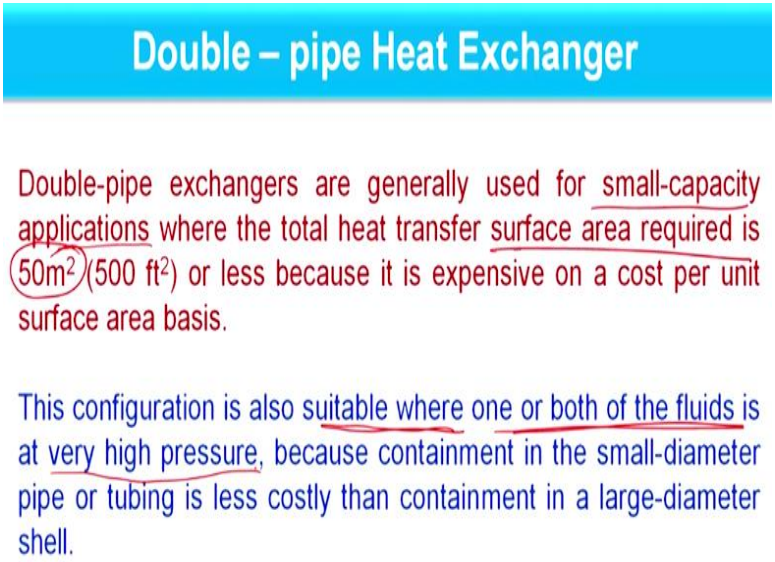

And here we are discussing some more important facts about the double-pipe heat exchanger. Double-pipe heat exchangers are generally used for small capacity applications where heat transfer surface area is around 50 meter square or less than that because though we are considering hairpin, but still it will consider a sufficiently large area on the floor in comparison to other heat exchangers.

Therefore we do not use double-pipe heat exchanger for large load or for very high load, load you understand the heat duty. So, heat transfer area up to 50 meter square we can consider double-pipe heat exchanger and if I am finding more heat transfer area than that we should choose other heat exchangers like shell and tube heat exchanger, etc., and this configuration is also suitable where one or both of the fluid is at very high pressure.

Because what is happening over here we have two concentrate pipes, right. So, the diameter of two concentric pipes is not very large. The diameter of two pipes are small and if I am considering very high pressure, then the double-pipe heat exchangers becomes cheaper in comparison to other heat exchanger like shell and tube heat exchanger and the reason is very simple because what will happen when I am considering high pressure accordingly I have to choose the thickness of the shell or thickness of the tube.

Now, if I am considering thickness of the tube how I can compute that it can be computed using the expression like T should be equal to P d0 by 2 fj + p that is the expression you can consider in mechanical design. So, as the pressure increases thickness will increase, fine. Along with this, there is another important parameter is the diameter. So, for very high pressure if I am considering diameter to be very large, it will consume sufficiently large material in comparison to a small diameter.

Because small diameter will give lesser thickness and large diameter will give larger thickness. So, obviously when I am dealing with very high pressure it means we have to reduce the size of the pipe, size of the pipe means diameter of the pipe. So, instead of including high pressure in shell and tube heat exchanger, we prefer to include high pressure in double-pipe heat exchanger because diameter is small.

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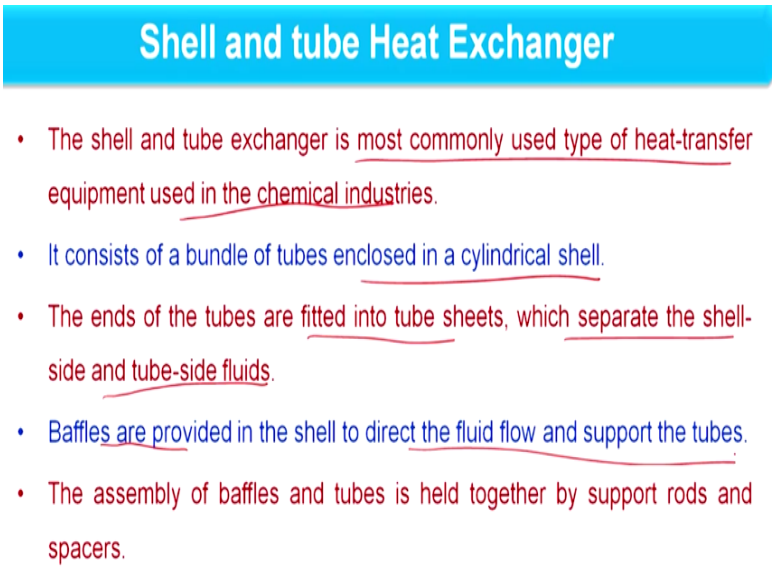

Now, next unit we have is the shell and tube heat exchanger. This is the most commonly used type of heat exchanger equipment used in a chemical plant. So, that is most commonly used. It consists of bundle of the tube enclosed in a cylindrical shell. So, usually in shell and tube

heat exchanger you are aware with that that it has a single shell where we have number of tubes inside this and that number of tubes we call that as tube bundle.

So ends of the tubes are fitted into tube sheet which separate the shell-side and tube-side fluids. So what will happen over here that we have to separate the fluid which is available in shell side and which is available in tube side and that separation is done through the tube sheet. Tube sheet has two purposes. First is it inserts the tube inside this. It lets the tubes inside this.

So, it basically holds the tube from two ends fine and this complete assembly we call as to bundle. Different other accessories are there which are included in bundle that we will discuss later on. So, that tube sheet one purpose is that it basically holds the tube and second is it separates the liquid which is flowing in shell side and tube side and this point will be more clear from next slide when they will discuss the shell and tube heat exchanger through schematic.

Further we are using baffles and these baffles are provided in shell to direct the fluid flow and support the tubes. So, what will happen? When I am considering that tube sheet is basically holding the tubes, but it hold the tube from two ends only. However, if we let the tube hanging between two tube sheets, what will happen? Because of high velocity vibration may occur in the tubes. Because of these vibration tubes may coincide in the shell.

So, to separate that tube or to hold the tube in between to support that you we use baffles and baffles purpose is also to direct the fluid inner shell side. So, that I hope you understand. So, the assembly of baffles and tubes is held together by support rods and spacers. So, what is support rods? Support rod is basically the rod which is inserted in the tube sheet and that rod also contain spacers. Spacers are what?

Spacers are basically used to provide definite space between the baffles because baffles are usually arranged at definite space and that is space we provide through spacers and those spacers are inserted in rods not the tubes because if it will be inserted in the tube so from where heat transfer will occur. So tube will remain open and those spacers are inserted in rods. I hope it is clear.

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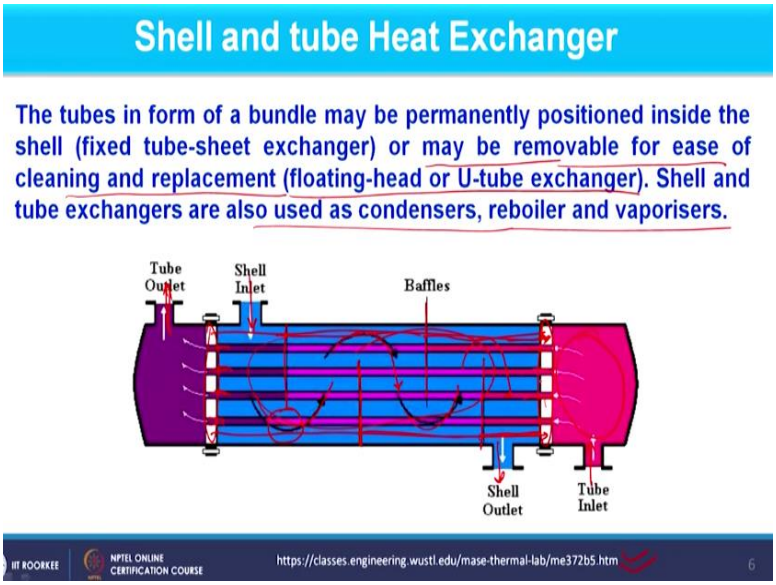

So, as far as shell and tube heat exchanger is concerned, the tubes is formed a bundle which may be permanently positioned inside the shell. So, when the tubes are permanently fixed inside the tubes, this we call as fixed tube sheet and in some cases tubes may be removable for ease of cleaning and replacement and this we call as floating head or U-tube exchangers. So usually fix tube sheets are sometimes permanently fixed with the shell and sometimes it is movable also.

But in most of the cases for cleaning and maintenance purpose it is movable so that we consider as floating head or U-tube exchangers and floating head comes with a different aspect and that aspect we will discuss when we will further classify shell and tube heat exchangers. So, it will come before design of shell and tube heat exchanger, so there you can understand the purpose of floating head or U-tube exchangers.

So, shell and tube heat exchanger are also used as condenser reboiler and vaporizers. So, these are some uses of shell and tube heat exchangers. Now here if you see we have the schematic of shell and tube heat exchangers, details you can find from this link and here you see we have this tube sheet. So, these are basically the tube sheets at both side of the tubes where tubes are inserted as you can see here.

Now what will happen? This tube sheet separates the fluid which is moving in the shell. Shell inlet is here, exit shell nozzle is here. So, you can see whatever fluid is moving in this shell, it will not interact with that available in tube side because tube side inlet pipe is there and outlet

pipe or outlet nozzle is here. So, you can see the tube sheet purpose is to hold the tubes as well as to separate the liquid of shell and tube side.

Now, next is we have these baffles. Some part of the baffle is removed so that liquid can move. So, these baffle basically provides the movement of the liquid in the shell side along with it holds the tube because in the pattern tube sheet has holes in the same pattern baffle will have the holes so that U can be inserted in the baffle. So, when I am considering tube bundle, tube bundle basically includes this tube sheet, these tubes, baffles and rods.

So, where rod is attached? Rod is attached here. This rod is not the part of the tube. And how this rod looks like? Iit is like you must have seen like TMT bars. So this rod is like TMT bar where spacers are provided like if I am considering this space between baffle and tube sheet. So, first the spacer will insert and then baffle will insert, then again we provide the spacer and then the baffle.

Similarly in this side. So, in this way we put the spacer in rod and then we insert the baffle. So, this is assembly for shell and tube heat exchangers, we will further discuss these each accessory when we will cover the shell and tube heat exchanger design.

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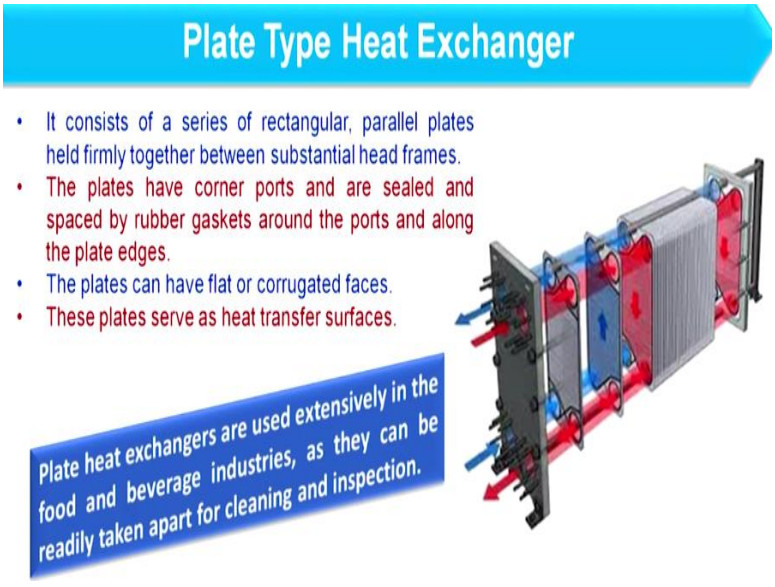

Now let me focus on plate type heat exchangers. As we have a tube and shell in shell and tube heat exchangers here we are dealing with the plates. So, it consists of a series of rectangular parallel plates held firmly together between substantially head frame. So, here

you see in plate type heat exchanger, we have the head frame that I will show. Let me show that first, fine. Now, if you see this is schematic this is structure.

This rectangular plate and this bar and over if you see at the top we have this bar also where these plates are hanging. So, this bar is available at top as well as bottom both side. So, each plate type heat exchanger has plates which are arranged parallel to each other like this and and this and it is firmly together with a substantial head frame and plates have corner ports and are sealed and spaced by rubber gaskets around the ports and along the plate edges.

Now, what is this? If you consider each plate, either you considered this plate, this plate or this plate each plate will have 4 corners, fine. Now, what is the purpose of these corners? The purpose of these corners are it basically let the fluid enter or let the fluid pass through it. So, each plate will have 4 corners and if you consider this particular plate the second plate here we have this black assembly and this black assembly is nothing but the gasket.

Now, if you focus on this plate what will happen when fluid is coming and how the movement of fluid occurs over here? If you see here we have the cold fluid, which enters from here and exits from here, similarly hot fluid enters from here and exits from here. So, when it is entering into the system or entering into the heat exchanger, between two fluids there is no fluid which can be entered in this region because here we have the frame only.

And this plate works as a heat exchanger plate, so what will happen? Whatever cold fluid is coming if you see this particular plate here we have the gasket and gasket closes this corner and closes this corner. So, whatever cold fluid is coming it will pass over this or it will spread over this plate and exits from here because it cannot enter to this corner or to this corner fine. In the similar line if I considered this third plate then what will happen?

Gasket is attached like this because it is putting a bar over here or hurdle over here it will not allow cold fluid to enter into this. Open space is available only for the hot side. So, these two nozzles you can consider for hot fluid, these two nozzles you can consider for cold fluid. So, because it is open for hot fluid, the fluid will come over here, spread over the plate and then exits from here.

So, all these plates are attached one by one and between two plates one fluid will move and in the subsequent side or in the consectutive side another fluid will move. So, if I am having this type of these two plates, here I am having cold fluid, then here I am having hot fluid, then cold fluid and then hot fluid, like this it will keep on moving and how we will ensure that only cold fluid will enter and only hot fluid will enter that is because of gasket.

I have already explained that how gasket is placed, so it will not allow any other fluid to enter into one plate or we can say the mixing of fluids on a plate which is not possible over here. So, separation of fluid will occur through this gasket. Now what will be the distance between two plates? How we will ensure the proper distance between the two plates? That distance is according to the thickness of gasket.

Because each plate will be placed so tightly that the space between two plates will be only equal to the thickness of gasket. And if I am not using that gasket, we sometimes weld that particular section. So, welding means what? Two plates will be joined permanently, welding or brazing means what two plates will be joined permanently, so it has an advantage and disadvantage also.

Some disadvantages are there with gasket also that we will discuss later on. So, plates can have flat and corrugated faces because each plate will have some structure, we have some depression in this, we have wavy structure also and because of this we can find more turbulence over the plates. When the fluid will move because of this hazy structure, more turbulence will be there over the plate which increase heat transfer coefficient.

So when you compare the heat transfer coefficient of plate heat exchanger and shell and tube heat exchanger for the same heat transfer area, heat transfer coefficient will be significantly higher in plate heat exchanger because of this structure only and these plates serve as a heat transfer surface. So, this point we have already discussed. So as far as utility of plate heat exchanger are concerned, these are used in food and beverage industry as they can readily taken apart for cleaning and inspection.

Now as I have told you that two plates are very compact or very close to each other, it means it has very high tendency of scaling and to avoid that usually plate type heat exchangers are

used for clean fluids, not the fouling fluids. So, that is the main point about plate type heat exchanger.

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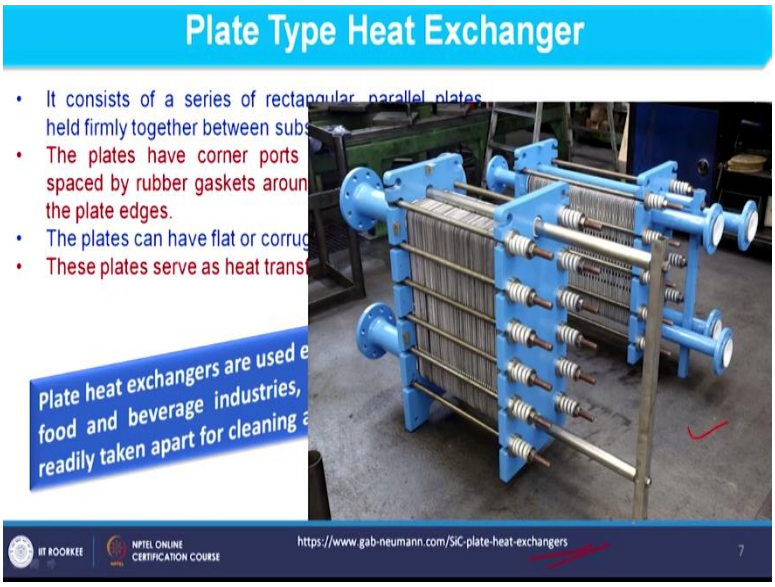

And if you see here we have this photographic view for actual heat exchangers and you can find details about this on this website. So that is about the plate heat exchangers.

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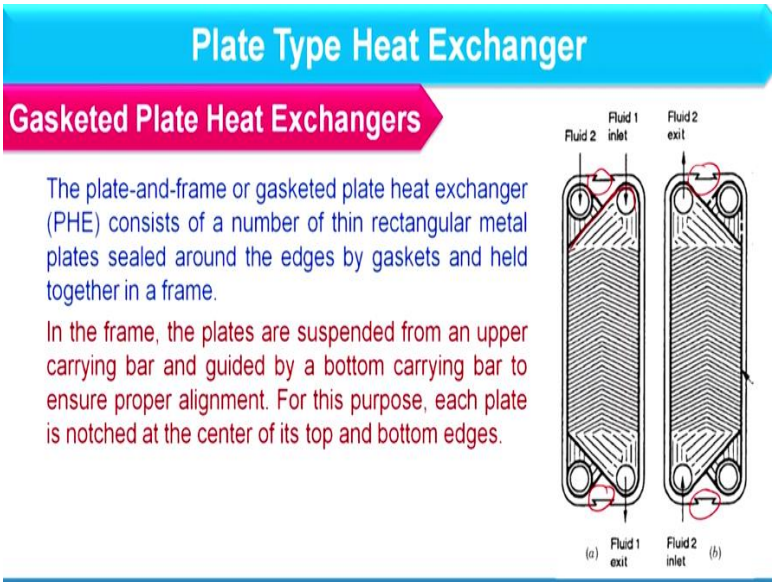

Now here we have gasketed plate heat exchanger where we put the gasket. This is basically the gasket from last figure, it is more clear in this figure. So, you can imagine this, you can see the gasket over here and if you consider this notches, here we have the notch, so these notches are basically used to hold this plates. So, as I have already discussed that frame is used where these plates are hanging.

So, hanging means what? It is basically fixed with this notches So, wherever required the plates can be removed clean and further placed at the right space. So that is with the gasket plate heat exchangers.

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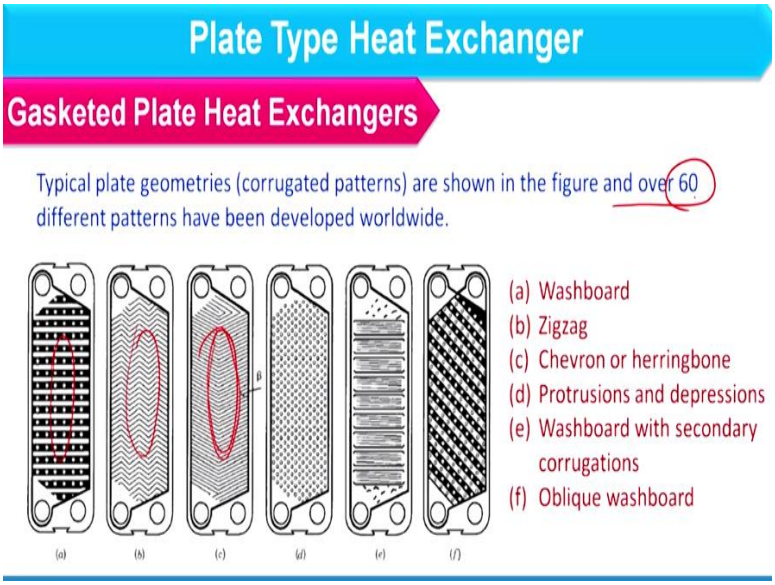

Here we have different types of plates. In some plate you can have this zigzag structure and in some cases this we call as herringbone type of structure and washboard are also there. So, you can see we have different types of plate and when we cover the whole total design over the plate it is more than 60 different patterns over the plate. So, you can understand the structure over these plates or the pattern over these plates.

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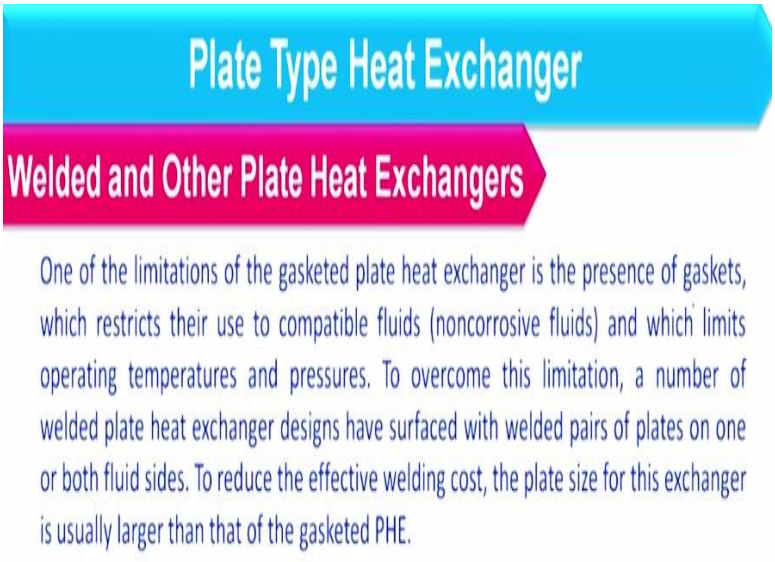

Now we will discuss welded and other plate heat exchangers. So, first of all now tell me what is the limitation of gasket plate heat exchanger. The material of gasket is usually rubber type,

fine. So, we cannot handle very high temperature or a very high pressure fluid in such type of heat exchangers when I am using the gasket because gasket will tear and fluid may come out and if I consider further because the reaction of fluid with the gasket material is significantly high in comparison to welding or other type of structure.

So, that is basically the limitation. So where I am having this type of condition, I basically weld the two plates together instead of gasketing it and when I am doing the welding, welding will be done in a similar line as we do the gasket like in one plate only corners which is free for hot fluid that will remain open otherwise it will be closed and on second plate we have to open the space for hot fluid to move.

So, accordingly we can weld the corners. So as far as welding, gasketing or brazing is concerned, the structure over the plate will remain same as we have already discussed. So, welding is done when we are dealing with high corrosive fluid when we are dealing with high temperature and high pressure of the fluid. Again we have the disadvantage with welded plate because it is permanently joined, so that will be difficult for cleaning purposes.

So, these are basically advantages and disadvantages and in which case which type of plate heat exchanger should be used all these we have already discussed and now we will focus on extended surface heat exchangers.

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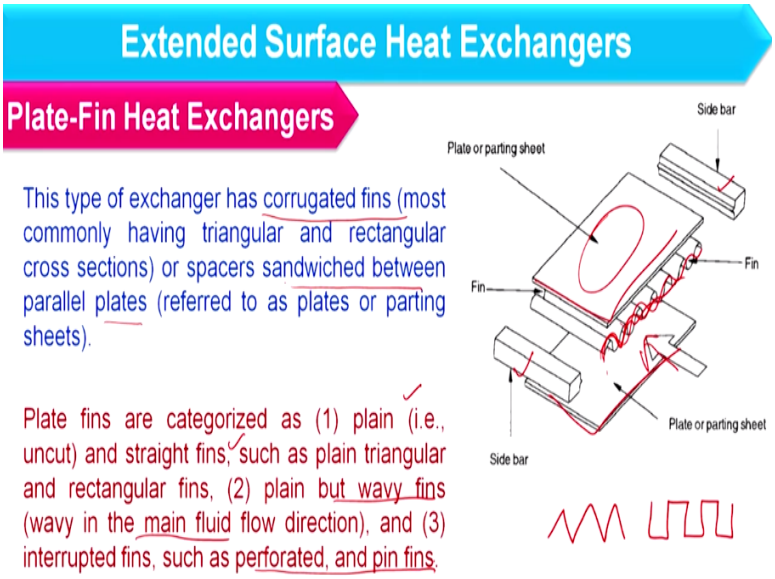

If you see here we have the schematic of this. Extended surface means we are basically using the fins and these fins are basically placed between two plates. If you see these two plates are

there and fins are in between and here at the side we have side bar. So, inside this fin we have one fluid, another fluid would be over the plate. So this is basically plate-fin heat exchanger. So, these type of exchangers have corrugated fins or spacers which are sandwiched between parallel plates as we have just discussed.

And plate fins are categorized as plain and straight fins such as plain triangular and rectangular fins like we have this type of fins or we have this type of fins. So, this is rectangular and triangular type of fins and in some cases it is wavy fins as we are discussing as we can see here and interrupted fins with some perforation and pin fins. So because of this perforation or pin fins, we can have more turbulence so we can increase the heat transfer coefficient.

Now the point is where I am using this fins and what I am saying that extended surface where I am finding lesser heat transfer coefficient, there we are considering plate fins because we are increasing the heat transfer area in that particular section. So, it is called the extended surface because we are extending the heat transfer area in a particular region. So because of that we are using plate-fin heat exchanger.

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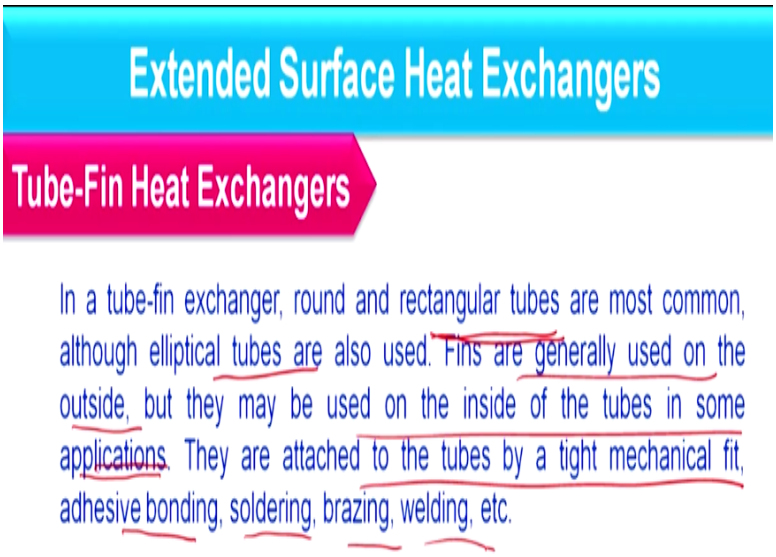

Tube-fin heat exchangers we also use and these type of heat exchangers and rectangular tubes are most common and sometimes we also use elliptical tubes. And fins are generally used on the outside, however in some cases inside also we put the fins for some specific applications and these fins are attached to the tubes by tight mechanical fit, adhesive bonding, soldering, brazing or welding. So, in this way we can place the fins in the tubes.

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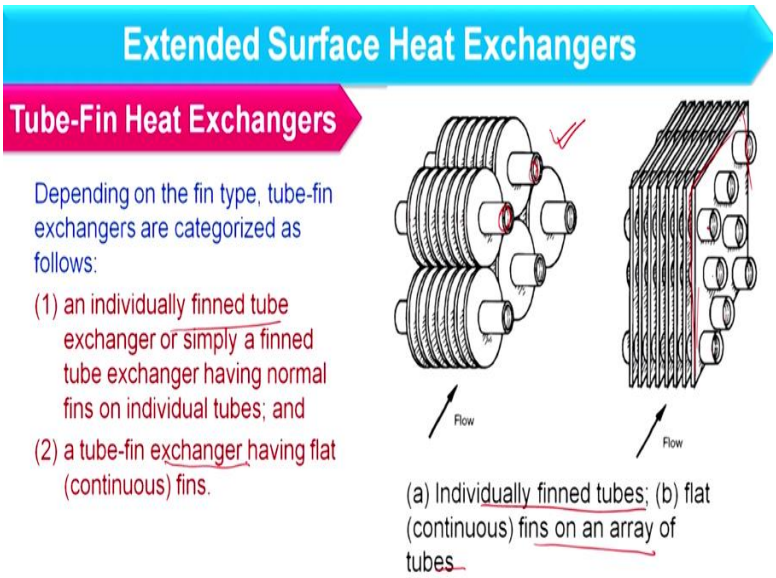

Now if we focus on this schematic here we have the tube fins and each if I consider this image here we have this tube, inside this tube fluid will move and over this tube we have this disk type of fins and because of this disk type of fins, the shape of this fins is tube type that is why it is called as the tube fin and it is attached over the tube. So, it is like when you put the CDs in a tube side by side.

So it is this type of structure and this we call as individually finned tubes and secondly we have number of tubes and we have an array of fins. This is basically an array of fins and this we call as flat fins on an array of tubes. So, in this way the tubes are arranged in a definite pattern, so this is basically the array and we are considering the plate fins over here, but because it is inserting over the tube it is called tube fins.

So depending on the fin types, tube-fin exchangers are categorized as individually finned tubes and tube-fin exchangers having plate fins as we have just discussed.

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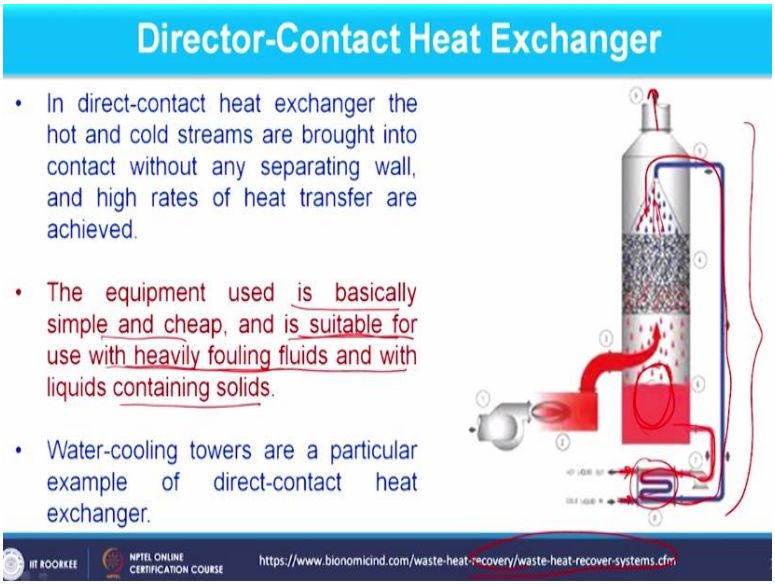

Now we are focusing on direct contact heat exchangers. So, direct contact heat exchanger we have already discussed when I am not having a separating wall between two fluids. So, hot and cold fluids will come in direct contact with each other. So, what will happen? If I am considering the separating wall that separating wall will provide the resistance to flow the heat and in direct contact type that separating wall is not available.

Heat can be transferred from one fluid to another fluid directly without any resistance. So, in that case we find high rate of heat transfer and that is obvious also. So, the equipment used for direct contact type is basically simple and cheap and is suitable for use with heavily fouling fluid and with liquid containing solids. So when I am dealing with high fouling fluid where we can have reduced heat transfer coefficient, so that fluid can be handled easily in direct contact type because further resistance is not offered in heat transfer.

So water cooling tower and air coolers are example of direct contact heat exchangers and here I am having one image of direct contact heat exchanger and details you can find here. So here hot gas enters into this and it exchanges heat with the cold water which is coming from the top or cold liquid and subsequently cold liquid is heated up and hot gas is cooled down and exits from the top.

And this hot fluid, hot liquid further gets cooled in this heat exchanger where heat transfer occur from this fluid and then it cools down and further recycles back to the cooling tower and this is basically the assembly of cooling tower we usually use to produce cold water in

chemical plant. So, that is about the direct contact heat transfer. Now I am having air cooled heat exchanger.

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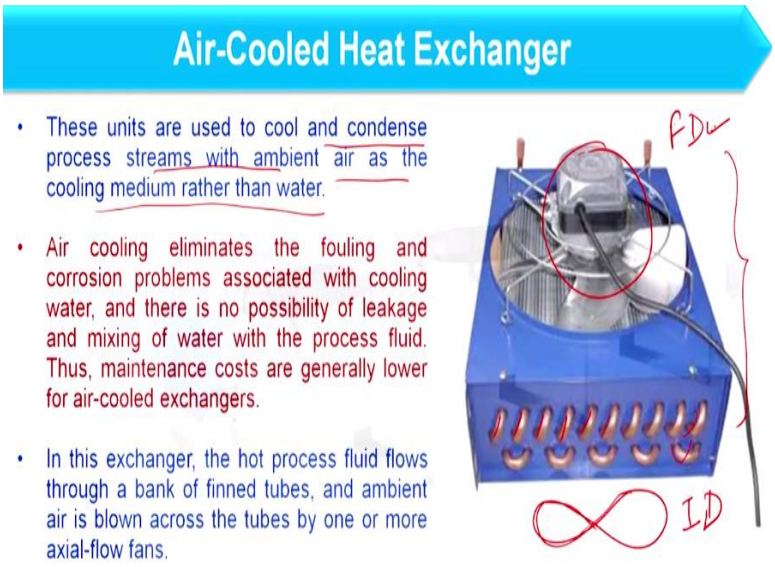

Air cooled heat exchangers are used to cool and condense processes streams with ambient air as cooling media rather than water. So, usually for condensation purpose we use water, but here we are using air as a cooling media and second fluid will definitely be the vapor which is to be condensed. So if you see this schematic when the fluid is to be condensed that fluid should move or should flow inside this copper tubes.

And this fan we are using to throw the air over these tubes and therefore these vapor which is flowing in the copper tube can be condensed and hot air can be exited from the bottom. So, in this air cooled heat exchanger if I am putting the fan at the top, at the top means before the process is going on because once air will be thrown by this fan, then condensation will take place. So, this type of placement of fan we called as FD fan or forced draft fan because it forces the air in the system.

It means it create positive pressure in the system. On the other hand, we can place fan at this side also instead of topside. So, considering this it means it basically sucks the air as it is placed after the operation. So, this type of fan is called as ID fan or induced draft fan and this induced draft fan basically creates negative pressure in the system and forced draft fan gives positive pressure in the system. So, these are basically air cooled heat exchanger.

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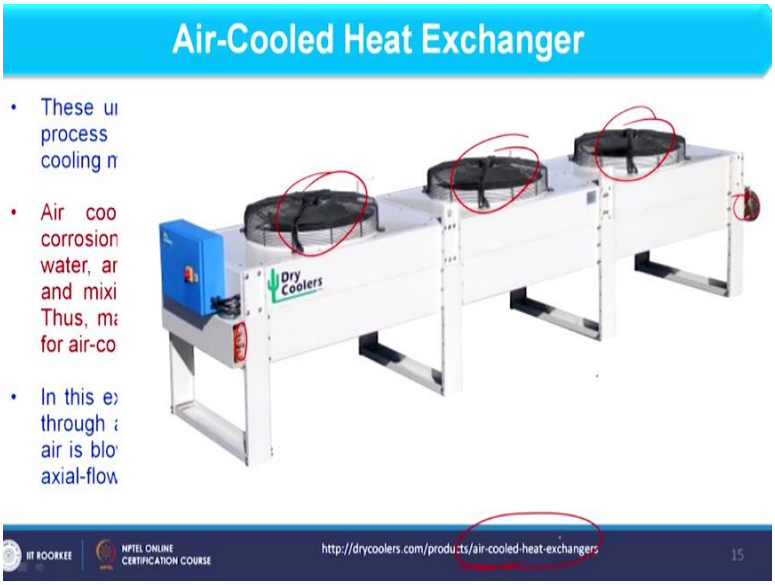

Here again we have the image where we have three coolers there and if you see here we have the copper coiling inside this. So this is another example of air cooled heat exchangers, you can find details in this site.

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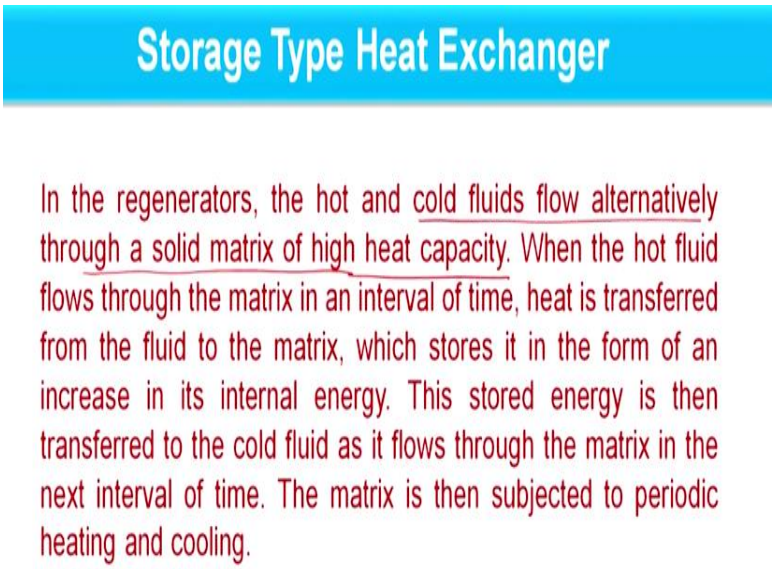

Now we will focus on storage type heat exchangers. Now storage type heat exchanger, these are basically called as regenerators where hot and cold fluids flow alternatively through a solid matrix of high heat capacity.

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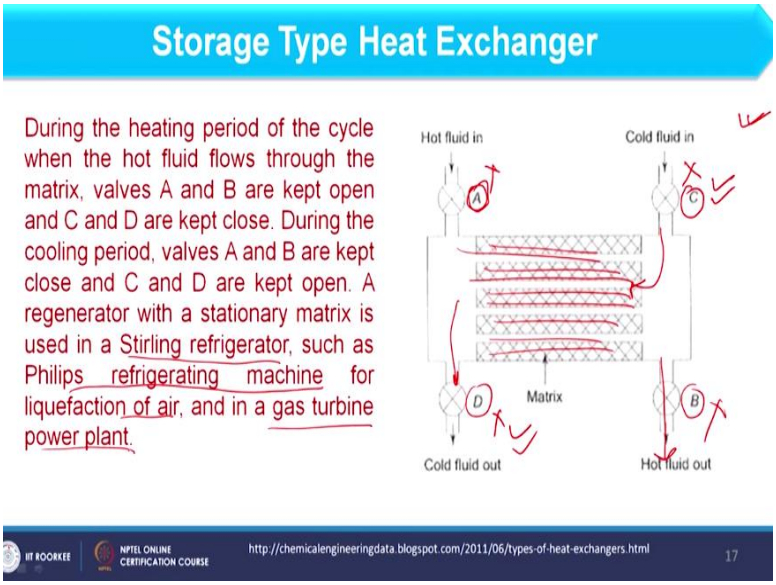

To illustrate that let me focus on this image. Here if you see in this heat exchanger, we have the solid matrix. This is the matrix, zigzag formation is there. So, this is the solid structure or we can consider that as packing and hot fluid enters from point A and exits from point B, cold fluid enters at C and exits at D nozzle. Now, what will happen? Now in this storage type heat exchanger, hot fluid first moves and at that time cold fluid nozzle will be closed.

So, hot fluid whatever is moving it will enter into this, transfer its heat to this matrix and then exits from here. Second time what will happen this will be open and this will be closed. So cold fluid will further pass through this and then it will take heat from the matrix and then exits from here. In this way, this is basically storage type heat exchangers and here matrix is used as a media to store the heat.

These are used in Stirling refrigerator such as Philips refrigerating machine for liquefaction of air and in gas turbine power plant. So these are some of the application for storage type heat exchangers.

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1	Backhurst, J.R. and Harker J.H., "Coulson and Richardson Chemical Engineering", Vol. II, 5th Ed., 2002, Butterworth-Heinemann.
2	Sinnott, R.K., "Coulson and Richardson's Chemical Engineering Series: Chemical Engineering Design", Vol. VI, 4th Ed., 2005, Elsevier Butterworth-Heinemann.
3	Serth, R.W., "Process Heat Transfer: Principles and Applications" 2007, Elsevier Ltd.
4	Shah, R.K. and Sekulic, D.P., "Fundamentals of heat Exchanger Design", 2003, John Wiley & Sons.

Here the references are there which you can use to study this topic more clearly and in more detail.

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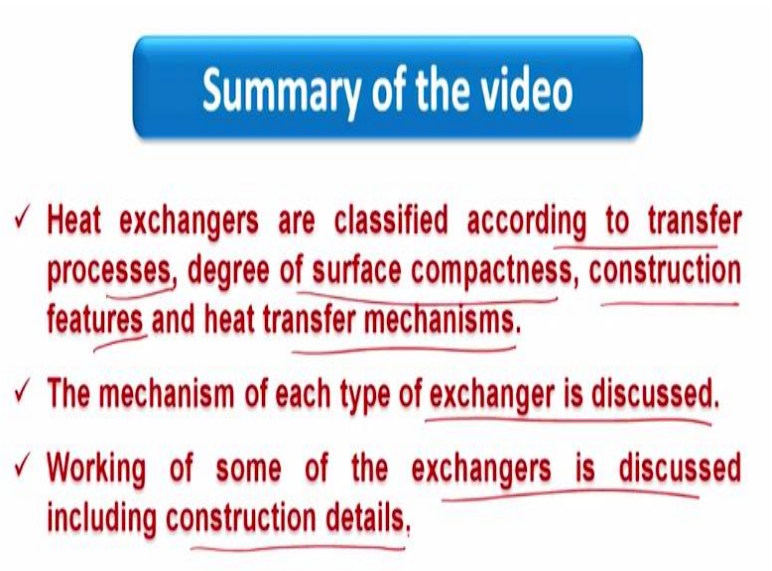

Now let me summarize this video. Now as far as the sumary is concerned, this is the summary of lecture 2 and lecture 3 of week 1, where we have discussed the classification of heat exchangers. So summary goes as heat exchangers are classified according to transfer processes, degree of surface compactness, construction features and heat transfer mefchanismas.

Mechanism of each type of heat exchanger is discused in detail and working of some heat exchangers is discussed including constructional details and that is all for now. Thank you.