Fundamentals of Food Process Engineering
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Lecture - 21
Heat Exchangers

Hello everyone. Welcome to NPTEL online certification course on Fundamentals of Food Process Engineering. Today we will going to start a new chapter on Heat Exchanger ok. So, heat exchanger is a very important component or equipment in most of the food process engineering, chemical engineering and many mechanical engineering operation and you are familiar with many kind of heat exchanger for example, you see you have seen normal water cooled condensers or radiator ok. So, those are example of heat exchanger.

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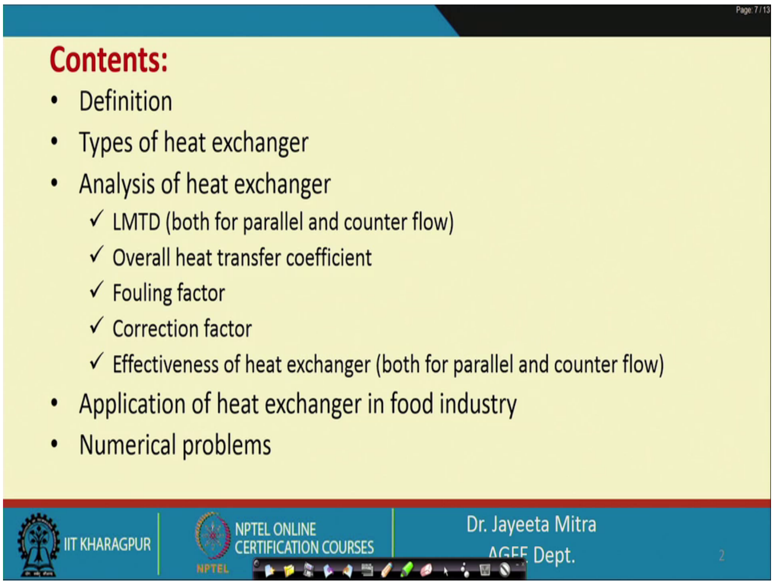

So, we will discuss today definition of heat exchanger, different type of heat exchanger, analysis of heat exchanger in terms of Log Mean Temperature Difference LMTD, we will discuss it for both parallel and counter flow heat exchanger, overall heat transfer coefficient, fouling factor, correction factor, effectiveness of heat exchanger again both for parallel flow and counter flow. Apart from this we will discuss a few application of heat exchanger in food industry and also solve some numerical problems.

So, this chapter of heat exchanger is very important and in many other chapter for example, in the last chapter when we have discussed about evaporator there also application of heat transfer and heat exchanger are involved. Because there also when the steam and the dilute liquid which were evaporated, they were you know they were transfer heat across a surface area ok. So, across that surface area exchange of heat happens. So, that is also some kind of heat exchanger. So, let us start with the topic ok

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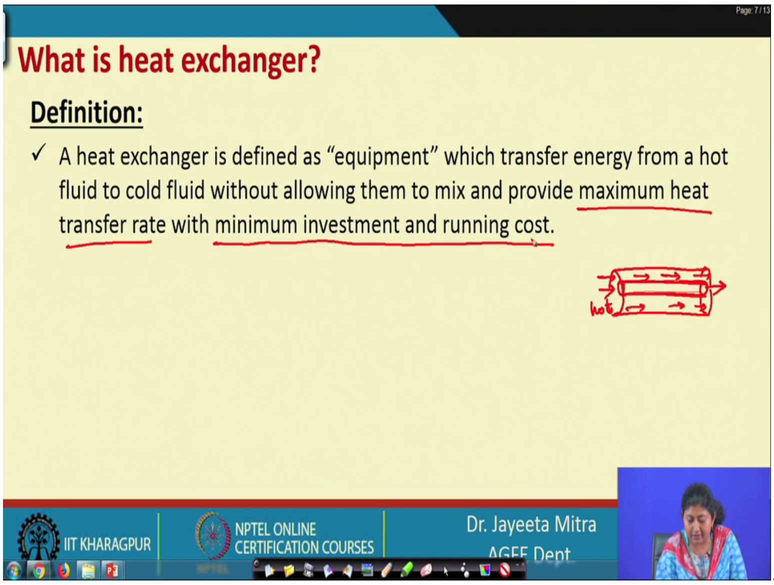

So, what is the heat exchanger, what kind of system can be termed as heat exchanger? So, a heat exchanger is defined as an equipment which transfer energy from a hot fluid to cold fluid without allowing them to mix ok. So, the basic you know fundamental is that there is a heat exchanger surface ok. So, let us see if it is a pipe through which hot fluid is coming in and going out and there is another pipe which is surrounded the inner tube or inner pipe ok. So, through which the cold fluid is flowing right.

So, they are going to exchange heat over the surface of this inside tube, inside the cylindrical section or the tube. So, that will be the surface area and there is no mixing between these 2 fluid and obviously, there will be temperature difference between these 2 fluid, one will be hot fluid and another will be the cold fluid because temperature difference should be the driving force for heat flux to be moved from the higher side to the lower side. So, that is the heat exchanger. And another important thing is that, here we get maximum heat transfer with minimum investment and running cost. So, heat exchanger is a very effective equipment.

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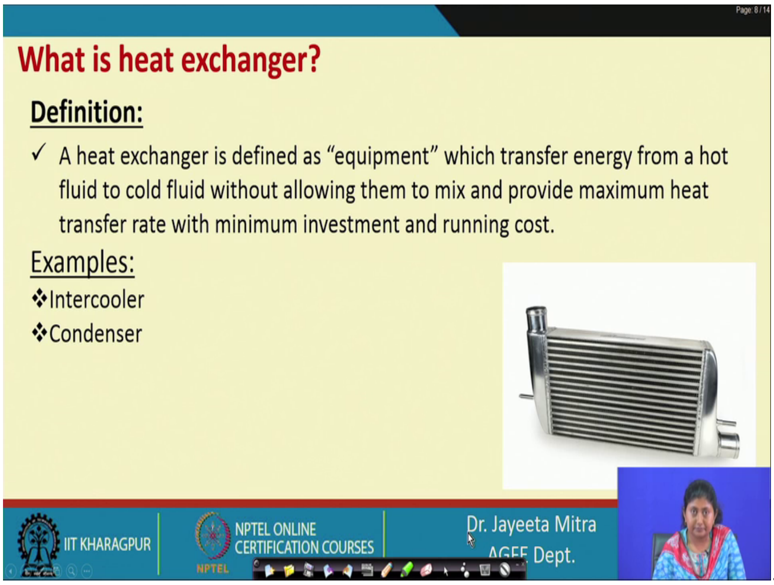

So, then if you see the example intercooler which is look like this, where there is from one side the hot fluid is entering and there is tubing inside the tube there is a exit and the you know very small fins are there inside this system the intercooler, and that will again increase the heat transfer area that we will a bit we will discuss a bit here and may be you have learned this in your in your heat transfer classes ok. So, this is one example of heat exchanger.

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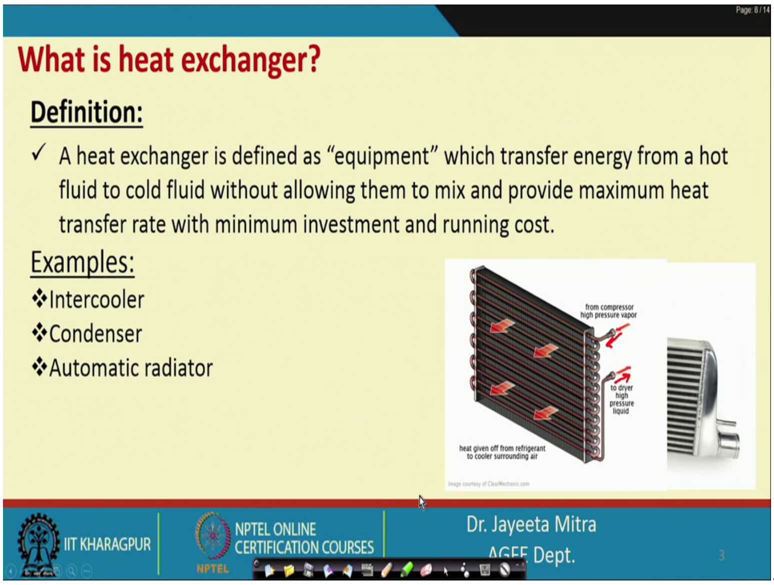

Another is condenser ok. So, condenser it may be air cool condenser or water cool condenser. So, here what happen that, from the compressor high pressure vapour is entering here in this tube the upper tube and there are coils tubes are in the form of coil they are fix here in the condenser, and this is the exit end from the bottom which is going to dryer the high pressure liquid ok.

So, this vapour is condensed here in the condenser and the heat given or from the refrigerant is going to the surrounding air ok. So, that is the heat is going to the air and here the temperature is not changing for this condensing vapour to liquid, because we know that when phase change happen then only the heat transfer occur. So, the temperature of this vapour and the liquid that is going to the going to the drag that are those are at same temperature ok. However, the temperature of that air will increase because it is taking the heat away ok.

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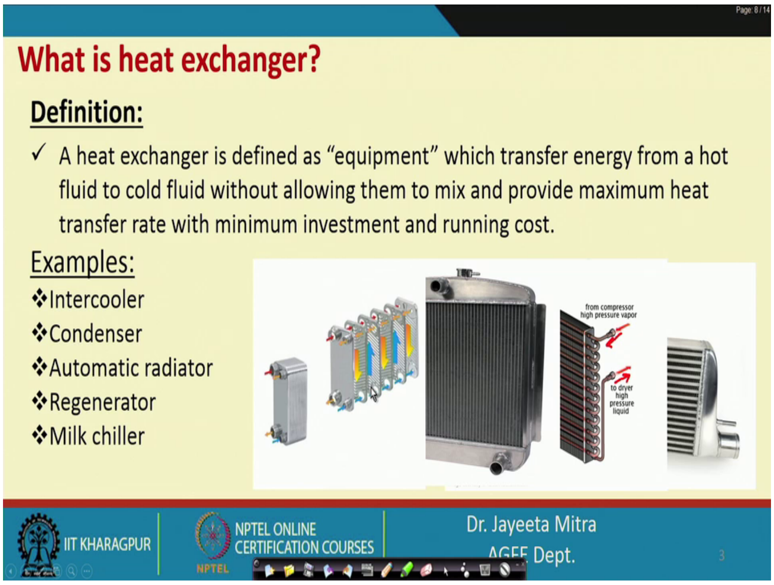

Automatic radiators are there, again regenerator. Regenerator means basically regenerators are one kind of heat exchanger where heat exchange between 2 fluids, but face change does not occur right.

So, therefore, we have seen the use of regenerated in the milk pasteurizer ok. So, what is the configuration of this regenerator? This is used as the milk chiller as well. So, there are plates stack of plates are attached together, and between 2 plates one fluid is going and the other set of 2 plates the other fluid is going the direction is reverse most of the cases and this is very effective heat exchanger we will come in detail of that. So, these are different kind of common use of heat exchanger ok.

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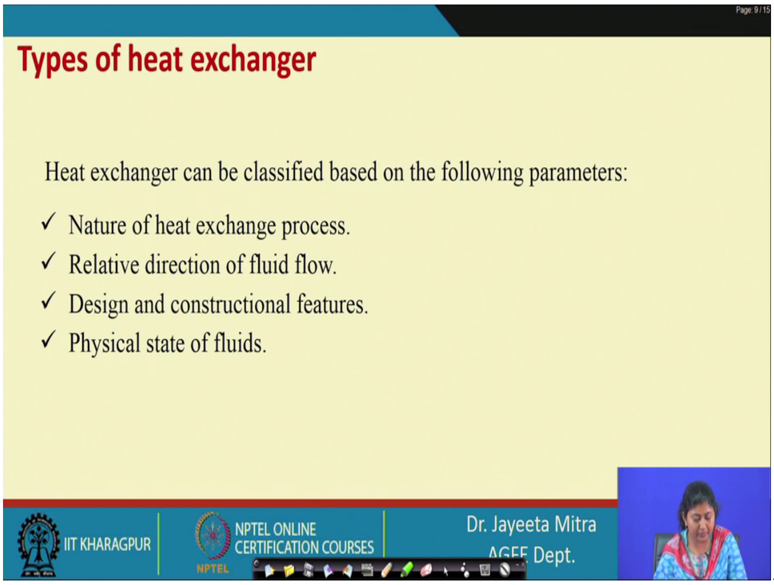

So, heat exchanger can be classified in many ways and some can be based on nature of heat exchange process. That means, whether heat is being exchanged via any surface or direct mixing of the gas and the liquid is taking place. Second is relative direction of fluid flow; that means, the 2 stream that we are considering, there is a direction of flow for those 2 streams.

So, whether that directions are parallel or counter or is there any different configuration so, based on that we can divide the heat exchanger. Design and constructional features this is another criteria by which we can separate them and physical state of fluid; that means, whether we are using different state or we are allowing only similar state. For example, liquid and vapour are going to exchange heat or only liquid and liquid is going to exchange heat.

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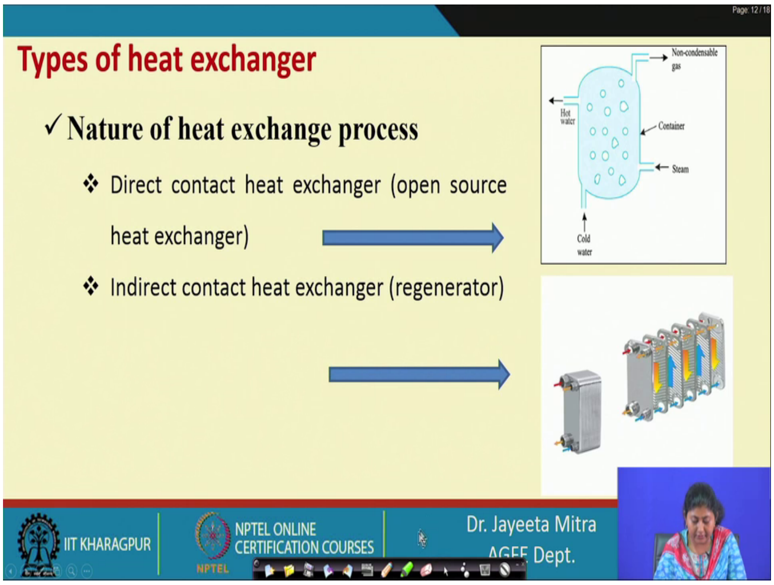

So, first we will discuss nature of heat exchange process. So, the direct contact heat exchanger or this is called open source heat exchanger. So, direct contact heat exchanger; that means, as the name suggest that there will be mixing of the fluid, mixing of the fluid streams and another is the indirect contact heat exchanger for example, regenerator as we have discussed just now. So, what happen in case of direct contact heat exchanger this is how it looks like. When steam is entering into the open source heat exchanger and cold water is also entering into the heat exchanger.

So, the latent heat of steam will be taken by the cold water and that is released as hot water here whereas, there are many non-condensable gases so that will be vented out ok. So, this kind of a system is called the direct contact heat exchanger and indirect contact heat exchanger; that means, those plate heat exchanger kind of method, where there is a there is no direct contact or mixing between the 2 stream.

So, those 2 streams are going in different direction. So, the fluid that is entering the hot fluid which is entering from one side of the channel, that is coming down following the corrugated path of the of the plates and going out of the other side whereas, the cold fluid which is entering from the different side and which will exchange heat wire a heat exchanger surface ok. So, these are called the indirect contact heat exchanger.

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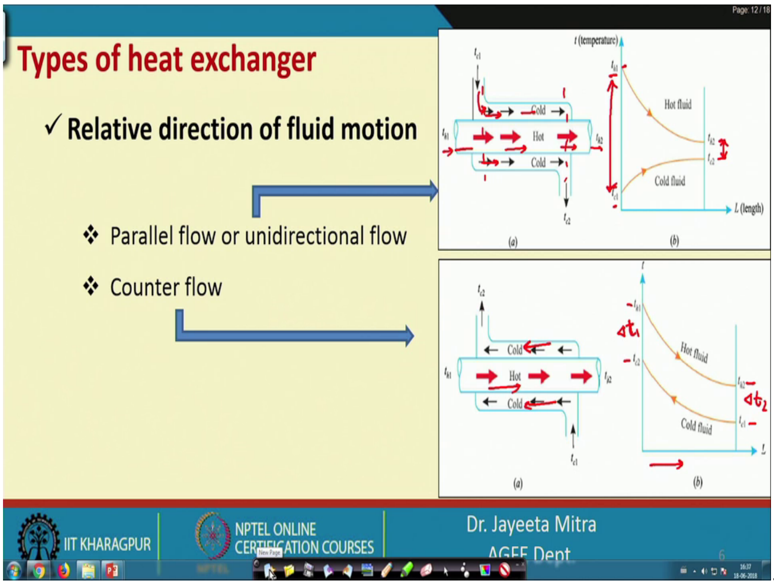

Now we will go to the next category that is relative direction of fluid motion. So, this is very important because we will see that based on different direction the heat transfer rate will going to effect ok. So, sometime for depending on the practical case, what kind of fluid what kind of direction is important so, considering that we need to design the heat exchanger. So, first is parallel flow or unidirectional flow; that means, that direction of the 2 fluid streams are similar second is counter flow; that means, the fluid stream are coming from 2 different direction or opposite direction in the heat exchanger.

So, first we will see that the parallel flow or unidirectional flow. So, here we are considering a case where hot fluid; hot fluid is entering from this inner tube ok. So, t h 1 is the inlet temperature t h 2 is the exit temperature whereas, the cold fluid is entering from this section and this is going out from the others other end. So, here the direction of the 2 fluid, direction of the cold fluid and the hot fluid are in the same direction. So, this is called the parallel flow heat exchanger. Now if from this point the inlet point to exit point we want to plot the temperature distribution along the length l of the heat exchanger or for that matter we can plot it over the area as well.

So, as it crosses over the surface area, what will be the nature of the temperature distribution. So, we can observe that t h 1 which is the inlet temperature of the hot fluid will going to reduce and coming to t h 2, where the cold fluid which is entering at t c 1 going to increase temperature. So, initially the deviation was very high and eventually that will reduce. So, this is the parallel flow or unidirectional flow.

Now, if you see the counter flow heat exchanger. So, this how a counter flow heat exchanger looks like the configuration. So, we can observe that; this is particular case where the direction of the flow is reverse ok; so, here the direction of the cold fluid and here the direction of the hot fluid right. So, in this case if we plot in a similar way that is across the length what will happen to the temperature of the 2 fluid.

So, we can find that t h 1 is decreasing to t h 2 whereas, t c 1 going to increase to t c 2 and here the difference between those 2 temperature are almost similar delta t 1 and delta t 2 right. So, we can see that how we can distribute them based on the relative direction of the fluid motion.

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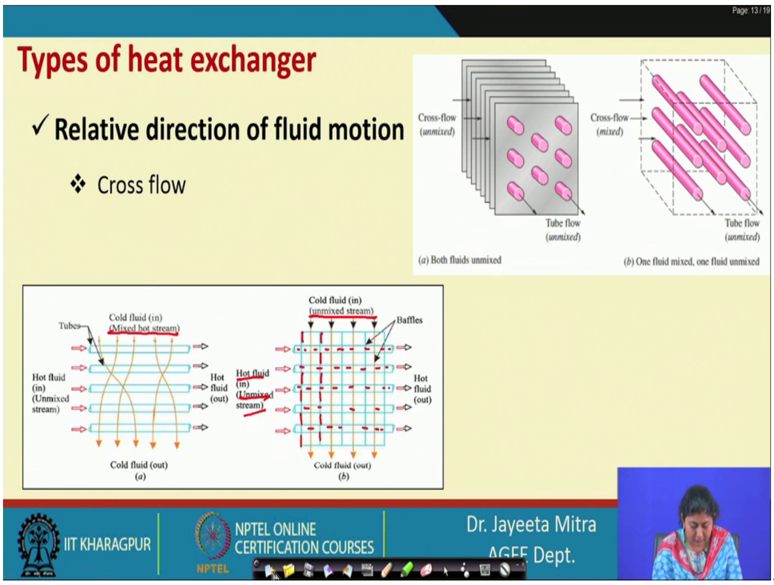

There is another category in the section is cross flow cross flow heat exchanger ok. So, cross flow heat exchanger this is again can be considered as 2 type. So, you can observe that first one which is called the unmixed type ok.

So, in this what happen that the hot fluid, which is entering from this pipe hot fluids are entering in this pipe there is a stack of pipe ok. So, it is going and it is exiting from the other end. Whereas, cold fluid which is entering to the entering in a heat exchanger at 90 degree or cross flow direction with the perpendicular to the direction of the flow of the hot fluid right.

So, there therefore, we are calling it cross flow heat exchanger and here also there are segments or baffles provided in between 2 entry point of the cold fluid. So, they are not getting mixed, as they enter from one channel they are exiting from the other. Although they are not tubes, but there are some partition or baffles or arrangements are provided so, that the fluids are not getting mixed with each of the each other streams right.

So, this baffles are helping them to channelize the cold fluid also in unidirection. Whereas, if you see the mixed stream then what happen; the hot fluid is entering through the tube and going out whereas, the cold fluid is coming in a cross flow direction that is perpendicular direction, but there is no baffles ok. So, there is chance that this fluid stream will be mixed and there will be abrupt temperature variation. So, they are not following any trend and the lateral mixing between the cold fluid stream will happen. So, this can be more clearly visualized in this figure. So, this is the cross flow and here the baffles are there. So, both fluids are unmixed and here where the cross flow air is coming over the tubes, over the bundle of tubes, but that is mixed right ok.

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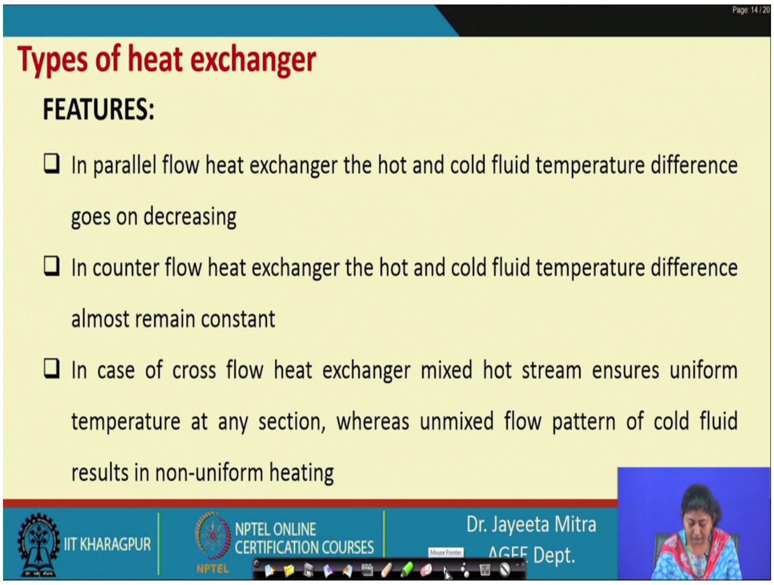

Then we will move on to the next category and also discuss certain features of that, the heat exchanger based on the relative direction of fluid flow. So, in parallel flow heat exchanger the hot and cold fluid temperature difference goes on decreasing that we have seen, and in the counter flow hot and cold fluid temperature difference almost remain constant. In case of cross flow heat exchanger mixed hot stream ensure uniform temperature at any section whereas, unmixed flow pattern of cold fluid result in non-uniform heating.

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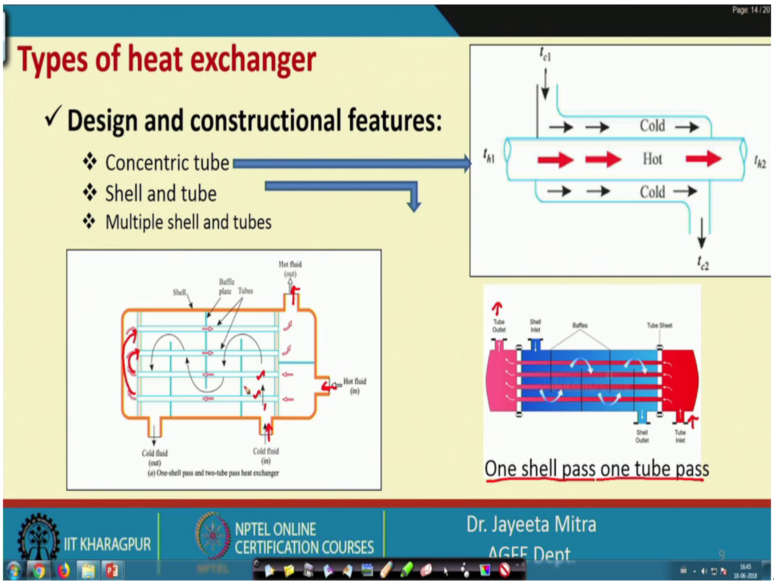

Then design and constructional features that based on this design and constructional features we can have different exchange heat exchanger for example, concentric tube, shell and tube heat exchanger and multiple shell and tube heat exchanger. Concentric tube means there is 2 concentric tube mostly the configuration is where from the inner fluid a inner tube the hot fluid is passing and the annular space cold fluid is passing, and the heat exchange they may be counter flow, parallel flow and second is shell and tube heat exchanger ok. Shell and tube again can be of many type and shell and tube are generally very bulky arrangement.

So, in industry application or processing plan or condenser, all those cases this kind of configuration shell and tube heat exchanger is used. But it is not used in the application where very light weight configuration is needed for example, radiator that is transport application or in aviation.

So, there this kind of systems are not used rather the cross flow systems of you know cross flow system with baffles those kind of systems are more common ok. And in case of shell and tube also if you see the most common configuration that is one shell pass one tube pass; that means, there is one big shell and in the shell here is the one side there is inlet of the fluid and through the tube it is going to the other side, and exiting from the outlet right. So, as the fluid is passing the whole shell, the fluid will going to interact with the shell fluid once right.

So, this is one shell pass one tube pass and there are baffles provided not just to hold the tube properly or giving a you know mechanicals strengths to the to the tubes proper holding to the tubes, because otherwise they may you know because of the heavy pressure and because of the flow sometime they get damage.

So, they are providing them the structural support, but also this baffles are orienting the fluid, the shell fluid to a particular direction. So, here the shell fluid is almost coming in a cross flow direction with the tube flow right. But if the baffles are not provided so, then the shell fluid it is entering from this side and straight away going to the other side. So, it may be counter flow arrangement in this particular case; however, through baffles here cross flow arrangements are maintained ok.

So, here what we have done? In the shell side we have divided them again to 2 different shell. So, what happen the hot fluid that is entering from this channel will go to this 2 tube first and then when it reaches the other side, it will redirect to the other 2 tubes and they will again it will flow and then going out from the top whereas, the cold fluid which is entering from the bottom side, this side.

So, again the baffles are provided these are the baffles. So, in a cross flow direction this is going and this is redirecting again and this is coming from the other side right. So, here it is example of one shell pass 2 tube pass or 2 shell pass 4 tube pass we can say because one shell side 2 tubes are there and we have divided into this way ok. So, this is one shell pass one tube pass and this is one shell pass 2 tube pass.

So, one tube is this to this and then it is redirecting this to this, now more complicated configuration can also be done.

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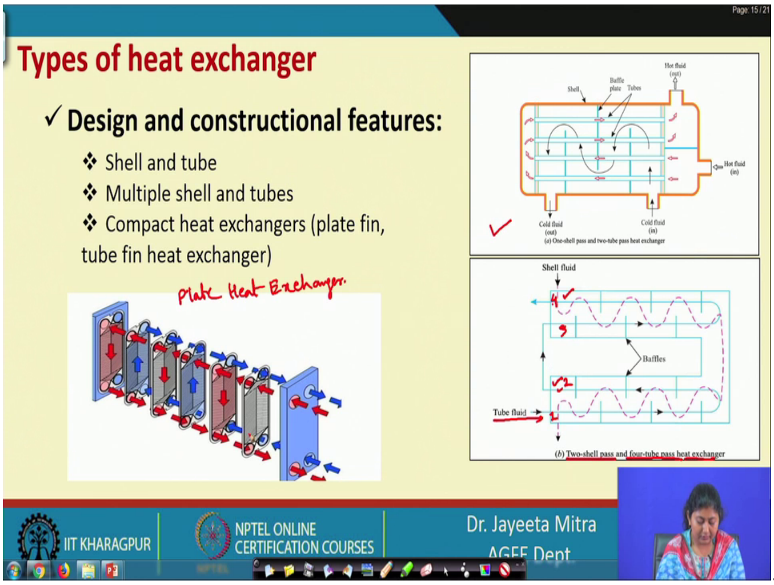

For example if you look into this figure, this is 2 shell pass 4 tube pass ok. So, this is the tube fluid which is entering and this is 1 shell. So, this is going in this way coming out of the shell again entering to the next shell and going out. So, this is 2 shell pass.

So, this is 1 shell and this is another 2 shell pass and 4 tube pass. So, this is 1 2 3 and 4. So, different configuration of shell and tube arrangement can be done based on requirement, and another is called a compact heat exchanger. Now when we discuss the compact heat exchanger basically we deal with the area density function, which is one parameter important parameter for heat exchanger and if the area density is very high we call them compact heat exchanger.

So, area density is generally you know defined by the surface area available for heat exchange divided by the volume of the liquid that the heat exchanger is going to handle ok. So, compact heat exchanger are if you know the value is around 700 to 1000. So, we call them the compact heat exchanger and one example is plate fin or tube fin heat exchanger ok.

So, fins are actually increasing the heat transfer area to a very large extent. So, that is very effective method and another method which is which is the plate heat exchanger. So, plate heat exchanger is like this as we have discussed. So, plate heat exchangers these are again very important one this is very important in terms of flexibility because you know there are many number of plates which are stacked after the other and the 2 fluids are channelized through them in just 1 layer and the 1 layer between the 2 plates and the other layer between the next 2 plates like that there will be no mixing ah. So, the advantage is that suppose you are implementing this you are using this in your milk chilling plant or regeneration plant, and you want to increase the capacity of your plant.

So, in that case just you calculate that how many number of plates are required and the extra plates in a series you just join them and you can increase your capacity whereas, this kind of arrangement cannot be done for shell and tube kind of heat exchanger right.

So, there is a flexibility that we can get in this case and there is one problem also that in this kind of plate heat exchanger we cannot use 2 different state of fluid like one vapour and one liquid, because you know there is a huge pressure difference involved in the handling the vapours and the liquid. Because vapours we generally have in the pressure in the range of megapascal and for the liquid we are having in the kilopascal range. So, because of that large pressure variation this plates might be getting damage, if you use them ok. So, for those cases we can use the other type of condenser like shell and tube and all, but for the plate we use strictly 2 fluid for the stream.

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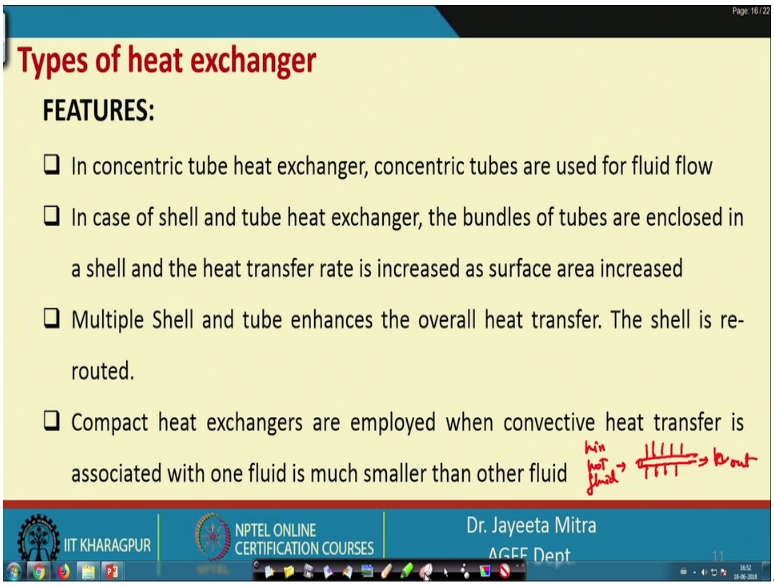

So, the basic features what we have learned here is that in concentric tube heat exchanger. Concentric tubes are used for fluid flow in case of shell and tube, the bundles of tubes are enclosed in the shell and heat transfer rate is increased as surface area increased. Multiple shell and tube heat exchanger if we use then overall heat transfer we can be utilized and the shell is rerouted. Compact heat exchangers are employed when convective heat transfer is associated with one fluid is much smaller than the other fluid; that means; compact heat exchangers are employed when the convective heat transfer is associated with one fluid is much smaller than the other fluid.

So, in that case suppose we are using liquid in one stream and hot liquid are entering in one stream, and we want that through the surface the air ok. So, hot fluid is entering and this is h in and h out.

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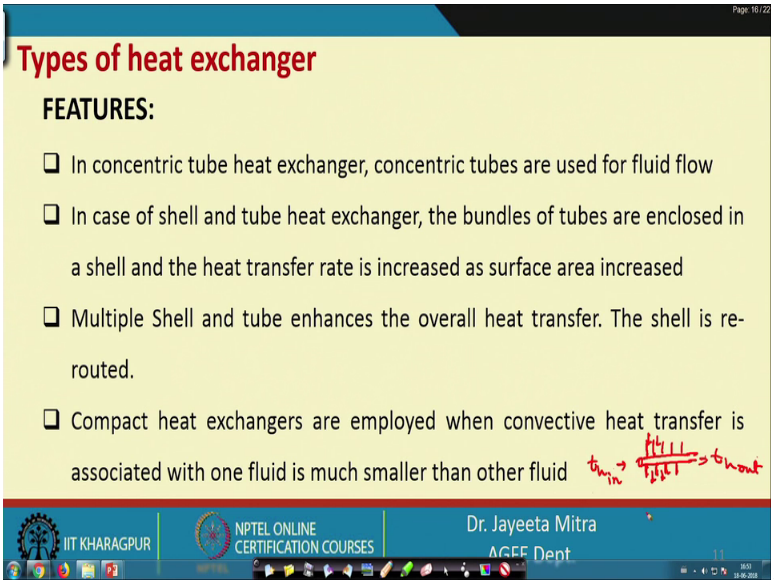

So, if or better to write it as better to write t h in and t h out so, in that section if we increase the surface area we use fin, very thin protruding or extension on the surface.

So, those fins are utilized for larger amount of heat transfer, because in this side there is air. So, convective heat transfer takes place and that has to be increased to higher amount. So, that is why we use this kind of finned arrangement ok. So, these are very compact heat exchanger that we use there.

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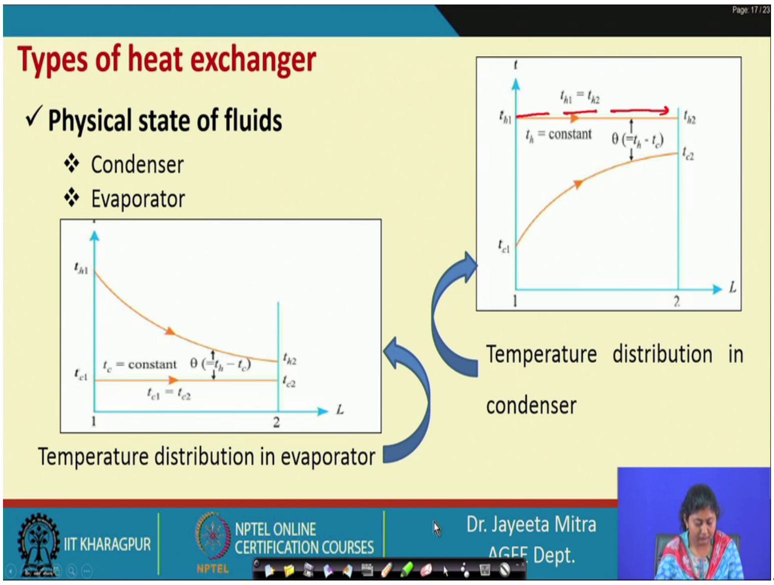

So, physical state of fluid as I said that condenser and evaporator when we used so, in that case in case of condenser where hot steam is entering, hot steam is entering and steam is a vapour, and it is coming to the liquid state. So, there is no change in the temperature.

So, t h will be throughout constant whereas, t c 1 that is the liquid or air that we are using for condensing that will increase its value. So, theta is the difference between those cold and hot fluid will gradually reducing. Similarly for evaporator if we consider. So, in evaporator the refrigerant that is evaporating, that will be constant that is going to change from the liquid state to the vapour state and it is taking the heat from the air in the in that section for exchanging heat, but the temperature of the cold fluid will remain constant. So, these are the condenser and evaporator that we can separate based on the physical state of fluid. So, we will stop here we will continue in the next class.

Thank you.