Principles and Practices of Process Equipment and Plant Design
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Module - 03
Lecture - 45
Design of Shell and Tube Heat Exchangers - a general overview

Hello and good day to you all. Today, we are going to start a new topic which is basically the design of Shell and Tube Heat Exchangers and we will start with a general overview. Let us look at the overall way we design heat exchangers.

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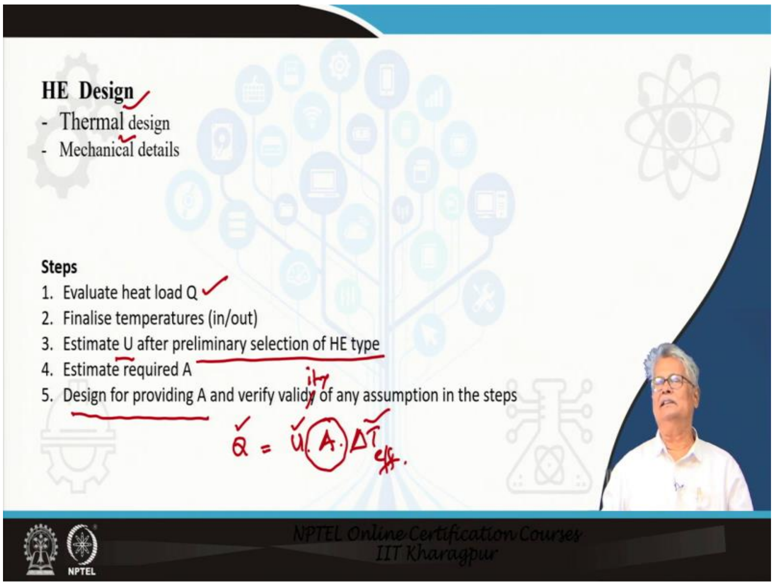

You already have done the module which covers double pipe heat exchangers. By this time, you definitely must have understood that whenever we talk about this kind of the heat exchanger, there are two aspects: one is definitely the thermal design, the other part is detailing the mechanical arrangement with which you realize the thermal design.

So, what are the steps? First thing is the design problem. You analyze, you look at the data that is available, you evaluate the heat load for the heat exchangers which is in kW. During this period definitely at least the three temperatures would be known or at least two. Then you decide on all the four temperatures of the two streams which are coming in and out.

Next you have a preliminary selection of heat exchanger type whether you are going to have a coil – coil or you are going to have a double pipe exchanger or you are going to have a shell and tube exchanger. Based on whatever you design or whatever you decide, you decide and go through the steps, find out the overall heat transfer coefficient U and you get an estimate of it.

Now, Q is known; U you have estimated; all the four temperatures are known for you; that means, the delta T is known for you rather you can say the delta T effective is also known for you which could be the LMTD. And, definitely if you look at the equation, the equation is a very simple form Q is equal to u into A into delta T effective which could be the LMTD or something with later on that we can see that it may require a correction.

But, whatever it is, Q is known, u is known, delta T is also estimated, so, we can always find out A. So, what is left? It is finding or deciding on the mechanical details in order to realize a practical version of this heat transfer area which is my exchanger in reality. So, you basically design for providing the A at during this period when you design immediately after and during the process itself you are also expected to validity of any of the assumptions in the earlier steps.

So, grossly speaking that is your heat exchanger design procedure and keeping this in mind we are progressing with our shell and tube heat exchanger design preliminaries at least today, and in order to do that by this time you must have realized that what we need to know right at the beginning is the physical details of such an exchanger.

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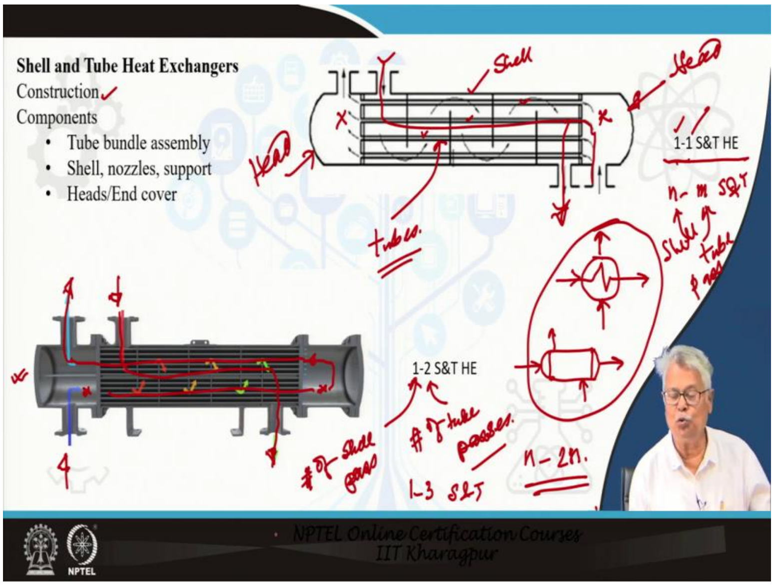

So, we start with that. The construction we need to know. All the time in your heat transfer heat transfer classes you have been either seen a symbol something like this representing a shell and tube exchanger or something similar to this which says and shows fluid entry from here, exit from here and a tube side fluid entry from here and exiting from here. Now, they are two representations of the same equipment. Let us have a schematic of this in the simplest form here we have a shell and tube exchanger where these are the tubes.

You have a shell, this is our shell and these are obviously, the tubes. You have a plate a circular plate inside a shell which is also circular. In fact, it is a cylindrical shell which is fixed inside the shell which we will see all these, to which my tubes are attached and both the ends of the tubes are open. You have a head or a closure you have a head here and there is head at the other end also. So, you will be expected to have two heads, one at each end.

Conventionally, where you have your tube side fluid entry that is your stationary head or just the head which through which the fluid to the tube enter. You also have the shell nozzles here is the shell nozzle for inlet, here is the shell nozzle for the outlet you will notice one thing it is a long equipment and it has got two sides. The first reference side is where the tube side fluid end enters.

So, you have two ends of your equipment and both the liquids the shell side liquid or other shell side fluid and the tube side fluid flow from one end to the other. The configuration which is shown here shows that the shell side fluid entering from here exits from here exits from here, what does it mean? That means, grossly it traverse from one end to the other end.

The same thing is true in case of the tube side fluid which starts from here and ends here. So, that also travels from one end to the other end only once. So, under this case we say the shell side has got one pass and a tube side also has got one pass. So, we call it a 1 – 1 shell and tube exchanger.

Definitely you must have learnt in your heat transfer that if you have an n – m shell and tube exchanger, n is the number of shell passes, m is the number of tube passes and this is a number of shell passes. So, that is the convention. Now, let us focus on another diagram that we have here. What we have here is something like this. We have we can see the tubes. We also see that the tube side entries from where The tube side entries? From here.

And, where is the exit? So, the tube side it travels from this point, goes all the way to this point then it changes its direction; that means, first time it has traveled the entire length from one end to the other, then it changes its direction comes out and goes out this way. That means, how many times the tube side fluid has traveled in this case? It is 2. So, it is a case of two tube passes. It is a two tube pass heat exchanger.

Now, let us look at the shell. The shell side fluid enters from here at the top. It exits from the other end. In that process it travels this way and travels the length only once. So, quite naturally, this is the number of shell passes number of shell pass and here you we have the number of tube passes.

I believe by this time you have understood and you can appreciate what is the option of construction you can have more than one shell pass, you can have more than one tube pass and very common is to have n – m tube passes or rather I will put it like this n twice n is a combination.

You will also look that it is possible to have 1 – 3 shell and tube exchangers; that means, a single shell pass and 3 tube passes it is permitted by the TEMA which we have mentioned in one of the earlier classes, but it is not very common because of the construction complications.

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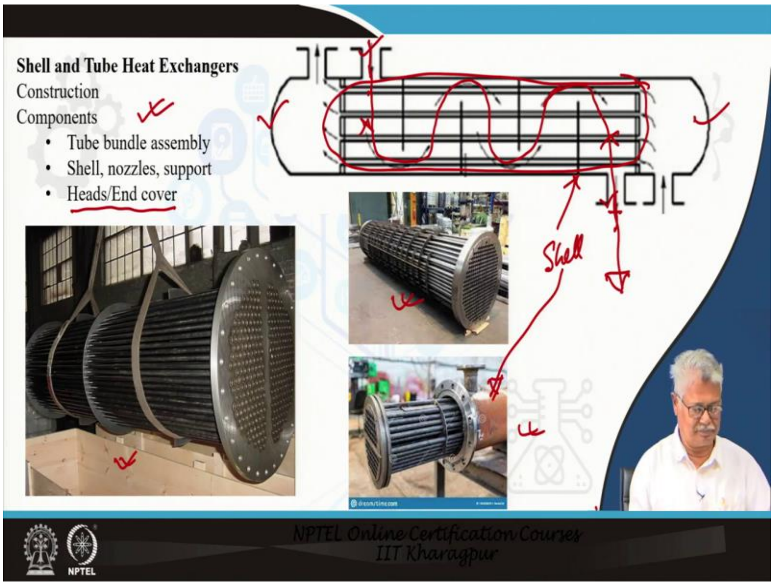

Now, what we do is let us see if we have two shells, but before that let us see look at the other components. It is the same diagram that we have here. This component is basically I have already mentioned there are tubes which are fitted to two circular discs which are called tube sheets and, the entire assembly is called a tube bundle assembly. What are the components of a tube bundle assembly? We will see just after this.

Here we have the diagram of the tube bundle assemblies. This is just the tube bundle assembly taken out possibly before assembling the total heat exchanger or just after maintenance. Here it is being transported basically is being packed possibly it is a new tube bundle that has been just manufactured and you are putting it in the box here. Here is an old exchanger through which the tube bundle has been pulled out.

Yes, you have to insert the tube bundle in the shell, this is your shell which is this. So, what you have here is the tube bundle will be inserted in the shell and your shell will have nozzles. Yes, you have the nozzles here. You will also have the heads or end cover; the heads or the end cover this is the stationary head because the tube sheet fluid enters from here and that is rear end cover.

So, we have an idea or we have an identification of the major components of the heat exchanger.

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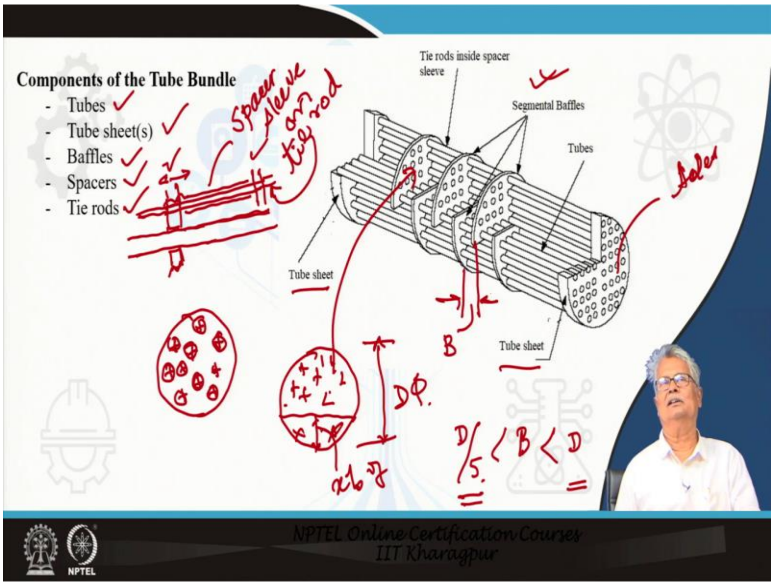

And, then we proceed now to look at the details of the tube bundle. I talked about the tubes being fitted to tube sheet which are circular sheets. Quite naturally if you have to fit a tube to a circular disc of a finite thickness we got to have holes. So, you will have holes through which you are going to insert and you are going to fix your tubes.

So, if you see here you see the holes, you can see the holes from one end. This is a cut-out section and it shows the tube sheet with a cut-out also and you can appreciate that it has got a reasonable thickness. In fact, possibly the first time you see a tube sheet you will be wondering why you really required such a tube such a thick sheet. We will talk about it later on. It is seen here that the tubes come and end at the tube sheet.

But, in between what you have are the baffles. The baffles that you see are segmental baffles. What does it mean? It means it is a segment of a circle typical segmental baffles could be 35 percent 37 and a half percent 25 percent cut and so on and that 25 percent is this height with respect to the diameter. This is x percent of the diameter D.

So, if you are you going to use 25 percent cut segmental baffles, what you have is this portion is missing. So, that is the cut portion and you will have the holes through which the tubes will pass through. You can see some of the tubes have been removed. So, you can see the holes here and you definitely will be understanding that this the presence of these makes a very interesting phenomena to happen.

We had said that the tube that the shell side fluid will be entering from here and exiting from here true and it has to travel from this point to the end point from one end to the other. But, it cannot take a straight path. It has to move like this because of the presence of the baffle. It has to go here, it has to come down again, it has to go here, come down and then only exit. That means, though it travels from one end to the other, across the bunch of tubes it has got cross flow.

Yes, this increases the turbulence in the shell side and improves the heat transfer coefficient. This is something very important because the overall heat transfer coefficient is contributed both by the heat transfer coefficient inside the tubes as well as the shell side fluid which is the out which is outside the tubes.

Now, there are certain practical ranges of spacing of baffle. If my spacing of baffle is B typically the spacing of baffle is kept between D by 5, D being the nominal diameter of your shell between D by 5 and D typically the baffle spacing is kept; that means, this baffles spacing is the gap between this baffle and the adjoining one, this is my B. I believe this will give you a fair idea of what the tube bundle consists of.

I will add only two more things. The baffles are basically and the tubes have to pass through the baffles the baffles have holes. Now, if I just have the holes here what we will find is if I have a baffle which has got a hole here something like this, sorry and my tube passes through this which is having which must have a little lesser diameter than the hole which is there in the baffle. The baffle will be moving this way or the other way.

So, what is done? The tube is provided with a sleeve that I mean the tube is not provided with the sleeve you have another type of rod which is called tie rod, that also passes through the baffle. And, you have a second baffle here. Now, in order that this baffle and this baffle remain at the same distance you have a sleeve which is nothing, but a tube which is placed on this. So, this is your spacer sleeve on the tie rod.

What is the tie rod? This is your tie rod. The tie rods here are not shown in details. The tie rods are this is the tie rod in fact. What you can see is you cannot see the tie rod because it is covered with a spacer sleeve and the spacer sleeve maintains the distance between the baffles.

Now, perhaps you will have a question. Where do the tie rods end? It is obvious that last time the baffle will have the tie rod going through and then there will be a nut which will be holding the tie rod and keeping and restricting the movement of the baffle itself. Exactly in the same way, one end of the tie rod most probably will be in one of the tube sheets. So, what are the components of a tube bundle now?

You definitely have the tubes. You require tube sheets. So far we have seen that all the exchanger that we have seen the diagrams that we have seen you require two tube sheets at the two ends of the exchanger. You require baffle to increase the turbulence in the shell side fluid, you require the tie rods so that you hold the baffles and sprays in the proper spacing with spacers which are nothing, but spacer sleeves on the tie rod.

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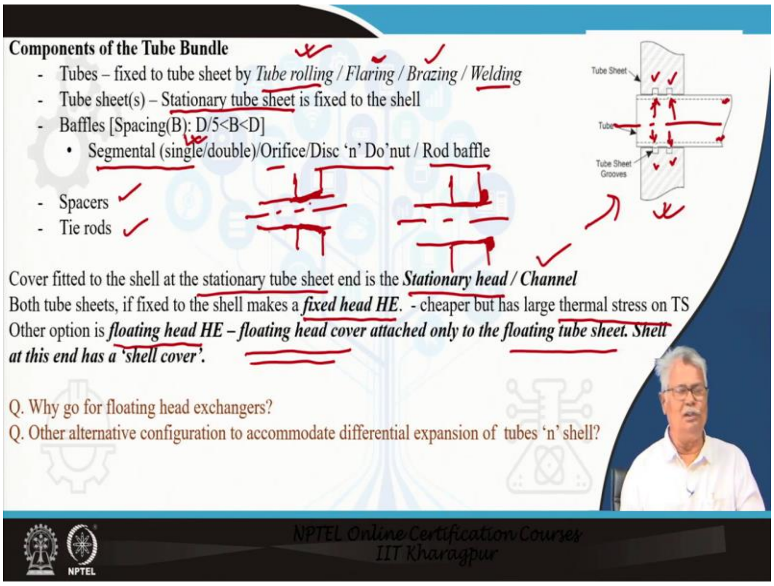

Perhaps the next question will come that how do you fix the tubes to the tube sheet? That is done in very different ways. It could be by welding for example, if this is my tube sheet and this is the end of my tube which passes through it, I could weld it here. This is not very common, but it is still there. I could use brazing also. I could also do something else.

If I if my tube sheet has got slightly different diameter hole, I could put in the tube and using a flaring tool I could expand it only the outer side. So, that would be by flaring that is also not very common and it is not used for high pressure system. What is most common particularly with almost any type of industrial exchangers is called tube rolling and the diagram is shown here.

What is done? This is your tube sheet. The tube sheet is usually provided with two grooves. They are circular grooves here. This is your tube which is placed in. You will notice here if you carefully notice this the dotted lines tells the thickness. The dotted line shows the thickness of the tube and it has been bent slightly if you see it has been bent inside the groove it has been bent inside a groove here, it has been bent inside a groove here and this is typically done using a tube rolling apparatus.

So, this makes almost a leak proof arrangement between the tube and the tube sheet and this is what is done industrially in most of the heat exchangers. Now, there is something. We know we have mentioned that there are two heads. The stationary head side tube sheet is fixed to the shell; that means, what is done there is you insert the tube bundle in the you insert the tube bundle inside the shell and then you fix it. We will see how the fixing is done.

We have talked about the baffles in the baffles we have said or we have seen what are segmental baffles. The segmental baffles what we have covered and what we have learnt so far is the use of only single segments that mean 25 percent cut, 37 and a half percent cut such things, but you can have double segmental baffles also.

You could also have orifice baffles, you can have disc n do nut baffles, you can have rod baffles. Rod baffles are normally used when your pressure drop is a limitation or it is a very highly fouling system. You have been told about the spacers and tie rod that you already have known.

The cover which is fitted to the shell at the stationary tube sheet covered which is fitted to the shell at the stationary tube sheet is the stationary head. It is also called channel. Both tube sheets may or may not be fixed to the shell. If you have both the tube sheets fixed to the shell, then it becomes a fixed head heat exchanger. So, it is something very interesting to note here. It is very cheap to build it, but what happens is you will always have a temperature difference between the shell side and the tube side liquid tube side fluid.

So, the expansion of these two will be different. So, quite naturally because of a differential disc because of differential disc expansion there will be a large amount of thermal stress on what the thermal stress has to be borne by the tube sheet. So, quite naturally even though you can go for a cheaper fixed head exchanger you should not use it when the there is large difference between the shell and the tube fluid temperatures. What is the other option? You fix only one end, the other end you keep floating.

In this case what is done is, the floating head cover the floating head cover will be attached only to the floating tube sheet; that means, not the stationary side, but the opposite side. The shell at this end has a shell cover. We will see why you require floating head exchangers or can there be another option for the floating head exchangers also just after this.

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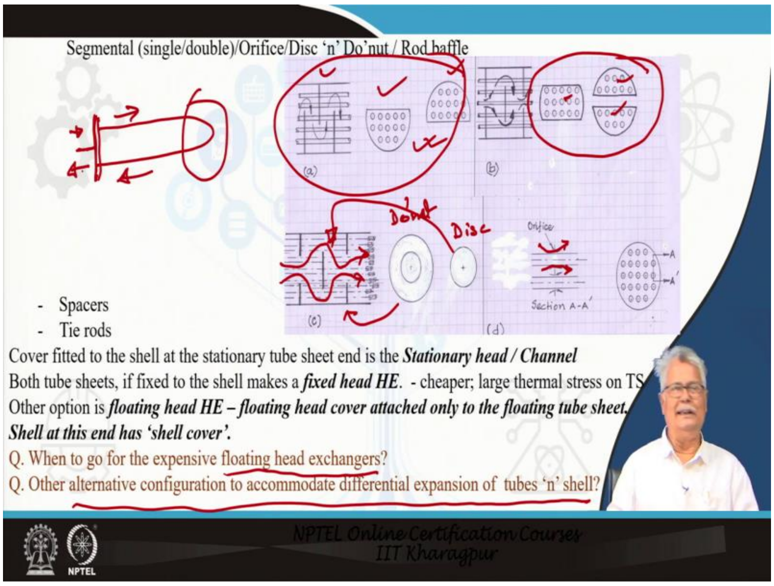

Here what we have is basically the single segmental baffles. Here every baffle set is basically consisting of multiple segments. So, it is a double segmental baffle here. So, there are three types of baffle shapes which make one pair and you can look at the flow how it takes place. Quite naturally the pressure drop in this will be slightly less.

You can also have disc n do nut baffles, where the flow rate of fluid will be like this and you have here basically the disc baffle here and there is a pairing donut baffle. Your donut is here and your disc baffle is this one. You can also have orifice baffles; that means, in that case the baffle does not have any cut, there is no segmental cut on it. So, what you have is the hole diameter is slightly larger than your tube diameter and the liquid flows through this particular opening.

There are different cases when you use different types of baffles which will not go in this particular code codes, but we in most of the cases will be using the conventional segment single segmental cut baffles. We are yet to answer the question why do we require floating head exchangers. You by this time you must have understood that in case of floating head exchangers, the floating head cover is fitted to the free end of the tube bundle and it is not fixed to the shell.

So, the tube bundle inside can expand. It can expand within the shell and definitely it can contract also. So, floating head exchangers though more expensive will be used when they will be used when you have a large difference between the shell and the tube temperatures and also when you have a large difference between the ambient temperature and the operating temperature of your system. It is primarily provided so that it can accommodate or it allows free expansion of the tube bundle and its difference with the shell side expansion.

Now, the second question is what is the alternative configuration to accommodate this differential expansion? The alternative accommodation is the alternative configuration is also pretty simple. Instead of having two tube sheets it is also possible to use U tubes. We will have here a tube sheet; this will be the direction of flow. It will go will not have any tube sheet at this end, but in this case definitely you have to have a minimum of two passes. So, this is what you find as an alternative to floating head exchangers.

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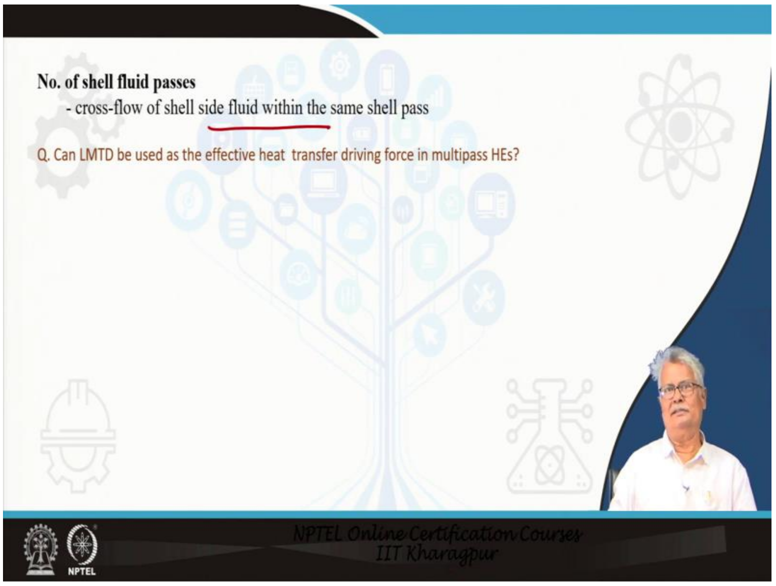

This is nothing, but what I had what I had written earlier the number of shell passes is basically how many times the shell side fluid goes from one end to the other and you will find here that even though it goes once in your 1 – 1 exchanger there is cross flow of the shell side fluid with respect to the tubes within the same shell pass.

I just leave a question here without answering it and will be answered when you go to the actual design calculations that LMTD can it be used as an effective heat transfer driving force in a multi pass exchangers? In case of double pipe exchangers, yes, it can be, but here in this case what you have is that you have due to the presence of baffles cross flow of the shell side fluid within the same within the same shell pass.

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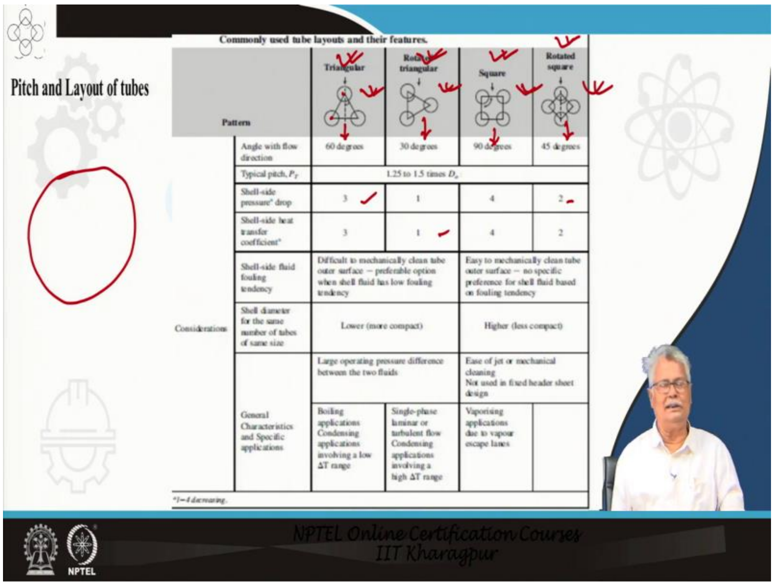

The tubes: the tubes are fitted to the tube sheet. It is a part of the tube bundle. It is possible to have within the shell or the tube sheet itself different options of layout of the tubes. It could be square as I have here, it could be rotated square, it could be triangular, it could be a rotated triangle also.

The differences basically with respect to the direction and the angle with this particular direction of the fluid flow during the cross flow. There are different cases when we prefer certain things one thing is obvious that if you have a triangular pitch of the same dimension P which is basically the center to center distance, if that be the case if you have the same pitch for the square and the triangular a shell can accommodate more number of tubes in the triangular thing, but your pressure drop would be more. You are providing more heat transfer area, but your pressure drop is more.

Now, the comparison between these you can see for yourself and you will notice one thing that 1, 2, 3 and 4 which are mentioned here for example, 1 to 4 is of decreasing parameter because you cannot have exact the values here for numerical comparison, but it is a qualitative compress which is presented.

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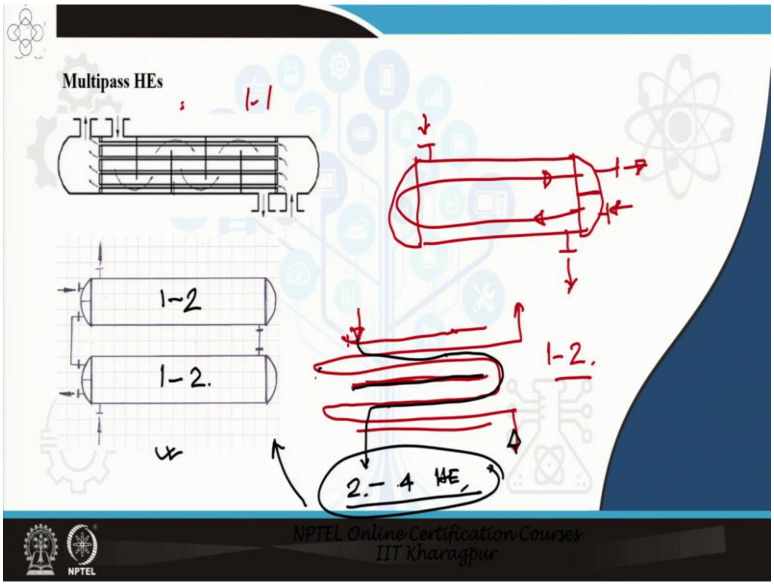

I just draw your attention to the multi pass heat exchanges. This one we know this is a 1 – 1 exchanger and I could also say that if I have a exchanger which is something like this. I am trying to draw the schematic here if I have a tube side a shell side entry from here, the shell side exit nozzle is for from this end and what I do is I have a pass partition plate which divides this particular head.

Here I provided entry nozzle for the tube side fluid which travels from here goes here, comes back here and I take it out and I take it out through this nozzle. As it looks now this is basically a 1 – 2 exchanger which is this which is not exactly this, but basically this also we have seen earlier, but my point is suppose instead of doing this what I do is I have a shell which is also divided. I have my tube side material coming in going in here going in here coming out here and finally, it goes out this is my tube side fluid.

And, what I have here is my shell side fluid comes here, it goes from this end I will just use another color of my pen so that we can trace it better. It will come this side and then go out; that means, how many times the shell side fluid has traversed? It has 2. How many times the tube side fluid has traveled? Once, second time, third times and fourth times. So, what we have here is a 2 – 4 shell and tube heat exchanger.

And, you will notice here that the same configuration can also be achieved by connecting properly one 1 – 2 exchanger and another 1 – 2 exchanger. That means it is possible to have a 2 – 4 exchanger configuration and the theoretical design calculations are kept the same. Even if you have two numbers of 1 – 2 exchangers properly coupled the way it is shown here, you can make a 2 – 4 exchanger without even having a partition plate on your shell. I think with this I will stop here today and we will continue from this point.

Thank you.