Principles and Practices of Process Equipment and Plant Design

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Module - 03
Lecture - 42
Double Pipe Heat exchanger

So, hello everybody. So, we have already started the module 3 of the course and you were already told that in the module 3 you will be dealing with heat transfer processes. So, the introduction has already been made to you in the previous lectures and in the introduction you were introduced to the basics of heat transfer, the modes of heat transfer and how heat transfer occurs.

And after that you were told the basic equipment of heat transfer, you were also told that you can have heat transfer either by direct contact, i.e. the most efficient, but for most situations we cannot go for direct contact heat exchanger. So, usually there is a surface across which the heat transfer occurs from the hotter fluid to the colder fluid.

Now, there can be two ways those were also told to you, one is a regenerator, where the hotter fluid heats up the some particular material and then the cooler fluid picks up the heat from that particular material. And the most common are the recuperators, what are the recuperators? In recuperator, the hotter and the colder fluid they simultaneously flow through an equipment, they are separated by some particular wall and through that particular wall heat transfer occurs as the two fluids flow through the equipment the equipment is nothing but a heat exchanger.

Now, depending upon the wall, you can have plate type heat exchangers, you can have a pipe heat exchanger, you can have different types. Out of these, in this particular module, we are going to cover the tubular heat exchangers where the heat transfer surface is in the form of tubes or in the form of pipes.

Now, the most common two tubular heat exchangers are - the simplest is the double pipe heat exchanger and the most common is the shell and tube heat exchanger. I understand that you are already exposed to the basics of these different heat exchangers in your heat transfer class. So, therefore, in this particular class we are going to discuss regarding the double pipe heat exchanger which is the simplest type of tubular heat exchanger.

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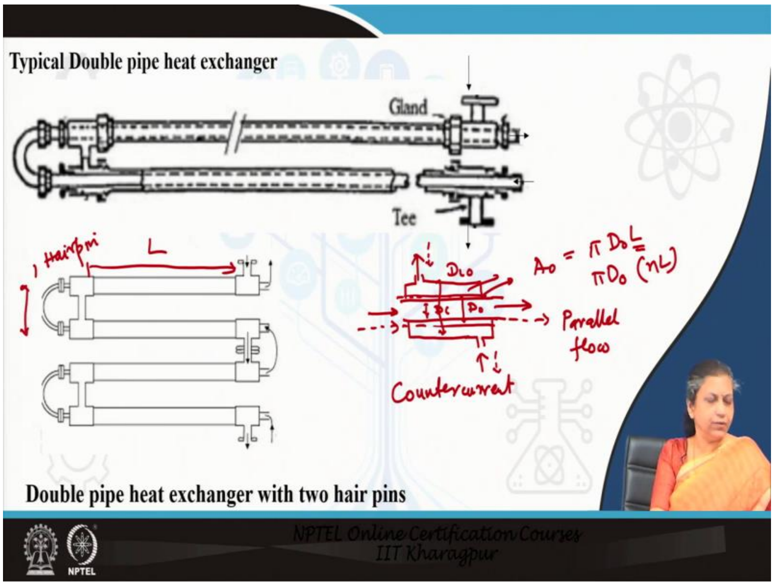

So, in this particular case what do you have? You have two concentric pipes as is shown here. You have one particular pipe through which any particular fluid is coming and over that or concentric to that you have another fluid flowing. Sorry I did not draw a concentric arrangement, but anyhow I will just correct it.

So, therefore, here you are going to have this arrangement. So, therefore, there is one inner pipe, through the inner pipe one particular fluid flows, say the fluid is flowing through this and it is going out through this particular direction. And there is an outer pipe through which the other fluid is flowing, say from here the fluid is entering and the fluid flows out from here.

And you also know that depending upon the direction of flow between the two fluids you can have either a counter current arrangement, which is shown here where the two flows fluids they flow in; they flow parallel to each other, but in opposite directions. You can also have a parallel flow where both the fluids flow in the same direction or in other words while one fluid flows in this direction, the other fluid also enters from the top it goes out from the bottom. So, that the both the fluids they have the same flow direction this is known as the parallel flow exchanger.

You can also have a cross flow type of exchanger where one fluid flows in one direction, the other fluid simply flows in a cross flow direction. Generally, in recuperators or tubular heat exchangers, we have either the counter current flow which is the most common. Why it is most common? We will be discussing after a while under some specific circumstances as was also told to you in the previous class.

We can have the conditions or the situations where parallel flow is either preferred over counter current flow or maybe it does not matter whether you have parallel or counter current flow you get that same heat transfer area.

So, therefore, the simplest arrangement as I have told you it is a concentric pipe arrangement where one fluid flows through the inner pipe and the other fluid flows through the annular area between the inner and the outer pipe. So, therefore, under this condition through which particular wall does the heat transfer take place. Heat transfer takes place through the wall of the inner pipe.

And therefore, this gives us the heat transfer surface. Normally what we do is that inside diameter of the inner pipe that is defined as D i, the outside diameter of the inner pipe that is defined as D o and the out inside diameter of the outer pipe that is designated as D io, right.

So, therefore, and mostly we say that the heat transfer occurs through the outer surface of the inner pipe. So, therefore, the heat transfer area this is equals to A o which is pi D o into L as was already told to you where, L is the length of the inner pipe across which the heat transfer is occurring. Now, usually in order to accommodate sufficient length such that we can get the heat transfer that is required very frequently we arrange the double pipe exchanger in the form of or rather we connect several lengths by means of return bends and this is known as a hair pin arrangement.

In this arrangement what we have the entire concentric pipe that can be connected through returned bends and we can have the heat transfer in this particular way we can make a much more compact arrangement and accommodate a larger length over some particular limited float space that we have. Very frequently it can happen because most of the pipes we would like to use standard pipes. So, standard pipes the maximum length is about say 6 meters.

So, we can take 6 meters or we make we may take 3 meter sections. And we can have a large number of such sections which are connected by return bends and as the two fluids they are flowing through these pipes we can have the heat transfer. So, therefore, two particular sections connected by a return bend this comprises of one hair pin it can happen that the inner tube that is connected by means of return bends and the shell it is attached on the straight portion of the inner tube.

Under this condition there is no heat transfer which occurs to the return bend and therefore, the heat transfer length per straight length that is given by this particular length L. And therefore, in that case the total length is going to be the number of times the turns (n) have been taken place. So, therefore, in this case the A o becomes pi D o into nL right. So, therefore, this is the simplest arrangement that we can have.

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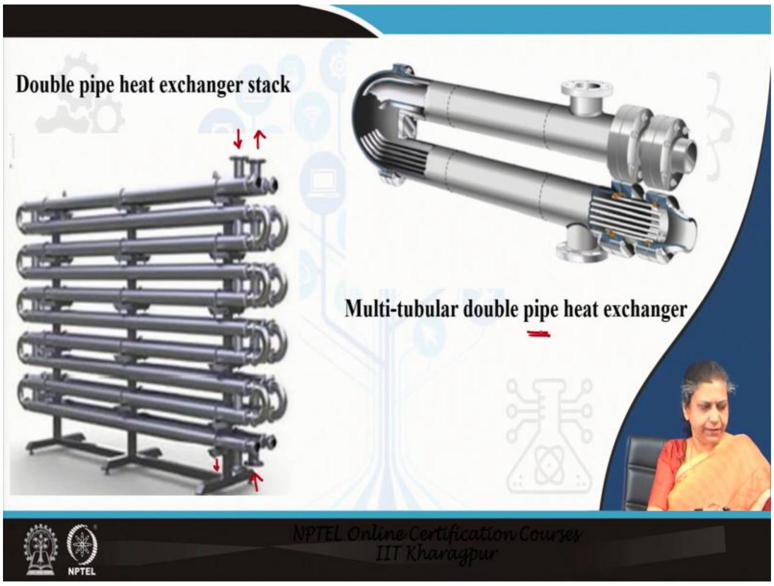

It can also and what we have such type of this hair pin arrangements which can be stacked one above the other and through one particular section say the one fluid it flows and it comes out and through the another nozzle the other fluid flows and it comes out through here. And therefore, through the entire length heat transfer can occur in this particular case we say that the different hair pins they are connected in series to provide a large amount of area.

We can have such parallel flow arrangement will be which will be discussing at the end of the discussions on double pipe under certain specific conditions I will just mention the condition. Say for example, the that fluid in the tube side it has a very high velocity and therefore, remember one thing when you are designing such heat exchangers after all basically these are pipes made from standard pipes.

So, therefore, they have to honor some pressure drop and some pressure conditions ok. So, therefore, it can happen that the pressure drop limitations are getting exceeded. So, therefore, in order to reduce the pressure drop per unit length of the heat transfer area we can divide the flow into different or rather we can instead of introducing the entire flow here we can divide the flow into different sections of the tube.

So, that the flow gets reduced and the pressure drop limitation can be respected. So, therefore, this suggests one particular advantage of double pipe exchangers, that is depending upon the number of hair pins that we have connected depending upon whether the different hair pins are connected in series and parallel they can be used for a wide range of flow conditions, pressure conditions, etc. etc..

So, this is one particular advantage of double pipe exchangers that is their flexibility in operation. We can also have one other arrangement where there can be a large number of tubes inside a shell this is somewhat similar to a shell and tube heat exchanger, the basic differences that we use pipes in this particular case and we use tubes in the case of shell and tube heat exchanger.

But, normally if you see that multi tubular double pipe heat exchanger it the design is almost similar to shell and tube exchangers. So, therefore, we will not be discussing about multi tubular double pipe exchangers here what we will be a primarily discussing are the simple type of heat exchangers which comprises of a single inner tube through fitted concentrically through an outer tube.

One fluid flows through the inner tube and the other fluid flows in the annular space between the inner tube and the outer space. Primarily, we will be discussing about this, we might be touching on multi tubular double pipe heat exchangers. But, mostly the way we design shell and tube exchangers almost in the same way the multi tubular double pipe exchangers they are designed.

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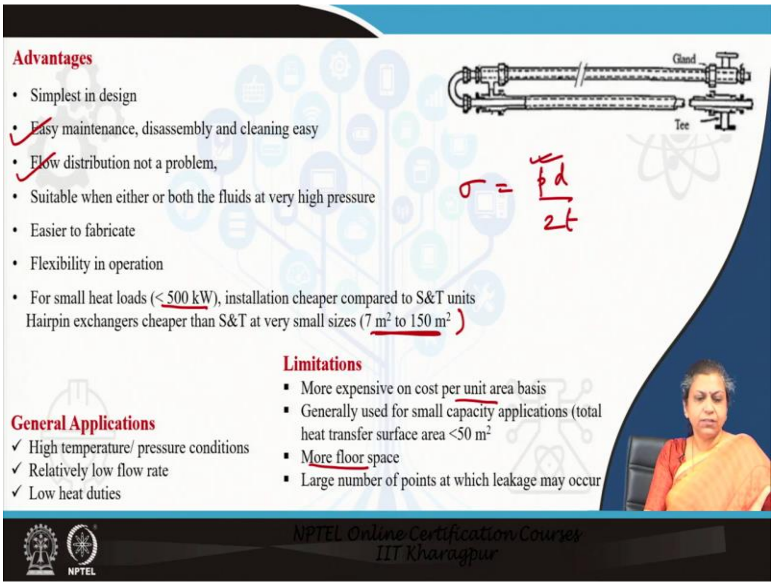

Now, let us see under what conditions we will be adopting this simplest type of heat exchanger. Since this is the simplest type of heat exchanger quite naturally the maintenance is quite easy, the cleaning is comparatively easy. In fact, the tubes are fitted in such a way that even without dismantling the shells we can approach the tubes, we can take them out, we can put them in, we can clean them so, therefore, cleaning is easy.

Flow distribution definitely you will understand, it is not a problem, you will understand it more when we go to shell and tube heat exchangers and we will see that under that condition we need to have some special arrangements to this to ensure a uniform flow, in this case we do not have to do anything of that sort.

The very important part is that it is suitable when either one or both the fluids are at high pressure. Now, in order to understand this, we know that the stress value, the yield stress is given by this particular equation. Now, since the double pipe exchanger both the outer pipe as well as the inner pipe, they are of comparatively smaller diameter. So, therefore, with the specified thickness it is quite natural that they can withstand a higher pressure.

And in fact, the important part or specific cases where the double pipe heat exchangers are used are specifically for high pressure fluids. Naturally it is easier to fabricate, it goes without saying flexibility in operation. I have already told you that since they can be arranged in modular arrangements. So, depending upon the requirement we can add some heat exchangers in series or we can remove some heat exchangers and they can be used to operate over a wide range of conditions.

But you need to remember that these are much more expensive on cost per unit area basis quite naturally because there are outer pipe and inner pipe. So, therefore, it is definitely much more expensive and it requires more floor space that is quite natural. But remember one thing although it is more expensive on cost per unit area basis, but suppose we are dealing with small heat loads say for less than 500 kilowatts.

Under that condition we find that often the installation its cheaper compared to the shell and tube heat exchangers and even hair pin exchangers they are cheaper than shell and tube heat exchangers for small sizes which range from about 7 meter square to 150 meter square right. So, therefore, whenever we are having high pressure fluids and the heat load is less or the heat transfer area required is less definitely will be going for double pipe exchangers.

Limitations are - naturally it is more expensive on a cost per unit basis and the other thing is it is economic only for small capacity applications when the heat transfer area is less than 50 to 65 meter square and also you will remember that the other limitation is that there are several points at which leakages may occur since we find that there are quite a number of fittings.

There is a union here which is connected to the pipe here, also we find there are some connections. So, therefore, since there are large number of connections there are several points at which leakages may occur. In fact, in order to prevent leakages the gland ceilings are provided so that the leakages can be avoided well.

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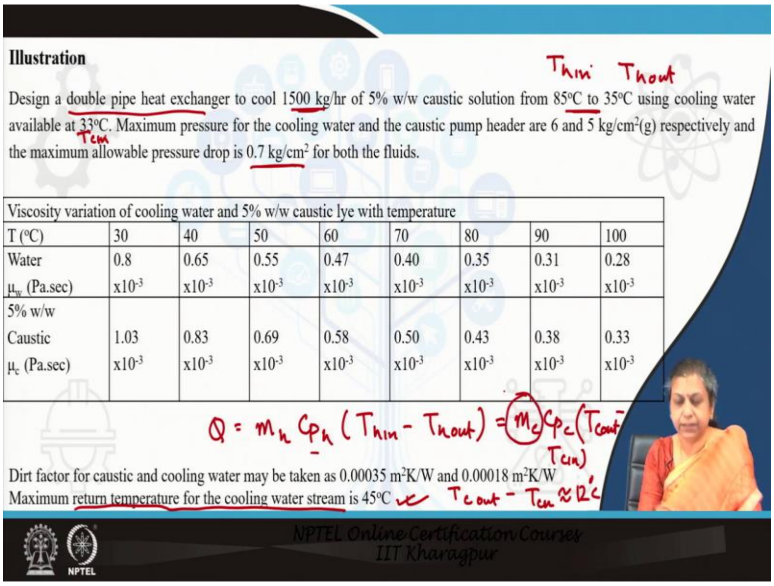

So, once you have understood this, we will go for the design. So, before going for the design I thought that I will just take up an actual problem and as we discuss the design this problem will be there in front of you. So, therefore, as we keep on discussing the different steps you can start actually using these particular numerical values and you can start calculating.

So, that at any point if you have any doubts you can come back to us to get your doubts clarified just listening and not practicing it, usually it is not very effective we have found for the teaching learning process. So, therefore, they are here. In fact, I have already mentioned that design a double pipe heat exchanger if this would not have been mentioned if just the service would have been mentioned that I have 5 percent weight per weight caustic soda solution the flow rate is already mentioned here it has to be cooled down, it is at a higher temperature.

So, therefore, it has to be cooled down and I have also mentioned that we will be using cooling water. So, normally under Indian conditions the cooling water it is available at say 33 to 35 degree centigrade. So, therefore, what my main intention is I want to cool 1500 kg per hour of 5 percent weight per weight caustic solution from some particular inlet temperature. So, this is the T hin and this is the T hout and I decide that for most such cooling purposes we use cooling water. So, therefore, the cooling water temperature T cin is also given.

Now, the maximum pressure for the cooling water side and the caustic pump header side that is also specified, now this is something you need to respect. Because according to these the heat exchanger has to be designed the maximum allowable pressure drop for both the fluids are also given.

So, after the design you are supposed to find out the pressure drop on the outer pipe or rather pressure drop incurred by the fluid flowing through the annular area which by convention is known as the outer fluid and the pressure drop incurred by the fluid which is flowing through the inner pipe by convention we are going to specify that as the inner fluid.

And then you need to check whether the pressure drop lies within the specified limit or not if it does not lie then you have to look for certain other options. Now, naturally when you have to do this you know that three temperatures are given and one particular flow rate is given right, the other flow rate is not given. Now, normally I have already told you that we use cooling water which is available at 33 degree centigrade.

Usually what we find is that in industry the maximum return temperature for the cooling water is around 45 degree centigrade as a result of which more or less we find that T c out minus T cin is near about equal to 12 degree centigrade this is standard industry practices.

So, accordingly we can decide the maximum return temperature for the cooling water. So, now we have all the four temperatures we have one flow rate we know that the heat which has been given out by the hotter fluid will be equal to the heat which will be taken up by the cooler fluid.

Or in other words Q equals to m h C p h T hin minus T h out will be equal to m c C p c all the subscript that I have written c refers to the cooler fluid and h refers to the hotter fluid. Hotter fluid will be cooled in the process, cooler fluid will be heated in the process. This is equals to T c,out minus T c,in. Now, using this if you have the data on C p h and C p c which are the specific heat capacity you will be in a position to find out m c right.

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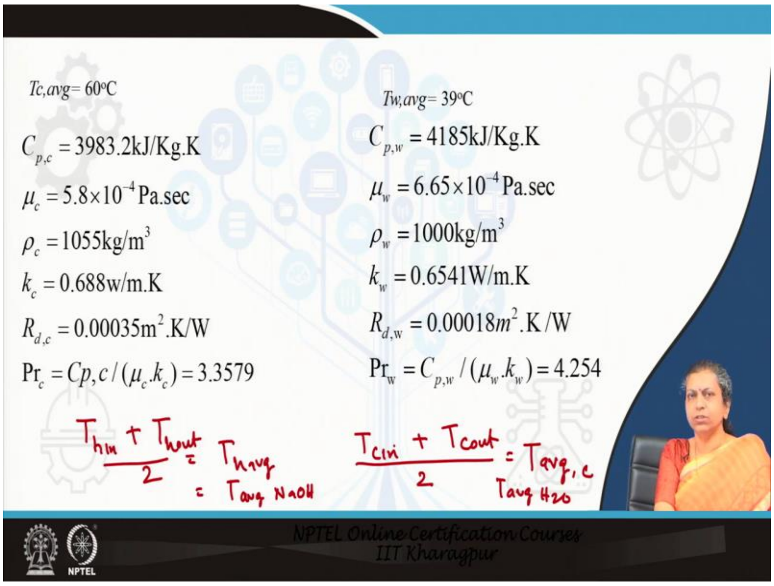

So, therefore, for that so, the properties also I have mentioned at the average temperature of the hotter fluid and the average temperature of the cooler fluid. Now, here this c actually it refers to caustic soda I should have used a different symbol, but anyhow. So, therefore, what is the average fluid of the of water it is naturally T c,in plus T c,out divided by 2 this is equals to T average for c which in this particular case is T average for water.

Same way in this particular case it is T h,in plus T h,out by 2 this gives you the T h, average or in other words the T average for the caustic soda. Accordingly the average temperatures have been found out and quite naturally the properties they will be defined under the average conditions because within that only the property varies, right.

And we assume that more or less the property variation is not very high such that the average values can give you a proper idea about the property physical properties of the fluids while they are flowing through the pipes.

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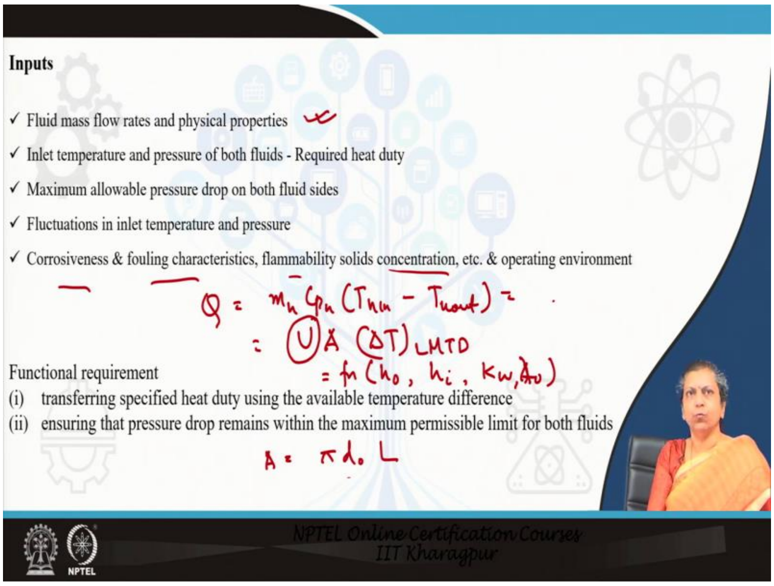

Well, now we come to the design, this is a typical heat transfer problem that I have given. In all such typical problems be it for a shell and tube or a double pipe exchanger these data have to be provided for you to proceed or else you need to assume some data then you can later on verify it or else you can take up some industry practices. Now, number 1 is fluid mass flow rate and physical properties, you know the mass flow rates will be requiring for the heat balance equation.

Physical properties apart from C p you need the other properties if you remember that in the last class it was told to you that Q; I will be writing it here that Q which is equals to say m h C p h T hin minus T h,out, same way m c c p c this is equals to U A, an effective temperature which we take as the log mean temperature difference. And it was also told to you that this U, it can be expressed in terms of the heat transfer coefficient of the hotter fluid or the outer fluid whatever you take.

Heat transfer coefficient of the inner fluid and the thermal conductivity of the wall which separates these two fluids and of course, the cross sectional area of heat transfer which in this case it is the outer surface of the inner pipe. And it was all some particular correlations were also shown to you for in order to estimate h o, h i in terms of the basic physical properties. So, therefore, in order to find out U you need to estimate h o, h i for estimating h o, h i you need to know those physical properties.

This another very important thing that you need to remember in this case. See the 1st thing is we would like to find out the area of heat transfer from the area of once we know the area of heat transfer what we do? We select some specific dimension of the pipes diameter of the pipes we decide the length then we decide the total arrangement everything, but again you have would note when you are calculating h o, h i you need to know the dimensions of the piping.

So, therefore, to find A you need U and to find U you need to know the geometric parameters. So, this automatically suggests that the heat transfer design is an iterative process. And for therefore, you need to do firstly, you need to assume some particular U based on certain heuristics find out A decide on the arrangement of the tubes the shell and the tube dimension etcetera find out h o h i etcetera. Then from them again recalculate U if the recalculated and the assumed U's are close you do not have to bother.

Normally they are not close and then in that case you have to again start with the assumed U and maybe certain iterations will be required before you come up to the final design. So, therefore, these are the things that you need you need to know the mass transfer rates, you need to know the inlet temperature and the pressure of both the fluids because based on the pressure only you have to decide upon the tube materials etcetera.

Maximum allowable pressure drop is also something very important fluctuations if at all there is there in inlet temperature pressure in this case there were no fluctuations if the fluctuations are there therefore, accordingly the heat transfer has to be; has to be designed. So, that any deviation from the normal operations can be taken care of by using the heat exchanger and definitely when two fluids are flowing they are in contact with the surface.

So, naturally the corrosiveness the falling characteristics flammability if at all it has any solids concentration because if there is some solids concentration there is a chance that the solid will deposit out so, therefore, all these things have to be known. Once these things are known as we have found out now, we go about to design the heat exchanger.

What is the design of the heat exchanger? You have to transfer a specified heat duty. What is the specified heat duty? The heat which has to be transferred in order to attain the cooling or the heating that we desire. Now, this particular specified heat duty using the available temperature difference has to be specified.

Accordingly, the heat transfer area and the layout has to be decided while ensuring that the pressure drop remains within the maximum permissible limit for both fluids. So, therefore, the design as I have said it is basically an iterative process we design and there are several checks which we have to respect as we go ahead with the design part.

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This I do not think it is very clear to you this is a typical double pipe data sheet where if you find that all the inputs are given and all the for the shell side tube side all the details have to be put in. You can look at this we will upload this particular data sheet. So, that you can see for yourself what a typical data sheet for a double pipe heat exchanger looks like.

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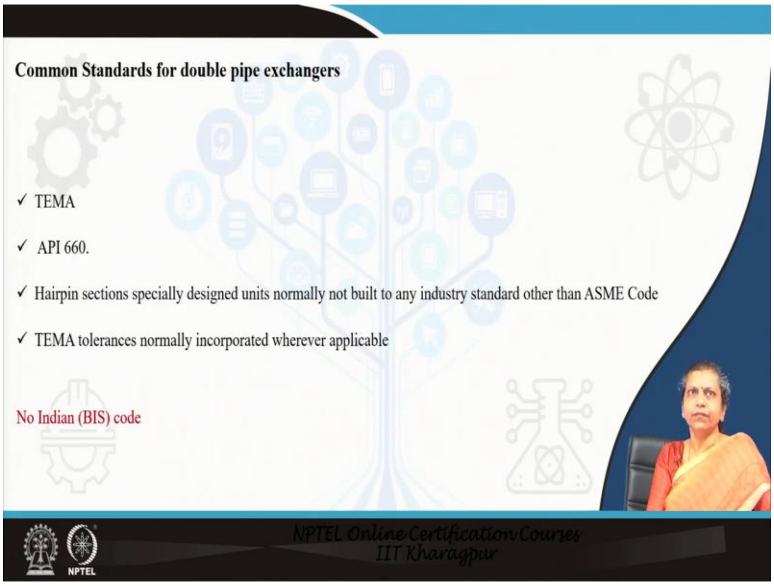

And well, when you go for the design its very important that you respect the codes because if we select the outer pipe, inner pipe as per codes quite naturally replacing them is much more easier and also the delivery time that is also very important that also gets reduced.

So, therefore, all sorts of designs be double pipe be shell and tube they are done as per the different codes. The general quotes have been mentioned to you I would just like to mention that for double pipe exchangers. There is no Indian or no BIS code normally we go by the TEMA code and API 660 also it is respected for petroleum facilities etcetera.

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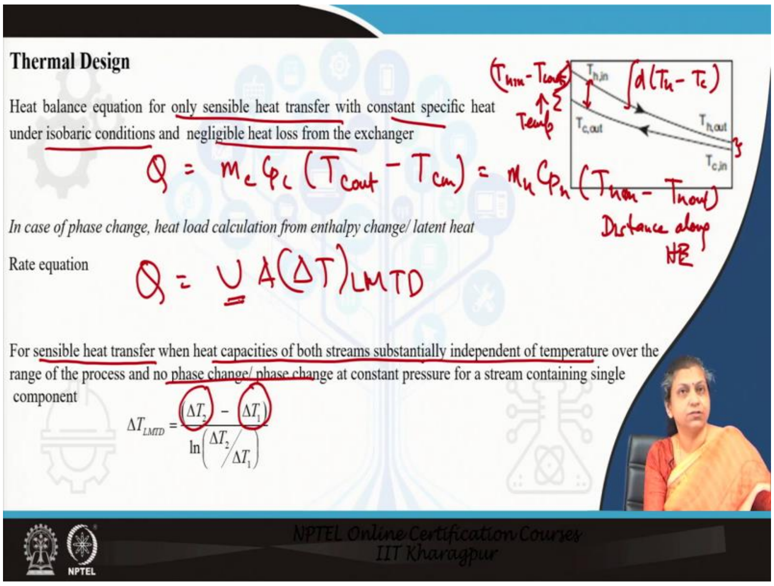

So, therefore, when we have come to the design I have already told you that this is the heat balance equation I have already written no point in writing it down just its important for you to consider the assumptions which are there in this particular in writing this particular equation T h,in minus T h,out.

So, therefore, this is applicable just for sensible heat transfer quite naturally and constant specific heat under isobaric conditions negligible heat loss from the exchanger it is quite evident. When there is a phase change quite naturally then the latent heat has to be considered I think these things do not need to be said. And there is also a rate equation which I have mentioned already this is nothing, but U A delta T LMTD.

Now, this expression I am very sure that in your heat transfer class this was derived that since the temperature difference at the at one end of the exchanger and at the other end of the exchanger they are different. So, therefore, the difference between the difference between the hot and the cold fluid may be if you can take it as d of T h minus T c that keeps on varying from one end to the other.

And depending upon whether the flow is core counter we find that at one end the difference in the for a counter current arrangement is T h,in minus T c,out while on the other end this particular difference is T h,out minus T c,in. And so, therefore, this particular differential while it is while we progress along the heat exchange in this case we for this graph this is the temperature axis and this is distance along the heat exchanger.

So, therefore, what do we find that this differential that keeps on changing and this varies from T h,in minus T c,out at one end to T h,out minus T c,in at the other end for a counter current exchanger. So, accordingly the if you solve it then finally, you get an expression of Q equals to U A this LMTD where LMTD is nothing, but the difference at one end minus the difference at the other end divided by the logarithmic of this two.

Now, again when you have done this integration you have done it for certain conditions. Conditions are again the same thing as you had derived for applicable for this equation sensible heat transfer heat capacities of both are substantially independent of temperature. There is no phase change or even if there is a phase change at constant pressure for a stream which contains single components.

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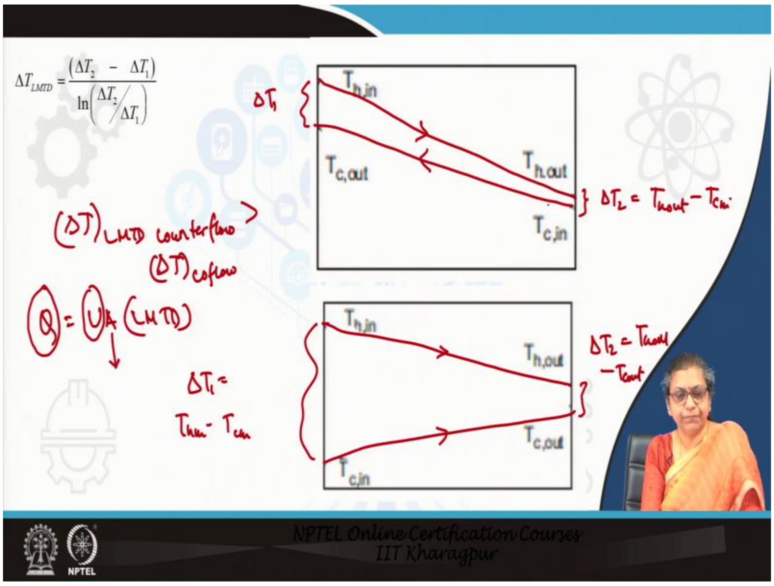

So, for these cases we had derived it and it was very evident that just the way I have told you that when it is a counter current flow arrangement as I have told that this is the flow of the hot fluid and the cold fluid it flows counter current to this. So, therefore, delta T 1 is this and delta T 2 this is equals to T h,out minus T c,in. If we have a parallel flow then in cat case what happens hot fluid it is flowing from T h, in to T h, out cold fluid also it flows from T h, in to T h, out.

So, therefore, in this particular case I have told you that delta T 1 this is equals to T hin minus T c,in and delta T 2 this is equals to T h,out minus T c,out in this particular case right.

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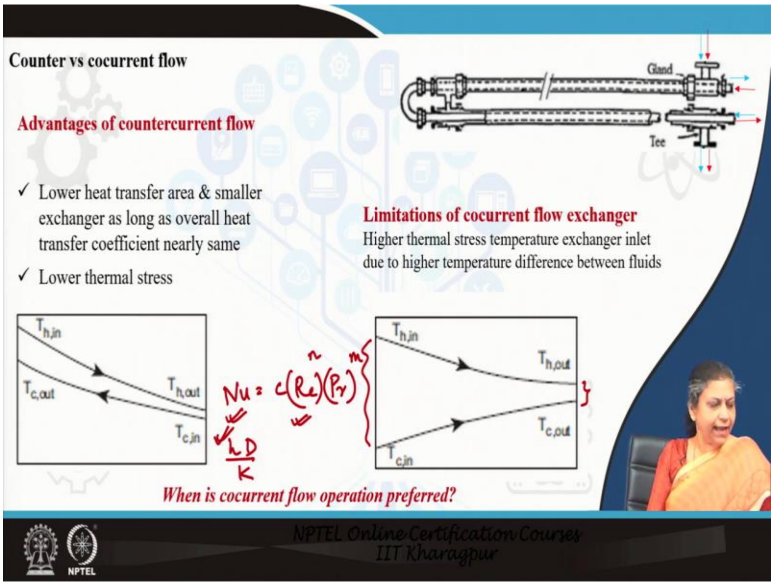

Now, tell me one thing that we have been repeatedly telling you that we go for counter current flow; unless otherwise mentioned we go for counter current flow. Can you tell me that just by looking at this particular graph or can you tell me why we prefer counter current flow? Normally, if you calculate the delta T LMTD you will find that for this particular case delta T LMTD will be higher as compared to this particular case.

So, usually we find that delta T LMTD for counter flow, this is greater compared to delta T LMTD for coflow. So, when delta T LMTD for counter flow is higher than what do you find UA LMTD. So, therefore, when this is higher naturally for exchanging this particular amount of heat when everything else is constant we will require a lower area. So, therefore, this is one particular reason why we prefer the counter current heat exchanger there is also another very important reason.

You will find that the temperature difference the delta T 1 and delta T 2 they will not be very wide apart from each other. So, therefore, when the two fluids are flowing and the heat is exchanging across the surface the surface is never subjected to a very high thermal stress during the entire flow process.

Now, these are the particular two reasons why we prefer counter current flow in the co current exchanger again if you find you will find that the temperature difference at one end is much different compared to the temperature difference at the other end. So, naturally under this condition the material between or the heat exchange surface it is naturally exert it subjected to much higher thermal stress.

Now, I have a question for you if this is the case then are there no cases where we would like to go for a co current operation can you cite any particular case where we would like to go for a co current operation? Say for example, you have a cold fluid which is very viscous right you introduce it here what happens at the entry it is subjected to a very large delta T.

So, naturally it gets heated up very fast and as it gets heated up the viscosity decreases, when the viscosity decreases, then what happens heat transfer coefficient improves, why does it improve? Recall in the last class what had you found out that Reynolds number it is a function of Nusselt number, its a function of Reynolds number raised to some particular power, Prandtl number raised to some other power.

So, therefore, when the viscosity decreases, Reynolds number increases for the cold fluid, naturally Nusselt number increases for the cold fluid. So, naturally h D by K h increases for the cold fluid. There is one other very big advantage, when your Reynolds number increases the pressure drop decreases. Recall the Reynolds number, the friction factor is a function of Reynolds number, pressure drop in the straight pipe is expressed in terms of friction factor.

So, therefore, when your Reynolds number improves its not only the heat transfer coefficient which improves, but the pressure drop also decreases. So, therefore, co current flow we prefer when we encounter a cold viscous fluid under that condition we prefer this.

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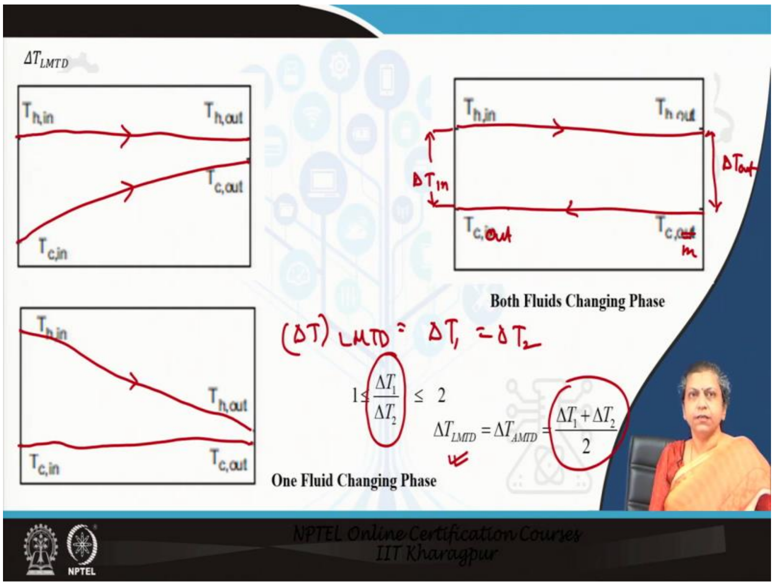

There are certain other cases where it hardly matters if we have a co current or a counter current arrangement. Say, in this particular case there is one particular fluid say the hotter fluid which does not change its temperature, in other words it changes phase and gives out heat in order to heat the cooler fluid. So, therefore, this is the parallel flow arrangement or else you can also have a case where the cooler fluid it is changing phase in order to heat the hotter fluid under these particular conditions. If you find out the delta T LMTD it hardly matters whether you are going for co current arrangement or for counter current arrangement. Now, there is one other thing also which I would like to mention say for example, both the fluids are changing phase.

So, therefore, what happens? This shows a co current arrangement. We find that the delta T here say delta T inlet with respect to h in this equals to delta T out with respect to the hot fluid.

How do we define LMTD for this particular case, delta T LMTD this equals to delta T 1 or this is equals to delta T 2. In fact, I would also like to tell you that when delta T 1 by delta T 2 it varies between 1 and 2 you need not go for the log mean temperature difference and arithmetic mean is sufficient it just gives you less than 4 percent error for - delta T 1 by delta T 2 equals to 2. You can work it out yourself and to find out that the error is less than 4 percent. Normally, delta T LMTD is less than delta T arithmetic mean, but for this case we can take up this assumption and this gives us a much better, much simpler approach.

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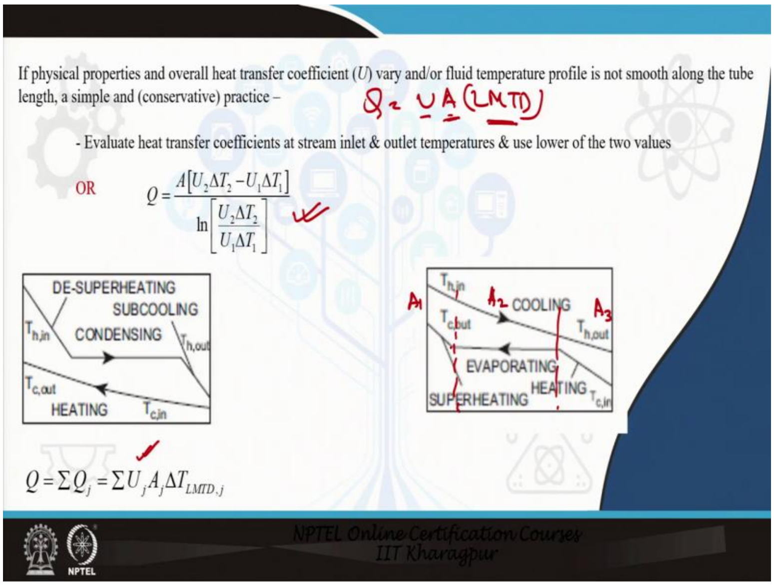

There is one other thing if you remember in this particular case what have I told you here that the derivation was made when all the heat capacities were substantially independent of temperature, sensible heat transfer, no phase change, etc. ete. Or in other words we had assumed for this derivation that u remains constant if it happens under certain cases that the physical properties are varying.

And therefore, the overall heat transfer coefficient may vary or maybe the fluid temperature profile is not smooth under that condition what will you do. You cannot use this equation directly. So, for that case you can do two things one is you can evaluate U at the inlet, you can evaluate U at the outlet.

Naturally, if you select the lower U you will get a higher A and so, that is going to serve your purpose or in other words in that particular derivation your U LMTD should be included in the integral and you can get this particular expression you can also use this. The last thing, which I will be telling you about LMTD and ending this class, that from the next class we go for discussions regarding U and how to find out A etc. etc.

So, the thing is that remember one thing LMTD was defined only when the temperature profile is smooth throughout or it is continuous throughout. Suppose say we take some particular fluid say we take some particular hot fluid in order to heat the cold fluid hot fluid say is a vapor right. So, therefore, what it does it cools down then it condenses and then the liquid it again cools down.

So, over this entire area it imparts heat and heats up the cold fluid this case what will you do, how will you find out the LMTD. Same thing is applicable in case suppose we are a cooling a hot fluid by using an evaporating liquid same thing. In this case what we do is we divide this into number of sections once we have divided into sections for this particular section you can evaluate delta T LMTD once you can evaluate delta T LMTD you can find out the area for this region.

This particular region you can evaluate delta T LMTD, once you have evaluated delta T LMTD, you calculate U for this case, you can find out the area under this condition same way you can find out the area here, add up all the areas then you can you get the total heat transfer area that will be required in order to bring about this particular change.

So, therefore, what we did we discussed the energy balance equation and also the rate equation from the rate equation we are supposed to decide upon the heat transfer area and the geometry. In the rate equation there is an overall heat transfer coefficient, there is a log mean temperature difference, we discussed different characteristics of the log mean temperature difference for co current flow for counter current flow, which one is more advantageous and the different characteristics when LMTD can be replaced by the arithmetic mean.

In the next class we will be discussing about how to estimate the overall heat transfer coefficient so that we can go about in for estimating the heat transfer area and then we can decide upon the that tube dimensions and we can go for the pressure drop calculations.

Thank you very much.