Principles and Practices of Process Equipment and Plant Design
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Module - 03
Lecture - 43
Double Pipe Heat exchanger (Contd.)

Hello everybody! Today we are in the second class to discuss the double pipe heat exchangers. In the last class we had discussed the general arrangement of the double pipe heat exchanger, it is a concentric pipe arrangement and all these concentric pipes are arranged one above the other in series. They can also be in parallel arrangement and in this particular case each particular hairpin comprises of two pipes connected by a return bend. This is known as one particular hairpin.

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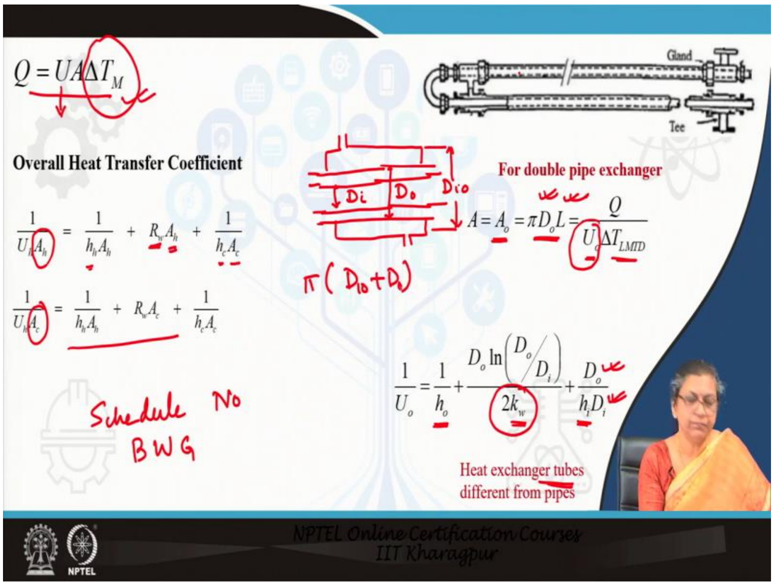

We had started discussing the design, we had discussed the heat balance equation and also the rate equation, and in this particular rate equation we had taken up each and every term and we had started discussing the log mean temperature difference and how to find it out for different cases.

Now, we come to discuss the overall heat transfer coefficient. You might recall that in your introduction class to this module 2 on heat transfer processes. The general equation was derived for the overall heat transfer coefficient and it was said that the overall heat transfer coefficient can be defined either in terms of the inner wall of the inner pipe or it can be, for example, defined in terms of the inner wall. I just draw it out here.

This is the inner pipe and this is the shell or rather it is not the shell it is the outer pipe we call it as a shell in a shell and tube heat exchanger. So, the inner diameter of the inner pipe is D i, the outer diameter of the inner pipe is D o and the inner diameter of the outer pipe that is D io.

So, therefore, you can very well see that the heat transfer coefficient can be defined either in terms of the heat transfer area of the hot fluid or in terms of the heat transfer area of the cold fluid.

This derivation was also given to you. Here h is the heat transfer coefficient of the hot fluid the area occupied by the area of heat transfer on the hot fluid side, this is the heat transfer coefficient of the cold fluid the area of heat transfer on the cold fluid side; and this is basically the resistance offered by the metal wall and this is again the since here it has been defined in terms of the heat transfer area of the hot fluid.

So, therefore, R w is multiplied with A h. Now, if we apply this general overall heat transfer coefficient equation to the specific case of a double pipe exchanger then in that case as I have already mentioned that the heat transfer area is taken as the outer wall of the inner pipe or in other words the area of heat transfer is A 0, which is given as pi into D 0 the diameter the outer diameter of the inner wall into the length the total length which will be required and this is obtained as Q by the since this is A 0.

So, therefore, U is defined as U 0 into delta T LMTD, delta T LMTD will not talk much how to find out this U 0 because moment you can find out this U 0 you can find out A 0. If you either find out D 0 or you select D 0, you find out L. At some conditions you select both D 0 and L to find out the number of hairpins whatever it is.

So, the standard equation from here if we just write it down with consistent nomenclatures. In fact, this was also mentioned to you in your introduction class. Then U 0 you find it is a function of heat transfer coefficient of the outer fluid, heat transfer coefficient of the inner fluid, the outside diameter of the inner pipe, inside diameter of the inner pipe, thermal conductivity of the wall between the two. Now, here I would just like to mention one thing that heat transfer tubes, they are slightly different from the or the normal pipes.

In normal pipes when they are specified by the nominal diameter which is neither the inside nor the outside diameter, it is a notational specification. In heat transfer tubes when we say nominal diameter it refers to the outside diameter of the tubes. There is also one other thing that you will be remembering in pipes there are two things that we specify one is the nominal diameter the other is the thickness.

The thickness is defined in terms of schedule number, higher the schedule number thinner is the pipe. In case of heat exchanger tubes we define the thickness in terms of Birmingham Wire Gauge or the BWG.

So, therefore, we just cannot select normal pipes for heat exchanger tubes, this I just wanted to mention before we go further details of the design. So, therefore, for U o more or less you need to find out k w if you have selected the material of the of heat transfer k w you know, h o and h i are the two things that you need to find out.

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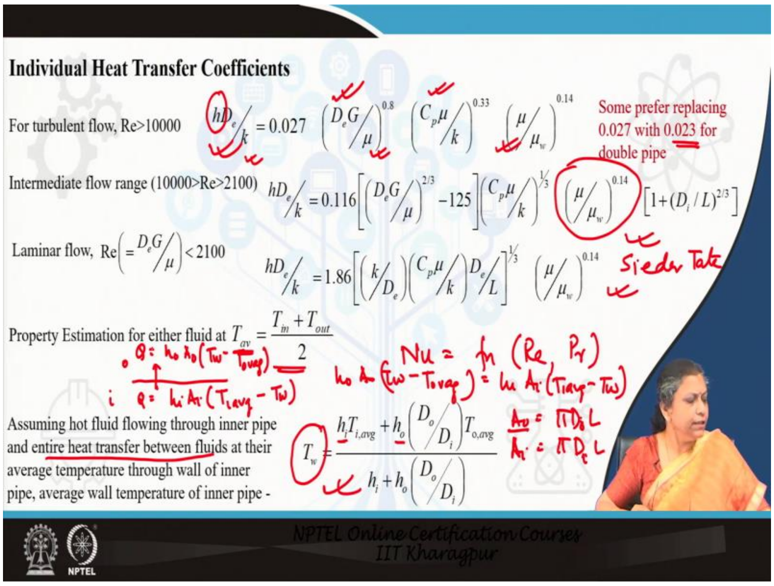

Now, if you remember again in a introduction class there were different correlations which were proposed for finding out h o for finding out heat transfer coefficient. The same correlations can be used for finding out h o and h i. There are different correlations but remember most of the all the correlations they have a generalized form which tells you that Nusselt number is a function of Reynolds number and Prandtl number.

Prandtl number is a property group, Reynolds number comes since the two fluids are flowing. You will remember Reynolds number comes for pressure drop, Reynolds number comes for finding out Nusselt number, Reynolds number is also present for finding out shell wood number.

So, this is the common thing. So, therefore, the different correlations they are provided here, mostly they are turbulent flow. So, therefore, this is the corelation and it is also mentioned that for double pipe often we use 0.023 intermediate range also the correlation is given for the laminar flow also the correlation is given. Now, for finding out h what are the things that you need, you need to know k, you need to know mu, you need to know C p.

If you have seen the problem that had given you the mu specified over a range of temperature and you will find that mu is quite a significant function of temperature, even if your k or C p they do not change much with temperature, but mu changes with temperature.

So, under what conditions are you going to evaluate these physical properties, this I had mentioned in the beginning of the previous class when I had shown you the design problem which you are suppose to work out as we progress with the discussions of the design.

Remember one thing, for both the inner and the outer fluid the properties should be evaluated at the average temperature which is nothing but T in plus T out divided by 2. Now, there is one other thing also which I would like to mention. Suppose it happens that the wall temperature is much different from the bulk temperature, under that condition we find that the viscosity of the liquid at close to the wall will be different from the viscosity of the bulk liquid.

And under that condition we require another additional correction term to the standard equation for Nusselt number. This particular term this was first proposed by Sieder Tate. So, therefore, this is known as a Sieder Tate correction factor which gives you that whatever h you are going to get from this equation that needs to be corrected by a mu by mu w where mu is the viscosity of the fluid under bulk conditions and where this mu can be evaluated at T average and mu w is the viscosity of the fluid under the average wall temperature.

So, therefore, what you need to do for this you need to find out the average wall temperature. It is very simple that if this is the wall and here what do you find in this particular case again from the heat transfer equation if you find that more or less on this wall on one side say the inner fluid is flowing on the other side say the outer fluid is flowing.

So, therefore, for this particular fluid what is Q equals to this is equals to h i A i and the heat transfer is occurring say in this direction say for example, inner fluid is the hot fluid. We just assume does not matter even if you assume the outer fluid to be the hotter fluid, it the derivation in no way it is going to change. So, therefore, the average temperature here is T i average minus T wall, the heat is going from here to here.

So, therefore, in this particular case Q equals to h o A o again T w minus T o average. T o average will definitely be given by T o in plus T o out by 2. T i average will be given by T i in plus T i out by 2. Now whatever heat it is being given out by the hotter fluid will be taken up by the cooler fluid we assume that there is no heat transfer or the entire heat is transferred between the fluids at their average temperatures.

So, therefore, we can equate these two, once we equate these two what do we get, we get h o h A o T w minus To average this is equal to h i A i T i average minus T w and we know how A o and A i they are related, A o is equal to pi D 0 L A i equals to pi D i L. So, therefore, A o by A i equals to D o by D i. So, therefore, you can replace one with the other by just multiple substituting by D o by D i.

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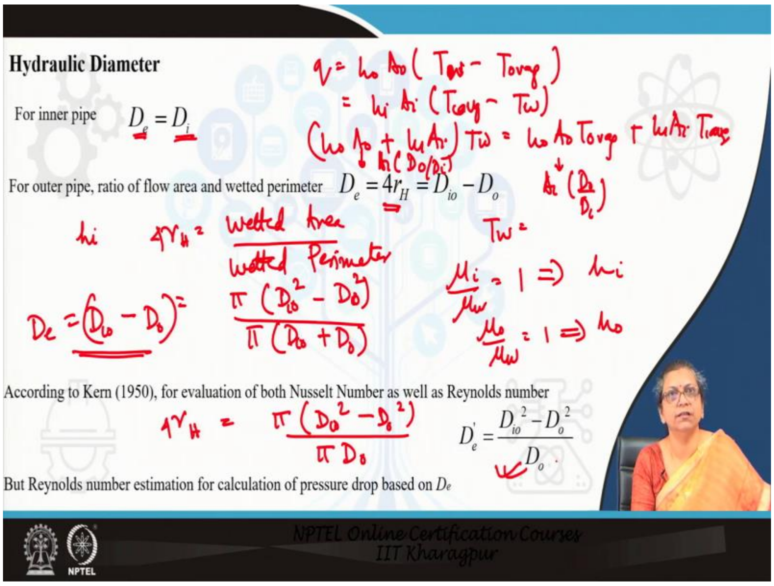

If you perform this particular derivation. So, therefore, in this particular case you can find out that q is equal to I will just write out once more and I will do it h o A o T o sorry T w minus T o average since the outer fluid is the cooler fluid this is equals to h i A i T i average minus T w.

So, from there if you equate these two then and then you can write it down as h o A o plus h i A i T w this is this will be equal to h o A o, you can do it yourself itself plus h i A i T i average. Now, for this for these A o you can replace them with A i D o by D i, here also you can replace it with A i D o by D i and then if you substitute all this then in that case you can get an expression of T w which is given in this particular expression.

So, you can work it out yourself you find that under this condition you get the average wall temperature. So, therefore, what you are require to do. Because this is an iterative process for finding out h you need this and for finding out mu w you need T w for finding out T w you need to know h i and h o.

So, what is the process that is used to start with you assume mu by mu w equals to 1. So, initially what we do we assume mu by mu w equals to 1 and once you can assume this you can find out this particular Nusselt number and you can find out h. After you have found out h you can find out in the same way you can find out h o h i by assuming the inner fluid by w equals to 1.

Same way you assume mu o by mu w 1 you find out h o. Once h o and h i they are found out then you substitute these two find out T w. Once you have found out T w you can find out mu w. Now, you can evaluate mu by mu w and then again you can find out h i and h o. Normally, we find that one iteration is usually sufficient we do not have to go for further iterations here. So, therefore, in this particular way you can find out h i you can find out h o.

Once you have found out h i h o you can find out U o. There are certain other things also which I would like to mention, other than the properties there is an equivalent diameter or the equivalent character characteristic dimension of the heat transfer surface which needs to be incorporated.

Now, when you are working with the inner tube fluid or when you are working with we are trying to find out h i, then in that case its very simple your effective or equivalent diameter is nothing, but the inside diameter of the tube. When you are working with the outerpipe then in that case the outer fluid it is flowing through the annular area.

We all know that for any annulus for single phase flow through an annular area the equivalent diameter is usually defined as the hydraulic diameter where the hydraulic diameter is four times the hydraulic radius. And the hydraulic radius it is defined as the wetted or rather cross sectional area divided by the wetted perimeter.

So, therefore, in this particular case we know what is the wetted area it is naturally pi D o square minus sorry pi D io square minus D o square, is not it. So, therefore, the cross sectional area which is occupied by the annular fluid and what is the wetted perimeter, the outside wall is also wetted if you find here for the annular fluid this wall is also wetted and this wall is also wetted. So, therefore, the wetted perimeter what it should be it should be pi D io plus D o.

So, therefore, in that particular case this is going to be pi o plus D o. So, therefore, from there what do you get you get that for the annular fluid the D e is nothing, but equal to D io minus D o, we can use this and for the inner fluid you can use this. Now, here I would just like to mention one thing this was pointed out by Kern.

And since we have been referring to the book by Kern, it is important for you to remember that what Kern had suggested is that he said that well this definition is fine as far is as you are going for the or finding out the pressure drop I have no problems, but when you are finding out the heat transfer coefficient and you are defining the the equivalent diameter under that condition. Then it should refer not to the wetted perimeter, but to the perimeter through which the heat transfer is occurring.

So, he said that for heat transfer case, the r H it should be defined. In fact, this is 4 r H that should be defined this should be defined as pi D io square minus D o square, this is the cross sectional area divided by pi D o since the heat transfer is occurring through the wall of the inner pipe.

So, according to him, he suggested that the equivalent diameter for heat transfer or in other words the equivalent diameter which is used in this Nusselt number in this Reynolds number they should be calculated by using this.

And when we calculate the Reynolds number for finding out the pressure drop under that condition we should be using this. Anyhow for our case we take up this particular definition of the equi-periphery diameter to calculate Reynolds number for both pressure drop as well as heat transfer coefficient. We take this up to calculate also the Nusselt number, we take up this particular definition also for calculating the friction factor. We use the same thing well this was regarding the hydraulic diameter.

Now, the thing is that if we really want to use these equations we first have to define the inner fluid and the outer fluid. We did not discuss it earlier, but when we go for design after we have decided the heat transfer equipment that we are going to use that definitely we will be deciding based on the heat transfer load and also the heat transfer area apart from other considerations. After that we decide the inner fluid and the outer fluid.

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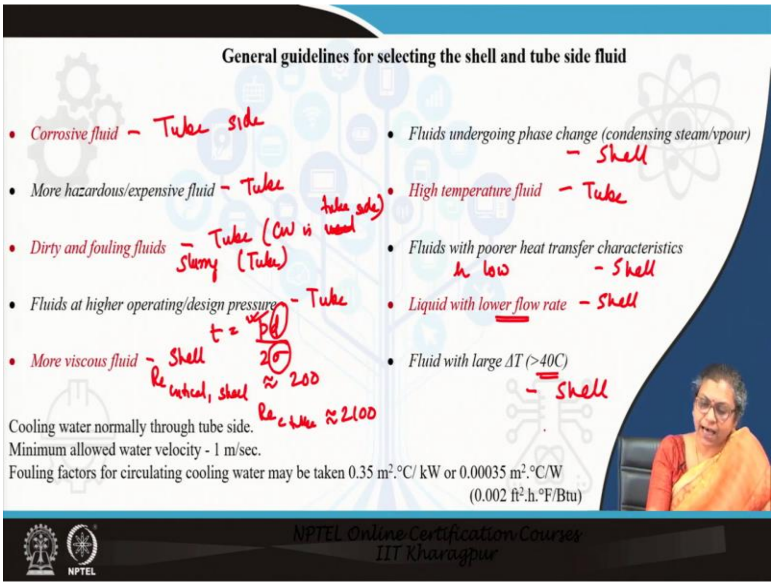

There are few guidelines that I have put up here. These guidelines they are common both for double pipe exchangers as well as for shell and tube exchangers. So, therefore, whatever we I am going to discuss regarding which fluid preferably will be on the outside and the inside will also be applicable regarding which fluid will flow on the shell side and tube side in the shell and tube exchanger.

There is another very important thing that I want you to remember. These are simply some guidelines and they are nothing sacrosanct and mostly we decide on the inner and the outer fluid based on the application based on the conditions at side or based on heuristics based on previous experience as well, these can just be used as guidelines when you decide regarding the inner and the outer fluid.

Certain things they are coming from common sense itself so, therefore, there is not much discussion on it also. Let us take up one by one and see that where will you prefer to put this particular fluid under generalized conditions, say for example, corrosive fluid it is quite evident that if you put the corrosive fluid on the shell side then what happens both the shell as well as the inner wall of the shell and the outer wall of the tube gets corroded.

You would definitely not want that. The other thing is if you take up the corrosive fluid and put it on the tube side then it is easier also to clean the tube and the other thing is it is easier to replace the tubes. Tubes are mostly bought out item so that you can very easily replace them.

In fact, you can take up take out tubes without even opening the shell. So, naturally if the tube in a surface gets corroded it is at least better. So, therefore, it is more preferable as compare to the shell side rather both the tube outer surface and the shell getting corroded.

So, therefore, we would prefer to keep a corrosive fluid inside the tube. Same way more hazardous fluid, definitely when you are working with a more hazardous fluid you would not want the fluid to leak out. If it is in the shell then there is every chance or a greater chance of leakages through the space between the you are the inner pipe and the outer pipe we put cascades etcetera, but then also there are chances of leakages.

So, naturally when we go for hazardous fluids or when we go for more expensive fluids we would prefer to keep it on the tube side. What about dirty fluids, dirty fluids mean the fluids which have some particular solids. These solids they can get deposited or may be fouling fluids which foul the tubes.

For these particular cases also we would like to keep them on the tube side for certain reasons. First thing is its easier to clean the cube inside surface number 1, next thing is while flowing in the tube there are lesser areas of stagnation points the flow is much more uniform.

So, therefore, when there are lesser stagnation points there are lesser areas where fouling fluids can accumulate. This is the reason why generally cooling water its the most common coolant that we use cooling water is generally rather it is generally the tube side fluid for this case. Second thing is, suppose, there are dirty fluids which have got some solid deposits etc. etc. the thing is inside the tube.

The tube diameter is lower as compare to the shelter rather the outer pipe diameter, when the tube diameter is lesser naturally the velocity of the tube side fluid will be higher, when a fluid is flowing at a higher velocity chances of depositing the solids etcetera decreases. So, therefore, for this particular reason again we prefer slurry to flow in the tube side fluid.

Other thing is fluid at a higher pressure, in this case also if you remember that I had told you that when the when a fluid is at a higher operating or a higher design pressure under that condition if you remember the t this is equal to pd by 2 σ. So, naturally we find that since the diameter of the tube is less, then quite naturally it can withstand a higher pressure, this I have already discussed, this is the reason why double pipes are preferred over shell and tube exchangers.

And this is the reason why the fluid at a higher operating or a design pressure is preferably introduced through the tube side. Now, we come to the more viscous fluid. Where will you like to keep it? Now, remember one thing, in the shell side if you remember the critical Reynolds number for the shell side or the outer tube this is near about equal to 200, while on the tube side Re critical on the tube side you know very well this is around 2100.

So therefore, we find that the chances of having a turbulent flow and therefore, greater mixing that is more on the shell side as compared to the tube side. So, therefore, when we have a more viscous liquid in order to ensure that the flow is turbulent we would like to introduce on the shell side, but remember one thing if the fluid is so viscous or the velocity is so less that even in the shell side it exhibits laminar flow characteristics under that condition.

Condition in order to increase the velocity, we would like to introduce the fluid on the tube side. Well the next is suppose a fluid is undergoing a phase change say may be a fluid which is vaporizing and with a latent heat, it is heating up another fluid, in this case what happens as phase change occurs it two phase flow, it has got a higher pressure compared to the single phase flow and also when vapour is formed you need some space for the vapour to accumulate.

It is easier to provide the space in the outer tube or in the shell side. So, for fluids undergoing phase change, we would like to introduce them on the shell side. Now, the next thing is when the fluid has a higher temperature, quite naturally if you have observed that whenever we are doing any derivations in the introduction here in this particular class we had always mentioned that let the hotter fluid flow through the tubes.

The reason is very simple, because if the hotter fluid flows through the shell then we have to provide an insulation to the cell. There are chances of greater heat loss if the high temperature fluid is flowing through the shell. This is number 1. The number 2 is that whenever the temperatures higher then naturally what happens the yield stress that decreases.

So, therefore, since the tubes they are having a lower diameter so therefore, chances of withstanding a higher pressure at higher temperature is more for the case of the tube as compare to the shell. So, therefore, higher temperature fluid we would like to put it in the tube side. When the fluid has a poorer heat transfer characteristic, on other words the h is low, then in that case if you put it on the shell side what happens the the critical as I have told you the critical Reynolds number for the shell side fluid or the outer fluid it is 200.

So, chances of attaining turbulent flow is higher. So, therefore, improved heat transfer characteristics we might get if we introduce the fluid with a low h on the shell side. So, we would like to prefer it to on the shell side. Next thing is liquid with the lower flow rate, again in this case we would prefer the shell side provided the flow rate is such that it exhibits turbulent flow when it is flowing through the shell side.

In case we find that even in the shell side that it exhibits laminar flow the Reynolds number is less than 200 for the shell side then we would prefer to flow it to the tube side because since the diameter of the tube or the cross sectional area of flow is less. So, therefore, the velocity chances of the velocity being higher will be more.

Suppose, there is a fluid which has to be heated or cooled over a large range say that delta T the t h in minus t h out or the t c in minus t c out, this is greater than 40 Degree Centigrade, in that case you imagine that if that fluid is flowing through the tube then in that case what happens there is a very large temperature difference and the tube sheet which is holding the tube and the both the ends are through the tube sheet.

So, therefore, the tube sheet will be subjected to larger stresses. So, for those particular cases we would be introducing the fluid through the shell side. So, therefore, these are the again I will repeat these are the general guidelines based on this since cooling water normally flows to the tube side, the minimum allowed water velocity is 1 meters per second, generally its always higher velocity to decrease its fouling tendency fouling factor is also given here.

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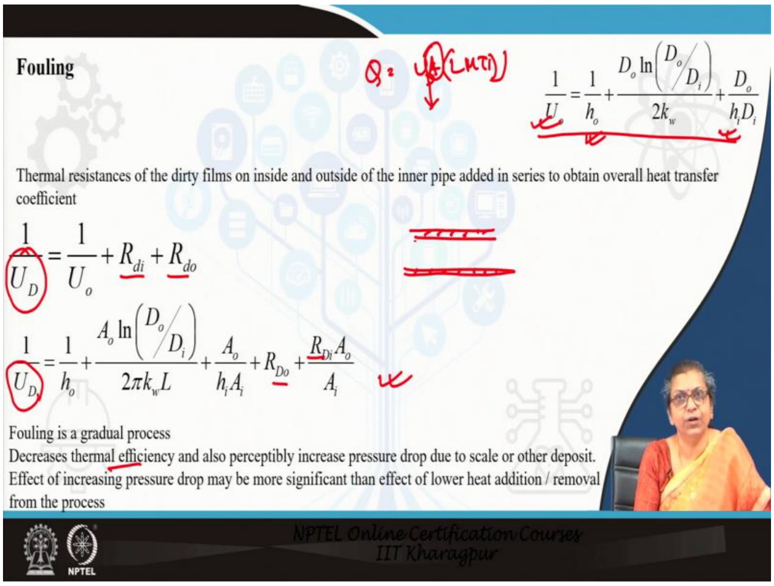

Well, this is something very important that I should have mentioned earlier. So, therefore, now in this particular expression you know how to calculate h o, you know how to calculate h i, you know everything you can calculate U o once, you have calculated U o then using these particular equations you can calculate A, but here there is something that I would like to mention the entire expression has been assumed rather has been derived assuming a clean tube.

Initially when you are; when you have started a new exchanger definitely the tube is clean, but as time proceeds what happens there will be some deposit, some corrosion, something on the tubes and as time proceeds due to the dirty films on the inside and outside what happens we have a tube here there will be an additional resistance to heat transfer due to the deposits etcetera.

So, therefore, if you do not consider this, then what happens with time as this deposits form they provide additional resistance to heat transfer. So, naturally whatever heat transfer was happening in the new condition does not happen, there is decreased heat transfer. So, therefore, the heated fluid will not be heated to the extent that you want or the cooled fluid will not be cool to the extent that you want.

If you want a heat exchanger to operate over a long period of time then in that case you need to consider this particular factor and or rather which is known as the fouling factors you need to consider and you need to incorporate them in the calculation of the design overall heat transfer coefficient so that using this particular U D the A that you calculate will be greater than the area which you are going to get without considering the dirt factors.

And therefore, this additional A that you are going to provide will ensure that even with sufficient fouling, even with ageing also the heat exchanger will be able to provide the heat extent that you want, the hot fluid will be heated to the extent that you want or the cooled fluid will be cooled to the extent that you want.

So, therefore, its very important that when you are designing a heat exchanger be it a shell and tube or a double pipe exchanger we take up the design overall heat transfer coefficient where this design overall heat transfer coefficient it accounts for the dirt factor or the deposit on the inner side of the tube and the dirt factor or the fouling factor on the outside of the tube ok.

So, therefore, the U D the U 0 is corrected for with these two dirt factors in order to obtain the design overall heat transfer coefficient using this overall design heat transfer coefficient we calculate the area of heat transfer. So, therefore, the expression of U D with R Do R Di incorporated when this U D is expressed in terms of A o is given in this particular expression.

It is quite evident that when fouling increases naturally decreases the thermal efficiency and there is one more important thing that you have to consider, its not only that when fouling occurs the heat transfer rate decreases, there is also other thing also the pressure drop also becomes higher along with lower heat addition.

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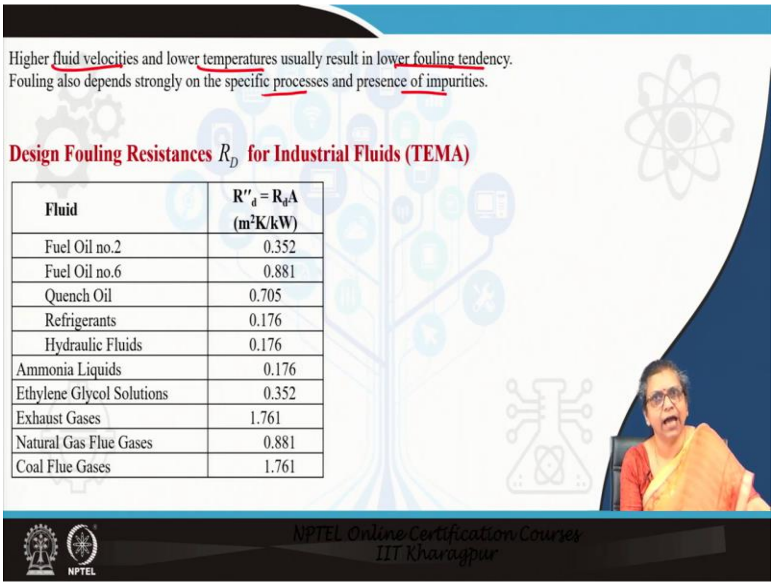

So, therefore, it is much more important to consider fouling factors not only from the heat transfer point of view, but also from the pressure drop point of view and it is also important see, suppose you have to clean the tubes very frequently that is not at all a desirable situation, normally tubes they are cleaned either by mechanical means or by chemical means.

And so, therefore, we would always like to schedule the cleaning of the tube with the original shutdown of the heat exchangers. So, therefore, you need to remember two things, when you are taking fouling factors into account you are providing some additional area to the heat exchanger.

This increases the capital cost of the heat exchanger, but at the same time you believe that you will be operating over a longer period and the you will be saving on the expenses for cleaning. So, therefore, an optimum has to be struck between the capital cost and the operating cost in order to account for the fouling factors.

Now, normally we find that quite naturally that when you have a higher fluid velocity lower temperature the definitely the fouling tendency is low and fouling it also depends upon specific processes and presence of impurities. This is something very important for you to remember for example, if you take naphtha from the crude distillation unit you will find that there is very less aromatics there and the fouling factor is very less.

But the same naphtha if you take from a cracking unit it contains the large number of olefins and so, therefore, due to the polymerization etcetera they provide the they deposit on the surface and under that condition the fouling factor is much higher. So, therefore, the fouling factor it is taking it sort of a safety factor, it is taken just to guarantee a longer life of the heat exchanger without cleaning and it is taken at the cost of increased capital cost expecting that the operating costs are going to be less.

Now, here what I have done is I have just given you the typical fouling factors of certain fluids that are used. Again remember just example of naphtha that I have given from that you know that fouling factor depends upon the specific processes. And so, therefore, these are just representative values these values can be taken for the design in order to get a rather in order to ensure a longer life without cleaning of the heat exchanger.

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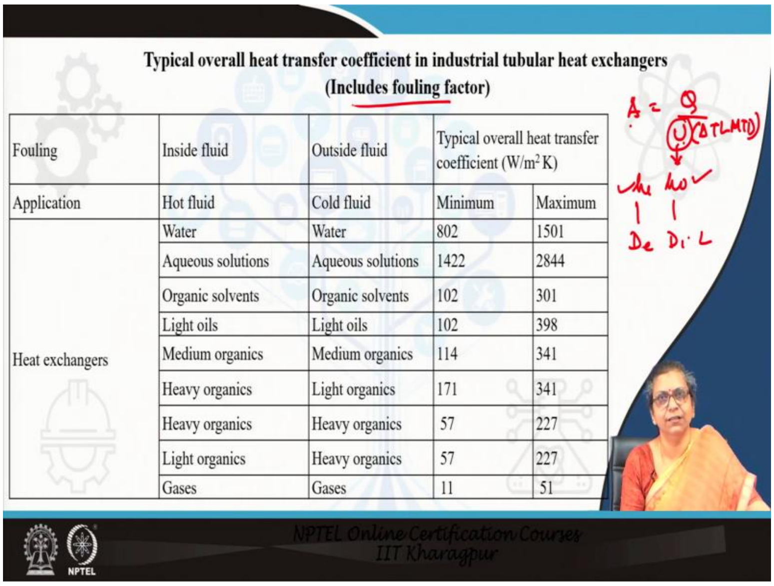

Typical overall heat transfer coefficient in industrial tubular heat exchangers (Includes fouling factor)

Fouling	Inside fluid	Outside fluid	Typical overall heat transfer coefficient (W/m^2K)	
Application	Hot fluid	Cold fluid	Minimum	Maximum
Heat exchangers	Water	Water	802	1501
	Aqueous solutions	Aqueous solutions	1422	2844
	Organic solvents	Organic solvents	102	301
	Light oils	Light oils	102	398
	Medium organics	Medium organics	114	341
	Heavy organics	Light organics	171	341
	Heavy organics	Heavy organics	57	227
	Light organics	Heavy organics	57	227
	Gases	Gases	11	51

Well, the only one thing that is left is that initially I had mentioned that when you want to find out A this is Q by U delta T LMTD. Now, to find out U you have to find out h i h o, to find out h i h o you need to know the, that the D e D i etc. etc. you have to know.

To start with you do not know anything. So, how do we start the design, this is an iterative process to find out A you need U, to find out U you need A. So, how to do it? So, therefore, what is provided here is some typical overall heat transfer coefficients in industrial tubular heat exchangers including fouling factor are provided here.

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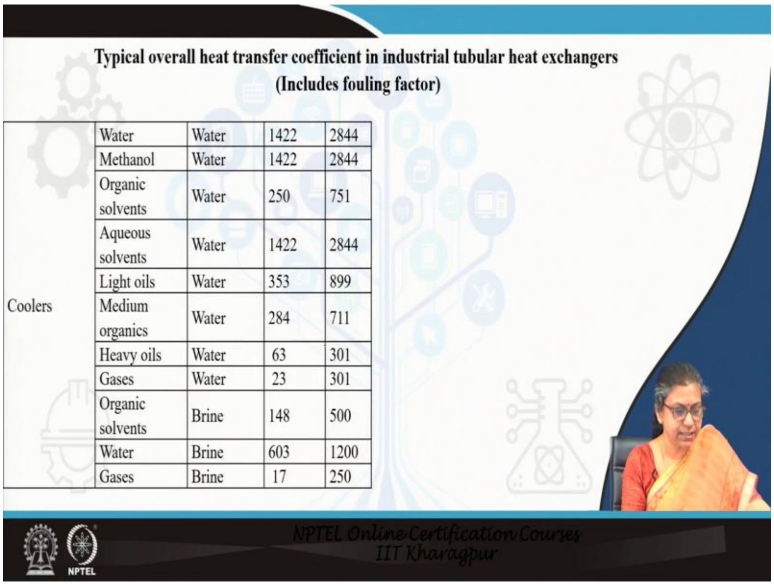

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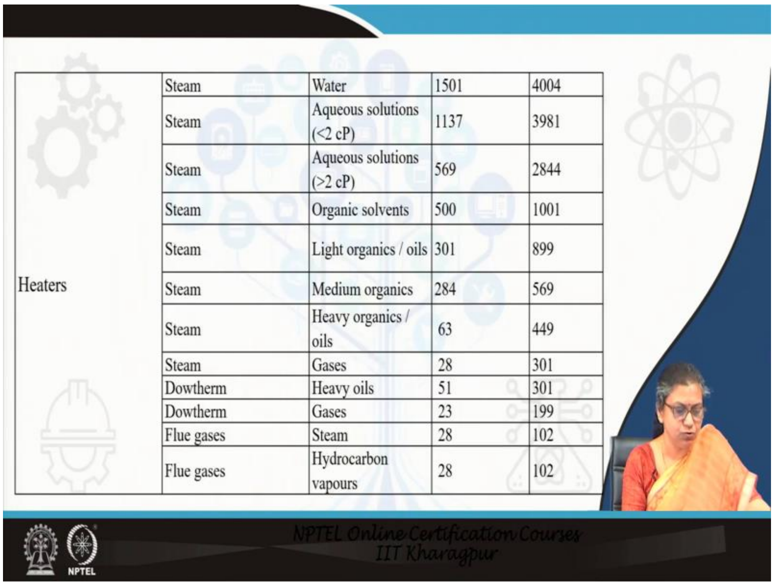

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Condensers	Aqueous vapours	Water	1001	1501
	Organic vapours	Water	700	1001
	Organics with non-condensable	Water	500	700
	Vacuum condenser	Water	199	500
Vaporisers	Steam	Aqueous solutions	1001	1501
	Steam	Light organics	899	1200
	Steam	Heavy organics	603	899

For say heat exchangers for coolers for heaters for condensers vaporizers etcetera these are provided. So, therefore, what you can do is that initially based on the application you can select the overall heat transfer coefficient some average between the minimum and maximum.

Using that U you found out A, from A you can find out D i D e D i L etcetera. Once you have found these out you find out h o h i using this h o h i again find out U, see if the U it falls within these limits or not if they fall you are lucky then you can proceed with the design that you have done.

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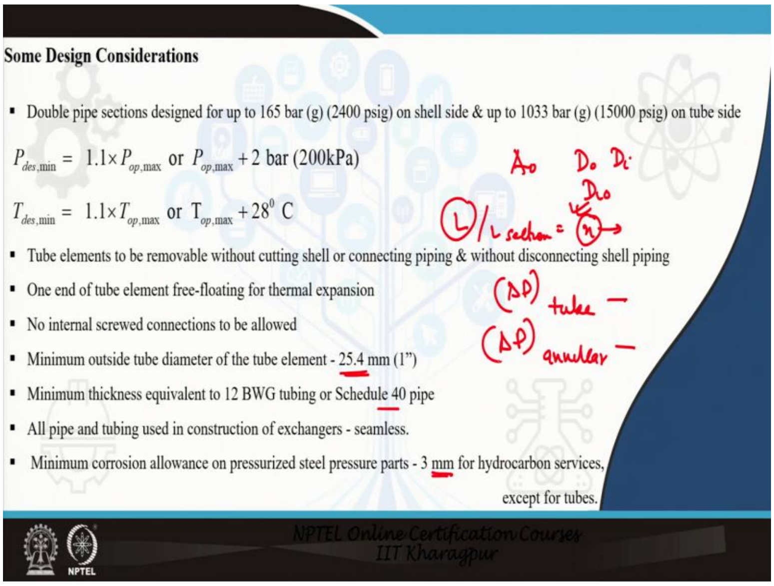

So, therefore, these are just to start the design once you have done the design you have found out A o. Now, you need to decide on the tube diameter and the tube length. Certain things I would like to tell you there are some rules with here which are again simply guidelines. For example, the minimum outside tube diameter should not be should it is actually 25.4 millimeters the minimum thickness is equivalent to a schedule 40 pipe.

So, the corrosion allowance is 3 millimeters, such some guidances are there based on which you can select the tube diameters again remember you have to refer to quotes to select the inner tube diameter and also to select the outer tube diameter. Generally, the lengths are also standard general they come in 6 meters or 3 meters length. So, therefore, once you have selected this you can find out the length the whatever length is there divided by the length of each section.

If you do it then you get the number of hairpins that you require, once you have found out the number of hairpins then the next thing which you need to do is to find out the delta P on the tube side find out the delta P on the annular side and check whether these are respecting the limits which are provided. So, in the next class we discuss the hydraulic calculations to find out the pressure drop.

And we discuss a few other salient features of double pipe heat exchanger specifically and your tubular heat exchangers in general and finish on the discussion on double pipe heat exchangers. So, till today we have finished off the thermal design of double pipe heat exchangers, we will be starting the hydraulic design in the next class.

Thank you very much.