Principles and Practices of Process Equipment and Plant Design

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Module - 03
Lecture - 44
Double Pipe Heat exchanger (Contd.)

Hello everybody, today is the third class and the last class on double pipe heat exchangers. So, in the last two classes what we had done, we had discussed about the double pipe heat exchangers, the hairpin arrangement, the series parallel arrangement, etc. and we had completed the thermal design.

The only thing that is left if you had seen the problem is, we had also mentioned in the problem, the pressure of the two fluids and also the allowable pressure drop. So, the last thing which is left is the hydraulic design where you are going to check up the pressure drop for the outer liquid or the outer fluid, the pressure drop for the inner liquid and just check up whether the they lie within the permissible limit of pressure drop or not.

There is one other thing which is very important when we define the pressure of the fluid in the annular area or in the inner pipe and for the shell and two heat exchanger in the shell or in the tubes, it is always the absolute pressure with respect to the atmosphere. It is neither the pressure drop nor the pressure difference between the inner and the outer fluid, it is always in terms of gauge pressure with respect to the ambient anyhow. So, without any delay I think we should be going now directly to the hydraulic design.

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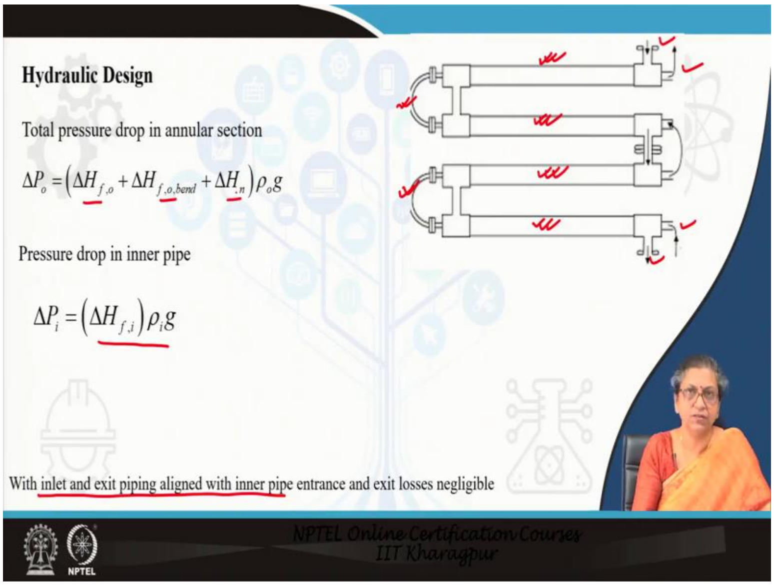

Now, you tell me to find out the pressure drop what are the things that you require? Very clearly if you see this particular exchanger arrangement that I have the drawn here, the most conventional arrangement, the series arrangement of two hairpins where there is counter current flow of the outer fluid as well as the inner fluid.

We find where pressure drop occurs. Definitely it will be occurring in the straight sections of the pipe. It is going to occur in the bend and it is also going to occur in the inlet and outlet nozzles. So, it is going to occur under in this particular nozzle, it is going to occur in the bend and definitely it is going to occur in the straight portions of the length.

Now, there is one thing for the annular fluid the pressure drop at the nozzle and also at the bend they are quite appreciable and have to be taken into account, but for the inner pipe usually we find that when the inlet and exit piping are aligned with the in inner pipe, the entrance and exit losses they are usually negligible and they can be neglected. So, what do we do in the inner pipe? It is just the pressure drop in the straight bend and in the annular section, it is the; it is the pressure drop these are in terms of heads of the liquid head, this is in the straight portion, this is in the bend and this is at the nozzles.

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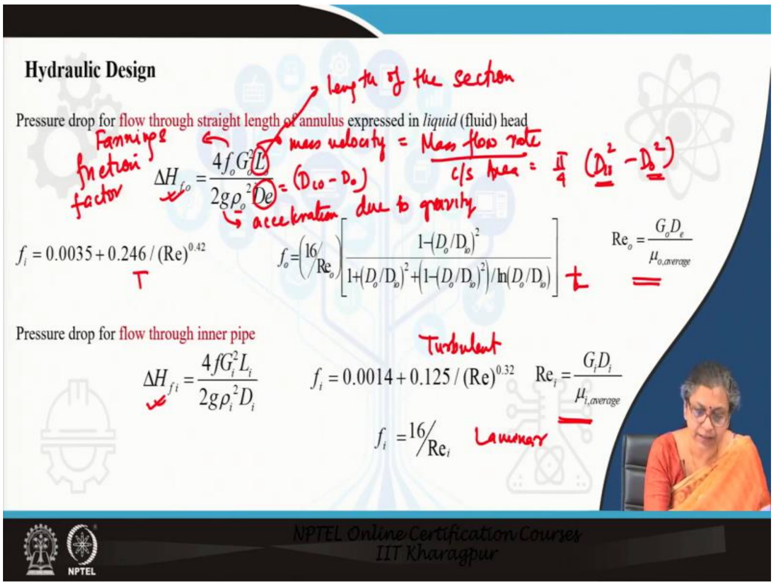

In the straight portion the pressure drop expression I did not say you have already studied this from your fluid flow, here this G is the mass velocity, what is the mass velocity? This is the mass flow rate divided by the cross sectional area. So, therefore, this is going to be this divided by the cross sectional area.

When we are talking about the annular portion or the outer fluid naturally for finding out the cross sectional area it is going to be pi by 4 D i o square minus D o square. Remember the notations that we had defined in the last class D i o it is the inner diameter of the outer pipe D o is the outer diameter of the inner pipe right.

Now, this is this you know this is nothing but acceleration due to gravity, this is the density and this is the equi periphery or the equivalent diameter. We had already defined this particular diameter it is the wetted cross section divided by the wetted perimeter and therefore, it was equal to D i o minus D o in our particular case that that we had seen here and what is this? This is the Fanning's friction factor and this particular L o this particular L o this is the length of the section length of this of the section.

So, it is the if the number of hairpins. So, it is the total length, length through which the flow is occurring. It can happen that there are some portions may be outside in the return bend or rather some portions even the straight pipe where heat transfer is not occurring, but since flow is occurring. So, it is going to be the total length of the corresponding section.

Now, as we know that the friction factor this is a function of Reynolds number we know it. Reynolds number for the outer fluid this is defined in this particular way, for the inner fluid it is defined in this particular way. For the outer fluid we find that the friction factor it is defined as shown here, for the and this they correspond to the friction factor in terms of Reynolds number for laminar and turbulent flow and this corresponds to the friction factor and Reynolds number term for turbulent flow and this one is for laminar flow, this is for turbulent flow right.

This is also for sorry this is for laminar flow and this is also for turbulent flow. So, in this particular way what we do? We first find out the Reynolds number for the outer fluid Reynolds number for the inner fluid and then we find out f o we find out f i. Once these are done everything else is known here, we find out this and we find out this.

Now, in this particular term that is just something which I would like to mention quite often we have those particular corrections; this is due to the viscosity change the effect on the friction factor.

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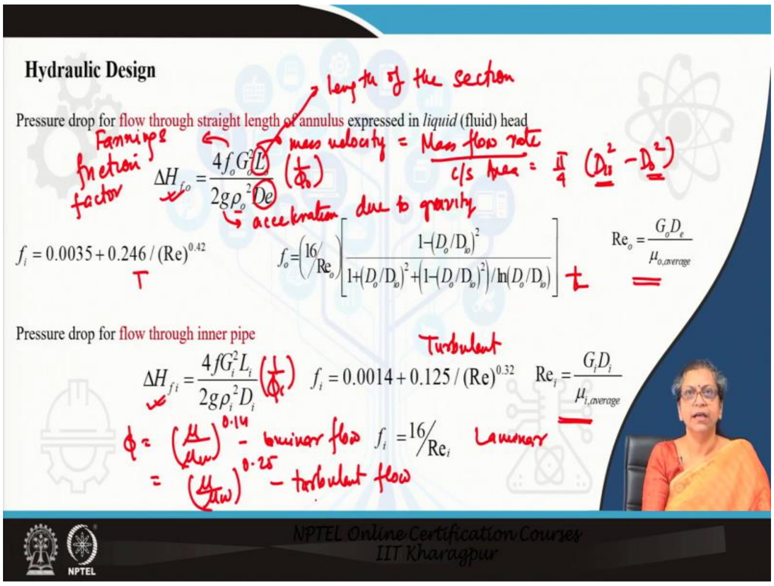

So, therefore, we often here we give some particular correction factor here, we often multiply this with some particular correction factor here where this particular phi this is equal to mu by mu w to the power 0.14 for laminar flow and this is equals to mu by mu w to the power 0.25 for turbulent flow. So, very frequently when we find that the viscosity is changing drastically under that particular condition it can happen that this gets quite influenced.

So, under that particular condition we often multiply this with 1 by phi o, 1 by phi i where these are the functions of the viscosity of the bulk fluid in this case it will be mu o, this case it is going to be mu i and the relationship for laminar and turbulent flow is given here. So, in this way you find out the pressure drop in the or rather the head loss in terms in the straight portion of the tube.

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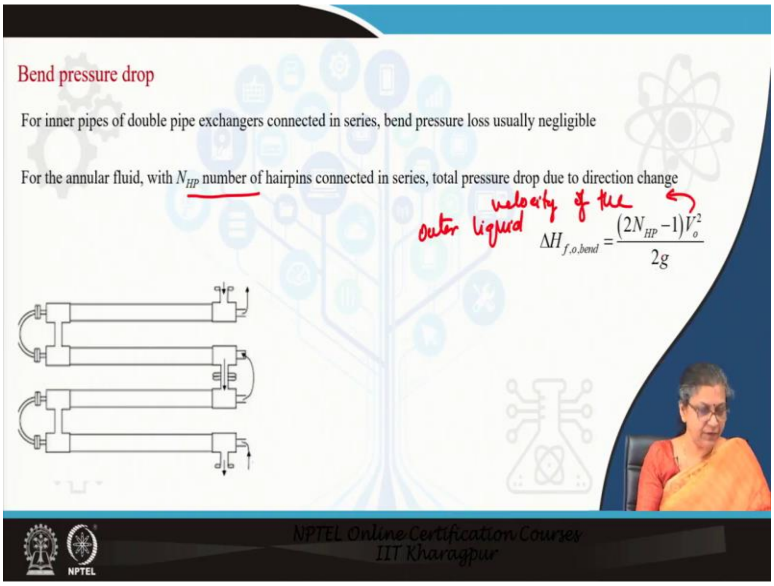

Now, for the bend portion. As I have already mentioned for the inner pipe the bend pressure loss is usually negligible and for the annular fluid suppose there are N HP number of hairpins then naturally the number of bends will be NH 2 N HP minus 1 right. So, therefore, from here we can find out the head loss at the bend where this particular V o this is nothing but the velocity of the outer fluid.

So, using this particular equation we know that for all such type of head losses across the bends, across the nozzles etcetera they are expressed in terms of the velocity head. So, therefore, the head loss is in terms of V square by 2 g if its pressure drop it will be rho V square by 2 g. So, accordingly we can do it.

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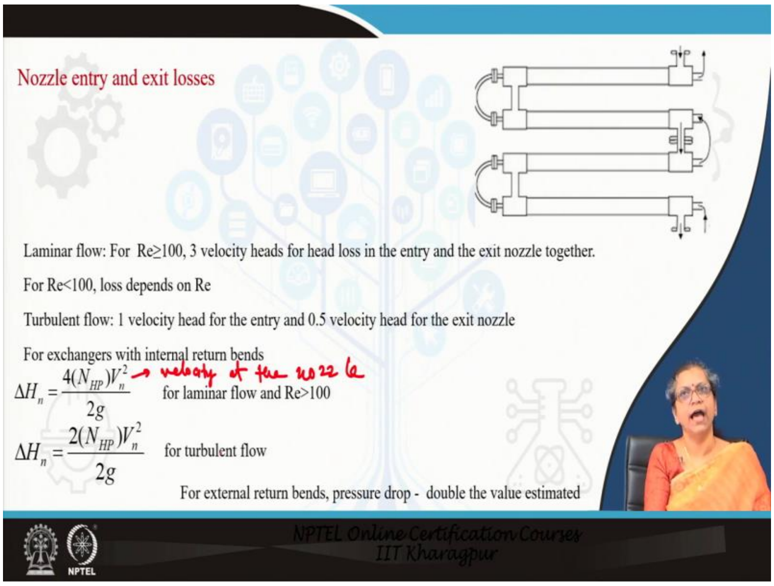

Same way the same type of expression it is applicable for the case of the head loss at the nozzles as well, in this case also it is primarily for the outer tube and for the inner tube we take it to be negligible and this gives you the velocity at the nozzle or this gives you the nozzle velocity right.

So, therefore, by using these particular equations you can very well calculate the pressure drop, you can calculate the pressure drop for the inner pipe you can calculate the pressure drop at the outer pipe, check if the pressure drop lies within the allowable pressure drop or not.

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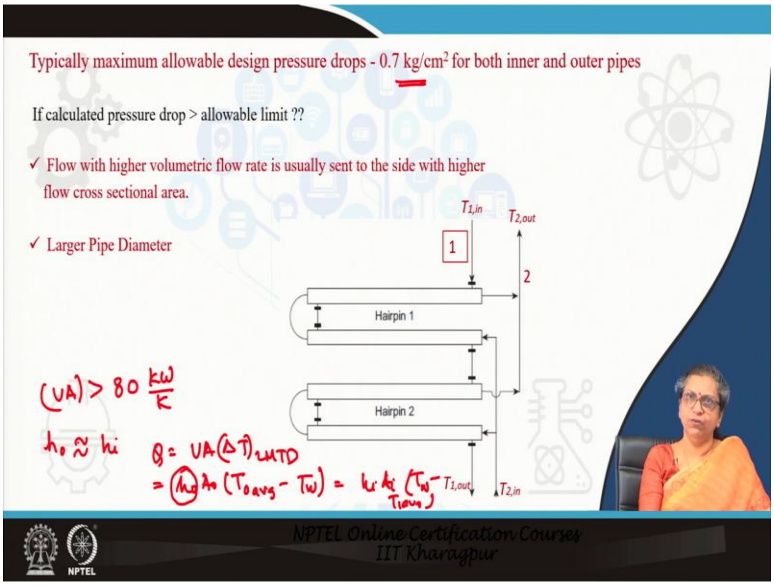

If it lies, then you are fortunate. In fact, in your particular problem you will find that it lies within the allowable pressure drop. So, therefore, you will not have to bother much about it. Typically, the maximum allowable pressure drop I have mentioned, but for your case it is slightly less than that I think 0.4, 0.5 kg per centimeter square, but anyhow it I understand that it will be respected in that particular case.

Suppose, you calculate the pressure drop and find that it is greater than the allowable limit. What are the things that you can do right? First thing is the flow which has a higher fall volumetric flow rate that can be sent through that particular area which has a higher cross sectional area right.

In fact, in your problem I have tried in that particular way. In your problem if you find out the tube has got a higher cross sectional area and time introduced cooling water through the tubes, but one thing you need to remember that anyhow also we would have introduced cooling water through the tubes right. So, therefore, if you can introduce the flow with the higher volumetric flow rate through the area or through that particular section which has a higher cross sectional area what happens? Its velocity reduces pressure drop reduces.

And you know that particularly for the outer fluid the pressure drop for the bends etcetera everywhere it is it increases in terms of V square. So, this is one thing which we can do you can simply interchange the fluids and you can try for yourself. The other thing that you can do that if this does not work also, then you can just opt for the next larger standard pipe size this also you can try and see right.

That if you go for the next higher pipe size of course, conforming to the course this can be one thing that you can do. If this also does not work, you can try out one other thing also you can simply the you can simply divide that fluid which for which the pressure drop exceeds the allowable pressure drop limit, you can simply divide that particular fluid and you can send them into consecutive hairpins while the other flow occurs in series.

For example, in this particular case if you see you will find that the fluid 1 which is flowing through the outer pipe, that fluid it flows in series and it goes out, but I assuming that the fluid 2 which flows through the inner pipe for that particular case I have done this particularly because I have introduced cooling water in the inner pipe. So, I assume that in the inner pipe the pressure drop if it exceeds the allowable pressure drop what I do? I simply divide it.

I divide it and then I allow the flow just the way I have done it in this case something not very similar, but akin to multi pass bubble cap trees in the distillation column. So, I simply divided the flow is half pressure drop naturally should be decreasing and I try it out this is also one thing that you can do. So, now, with this more or less the thermal design as well as the hydraulic design both are completed for a simple double pipe heat exchangers comprising of a number of hairpins right.

Normally, we do not opt for multi tubes inside an outer pipe, we would like we would rather prefer a shell and tube heat exchanger for that particular case. Particularly, if we find that the UA if we calculate and that is greater than 80 kW per Kelvin, then definitely this is not an economic option. So, we are not discussing much about that multi tube double pipe heat exchangers because the design is also almost similar to shell and tube heat exchangers which will be doing just after this particular after we compute the double pipe exchanger.

There is one thing which I would like to tell you, see the problem which has been given the discussions which have been done till now all of these they are primarily referring to two liquids. When they are referring to two liquids it is more or less implied that the overall heat transfer coefficient for one liquid it is even if it is not similar more or less the overall heat transfer coefficients they are close to one another.

Now, suppose it happens that for one particular fluid say it is air or any particular gas, it can also be a liquid with very high viscosity, the overall heat transfer coefficient is very less compared to the heat transfer coefficient for the other fluid. It is not the overall it is the heat transfer coefficient for one fluid it is much less compared to the heat transfer coefficient of the other fluid then in that case what do we do?

To improve the heat transfer or just to augment the heat transfer rate, what is heat transfer? This equals to UA delta T LMTD you can also write it down for the all the individual fluids, you can write it down this will be the T o, say average minus T wall h i A i T wall minus T i average.

Whether it is going to minus or plus it just depends upon which fluid is the hotter fluid in this case I have assumed that the outer fluid is the hotter fluid ok. So, therefore, this is there. Now suppose, I see that h o it is very less, then in that case what to do? How can I augment h o? If h o is much less compared to h i one thing I can do, I can increase the area for heat transfer right.

This is something which is commonly done when we have air as the cooling medium or we have a heat transfer between air or any other gases and say a liquid whose heat transfer coefficient is much higher or maybe a liquid as I have already mentioned which has a very high viscosity. So, very low Reynolds number. So, very low Nusselt number and very low heat transfer coefficient.

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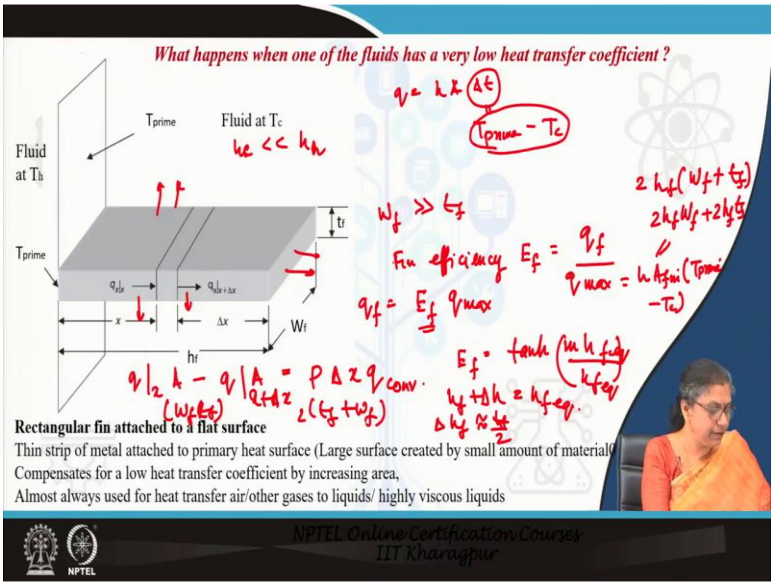

How do we increase the area just as I have shown you that in that case one thing we can do, we can increase the heat transfer area. Now, a very simple way of increasing the heat transfer area if you see in this particular case, say this is the separating wall we have a fluid here I assume that the fluid which I have here that is the that fluid is at a higher temperature, say as you and this fluid is at a lower temperature and this is the heat transfer area.

Now, what can I do? I can just take up some particular protrusions from the heat transfer area such that the effective area of heat transfer on the fluid side which has the lower heat transfer coefficient; that means, in this case h i or even if I make it h c this is much much less than h o or h h in whatever way right. So, therefore, the effective heat transfer area on the fluid side where the heat transfer coefficient is very low that gets enhanced.

This is definitely I can do what we can do. We can simply attach in this particular case I have shown a rectangular fin, these protrusions they are known as fins. So, they can be attached to the heat transfer surface. In this case just for simplicity there is I have taken a flat surface and a rectangular fin for your case it is the outer wall of the inner pipe over, which you are going to fit this type of thin strips of metal which are attached to the main outer surface of the inner wall which we call as the primary heat surface and the temperature there.

In this particular case I have defined it as D T prime or T primary. Now in the since these particular protrusions they are made of very thin metals of very high conductivity say copper or aluminum we take. So, we can create a large surface area by a very using a very small amount of material, this is done to compensate the low heat transfer coefficient by the by increasing the area right, but when we do this there is something that you need to remember here.

Definitely by these protrusions we have increased the cross sectional area. Have we increased the heat transfer rate in a proportional amount? That means, has the heat transfer rate increased by the same proportion by which the cross sectional area has increased let us see what happens?

You know in a heat transfer equipment what is there? There is a fluid here through the from the fluid here to the fluid here the heat is conducted through the walls right and from the wall to the fluid, the heat is conducted sorry it is transferred by convection fine. So, therefore, when the heat is it is convected away the expression is h A delta t, what is this delta t?

This delta t is the temperature difference between the surface and the fluid with which heat transfer or heat interactions are taking place. So, therefore, on the primary surface what do we have? We find this delta t this is equal to T prime minus T c. For the fin what happens you tell me? When the fin is there naturally what will happen? The heat from the primary surface will be conducted through the fin and whatever is being conducted that will be convected away from the fin to the fluid outside in these directions.

There will be less in this direction definitely mainly the convection will happen on the top and the bottom surfaces assuming in this particular case W if or rather the width of the fin is much much greater as compared to the thickness of the fin right. Now, how much heat will be convected away from this particular fin?

It will be the amount of heat that the fin receives from the primary surface is not it? Primary surface definitely is a T prime. From the primary surface the heat which is convected away this this will depend upon the temperature difference here. Now, in the fin if we consider we will find that the portion where the fin is connected with the primary surface or in other words the base of the fin, there the temperature is T prime then gradually the heat is conducted.

Definitely the fin is made of a high thermal conductivity. So, therefore, heat gets conducted and as heat gets conducted and accordingly heat is lost to the surroundings. We find further we go from the primary surface the lower is the temperature difference between the ambient and the fin surface.

And if we go far enough we will find that the temperature at the fin surface and the surrounding fluid they can be the same and there is no particular heat convection between the film sorry between the fin and the heat surface. So, what I mean to say that the rate of heat transfer which happens by convection from the fin that depends upon the temperature difference and so, therefore, we cannot assume that whatever heat by convection was being removed from the primary surface, the same amount of heat will be removed from the fin.

So, therefore, we do not have a proportional increase of the rate of heat transfer by convection by the attachment of fin and in order to quantify this, we define an fin efficiency factor or we define a fin efficiency which is defined as E f. Different people have got different notations they take eta f etcetera we have defined it in terms of E f what is E f? It is the actual amount of heat transfer from the fin surface divided by the maximum amount of heat that could have been transferred from the fin surface.

What is the maximum amount of heat that could have been transferred from the fin surface? If the entire fin would have been at the T prime temperature. So, therefore, this q max this is equal to h A fin into T prime minus T c which is the temperature of the fluid with which the fin is in contact. What is this A fin if you can tell me? A fin if you find this is going to be 2 h f W f note h f is the if you call it the length or whatever this particular dimension, W f is the width of the fin this is going to be 2 h f W f plus 2 h f t f.

We neglect more or less the heat transfer through this particular surface right or in other words this can be written down as 2 h f W f plus t f. So, therefore, you know what will be the maximum amount of heat that can be transferred from the fin which is never transferred quite naturally because there will be some amount of protrusion and whatever be the protrusion naturally you know that since this temperature and this temperature are not the same.

So, therefore, the heat transferred will be less as compared to the heat transfer that you would have assumed had you had the entire fin been at this particular temperature. So, therefore, we define a fin efficiency and then what we do? We multiply the q max with the efficiency to find out what is the actual amount of heat that is being transferred from the fin. Now in order to find out this e efficiency normally what we do? We strike a heat balance equation where we assume that we take this simple heat balance equation we take a differential strip here.

And then we say that assuming that whatever heat has come by conduction to this point gets convected away we can say q at x minus q at x plus delta x at A, this will be equal to P delta x q which is lost by convection right. So, what is this P? This P is going to be 2 into t f plus W f the area from which it is going to be convected, this A is the cross sectional area.

So, naturally this is going to be W f t f. So, if you solve this equation assuming that at the base it is the temperature is T prime from this particular equation we get an expression of E f as tan h m h f by h f right. Now, one thing you have to remember that when we have assumed when you have made this balance, we had assumed the one dimensional heat transfer we assume that there is no heat transfer along the sides.

But in reality there is some amount of heat transfer from the sides. So, just to account for that what we do? To account for this extra heat transfer we simply increase this h f by an amount say h f plus delta h which gives us h f equivalent and we express this equation in terms of h f equivalent.

Now, from geometry you can find out that this delta h f that is close to equal to t f by 2. So, therefore, we find that the fin efficiency it can be expressed in terms of the equation the expression that I have given you where this particular m square I have already written down.

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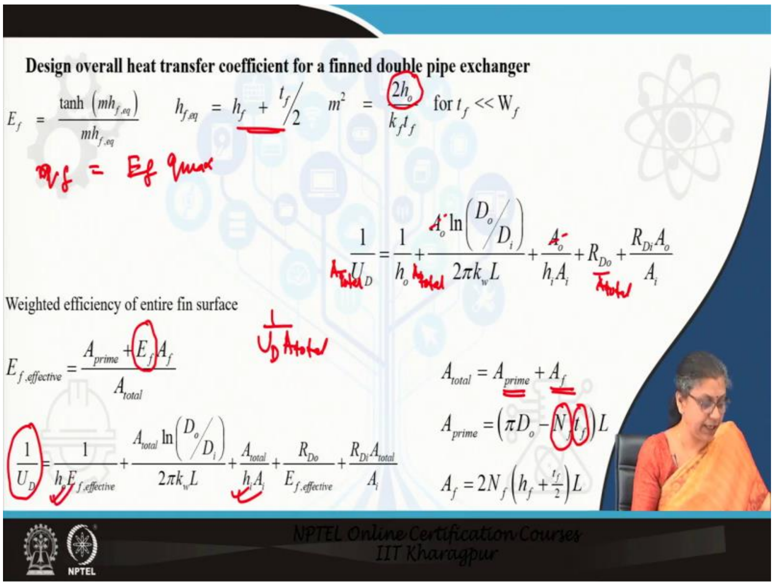

This can be this is a function of the heat transfer coefficient of the outside fluid with which it is in contact, the thermal conductivity of the fin the thickness of the fin. So, therefore, once you know m square which you can find out you know h f equivalent which I have already defined you can find out E f. Once you can find out E f you can find out q f as E f into q max right.

So, therefore, this is what has been done. Now, once we have an additional heat transfer from the fin surface, next there are certain things that we have to some changes that we have to make in the heat transfer equations. First is, what is the change that we need to make in the overall heat transfer equation? See the equation that we had derived.

Well this equation was in terms of A o. So, therefore, there was a A o here, there was a A o here, this A o then would not be there, this would not be there. So, in this there was an A o here right. Now what we have? Now what we will be having instead of A o, we will be having the total A here also there will be a total A right. So, therefore, everywhere we are supposed to define the design overall heat transfer coefficient in terms of the total area what is the total area? Area of the prime surface plus the area of the fin surface.

We assume that the number of tubes inside the double pipe exchanger is 1, for a single tube then in that case it is very easy if the number of fins is N f and its the thickness is t f then you can very well find out the what is A prime and you can also find out what is the A fin you can find out A total, then in that case this U D it has to be defined not in terms of just the outer surface of the tube, but in terms of the total area. So, in that way if you define then in that case you get an expression of this form.

Now, in this expression if you find. In fact, we had multi we have the total heat transfer the resistance to heat transfer was in this particular case 1 by U D A total in that particular way we had written down and one thing you need to note here that instead of taking up just the fin efficiency, we had taken the weighted efficiency of the entire fin surface for greater accuracy and accordingly the overall heat transfer coefficient has been written down in this particular expression.

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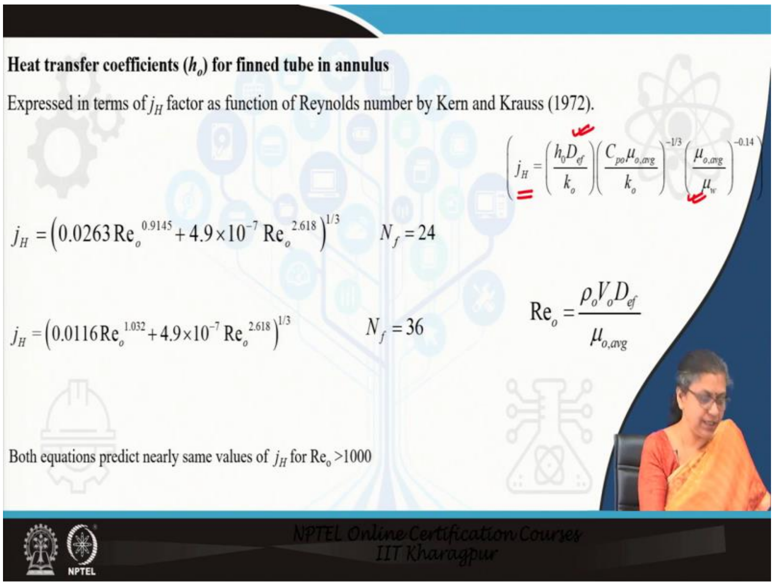

Now, in order to find out this heat transfer coefficient we need to find out h i, we need to find out h o. Now you would you must be remembering that when we had discussed the an unfinned surface, we had expressed the heat transfer coefficient in the form of Nusselt number in terms of Reynolds number and Prandtl number. In this particular case also usually the heat transfer coefficient is expressed in terms of j H where j H is expressed in terms of Reynolds number for different fin numbers.

In this j H you will find that what are the things that you need to define, every other thing its known to you. Only thing is the effective diameter of the outer surface that changes because the surface has fins now and the mu w that is also going to change because remember one thing mu w was defined in terms with respect to t w, now the t w is going to change because the it has fins on the top.

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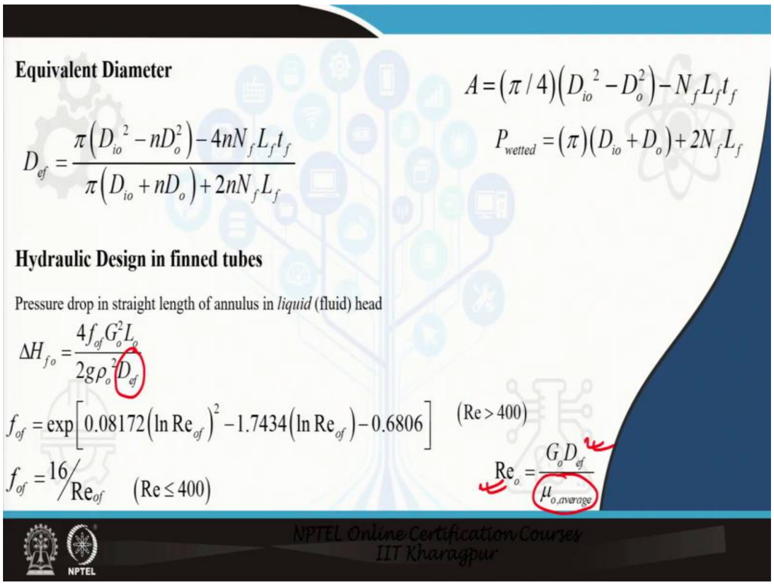

So, for the finding of the equivalent diameter it is very easy you can find out the actual area activated perimeters they are just from geometry you can find out the equivalent diameter. Remember one thing in the hydraulic design also nothing is going to change just the pressure drop across the straight length for the outer fluid is going to change everything else is going to remain the same.

So, therefore, naturally this is also going to change because this D effective has changed. So, we need to substitute this and definitely for that particular case since D effective has changed. So, R e o and mu o average will also change remember. So, therefore, R e o is also going to change. So, there are two expressions of friction factors which you can substitute and you can find out the hydraulic pressure gradient.

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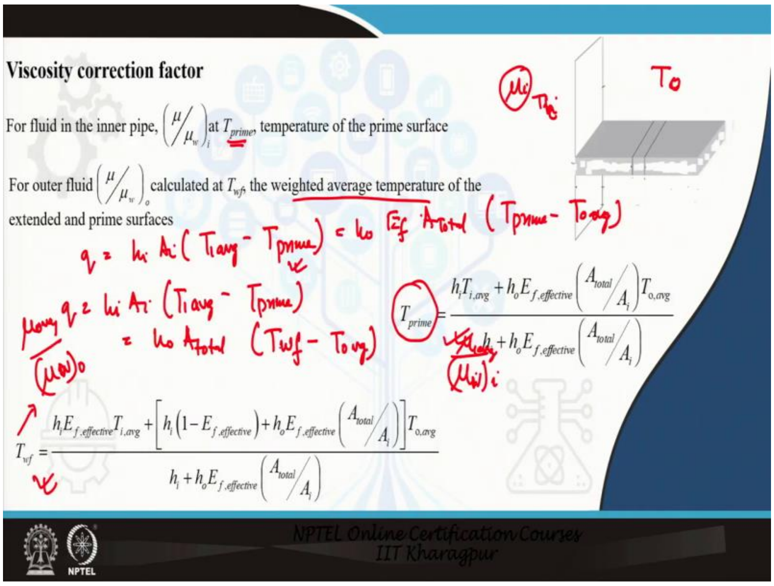

Now, for the viscosity correction factor as I have already told you that this particular viscosity correction factor it has to be defined with respect to the wall temperature. What is the wall temperature if you see? For the inner fluid say if it was at T h, the wall temperature is the temperature at T prime what is the temperature the wall temperature for the outer fluid? This has to be some sort of a weighted average temperature of the extended surface and the prime surface right.

So, therefore, again for this case also just the way we had done assuming that the entire heat which is being transferred from one fluid to the other fluid through the wall we can very well write down what is q equals to. It is h i A i T i average in this case it should be t h average anyhow let me put it T i T o just for the convenience, T i average minus T prime will be equal to h o E f A total T prime minus T o average is not it? This should be the thing from here you can find out T prime you will find that this is the expression.

With respect to T prime we are going to define the mu i for the inner fluid. What about the outer fluid? For that particular case the heat transfer this h a A i T i average minus T prime this we should be accounting for the h o A total the weighted average the temperature minus T o average. From this particular equation if you substitute T prime from here, we are going to get the temperature of the weighted average for the extended surface.

So, from here you can find out T prime according to T prime you can find out mu i. Find out T wf according to T wf you can find out mu o. Once these are done you can calculate the sorry this is mu w for the inner fluid I am very sorry this is mu w for the outer fluid.

Once these are done then you can find out the Sieder Tate correction this is simply mu i average and this is simply mu o average and then you can find out the Sieded Tate correction. Once you have found out the Sieder Tate correction then you can find out j H in terms of R e o from there you can find out h o and you can proceed for this for the inner pipe you can just use the previous expression and in this particular way.

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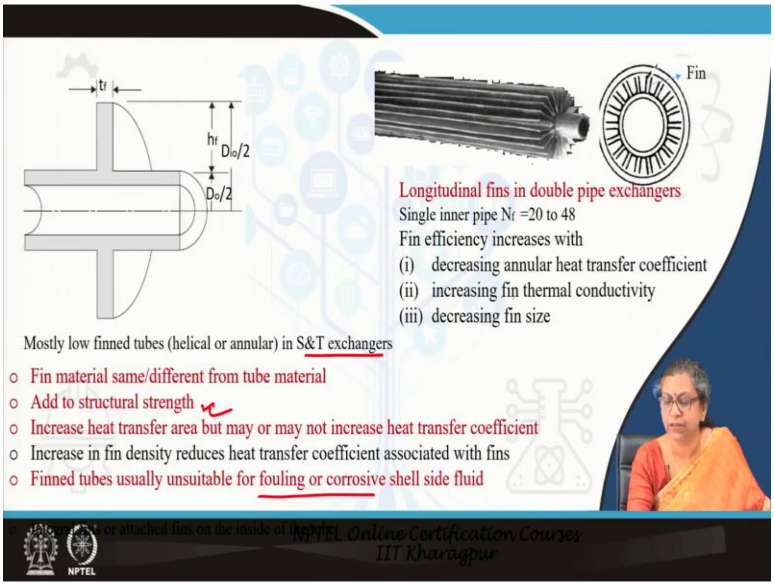

Well. So, therefore, now you have understood that for these particular cases where we have one particular fluid which is at a much lower much has a much lower heat transfer coefficient what we do? We try to increase the surface by means of fins, but remember one thing fins they increase the area, but they may or may not increase the heat transfer coefficient and the increase in heat transfer rate that will depend upon the fin effectiveness.

The fin effectiveness is a function of the fin dimensions the thermal conductivity of the fin and also the overall heat transfer coefficient of the outside fin. Now, there is something and also one more thing fin also adds to the structural strength and you are that is not important there is something which I would like to mention. It may happen that the fin material and the tube material are the same, it may happen that they are not the same.

For example, suppose inside the tube there is a very corrosive liquid flowing. So, therefore, we would like to adopt stainless steel as the tube material, but the outside fluid is not so, corrosive. So, we can take up carbon steel as the fin material, fin material fins are usually either soldered or welded to the outer surface.

Quite naturally, they are not suitable for fouling or corrosive liquid, it is quite natural and usually we find that for shell and tube heat exchangers we use either helical or annular fins for double pipe exchangers we usually use longitudinal fins. And if you look at the expression of the fin efficiency, it is very evident to you, efficiency increases with decreasing annular heat transfer coefficient, increasing fin thermal conductivity decreasing the fin size these things are very well known to you well.

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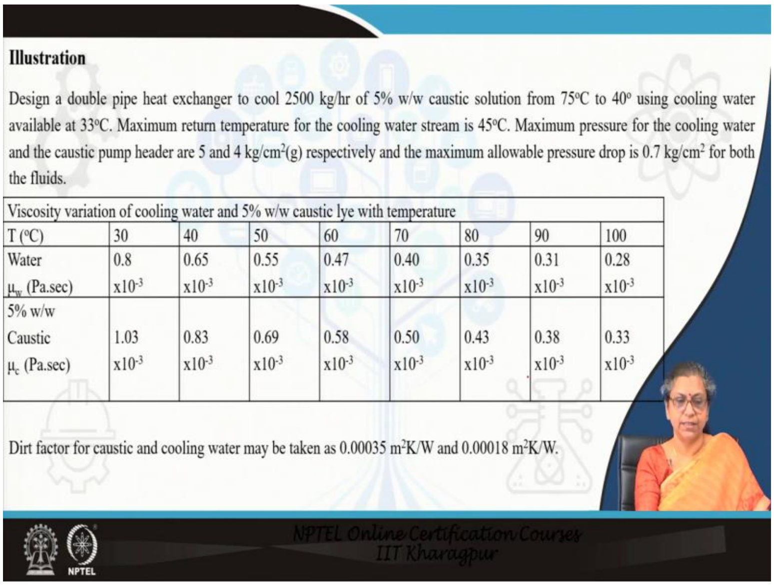

So, once all these things have been done more or less we have completed the design both the thermal design and the hydraulic design, the process design for a double pipe heat exchanger, we have discussed the how to find out the heat transfer area, how to proceed we have discussed, how to check the pressure drop, etc. So, based on that you can go ahead. For this problem you are not going to face much problems because it is between two liquids that you do not need fins and expectedly the pressure drop limitations will also be respected.

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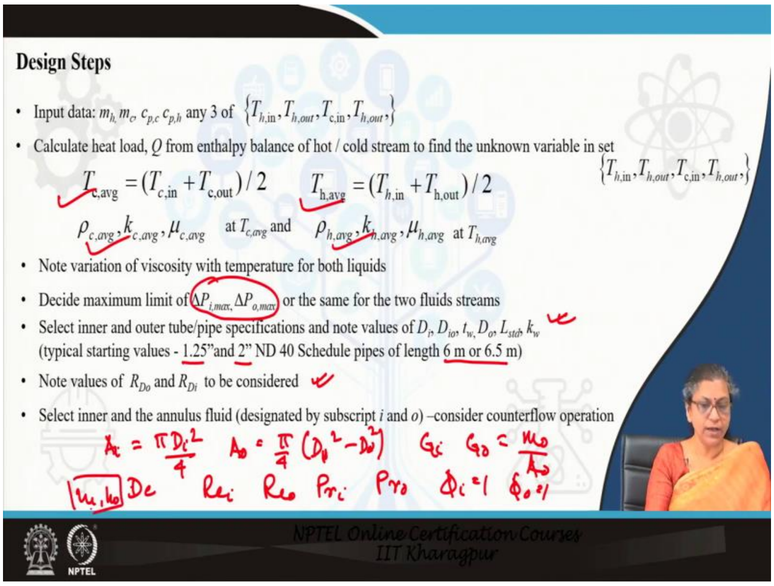

Here in this case I will not be going into the details, I have just mentioned the different design steps which you should be following a general design steps which you should be following when you are solving a double pipe heat exchanger it is very evident all the input data are given.

So, that you calculate heat enthalpy and find out anything unknown. In this particular case the unknown is the flow rate of the cooling water that you need to find out, then definitely average properties of everything note the variation, the maximum limit these are already specified for you.

And after that generally what we do? We generally we select the inner and outer pipe and these are the dimensions that we generally take. Usually, the length of the pipes are taken accordingly all these values can be found out this also can be found out and then we decide on the inner and the outer fluid.

Once we decide on the inner and the outer fluid we can find out the inner cross sectional area, we can find out the outer cross sectional area and we can also find then we can find out the G i, we can find out the G o m o by A o. G o is also m i by A i, you can find out D e and then you can find out R e i, you can find out R e o, you can find out Prandtl number you can find out this. To start with I have told you just assume the viscosity correction factors to be 1 and then you compute h i and h o right.

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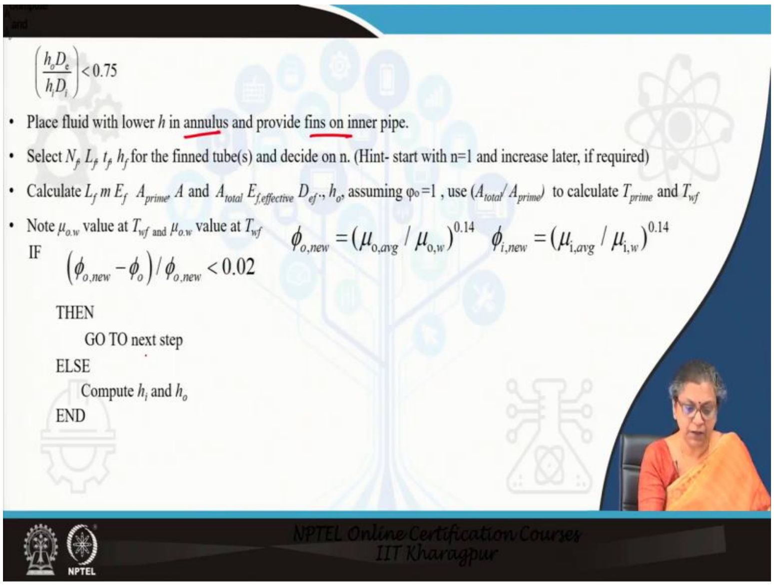

Once h i and h o are computed just check up for this. If this is fine then in if this is less than 0.75, then fluid with the lower h is placed in the annulus and fins have to be provided. Remember one thing usually fins are provided on the outer surface it is very rare to have fins on the inner surface.

So, therefore, the fluid where the lower heat transfer coefficient has to be placed in the annulus. Once these are done then suppose you have to provide fins then you have you can calculate all the different areas and how you will be starting etcetera is given and then you have to find out the viscosity correction factor, check up if the viscosity correction factor more or less its fine, then you can proceed and you can find out h i by h o in this particular case.

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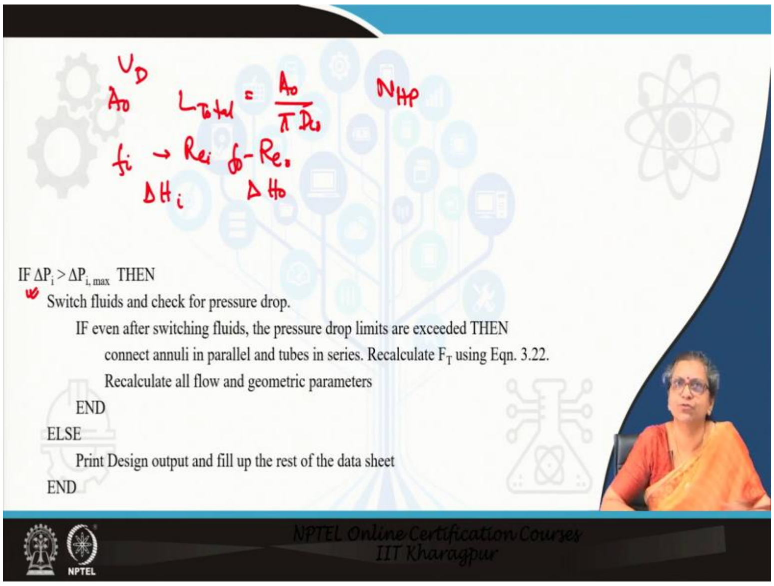

Once h i h o has been found out, then you need to find out that the design coefficient then once U D is find out found out you have already decided on the tubes that you are going to take you can find out, A o you can find out the L total by A o by pi D i o, then you can find out the number of hairpins that are there, one thing is for sure you just try to see that more or less L total it is rounded off to the next value then you are supposed to calculate f i corresponding to R e i calculated R e o.

And then for this you need f o calculate R e o, then calculate delta H for the inner fluid calculate delta H for the outer fluid. And just check up if that for each fluid this particular it is the pressure drop is less than the allowable or not. In case it is not we have already discussed what you can do and you can try it out.

Once the whole design is completed then you need to fill up the data sheet which I had shown you earlier and that brings you to the end of the double pipe heat exchanger. We have discussed the design of double pipe heat exchangers for two liquids transferring heat from for a gas and liquid transferring heat with fins without fins when and with the number of hairpins connected, the connections as I have said they can be they are usually in series they can be in parallel.

A combination of series parallel connection can be done in order to achieve the heat transfer that we want and this modular arrangement gives additional flexibility to the double pipe heat exchanger. So, with this we come to the end of this particular lecture and in the next class we are going to start the shell and tube heat exchanger.

Thank you so much.