Process Equipment Design
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Lecture - 06
Double Pipe Heat Exchanger-1

Hello everyone. Welcome to the second week of this course, that is Process Equipment Design. So here we are having first lecture of this week and this is basically sixth lecture of this course. And this lecture covers the design of double pipe heat exchanger, okay. So here first of all we will discuss double pipe heat exchanger and then we will proceed to the design of this exchanger, okay.

So double pipe heat exchanger as I have also discussed previously that it is the simplest type of heat exchanger

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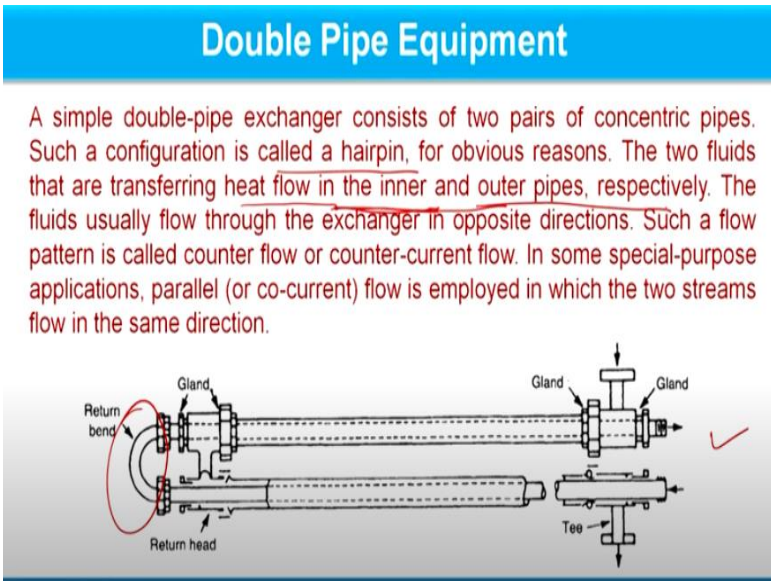

where two pipes are placed concentrically where lesser diameter pipe is inside the larger diameter pipe, okay. So this is basically a simplest heat exchanger okay and such a configuration is called as the hairpin okay and because of this return band it is called as hairpin and the reason is very simple because it is completely similar to the hairpin we usually use okay.

So the two fluids are transferring heat and one is flowing inner side and one is flowing inner and one is flowing at inner pipe and another is flowing at annular side okay as we also have discussed previously. So here usually, so in this double pipe equipment, double pipe exchanger usually we have counter current flow. However in some cases we also consider co-current flow okay.

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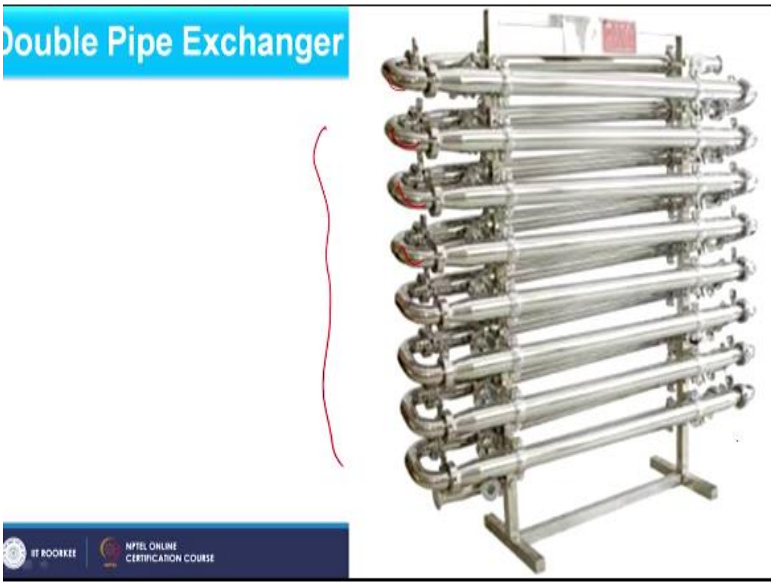

So this is basically the so this is basically the double pipe heat exchanger we consider in industry where these are basically return bends and we call that as hairpins, okay. So this image shows 16 hairpins double pipe heat exchanger, as you can count the hairpins over here, okay.

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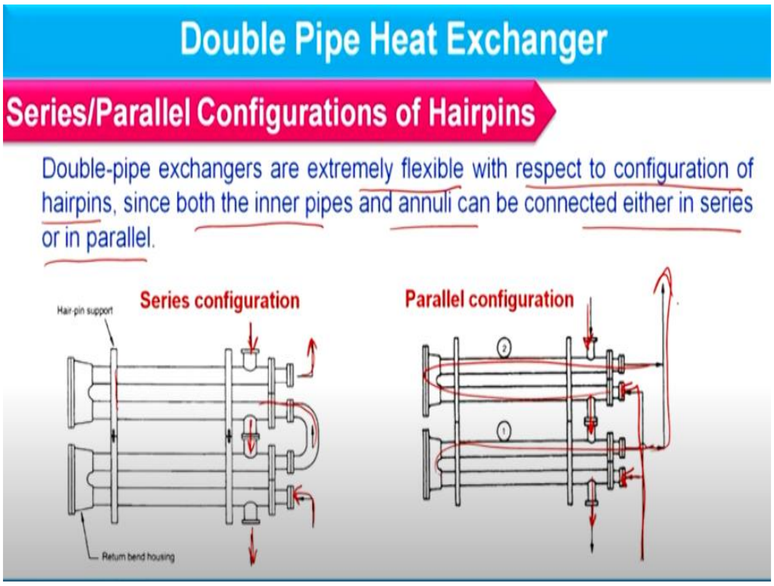

And now we will discuss the configurations of hairpins and these configurations are basically series configuration and parallel configuration. So double pipe exchangers are extremely flexible with respect to configuration of hairpins, okay. And since both inner pipes and annuli can be connected either in series or in parallel, okay. So how we can connect that?

First of all we will see for series and then we will go for parallel design or parallel configuration. So this is basically the series configuration, which we also have discussed in previous lectures of last week. And here we have the fluid which is moving in annular side from this and then from this and then it exits from here. Similarly, in tube side fluid will enter from here and pass through this return bend, and again pass through this and then it exits from here.

It means fluid exits from one bend and then enters to another bend, okay. In that way it moves in a series. You can understand the series configuration. And similarly if I am speaking about parallel configuration, fluid is entering in a different hair band or different hairpin differently, okay. And it exits differently in parallel configuration. What is the difference? Let us see with this schematic.

So here if you see in annular side, fluid enters from here, then pass through from this and then it exits from here, okay. And when I am considering the inner pipe, and when I am considering inner pipe configuration, it will be divided in two sections and then half will travel here and half will travel here and then combinely it will exit. So that is basically the parallel configuration.

So here we consider both configuration and we can design the double pipe heat exchanger accordingly, okay. So when I am considering series or parallel configuration, how I should consider log mean temperature difference or the mean temperature difference. So let us discuss that.

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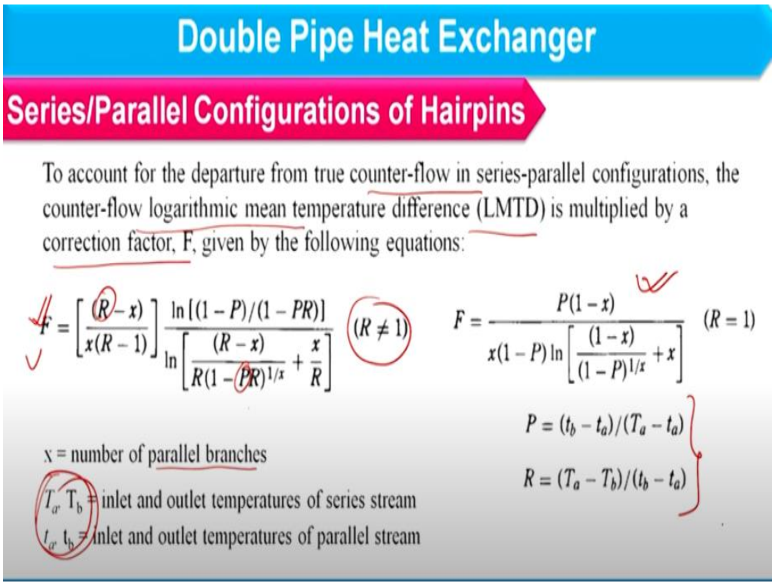

So to account from the departure from counter current flow in series parallel configuration, the counter flow logarithmic mean temperature difference that is LMTD is multiplied by a correction factor, okay. So when I am having series configuration and parallel configuration, we have some time co-current flow, we have some time counter current flow. So obviously LMTD which we have defined it is only for a specified flow, either counter or current, okay.

But here we have different approach and therefore, we have to consider FT correction factor and that FT correction factor we can consider through the following equations and these equations are shown over here. We have this capital F which is nothing but the FT factor R and this P this we have already discussed okay. And here we have x, x is basically number of parallel branches, okay.

So whatever would be the branches like in the previous diagram we have like in the previous diagram we have seen two parallel branches. So x will be two in that case. So we can simply count the parallel branches that is the x value and then we can calculate F value okay. So here we have terminal, so here we have terminal temperatures of both fluids which is moving in series or in parallel, okay.

When I am saying the parallel configuration what is the meaning of that? Parallel configuration means parallel in terms of whatever is flowing in tubes or whatever is flowing in inside the tube. In annular side flow will remain in series, okay. So parallel or series will depend on how the fluid is moving in inner side of the exchanger or inner pipe of the exchanger. So if R is not equal to zero we can use this expression.

Otherwise we can use this expression. And here P and R which we have already discussed that we can calculate here as well in the similar line okay. So here you can consider FT correction factor along with LMTD.

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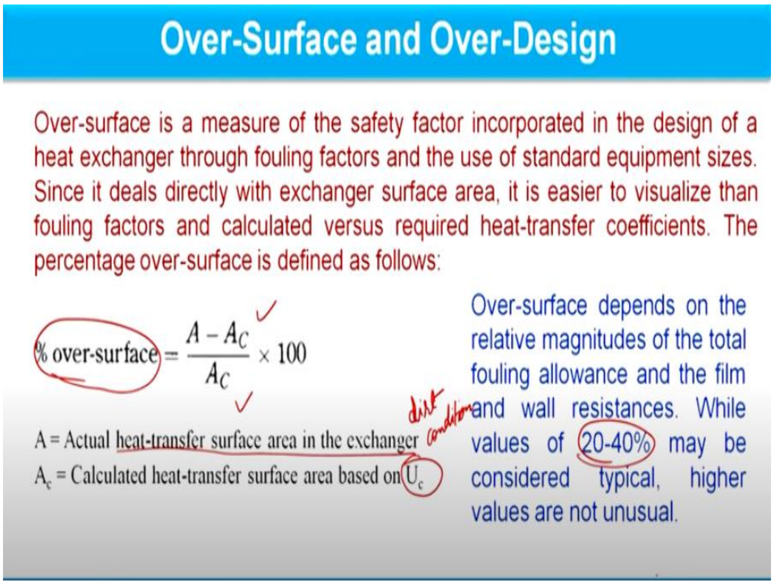

And further as far as design of double pipe heat exchanger is concerned we should consider over-surface and over-design, okay. Now what is this over-surface and over-design? So what is this over-surface and over-design to which I am calling as over-design to which I am calling as over-design. I am calling over-design as the extra area, okay. And why I am providing extra area because I am considering dirt factor okay?

So we will find out overall heat transfer coefficient for clean condition and for dirt factor condition. So if I am considering clean overall heat transfer coefficient it means in the overall heat transfer coefficient expression dirt factors are not considered, right. And if I am considering overall heat transfer coefficient with dirt factor, its value will different than the clean overall heat transfer coefficient and so the area will differ.

So you can understand over here if I am comparing U at clean condition and U at dirt condition, obviously U at dirt condition will be smaller in comparison to U at clean condition and so the increment in area can be observed, okay. So over-surface percentage how I can calculate that we can consider this expression A – A C divided by A C into 100, okay. What is A? That is the actual heat transfer surface area in the exchanger.

Actual means at dirt condition. So A C means calculated heat transfer surface area based on U c. That is the clean overall heat transfer coefficient. So when you consider this over-surface percentage it is up to 20 to 40% okay, it is up to 20 to 40% and sometimes even higher than this and then we consider that the design is not feasible or that is unusual condition okay.

So when we design any equipment, we definitely consider some over designing considering dirt factor in overall heat transfer coefficient and that we consider as the actual condition also. Because in real situation dirt will definitely be formed whatever would be the fluid is okay. So accordingly we can consider over design and over surface in double pipe heat exchanger also, okay.

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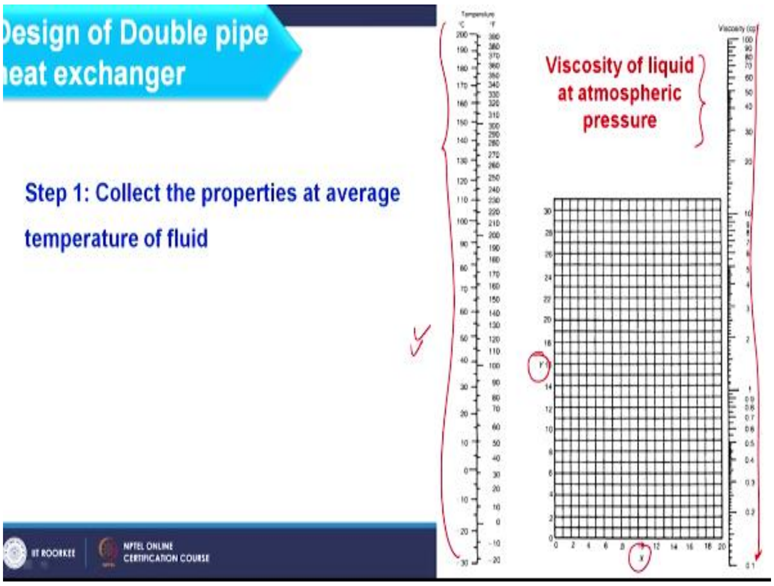

Now let us start the design of double pipe heat exchanger. Here we are going to discuss different steps which are involved in designing. So let us start with step 1. And the step 1 is we have to collect the properties at average temperature of the fluid, okay. That is very important parameter that we have to collect the property of the fluid, okay. But that property should be at average temperature not the inlet and outlet temperature but the average of that too, okay.

And in different equipment we have different condition to average the temperature. That we will discuss as we will discuss the equipment, but here you can consider average temperature as simply the arithmetic mean of inlet and outlet temperature of a fluid okay. So if you know the average temperature you can collect the physical properties, okay. Now how you will collect the physical property?

First of all let us discuss the viscosity of liquid at atmospheric pressure, okay. Now as far as the properties are concerned what property you have to collect? When you have to make the energy balance between two fluids that is m C p dT you have to collect the specific heat of the fluid okay. And when you are calculating heat transfer coefficient of the fluid you have to consider you have to consider density, viscosity etc., to find out Reynolds number and Prandtl number okay.

So all these properties you have to collect at average temperature. So here we should first focus on viscosity of the fluid okay. So this is the graph from which you can calculate the, you can collect the physical property or you can collect the viscosity specifically of a fluid. And if you see here we have y as well as x and this block okay. On this side we have a temperature and these temperatures are and this temperature is the average temperature okay.

And here we have the viscosity values. Now how you will obtain that y and x value, okay.

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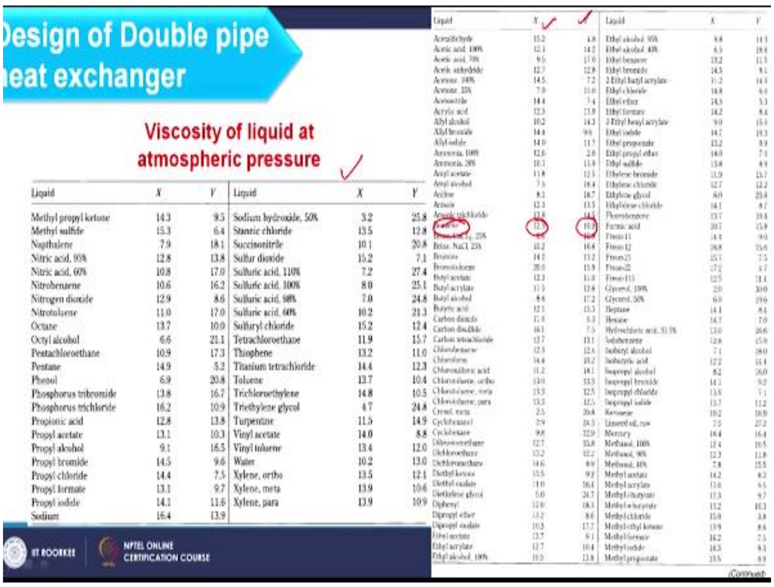

It will depend on different fluids like here we have X and Y value depending upon the fluid okay. And this table continues here as well okay. So you can consider any fluid and accordingly you can consider Y and X value, okay? So for example, if I am considering let us say benzene okay, if I am considering benzene then X value is 12.5 and Y value is 10.9 right. So let us move towards the previous graph.

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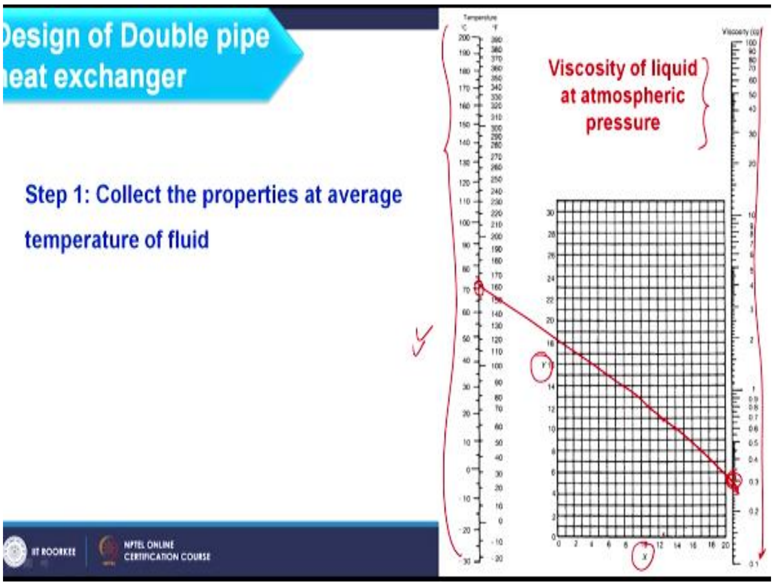

So here we have 12.5 and 10.9. So 12.5 will be somewhere here, okay, and Y is basically 10.9. So 10.9 will be around here, will be here. So this is 12.5 and 10.9 will lie here. So okay so here we can put a point fine. So here we can put the point fine? Now on this side, on this temperature side, we already know the average temperature, okay. So let us say my average temperature is 70 okay?

So what I have to do? I have to draw a line joining this point and wherever it will cut on Y and wherever it will cut on this axis, this value we can consider as the viscosity value of the fluid okay? Here this is not a perfect straight line, but you can draw that through scale and then you can read the value of viscosity. And similarly you can read the viscosity value for other fluids okay, but that should be at average temperature.

And you can see the value of Y and X from the table which we have already discussed, okay. So this is for the viscosity of the liquid. In the similar line we can calculate or we can see the viscosity of the gases, okay.

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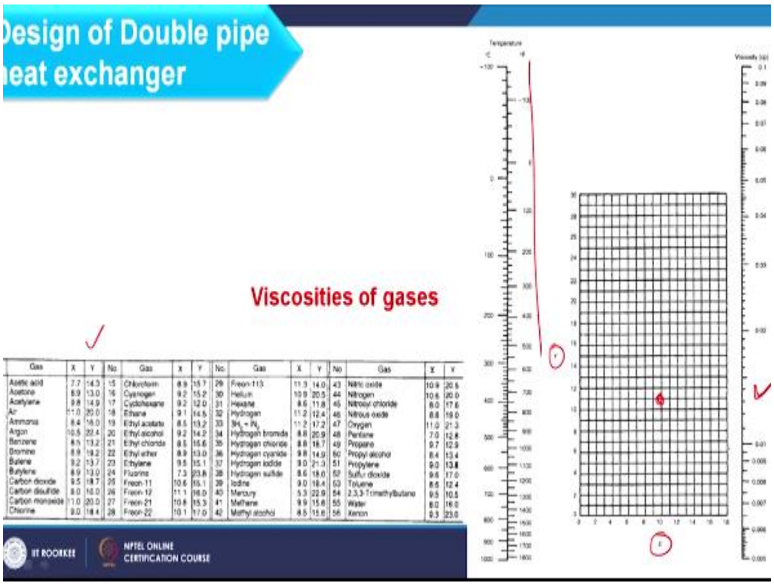

If you see here we have the X Y table for different gases. And here we have this graph where X and Y values are shown. So depending upon the average temperature and the respective point at and the respective point on this graph you can read the value of viscosity from this side right. So in this way I can consider viscosities. So in this way I can consider viscosity of different gases okay.

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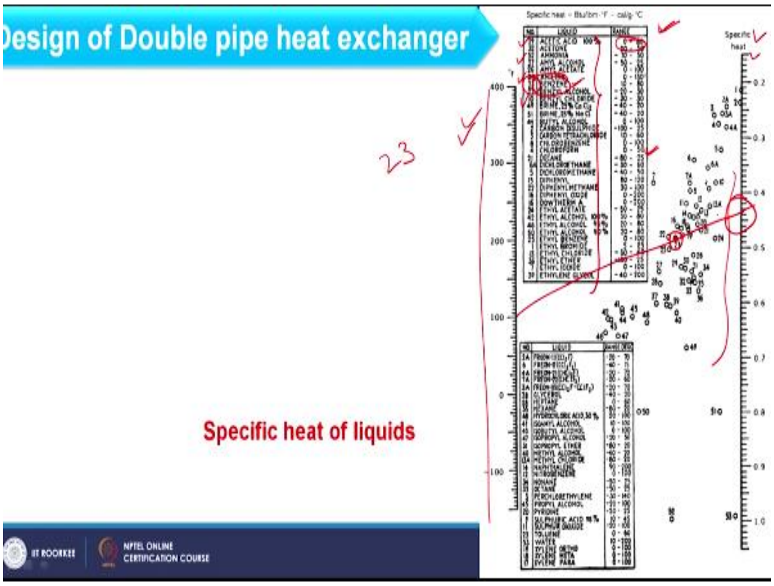

And once I am having the viscosity we have to collect the specific heat of the liquid okay. And for specific heat of the liquid, we can consider this graph okay. And these are basically standard graphs, you cannot change these graphs okay. And these graphs I have taken from R.W. Serth book okay. So in the appendix these graphs are given and you can read the value from these graphs okay.

So what will happen? Here we have the specific heat value fine? On this side left side we have temperature and this is again the average temperature. And on right side we have a specific heat values right. Now here we have different fluids. Here we have different liquids and corresponding to each liquid we have different number okay? And here we have the range.

So this is the specific range where these values are correct okay. And the feasibility of this value will lie in this range right. So let us say again I am considering the example of benzene fine? I have taken the benzene and number corresponding to benzene is 23 if you can see over here fine? So that 23 you have to locate from this bunch okay? So if you see where is 23? Here I am having 23.

So this is the circle of benzene okay. And from left sides and from left side, you can consider the average temperature and let us say my temperature is 100 Fahrenheit that should be the average temperature. I will draw a line through this circle and wherever it will cut this right axis that value I can note as the specific heat of the material.

So in this way, you can consider specific heat of the liquid, viscosity we have already discussed right? And now we will focus on the thermal conductivity of the fluids okay?

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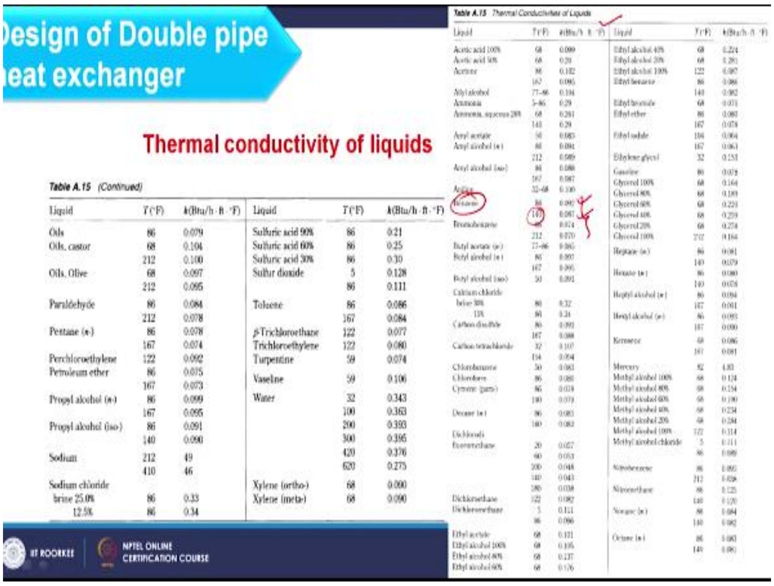

Liquid	T(°F)	k(Btu/h · ft · °F)	Liquid	T(°F)	k(Btu/h · ft · °F)
Oils	86	0.079	Sulfuric acid 90%	86	0.21
Oils, castor	68	0.104	Sulfuric acid 60%	86	0.25
	212	0.100	Sulfuric acid 30%	86	0.30
Oils, Olive	68	0.097	Sulfur dioxide	5	0.128
	212	0.095		86	0.111
Paraldehyde	86	0.084	Toluene	86	0.086
	212	0.078		167	0.084
Pentane (n-)	86	0.078	β-Trichloroethane	122	0.077
	167	0.074	Trichloroethylene	122	0.080
Perchloroethylene	122	0.092	Turpentine	59	0.074
Petroleum ether	86	0.075	Vaseline	59	0.106
	167	0.073			
Propyl alcohol (n-)	86	0.099	Water	32	0.343
	167	0.095		100	0.363
Propyl alcohol (iso-)	86	0.091		200	0.393
	140	0.090		300	0.395
Sodium	212	49		420	0.376
	410	46		620	0.275
Sodium chloride			Xylene (ortho-)	68	0.090
brine 25.0%	86	0.33	Xylene (meta-)	68	0.090
12.5%	86	0.34			

So here we have this table thermal conductivity of the liquid depending upon the temperature, you can see depending upon the temperature. But thermal conductivity does not vary significantly when we are considering liquid that will depend on the temperature. So according to temperature, value of thermal conductivity of the liquid will not vary much okay. So here again I am taking the example of benzene.

So at 86 this is the value and at 140 value is this. So you can take. And these temperature are basically and these temperatures are basically the average temperature. So if you are finding value in between these two you can interpolate the value. Otherwise you can consider the extreme values okay. So in that way you can find the thermal conductivity of the liquid. And similarly, I can find out the density of the liquid.

Density of the liquid or fluid you can directly see from the tables as you can see the values of the, as you can see the values of thermal conductivity of the liquid okay. So that density values are available in books. You must have heard about the Perry's handbook. So in that you can find the density value of the liquid and gases okay. So in this way you have to collect the property of the fluids.

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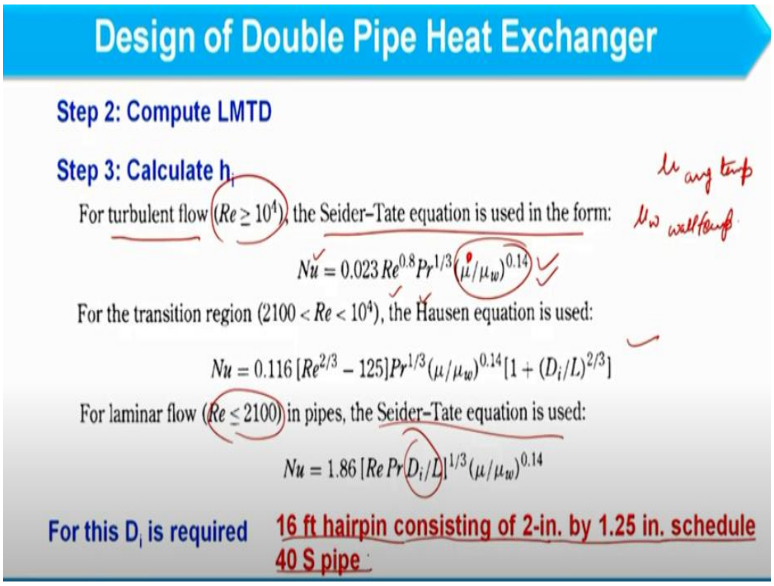

So next step is the step number two where I have to calculate LMTD and LMTD expression is known to you. If it is parallel or series kind of combination, you have to consider FT correction factor along with LMTD for counter current flow right; LMTD for counter and then FT factor. Further I have to calculate heat transfer coefficient. Further I have to calculate heat transfer coefficient inside the tube, okay.

And when I am considering inside the tube, it means that it is the heat transfer coefficient in straight pipe where fluid is flowing inside the tube not over the tube, right. So in that case, we consider different flow region and we will apply the empirical correlations given for that particular region. So first of all, we should consider the turbulent flow where Reynolds number is more than or equal to 10 to the power 4.

Here we will use the Seider-Tate equation okay. So there so here we have Nusselt number is a function of Reynolds number and Prandtl number. And here we have viscosity correction factor. And this viscosity correction factor is what? This is of the fluid okay at average temperature okay. So that mu is at average temperature okay and mu w is the viscosity of the fluid at wall temperature.

How we will consider that wall temperature that we will discuss okay. So this is basically the viscosity correction factor. Reynolds number, Prandtl number you can calculate and you can apply this equation. And if I am having transition region where 2100 to 10 to the power 4 Reynolds number is applied, there we can use this Hausen equation, this equation you can use.

And further if I am having laminar flow where Reynolds number is less than or equal to 2100 we will consider Seider-Tate equation again. But equation will be slightly different because here Nusselt number is a function of D i by L along with Reynolds number and Prandtl number okay. So according to the type of flow you can calculate or you can apply the respective equation to calculate heat transfer coefficient at inner side of the pipe, okay.

Next is we have to decide the diameter okay, diameter of pipe, inner diameter of the pipe we have to decide. Now the question is how we will decide that? To give an example we are considering like 16 feet hairpin consisting of 2 inches by 1.25 inch schedule 40 S pipe, okay. So this is basically the dimension and you have to choose the pipe accordingly, you have to choose the tube accordingly, okay.

So what is the meaning of this 16 feet hairpin? It means 16 feet is the total length where one hairpin is lying, right consisting of 2 inch by 1.25 inch schedule pipe which is numbered as 40 S right. So 16 feet hairpin means 16 feet is the total length of the pipe, one hairpin is there consisting of 2 inch by 1.25 inches. It means 2 inches corresponding to the outer pipe and 1.25 inch corresponding to the inner pipe okay.

So how I can choose the correct D o or D i okay? To choose that we will to choose that we will discuss the pipe table in detail, okay.

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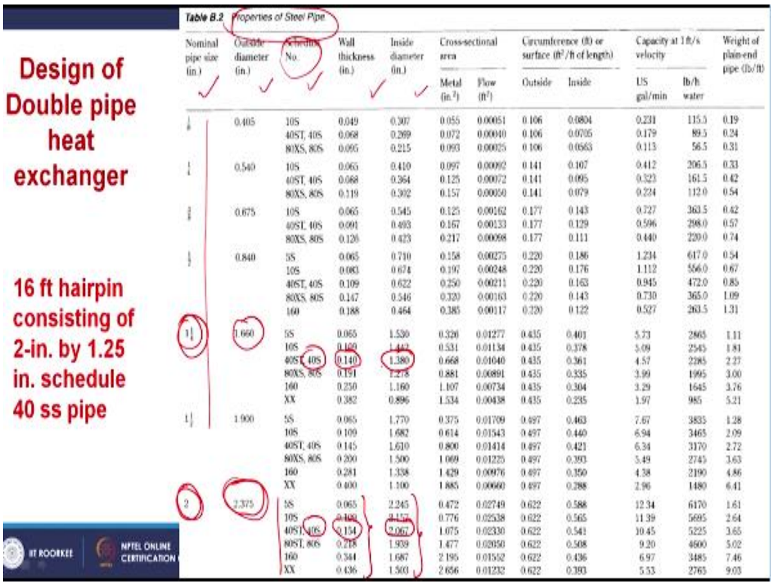

Table B.2 Properties of Steel Pipe

Nominal pipe size (in.)	Outside diameter (in.)	Schedule No.	Wall thickness (in.)	Inside diameter (in.)	Cross-sectional area: Metal (in.²)	Cross-sectional area: Flow (ft²)	Circumference (ft) or surface (ft²/ft of length): Outside	Circumference (ft) or surface (ft²/ft of length): Inside	Capacity at 1 ft/s velocity: US gal/min	Capacity at 1 ft/s velocity: lb/h water	Weight of plain-end pipe (lb/ft)
1/8	0.405	10S	0.049	0.307	0.055	0.00051	0.106	0.0804	0.231	115.5	0.19
		40ST, 40S	0.068	0.269	0.072	0.00040	0.106	0.0705	0.179	89.5	0.24
		80XS, 80S	0.095	0.215	0.093	0.00025	0.106	0.0563	0.113	56.5	0.31
1/4	0.540	10S	0.065	0.410	0.097	0.00092	0.141	0.107	0.412	206.5	0.33
		40ST, 40S	0.088	0.364	0.125	0.00072	0.141	0.095	0.323	161.5	0.42
		80XS, 80S	0.119	0.302	0.157	0.00050	0.141	0.079	0.224	112.0	0.54
3/8	0.675	10S	0.065	0.545	0.125	0.00162	0.177	0.143	0.727	363.5	0.42
		40ST, 40S	0.091	0.493	0.167	0.00133	0.177	0.129	0.596	298.0	0.57
		80XS, 80S	0.126	0.423	0.217	0.00098	0.177	0.111	0.440	220.0	0.74
1/2	0.840	5S	0.065	0.710	0.158	0.00275	0.220	0.186	1.234	617.0	0.54
		10S	0.083	0.674	0.197	0.00248	0.220	0.176	1.112	556.0	0.67
		40ST, 40S	0.109	0.622	0.250	0.00211	0.220	0.163	0.945	472.0	0.85
		80XS, 80S	0.147	0.546	0.320	0.00163	0.220	0.143	0.730	365.0	1.09
		160	0.188	0.464	0.385	0.00117	0.220	0.122	0.527	263.5	1.31
1 1/4	1.660	5S	0.065	1.530	0.326	0.01277	0.435	0.401	5.73	2865	1.11
		10S	0.109	1.442	0.531	0.01134	0.435	0.378	5.09	2545	1.81
		40ST, 40S	0.140	1.380	0.668	0.01040	0.435	0.361	4.57	2285	2.27
		80XS, 80S	0.191	1.278	0.881	0.00891	0.435	0.335	3.99	1995	3.00
		160	0.250	1.160	1.107	0.00734	0.435	0.304	3.29	1645	3.76
		XX	0.382	0.896	1.534	0.00438	0.435	0.235	1.97	985	5.21
1 1/2	1.900	5S	0.065	1.770	0.375	0.01709	0.497	0.463	7.67	3835	1.28
		10S	0.109	1.682	0.614	0.01543	0.497	0.440	6.94	3465	2.09
		40ST, 40S	0.145	1.610	0.800	0.01414	0.497	0.421	6.34	3170	2.72
		80XS, 80S	0.200	1.500	1.069	0.01225	0.497	0.393	5.49	2745	3.63
		160	0.281	1.338	1.429	0.00976	0.497	0.350	4.38	2190	4.86
		XX	0.400	1.100	1.885	0.00660	0.497	0.288	2.96	1480	6.41
2	2.375	5S	0.065	2.245	0.472	0.02749	0.622	0.588	12.34	6170	1.61
		10S	0.109	2.157	0.776	0.02538	0.622	0.565	11.39	5695	2.64
		40ST, 40S	0.154	2.067	1.075	0.02330	0.622	0.541	10.45	5225	3.65
		80ST, 80S	0.218	1.939	1.477	0.02050	0.622	0.508	9.20	4600	5.02
		160	0.344	1.687	2.195	0.01552	0.622	0.436	6.97	3485	7.46
		XX	0.436	1.503	2.656	0.01232	0.622	0.393	5.53	2765	9.03

So if you see here I am having the pipe table where properties of steel pipe are shown, okay. If you see, this is a table B 2. So this is again from R.W. Serth book, appendix B you can refer. And here I am having nominal pipe size, outer diameter, schedule number, wall thickness, inner diameter and so on, okay. So here we have this nominal diameter. And when I continue with this table here we have another section of this table where I am having 2 inch and 1.25 inches, right.

So this 2 and 1.25 is basically the nominal dia of the pipe right? So if I am considering 2 inches and 40 S pipe okay. So how I will choose, corresponding to 2 inches this would be the outer diameter of the tube, okay and if you see for 1 OD of the tube we have different numbers okay, and these are basically schedule number, okay. And according to this schedule number wall thickness vary and so the inner dia, right.

So what is schedule number? Schedule number decides the thickness of a pipe, fine? For a given OD we can have different schedule numbers and according to the schedule number, we can have different thickness of the wall of the pipe and we can have different inner diameter of the pipe though outer diameter will remain same, okay as you can see from this table. So what inner diameter you can consider?

Here schedule number is given as 40 S okay? So corresponding to 2 inch nominal diameter, I am finding this as OD. Now 40 S if you are considering, this is 40 S, so this much wall thickness you should consider and this is the inner diameter. So once you are fixing that OD of the tube and 40 S as a schedule number of the tube, you can fix the tube ID okay.

So in this way you have to select the proper pipe for, you have to select proper pipe for design of double pipe heat exchanger, okay. Now inner pipe size is 1.25 So 1.25 nominal size is there, this is the OD. Again we have 40 S schedule number for this. So this is the tube wall thickness and this is tube ID okay. So in this way we can consider OD and ID of the pipe depending upon nominal size of the pipe, right.

So similarly you can use this table to find out the dimension of other, dimension of other nominal size pipes okay.

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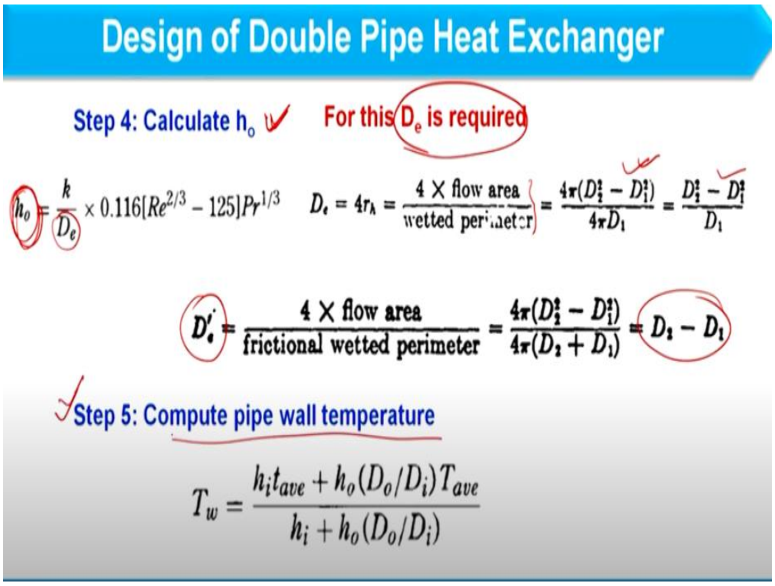

So let us continue with the design of double pipe heat exchanger. Here I am having step number 4 where I have to calculate overall, where I have to calculate heat transfer coefficient at outer layer of outer surface of inner pipe. And for this I need to find out equivalent diameter that is D e, okay. So this is the expression to calculate heat transfer coefficient on outer surface of the inner pipe, okay.

Here I am having this equivalent dia. So equivalent dia you can define as 4 into flow area by wetted perimeter. So you can consider the geometry and calculate the equivalent diameter, okay. And here we are considering this at the annular side okay. So here basically heat transfer I am considering and here basically I am considering heat transfer on annular side when I consider both diameter, when I consider both diameter okay.

So accordingly you can find D equivalent as D naught – D i okay. Now once you have this equivalent diameter, we will move further to step 5 where I have to calculate pipe wall temperature. And this wall temperature I have to find out to compute mu w. That is the viscosity of the fluid at wall temperature and that will be used to find out viscosity correction factor okay.

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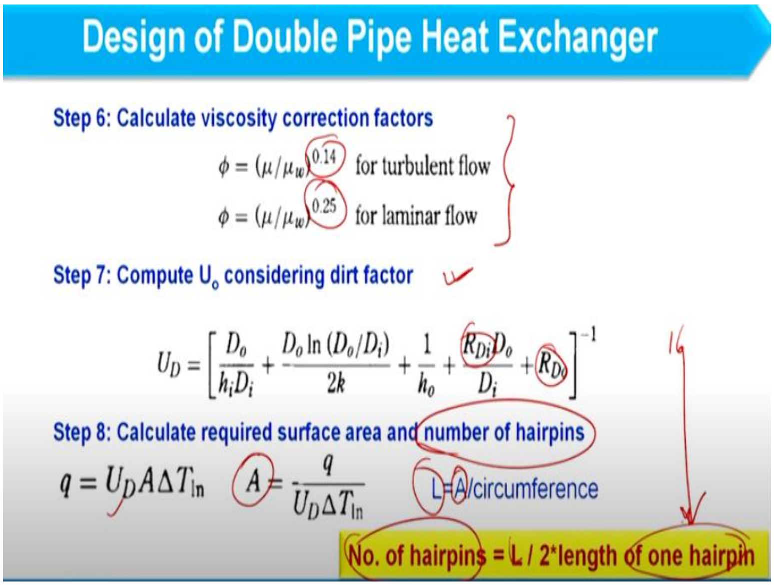

So once I am having wall temperature, I can calculate viscosity correction factor for turbulent flow and laminar flow. So here you can see the change in power factors and once I am having h i and h naught I can calculate overall heat transfer coefficient with dirt factors, okay. So here I am having these dirt factors, okay. So once I am having U D value I can calculate heat transfer area of double pipe heat exchanger okay?

And then I can decide number of hairpins okay, because you have already decided the length. Because if you consider the previous example, we have 16 feet length okay. So total area you have found and that should be divided by circumference. So we can consider the length of the tube, okay. So number of hairpins will be what? Number of hairpins will be complete length divided by 2 into length of 1 hairpin.

So length of one hairpin is basically the 16 feet and this L. What is this L? This is basically total length of double pipe heat exchanger required for sufficient transfer of heat considering total heat transfer area, okay. So that circumference corresponds to the circumference of the tube, okay. So accordingly you can calculate the total length and then you can find out number of hairpins because you need the total length and length of one hairpin okay.

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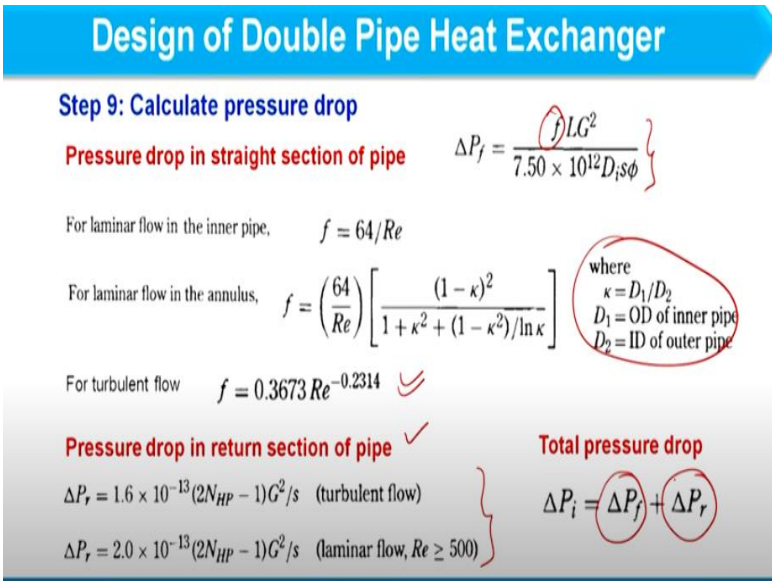

And now we will calculate further and now we will calculate the pressure drop in double pipe heat exchanger, okay so that pressure drop. So as far as this pressure drop is concerned, in double pipe we have two section. One section is the straight section of the pipe okay and second section is the bend when I am considering hairpin, okay. So we have to consider the pressure drop in a straight pipe and pressure drop in the return pipe or the bend pipe also.

So first let us focus on pressure drop in straight section of the pipe okay. And to calculate this we have this empirical correlation and here we have this f factor that is the frictional factor. So it will depend on the type of flow. So for laminar flow in inner pipe, we can consider f as 64 by R e. For laminar flow in annular, we can calculate f factor from this expression where different nomenclatures are shown over here.

And similarly for turbulent flow we can consider f factor depending upon the Reynolds number. However, Reynolds number dependence is available for other factors also. And then we will calculate the pressure drop in return section of the pipe okay, because I have already told you that we have two sections, straight section and return section or the hairpin section.

And in this section you can use these empirical correlations for turbulent as well as laminar flow. So overall pressure drop in double pipe heat exchanger is the pressure drop due to friction in a straight pipe and pressure drop due to friction in return pipe okay. So that will give the total pressure drop. So that will give the total pressure drop in double pipe heat exchanger.

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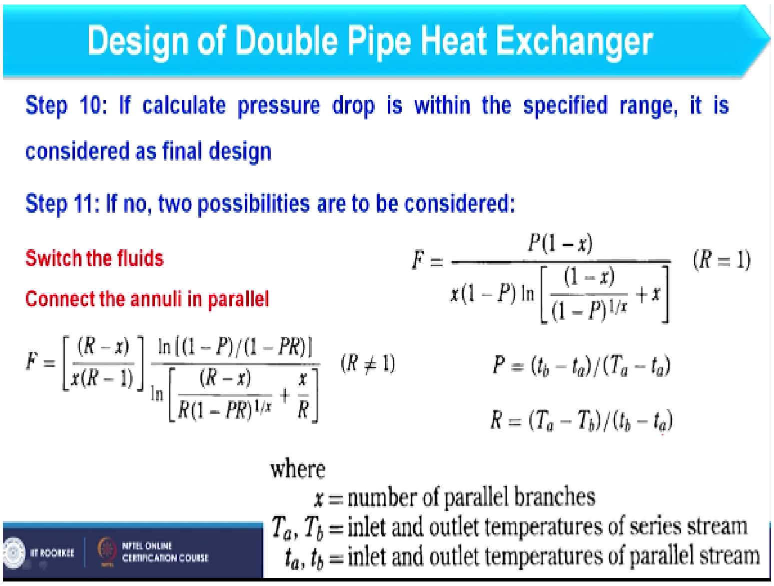

So now we will compare the calculated pressure drop with the permissible limit. If it falls within the permissible limit or within the specified range, we can consider that as a final design, okay, we can consider that as a final design. However, if it is not falling within the specified range, we have two possibilities. Number one is we have to switch the fluid.

Switch the fluid means whatever we have allocated to inner pipe that should be allocated to annular side. And whatever is allocated to annular side that should be allocated to inner side, okay. So we have to switch the fluid. Next is we have to connect the annuli in parallel, okay. So once I am considering the parallel connection, we have to consider FT correction factor according to the R value.

So if you are finding R equal to 1 or not equal to 1, you can choose the FT correction factor accordingly. And then you can consider the LMTD. And then you can consider LMTD also, okay. So in this way we can complete the design of double pipe heat exchanger. In the next lecture we will demonstrate this design or we will illustrate this design with the help of some examples. So then the concept of design or steps of design of double pipe heat exchanger will be more clear to you. So I am stopping over here. So thank you everyone.