Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology-Roorkee

Lecture - 07
Double Pipe Heat Exchanger-II

Hello everyone. This is second lecture of week two of the course Process Equipment Design and here we are going to discuss double pipe heat exchanger. Now if you remember we have started this topic in last lecture that is lecture sixth or first lecture of week two. In that lecture we have discussed design steps about double pipe heat exchanger okay.

And in this lecture, we are going to illustrate the design of double pipe heat exchanger through an example, okay. So let us start with the example. Now before starting that example, here I am having one table where property data of organic liquids are shown, okay. Now if you remember the last class or now if you remember the last lecture, there we have discussed properties of different liquids or different fluids, right.

So in that, so in that property, we have not discussed the density data, right. I have told you that you can find that data in Perry's handbook or similar handbooks also.

(Refer Slide Time: 01:42)

Properties of Organic Liquids

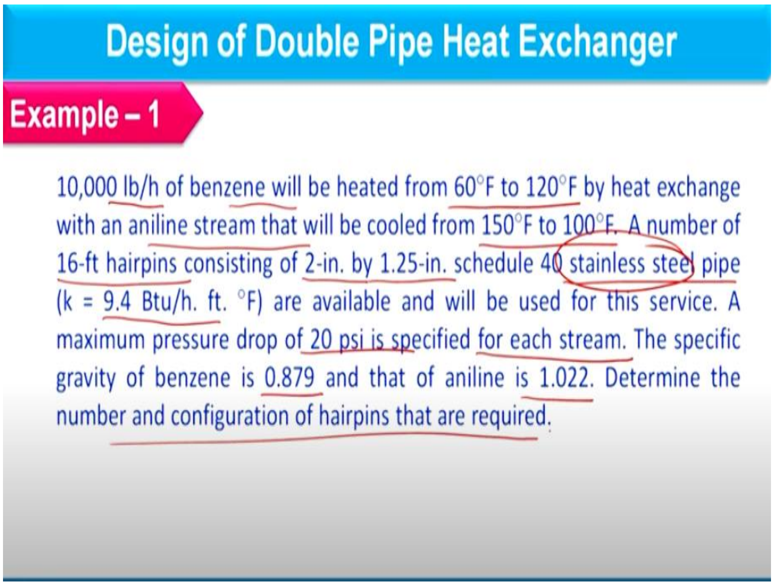
Table A.13 Properties of Selected Organic Liquids at 20°C

Liquid	Chemical formula	ρ (kg/m³)	$\beta \times 10^4$ (1/K)	C_p (J/kg·K)	k (W/m·K)	$\alpha \times 10^9$ (m²/s)	$\mu \times 10^4$ (N·s/m²)	$\nu \times 10^6$ (m²/s)	Pr	$g\beta/\nu^2 \times 10^{-8}$ (1/K·m³)
Acetic acid	$C_2H_4O_2$	1049	10.7	2031	0.193	90.6	-	-	-	-
Acetone	C_3H_6O	791	14.3	2160	0.180	105.4	3.31	0.418	3.97	802.6
Aniline	C_6H_7N	1022	8.5	2064	0.172	81.5	44.3	4.34	53.16	4.43
Benzene	C_6H_6	879	10.6	1738	0.154	100.8	6.5	0.739	7.34	190.3
n-Butyl alcohol	$C_4H_{10}O$	810	8.1	2366	0.167	87.1	29.5	3.64	41.79	5.99
Chloroform	$CHCl_3$	1489	12.8	967	0.129	89.6	5.8	0.390	4.35	825.3
Ethyl acetate	$C_4H_8O_2$	900	13.8	2010	0.137	75.7	4.49	0.499	6.59	543.5
Ethyl alcohol	C_2H_6O	790	11.0	2470	0.182	93.3	12.0	1.52	16.29	46.7
Ethylene glycol	$C_2H_6O_2$	1115	-	2382	0.258	97.1	199	17.8	183.7	
Glycerine	$C_3H_8O_3$	1260	5.0	2428	0.285	93.2	14,800	1175	12,609	0.0000355
n-Heptane	C_7H_{14}	684	12.4	2219	0.140	92.2	4.09	0.598	6.48	340.1
n-Hexane	C_6H_{14}	660	13.5	1884	0.137	110.2	3.20	0.485	4.40	562.8
Isobutyl alcohol	$C_4H_{10}O$	804	9.4	2303	0.134	72.4	39.5	4.91	67.89	3.82
Methyl alcohol	CH_4O	792	11.9	2470	0.212	108.4	5.84	0.737	6.8	214.9
n-Octane	C_8H_{18}	720	11.4	2177	0.147	93.8	5.4	0.750	8.00	198.8
n-Pentane	C_5H_{12}	626	16.0	2177	0.136	99.8	2.29	0.366	3.67	1171
Toluene	C_7H_8	866	10.8	1675	0.151	104.1	5.86	0.677	6.5	231.1
Turpentine	$C_{10}H_{16}$	855	9.7	1800	0.128	83.2	14.87	1.74	20.91	31.4

So in this slide, I am showing the density data along with other data of the fluids. For example, if you see, here we have this liquid and corresponding to each liquid we have this density data. So you can collect the density data from this table and other data are also here. So either you can collect the data from the graph, which we have discussed in the last lecture or you can directly collect that data from this table, if that fluid is falling in this table, right.

So that is about the density data information. And from now, we will start the example to design a double pipe heat exchanger.

(Refer Slide Time: 02:30)



So here I am considering example 1 where around 10,000 pound per hour of benzene will be heated up from 60 to 120 degree Fahrenheit by heat exchange with an aniline stream which is cooled from 150 to 100 degree Fahrenheit, right. So number of 16 feet hairpins consists of 2 inch by 1.25 inch schedule 40 stainless steel pipe. So I think you remember that what is the schedule number.

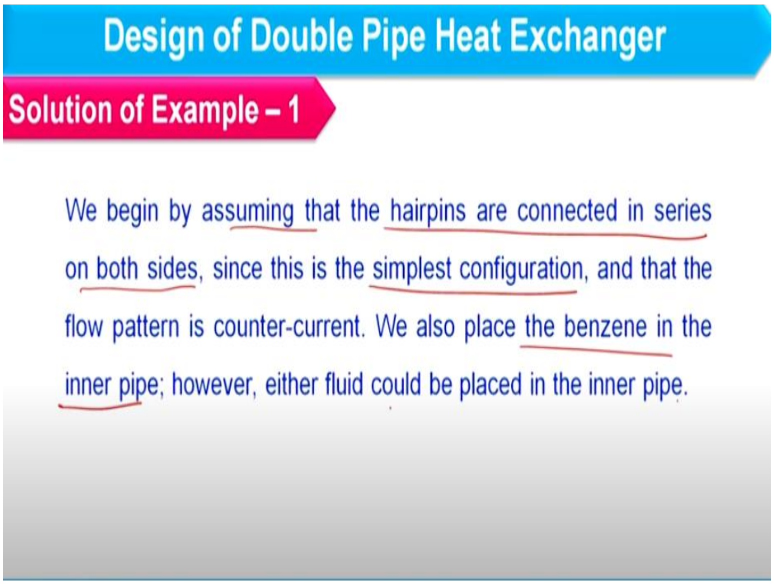
If I am saying that 2 inch by 1.25 what is the meaning of that? 2 inch represents the outer diameter of the exchanger and 1.25 inch represents the inner diameter of the exchanger, right. What I can say this is basically the nominal diameter of the equipment or what I can say this is basically the nominal diameter of the pipe like 2 inch is the nominal diameter of outer pipe, 1.25 inch is the nominal diameter of inner pipe, right.

And here I am having k value also which represents the thermal conductivity of the material. As you can say, we have stainless steel pipe, fine. So here we have a benzene as well as aniline. One among that will flow in inner pipe and another will flow in annular pipe. So we can see the combination of allocation of fluid to inner pipe or outer pipe right.

Now if we further see, now if we further see, we can have maximum pressure drop of 20 psi, which is for both streams right. So we will calculate the pressure drop of each side and that should come lesser than 20 psi, fine? Specific gravity of benzene 0.879 and four aniline it is 1.022. So you can get the density data from this problem only. And next we have to determine the number and configuration of hairpins that are required, okay.

So here we are going to design the double pipe heat exchanger where we will fix the number of hairpins and the configuration. Configuration means whether it should be operated in series or parallel, right. That we have already discussed in the last lecture. So let us start the solution of this problem.

(Refer Slide Time: 05:07)



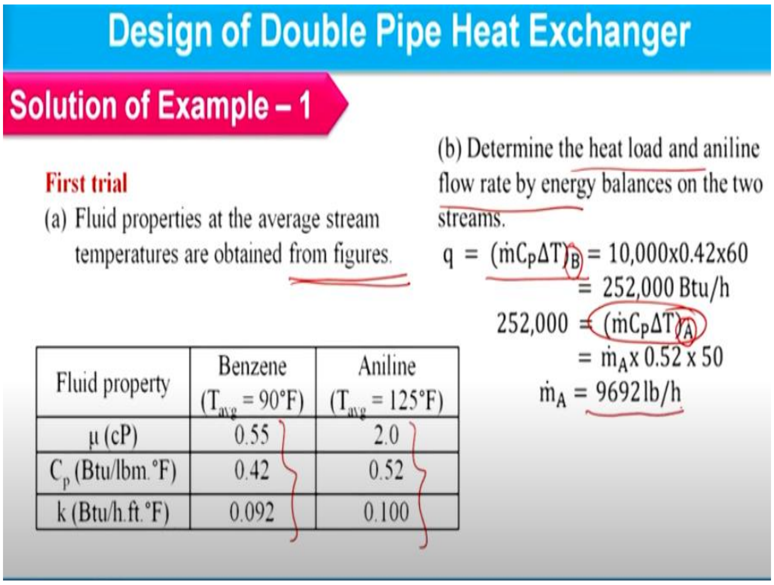
So here we have to start with an assumption that the hair pins are connected in series on both sides. Like I am considering the simplest configuration okay. So if you remember what we have to solve in this problem is we have to find the hairpins number as well as the configuration. So first time considering series configuration, where both fluids are entering in series in double pipe heat exchanger okay.

And for calculation purpose, we can consider that benzene is flowing in inner pipe and aniline is flowing in outer pipe, fine. And either fluid could be replaced in inner pipe. So if we are considering first that benzene is flowing in inner pipe, if all design conditions will be satisfied, we will consider this configuration or consider this flow, otherwise we relocate the liquid to inner side or annular side, fine.

And here we are considering that counter current movement between two fluids is occurring because we are considering series configuration. So let us start with the solution of that with this assumption. So what we have to compute first? We have to first collect the properties. And as you know that we have already discussed in the last lecture that property we usually collect at average temperature, fine.

So here fortunately for both fluids, you know the terminal temperatures, inlet and outlet temperature of both fluids are known to you. So you can simply calculate the average temperature and you can see the properties, properties like viscosity thermal conductivity and specific heat of two fluids and all these information are available in the graph which we have discussed in the last class. I hope you understand how to collect the data from that graph, right.

(Refer Slide Time: 07:22)



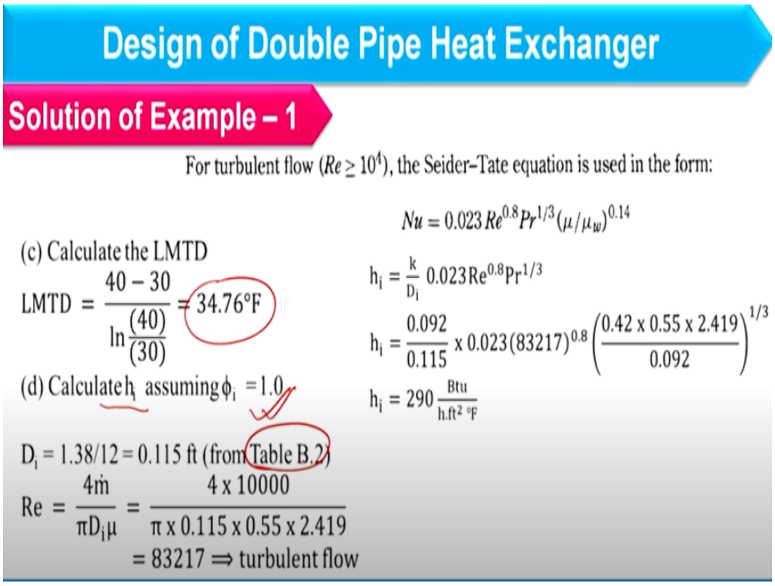
So considering those figures, considering so considering those figures we can consider the viscosity that is in centipoise specific heat and thermal conductivity of benzene as well as for aniline. Along with that, you already know the density data that is specific that is a specific gravity of the fluids are known to you, right. So considering these properties, we will first calculate the heat duty of the exchanger, fine?

So let us determine the heat duty and further we will calculate the aniline flow rate because here 10,000 pound per hour flow rate is given corresponding to benzene only. So first of all we will make the heat duty and then balance the heat with the heat of another fluid to find out the flow rate of another fluid, right. Because temperatures of both fluids are known to you fine.

So to compute this we need the specific heat as a property which we have already collected. So here I am having heat duty as q and that will be nothing but mCp delta T for benzene. B is representing for benzene. So here you can simply make the balance, fine? So 2,52,000 Btu per hour is the heat duty which should be balanced with the mC p dT of aniline, right as A represents the aniline.

So when I am making the balance, I can find that 9692 pound per hour flow rate is available for aniline. So if you compare the flow rates of two fluids, it is almost equal, right.

(Refer Slide Time: 09:18)



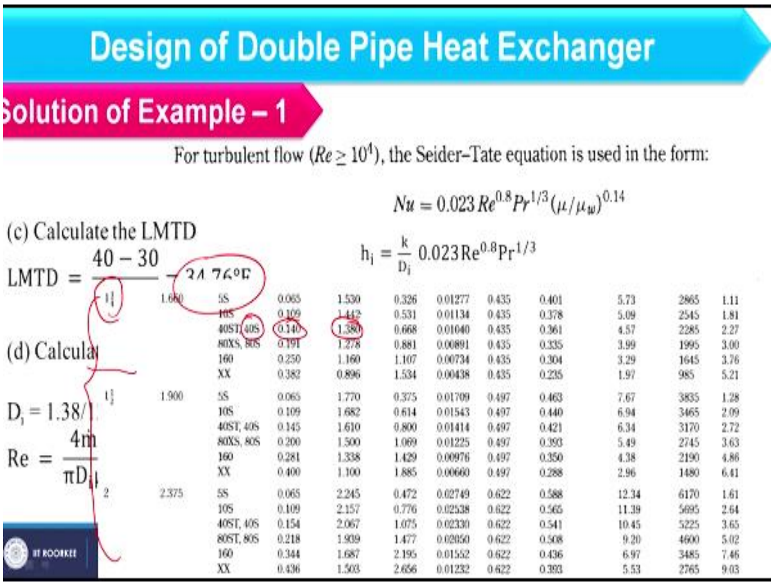
So once I am having the heat duty and flow rate of aniline, we will next calculate log mean temperature difference. And you understand here that I am considering counter current flow. So you can simply calculate LMTD because that is a well known expression and you all know this expression being a chemical engineer.

So here I am having this LMTD which I have found as 34.76 Fahrenheit and then we will further calculate heat transfer coefficient at inner pipe or at annular side assuming psi i as 1. It means at present I am, it means psi represents what? Psi represents the viscosity correction factor fine. So that I am considering 1 because right now, I am not considering viscosity correction factor.

That I will calculate further and then we will multiply that with the h i or h o whatever we will obtain, fine? Now here we should also consider the diameter because, what you know? You know the nominal diameter of outer pipe that is 2 inches and nominal diameter of inner pipe that is 1.25 inches, right. So we have to find out D i and D o, fine? Now if I am considering h i, what I have to focus on?

I have to focus on D i value. So that I can collect from, so that I can collect from table B 2. And what is that table B 2? If you remember the last lecture, we have discussed the pipe information fine? And that is corresponding to the nominal diameter, outer diameter, and schedule number if you remember fine? So here I am having for inner pipe nominal diameter as 1.25, schedule number 40, fine?

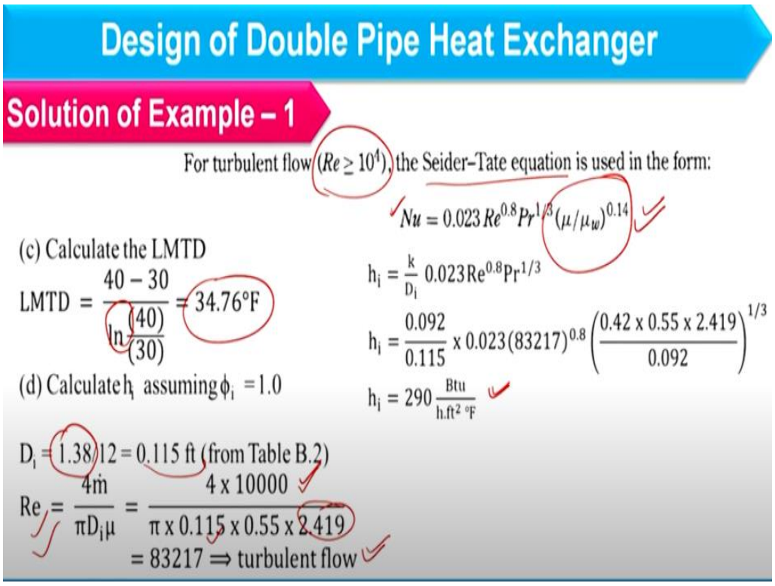
(Refer Slide Time: 11:26)



So let us discuss table B 2. Now if you focus on table B 2, what is given over here? This is a part of, this is a part of table B 2. Detail of this table we have already discussed in the last lecture. So if you see, so here I am having 1.25 as a nominal diameter, if you remember the first column. Second column corresponds to the outer diameter. So that is 1.66. Now what we have to find over here, we have to find out the inner diameter of inner pipe, fine?

And that should correspond to 40 schedule number, fine? So 40 schedule number if you see it is available over here and if you consider this fifth column okay that corresponds to inner dia, fine? And this is what? This is basically the thickness of pipe corresponds to 40 S, corresponds to 40 schedule number. So here D i should be 1.38, fine?

(Refer Slide Time: 12:30)



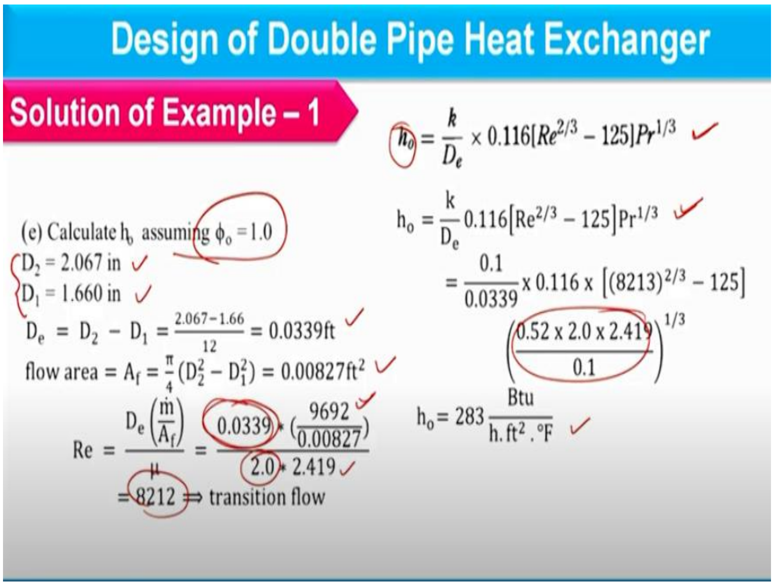
So you see here I am already having 1.38 as inner dia and that is in inches. So we can convert that into feet and then we can calculate Reynolds number, fine? So that is corresponding to the benzene. So 10,000 pound per hour flow rate of benzene is given. Now here we have this pi D i mu. So D i you have already calculated and 0.55 is the viscosity of benzene, fine if you refer the property table.

And 2.419, this is basically the conversion, okay because that viscosity is available in centipoise. So considering these values we can obtain Reynolds number as 83217 and it is falling under turbulent flow zone. Now for turbulent flow zone when I am having Reynolds number greater than 10 to the power 4 we can simply use Seider-Tate equation and this equation you can refer.

And if I elaborate Nusselt's number that would be h i D i by k. So simply you can calculate considering this equation the heat transfer coefficient value and that comes as 290 Btu per hour feet square degree Fahrenheit, okay. Prandtl number you can calculate because you already know the properties.

Now here what we have considered, we have considered the heat transfer coefficient value without viscosity correction factor, fine because I am not focusing on psi value right now. That I have assumed as 1. So here I am having the value of h i.

(Refer Slide Time: 14:28)

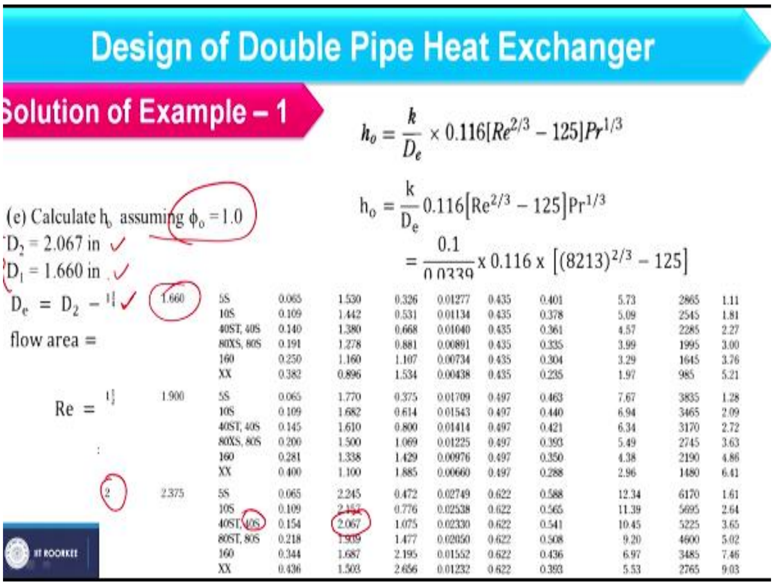


Next is now further we have to find out heat transfer coefficient in annular side right where aniline is moving, fine? So to calculate that h o we are further assuming phi naught equal to 1 because I am not considering viscosity correction factor and further we have to find out D 2 and D 1, fine? So how I can find these values?

These should be corresponding to 2 inches and 1.25 inches, nominal diameters if you remember, fine because in annular side we have to consider equivalent diameter not D i or D naught. So for that purpose we have to calculate the D i and D naught. Now what is D i over here? D i, if I am considering double pipe heat exchanger D i is what?

D i is the outer diameter of inner pipe, right. And D naught or D o will be what? That will be the inner diameter of outer pipe. I hope you are understanding. So let us collect that values from the table B 2.

(Refer Slide Time: 15:48)



So again I am considering this table B 2, the part of table B 2. So if you see we have 1.25 okay and what I have told you that D i corresponds to the outer diameter of inner pipe. So inner pipe nominal diameter is 1.25 and this is the outer diameter of 1.25 nominal diameter pipe, right. And for 2 inches, we have to consider the inner diameter corresponds to 40 schedule number.

So if you see value should come as 2.067. I hope you can understand that. So corresponding to this we can have D i and D 2 value and we have just seen how these values have been obtained. Now once I am having D 2 and D i, now once I am having D 2 and D 1 which I have also represented as D naught and D i corresponding to annular side not D i of inner pipe right, which we have discussed in the last slide.

So here we have D 2 and D 1 value and considering this we can calculate equivalent diameter as 0.0339 feet, fine? And next we can find out the flow area pi by 4 D 2 square minus D 1 square. That is simple calculation. So you can find this value and further we can find out the Reynolds number in annular side, right. So this equivalent diameter we have.

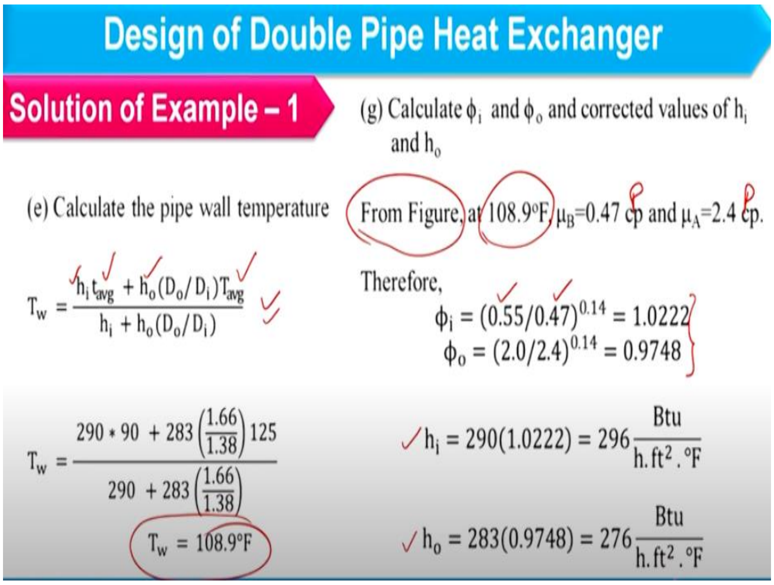
So this equivalent diameter we just have calculated and considering mass flow rate of aniline and viscosity of aniline with the conversion factor we can find out Reynolds number as 8212. So if you see this range of Reynolds number the flow is transition flow, okay. So that should be so if I am having the transition flow, we have to use another equation which is shown over here, okay.

So you can consider this equation, okay. This is basically the Hausen equation, if you remember the last lecture. And here I can find out h naught corresponding to thermal conductivity of aniline and equivalent diameter. So this is the whole expression. And when you put the values over here, thermal conductivity and Reynolds number, Prandtl number value, fine?

So corresponding to all these value you can find out h o value as 283 Btu per hour feet square degree Fahrenheit. So in this way you can calculate h i and h naught. And now, we will focus on the psi values where I have to focus on viscosity correction factors, right. Now how to calculate viscosity correction factor? Viscosity correction factor if you remember that is basically mu by mu W.

And mu W is what? mu W is basically the viscosity of the fluid at wall temperature, okay. And mu is the viscosity of the fluid at average temperature which we already having in a property table, fine? So let us first consider the wall temperature how to calculate that.

(Refer Slide Time: 19:20)



So this is the expression for wall temperature and T average and this capital T average these values of temperature of both fluids are known to us. So we can simply calculate that; h i and h naught we have already calculated. So considering all these values we can find out wall temperature as 108.9 degree Fahrenheit okay. Now corresponding to the figures, figures of what?

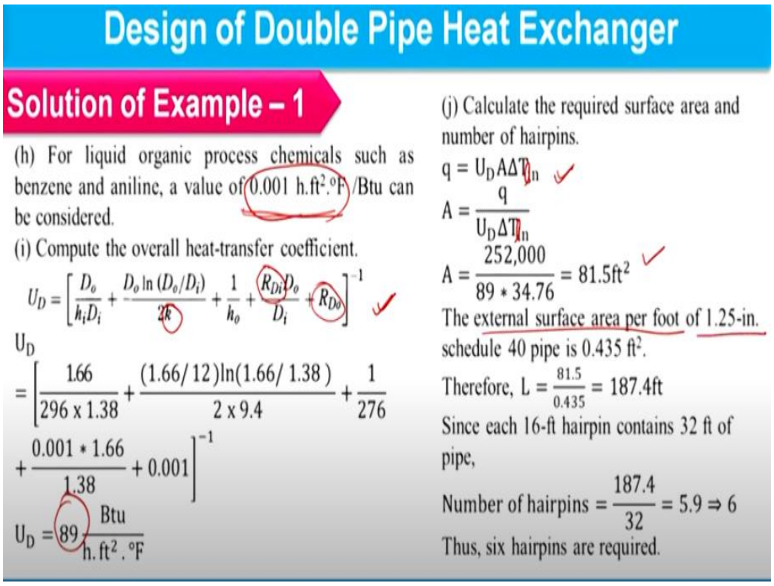
Figures of viscosity data fine, we can find out benzene viscosity and aniline viscosity at 108.9 degree Fahrenheit and it comes out as mu B as 0.47 centipoise and here P should be capital, sorry for that. P should be capital, fine? So here mu B is 0.47 centipoise and mu A is 2.4 centipoise, okay.

Considering these values of viscosity at wall temperature and viscosity at average temperature of both fluids, we can find out viscosity correction factors like this, where psi i is equal to 1.0222 and psi naught is equal to 0.9748, fine? So considering these value we can calculate h i and h naught as 296 Btu hour feet square degree Fahrenheit and 276 Btu hour feet square degree Fahrenheit respectively.

So in this way you can find out h i and h naught with viscosity correction factor. Now once you are having this h i and h naught what we have to calculate first? Obviously, the overall heat transfer coefficient, fine? So if you remember the overall heat transfer coefficient expressions it includes five terms in which two terms corresponding to dirt factor of both fluids fine.

So in this case both fluids like benzene and aniline these fluids fall in organic liquid range, fine? So in both fluids we can consider same dirt factor, okay because both are falling in same category.

(Refer Slide Time: 21:47)



So for that purpose we have considered dirt factor as 0.001 hour feet square degree Fahrenheit per Btu, okay. So this is for both fluids. Considering this we can calculate overall heat transfer coefficient using this expression where R D i and R D naught are dirt factor value and in some expressions we can use dirt coefficient.

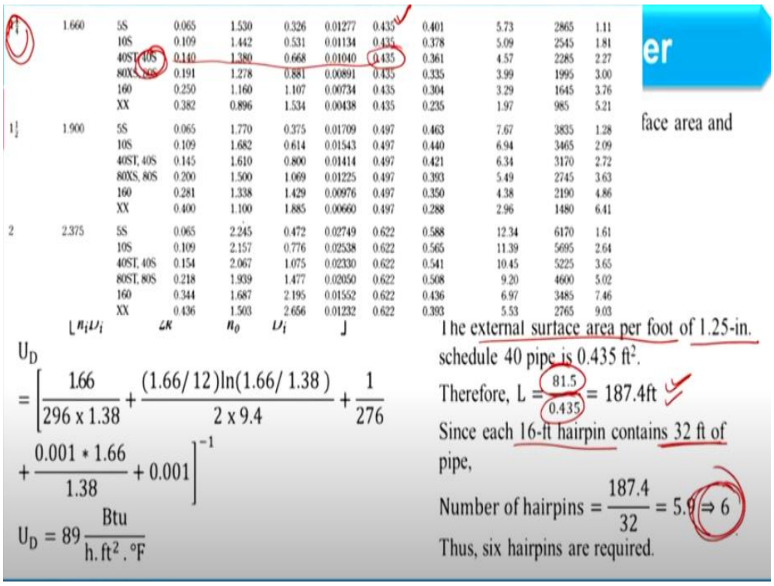
That would be hod or hid if you remember the basic design parameters lecture, right? So considering D i, D naught, h i, h naught and thermal conductivity of the material that is already given in the problem. So considering all these value we can find out overall heat transfer coefficient at dirt condition as 89 Btu per hour feet square degree Fahrenheit.

So here you can calculate overall heat transfer coefficient and next what we have to find out? We already have calculated the heat duty, overall heat transfer coefficient and LMTD is already with me. So what we have to calculate next is the heat transfer area, fine? So this is very common equation for heat transfer area that is the duty should be equal to U A delta T mean and that should be L m.

And here it is not i n it should be ln, that is the log mean temperature difference, fine? So considering all these value we can find out area as 81.5 feet square. And next what we have to find out? We have to find out the overall length of the exchanger, okay because we have to calculate the hairpins. And one hairpins, one side of that is 16 feet, fine?

So we will first calculate the overall length and then we will find the hairpins number by dividing that value with the length of one hairpin, okay. So let us focus on the calculation of total length of the exchanger. And to calculate that we need the external surface area per foot of inner pipe, that is 1.25 inch schedule 40 pipe okay. And that value comes as 0.435. So how I can obtain that value?

(Refer Slide Time: 24:22)



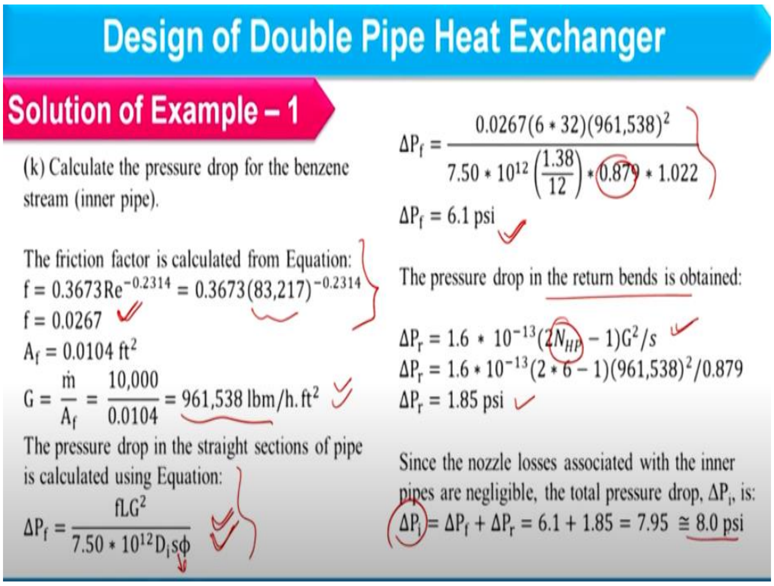
That value I can extract from this table which is a part of table B 2. Now here I am having 1.25 nominal diameter pipe. And if you see here we have the, if you see the table B 2 properly at the top we have different column names okay. And this column corresponds to the surface area per unit length, okay. So correspond to 40 S, correspond to 40 schedule number we can find out value as 4.435, okay.

So 435 feet square per unit length, fine? So total heat transfer area I already know and I will consider this 0.435 as a perimeter. So you can consider 187.4 feet is the total length of double pipe heat exchanger, okay. And further if I am considering 16 feet hairpin, so total length of the pipe is 32 feet, right? Now if you remember the last lecture, in that lecture I have told you that hairpin length is 16 feet.

So that is the total length but that is given as half of the length, right? So if I am saying 8 feet hairpin or 16 feet hairpin, it means it is only the half length of the total pipe, fine? So if I am having 16 feet 32 feet is the total length and 187.4 feet length we have already seen as a total length of exchanger. So we can simply find out 6 hairpins as total number of hairpins, right in this example.

Now further we will focus on pressure drop calculations. So first of all we should focus on pressure drop of inner pipe where benzene stream is available okay.

(Refer Slide Time: 26:32)



So for that purpose we can calculate the frictional factor first. So that expression we have already discussed in the last lecture. So corresponding to the Reynolds number you can choose the f factor. So in this case Reynolds number is 83,217 and other parameters are not required. So we can simply calculate dirt, we can simply calculate friction factor over here.

We can simply calculate friction factor over here and the flow area we can find out and division of mass flow rate divided by flow area will give the capital G value that mass flow rate per unit area, right. So value comes as this value. Now the pressure drop in straight section of the pipe is calculated using following equation.

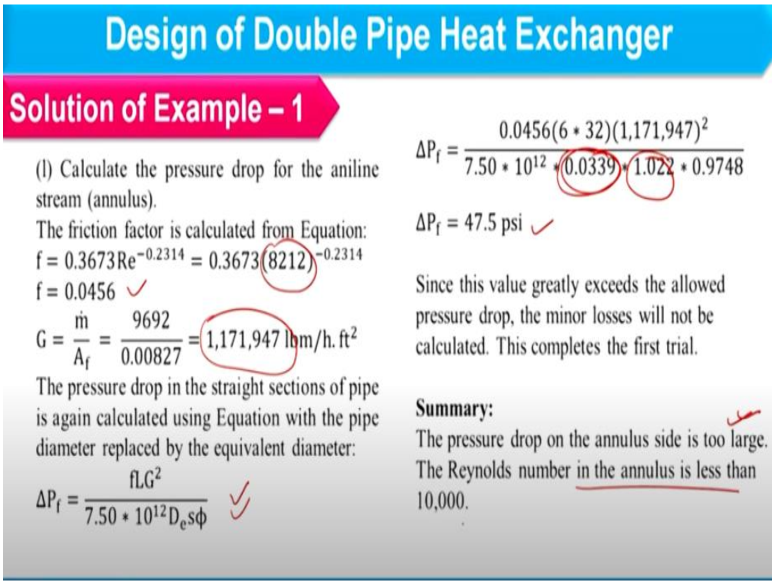
Now if you remember the pressure drop per discussion, now if you remember the pressure drop calculation, which we have discussed in the last lecture, in double pipe heat exchanger, we have two sections. First is the straight pipe where flow is occurring in a straight pipe and second is the bend okay, return bend.

So we can consider pressure drop in two section simultaneously and then that and then we add those pressure drops to find out total pressure drop in double pipe heat exchanger, in inner side or in annular side, right? So this is the expression to calculate pressure drop in inner pipe and considering all these value where this s corresponds to the specific heat of the, where this s corresponds to the specific gravity of the benzene, fine?

So that value you already can see from the problem and putting all these value we can consider pressure drop as 6.1 psi, that is in a straight pipe only. Now pressure drop in a return pipe or in return bend we can consider this expression because it will depend on the number of hairpins that we have computed as 6. You know all other parameters and you can simply find out pressure drop in return pipe as 1.85 psi, okay.

And addition of these two will give the total pressure drop in inner pipe, right. So here I am having total pressure drop as 8 psi. So if you recall the limit of pressure drop that is 20 psi should be the maximum limit, okay. But here I am getting 8. So here I am working in safer side, right.

(Refer Slide Time: 29:23)



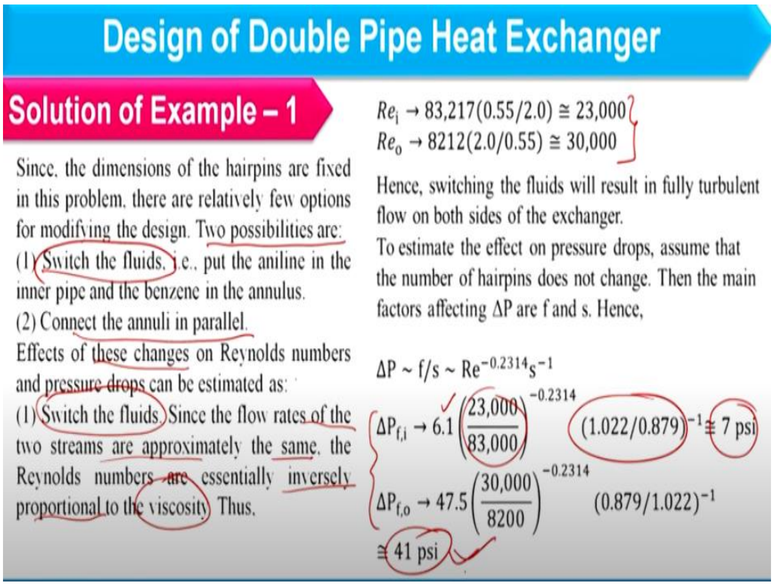
So now calculate the pressure drop of aniline which is flowing in annular side, fine? So here we have the expression corresponding to the Reynolds number. So you can find that value of f like this, okay. And further we can calculate the flow area, okay. So if you recall the last slide there we can obtain the flow area and that flow area you can simply find out through table B 2, fine?

So all these values are given, okay. So here I am having the flow area and corresponding to this G value you can obtain like this. And further we can find out the pressure drop in a straight pipe and pressure drop in a return pipe. So we will first calculate the pressure drop in straight pipe. So you have all values including the specific gravity of aniline and including the annular and including the equivalent diameter, right.

So pressure drop in a straight pipe you can find out as 47.5 psi fine? So here you should not calculate the pressure drop in bend, pressure drop in return bend because this pressure drop is already exceeding than the permissible limit, which is 20 psi fine? So here my design becomes infeasible. We have to design in such a way so that both pressure drop should lie within 20 psi, okay.

So here we have to start the second trial, okay. But what we can summarize from this first trial is the pressure drop and annular side is too large, that we have already seen and Reynolds number in annulus is less than 10,000. So flow in annular side or flow in annulus is in transition zone which we should not use, okay.

(Refer Slide Time: 31:40)



So what we can do to overcome this that we have two possibilities. First is we can switch the fluids, okay. And second is we can connect the annuli in parallel, fine? Because what we have to do over here? We are not focusing on inner side. We are not focusing on inner side because there already we are in a safer side, right. But in annular side or annulus or annuli, we can consider lesser pressure drop and therefore, we will divide the flow in annular side only not in inner pipe okay.

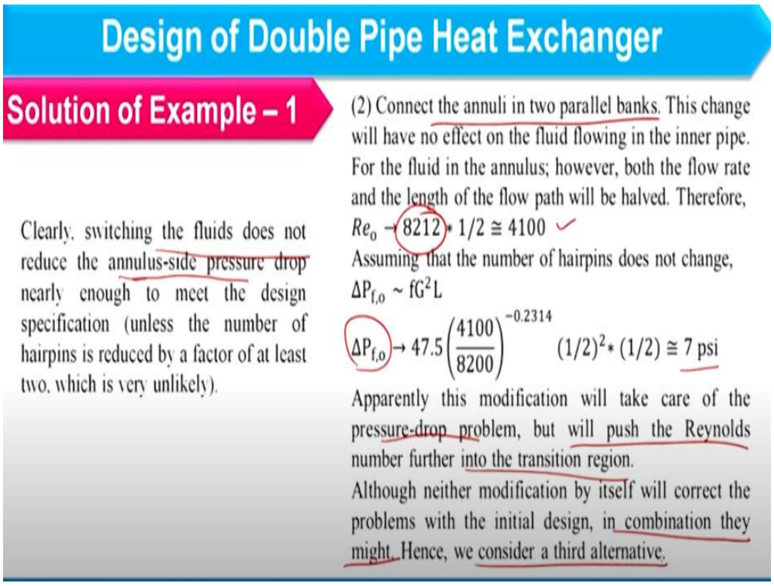
And these two possibility I have already discussed in lecture one also because what we should do when the infeasibility occur. So these two options we have already focused there also, okay. So effect of these two possibility changes on Reynolds number and pressure drop can be estimated as first of all if I am switching the fluid okay. So what will happen?

Since the flow rates of two streams are approximately the same, okay because both fluids are more or less 10,000, one is 10,000 and second is 96 197 something like that. So both of the fluids are in same flow, okay. So Reynolds number will definitely be the function of viscosity over here, okay. And that should be inversely proportional too, fine? So considering this we can simply switch the fluid that aniline is flowing in inner pipe and benzene is flowing in outer pipe.

So if I am considering that reverse of Reynolds number or switching of Reynolds number we can find these Reynolds number in inner pipe and annular side. It means both are falling in turbulent zone, fine? So **so** once I am having the Reynolds number of two side we can calculate the pressure drop of two side. So pressure drop changes we can further find out based on specific gravity value, okay.

So Reynolds number so pressure drop of annular side for straight pipe 6.1 we have obtained and this is the switching of Reynolds number. So here we can find out final Reynolds number is 7 psi in inner pipe and 41 psi in annular side okay.

(Refer Slide Time: 34:27)

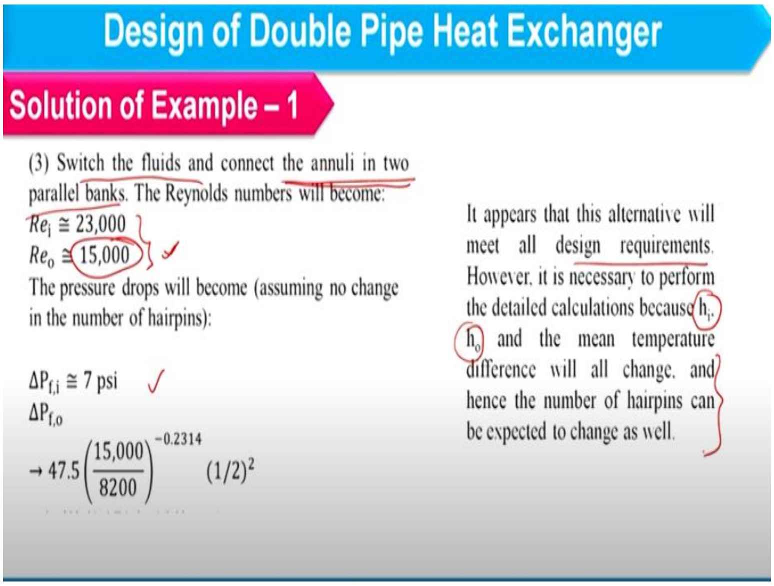


So here again it is more than 20 psi. So obviously switching the fluid does not solve my problem as it is not reducing annulus side pressure drop, fine? So we have to connect, so we have to go for the second option and that is to connect the annuli in two parallel banks, okay. So in this case what will happen? Because whatever would be the Reynolds number it is divided in two section because we are considering the parallel flow, right.

So here I am having the Reynolds number like this, which we have divided in, which we have divided by 2, so 4100 Reynolds number is in annular side and you see further and you see the revised pressure drop in annular side we can obtain as 7 psi. So apparently this modification will take care of the pressure drop, but we will push the Reynolds number further into the transition region because now the Reynolds number is less than 10,000, fine?

So what we can consider switching the fluid and changing the pattern. Changing the pattern means changing the configuration is not solving my problem, okay. Though it is falling under a required pressure drop, but it is putting the liquid to the transition zone, which we should avoid. So what we can consider, we can consider the combination of two options together.

(Refer Slide Time: 36:08)

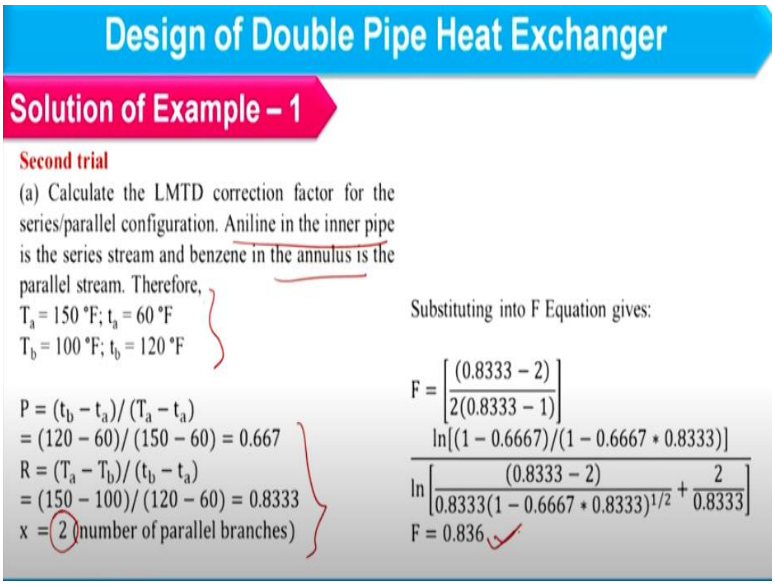


So considering this we can make a third alternative where switching as well as connect the annuli with, connect the annuli in two parallel bank, both we should consider. So here I am having the Reynolds number. Now if you remember this value was 30,000 when I have considered switching of the fluid, but because of the half, because of the parallel flow this value becomes half, okay.

Considering this we can consider, considering this we can find out the pressure drop. So that comes as 7 psi, right. So it appears that this alternative will meet all design requirement. However, we have to carry out sufficient calculation to find out h i and h naught further and mean temperature difference because all configurations are changing and we also have to see the effect of that on hairpin number.

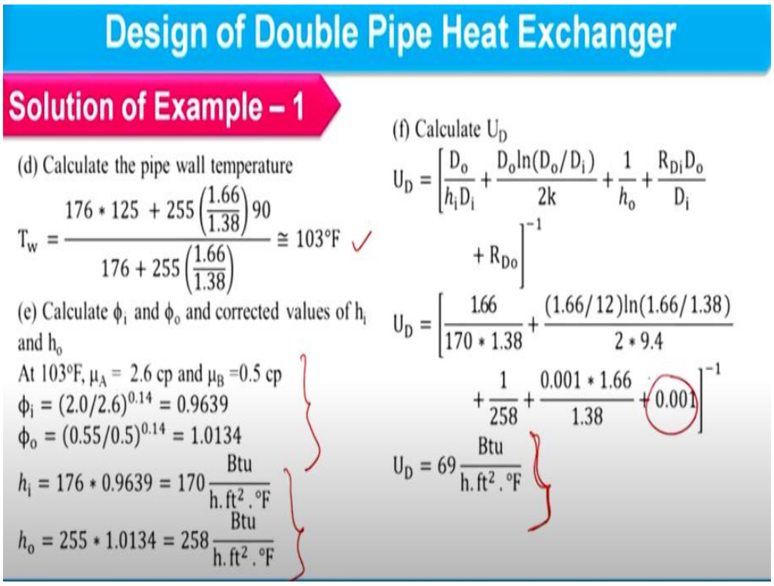
So let us consider the another trial which I am saying a second trial because here I am calculating, here I am revising all calculations for second time, okay.

(Refer Slide Time: 37:20)



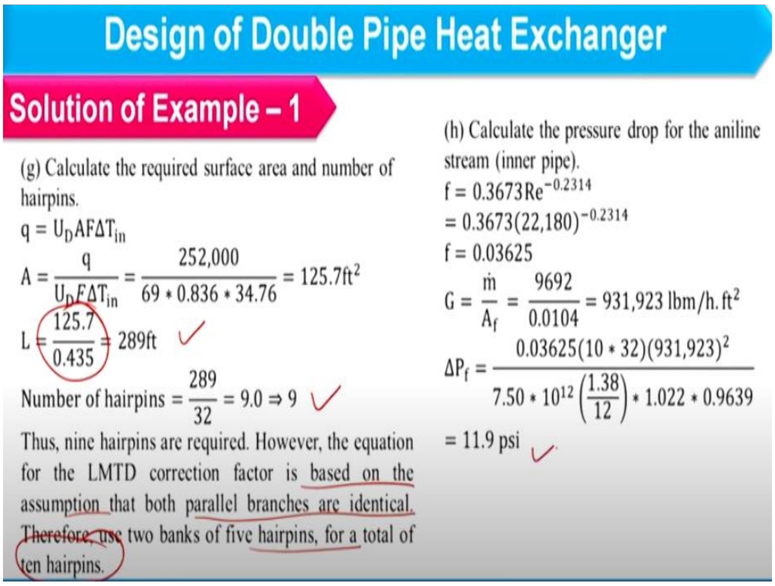
So here I am having benzene in annulus side and aniline in inner pipe. So here I am having the temperature differences. And because I am considering parallel flow I have to calculate F t factor also and that we can consider depending upon the branches. So we can consider two branches over here. So F t value we can obtain as 0.836.

(Refer Slide Time: 37:43)



Considering this we can calculate h i value and h naught value like this. I am not going into detail of that, because this we have already discussed in first trial. We can calculate the wall temperature and then the viscosity correction factor and then the revised h i and h naught value and so the dirt factor and so the overall heat transfer coefficient considering dirt factor, right?

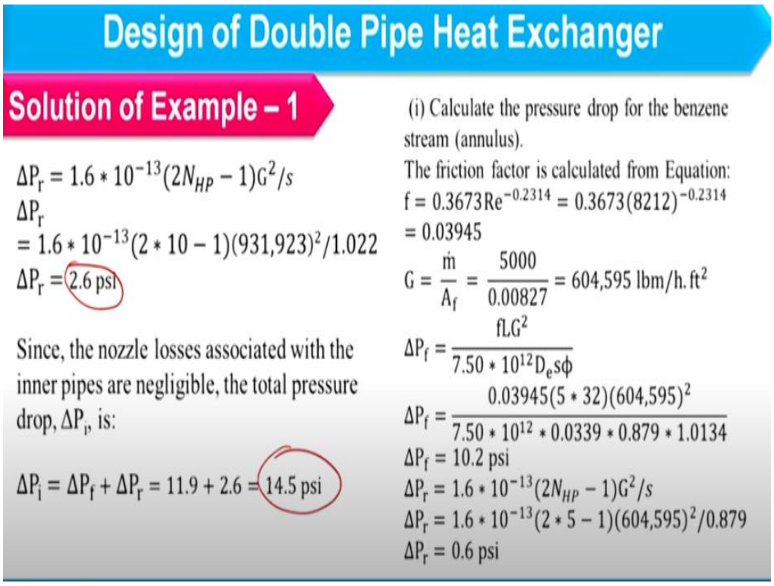
(Refer Slide Time: 38:13)



And then we will further calculate the total length, how much total length will be required. So that comes out as 289 and this is corresponding to the previous calculation only. So I am not going into detail of this. If you consider the hairpin, that comes as 9, okay. So 9 hairpins are odd number. However, the equation for LMTD correction factor is based on assumption that both parallel branches are identical.

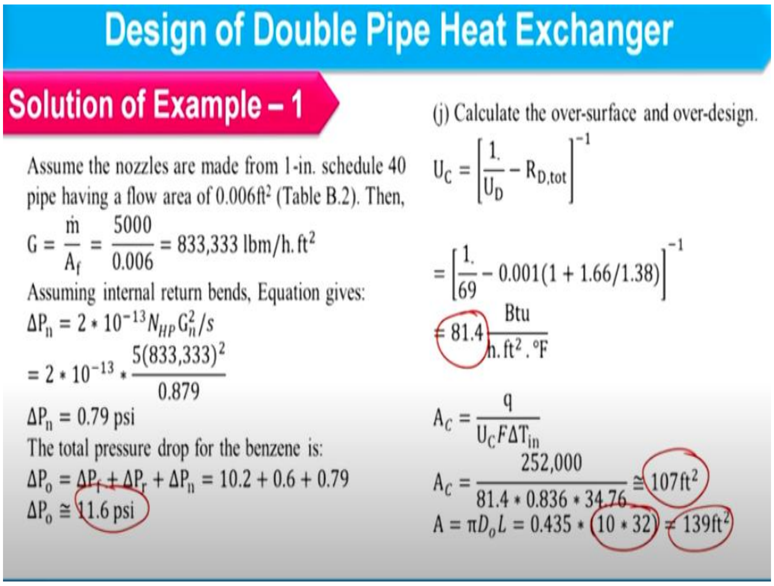
And therefore, we use two branches for 5 hairpins or two banks of 5 hairpins. So total number of hairpins will be 10, okay. So considering this we can calculate the pressure drop for inner side. So it comes as 11.9 psi.

(Refer Slide Time: 39:04)



And for reverse side or the return bend we can consider pressure drop as 2.6. So total pressure drop in inner pipe is 14.5.

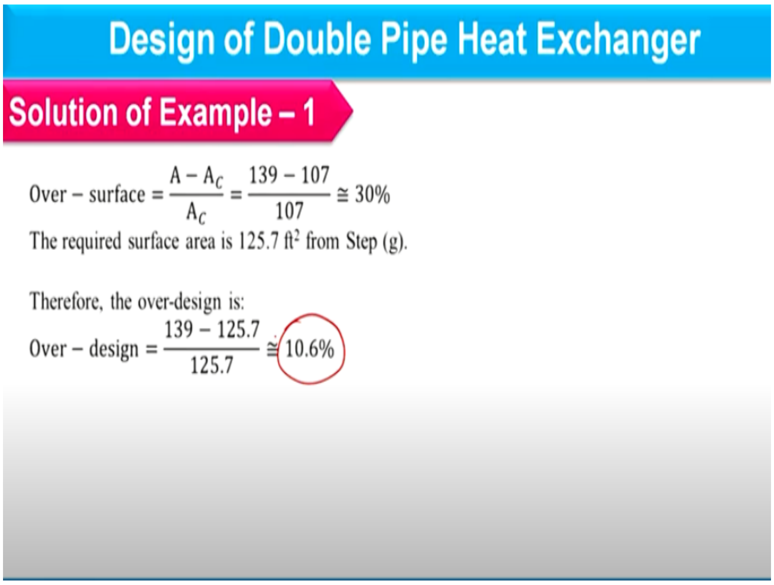
(Refer Slide Time: 39:16)



And similarly, we can find out the pressure drop in annular side and that should be 11.6. So both pressure drop are falling in a range. Now finally, we have to find out that how much over design we are considering. So that we have to calculate overall heat. So that so for that we have to calculate area for clean condition and for dirt condition, okay.

So you can calculate overall heat transfer coefficient at clean condition and area you can obtain as 107 feet square, right. And for 10 hairpin of 20 and for 10 hairpins of 32 length, you can find out area as 139 feet square.

(Refer Slide Time: 40:03)



Comparing these two will give the oversize as 10.6%. So this much is the oversize. We have considered all feasibility and we met all design in a feasible limit, okay. So that is all about example 1 and that is all about this lecture. So that is all for now. Thank you.