Process Equipment Design
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Lecture –33
Design of Reboiler-7

Hello everyone. I welcome you all in this lecture which is lecture 33 of the course Process Equipment Design and this is the 3rd lecture of 7th week and here we are going to discuss design of reboilers. If you remember 31 and 32 lecture, in 31th lecture we have discussed design of kettle reboiler with the help of two examples. And similarly in 32nd lecture, we will discuss design of vertical thermosyphon reboiler with the help of two examples.

And here we will further consider a few examples to illustrate design of reboiler which are kettle as well as vertical thermosyphon reboiler so that method is clear to you. So, let us discuss example 5. This is not a detailed example. We are discussing of design of some section of reboiler with the help of small examples.

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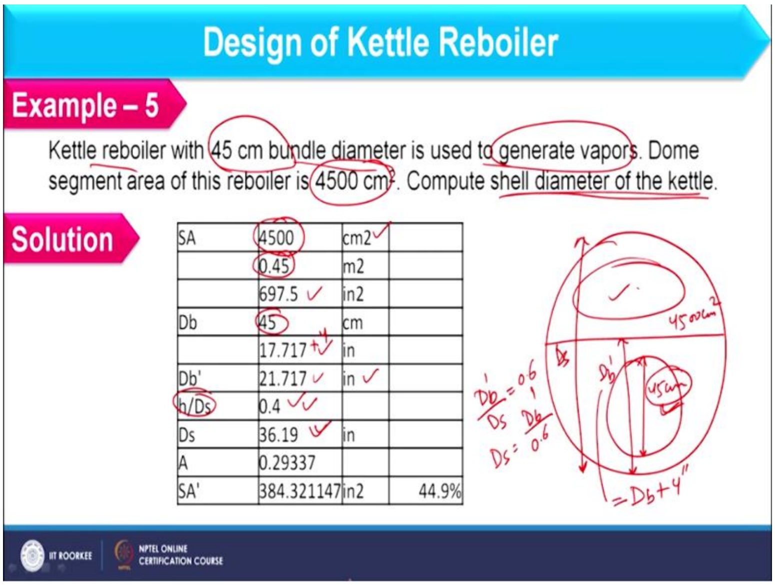

So, here we have example 5 as kettle reboiler is having 45 centimeter bundle dia. So, bundle dia is given as 45 centimeter where vapour is generated. So, dome segment area of this reboiler is 4,500 centimeter square and we have to compute shell diameter of the kettle. So, if you see here we have the cross sectional view of the shell, bundle is this. So, bundle dia given to us as 45 centimeter.

Here we must have the weir and dome segment area means area of this particular section 4,500 centimeter square. So, what we have to find? We have to find this shell dia that is Ds. So, let us start the calculation we have SA that is dome segment area as 4,500 centimeter square which will convert it into meter square and it is 0.45. And further we can consider this into inch square and that is 697.5 inch square.

Bundle diameter given to us as 45 centimeter as we have also seen here. So, when I convert this into inch it is 17.717 inch and we have to further find out this distance and that we consider as Db dash and you know that Db dash should be equal to Db + 4 inches. So, therefore we are converting 45 into inch. So, 17.7, is the Db we will add 4 over here. So, Db dash we can obtain as 21.717 inch and what we have to find further?

We have to compute the shell diameter. So, for that method is already discussed in 31 lecture as well as 6th week lectures that we have to fix h / Ds in such a way so that the revised segment area should be equal to dome segment area which is given as 4,500 centimeter square. So, let us calculate shell diameter and for that we have to initiate h / Ds value as it should be equal to 0.4 because this is a thumb rule that h value should be 40% of shell dia.

So, initial guess of h / Ds you can find as 0.4. So, once I am having h / Ds as 0.4 we can obtain Db dash / Ds as 0.6. So, you can find Ds value as Db dash / 0.6. So, in this way shell diameter you can find out as 36.19 inch. So, further to find out revised segment area we have to find out area sector factor and that we can obtain from the table appendix 10 A and this appendix is given in R.W. Serth book.

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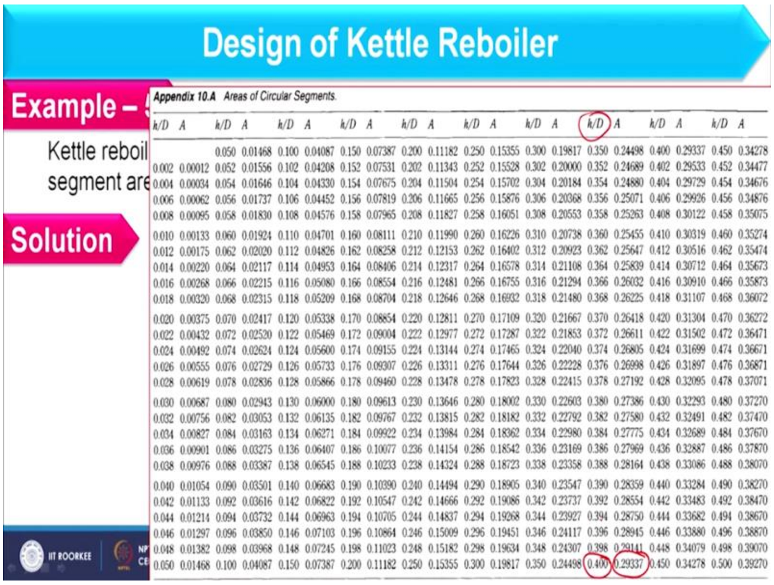

So, here we can have area factor as 0.29337 which is corresponding to h / D value as 0.4. So, here we have A value as 0.29337 and when we multiply this A with Ds square we can find out revise segment area as 384.32. So, this area is in inch square. However, whatever area I required is 697.5 inch square. So, what we have to do? We have to provide more value of SA dash and that we can do while providing more h value.

So, this comparison will tell you where you have to proceed, further either you have to reduce the h value or you have to increase the h value. So, in this case we have to increase the h value. So, h / Ds value should be more now.

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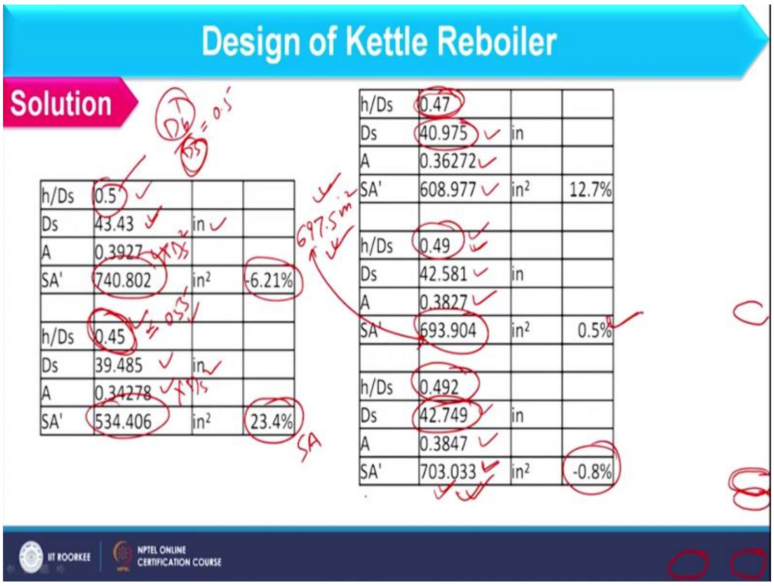

So, next value we are considering as 0.5. So, if I am having h / Ds as 0.5 I can obtain Db dash / Ds as 0.5. So Db dash value is given to you already. So, Ds value you can obtain which comes as 43.43 inch. So, corresponding to h / Ds 0.5 we can find out A factor as 0.39270. So, you see here we have A value as 0.3927 it will be multiplied by Ds square. So, revise segment area we can obtain as 740.8 inch square.

However, value we required at 697.5 inch square. So, if we compare the SA as well as SA dash we can obtain that SA dash is slightly higher than SA. So, what we have to do? We have to further reduce h / Ds value. So, h / Ds value we can consider now as 0.45. So, again Db dash / Ds value should be 0.55. So, considering Db dash value and this 0.55 we can find out shell diameter which is 39.485 inch.

And corresponding to 0.5 h / Ds value we can find out A value as 0.34278 so that you can consider here. It should be multiplied by Ds square and SA dash you can obtain as 534.6 inch square which is further lesser than SA. So, now what we have to do? We have to take the value of h / Ds between 0.45 and 0.5. So, next value of h / Ds I am considering as 0.47. So, accordingly you can find out the shell diameter as I have already explained.

And that value you can obtain as 40.975 inch. Corresponding to h / Ds value as 0.47 you can find out A factor as 0.36272 so that you can obtain here. It should be multiplied by Ds square. So SA dash you can obtain as 608.97 which is further lesser than the required value. So, we have to further increase h / Ds. So, now h / Ds we are considering as 0.49 corresponding to this shell diameter is 42.58 inch.

And corresponding to 0.49 h / Ds you can find A factor as 0.3827 as it is shown over here. So, SA dash now; you can obtain as 693.9 which is further lesser than the SA value. So, we have to slightly increase h / Ds and next value I am considering as 0.492. So, corresponding to this we can find out Ds as 42.749 inch.

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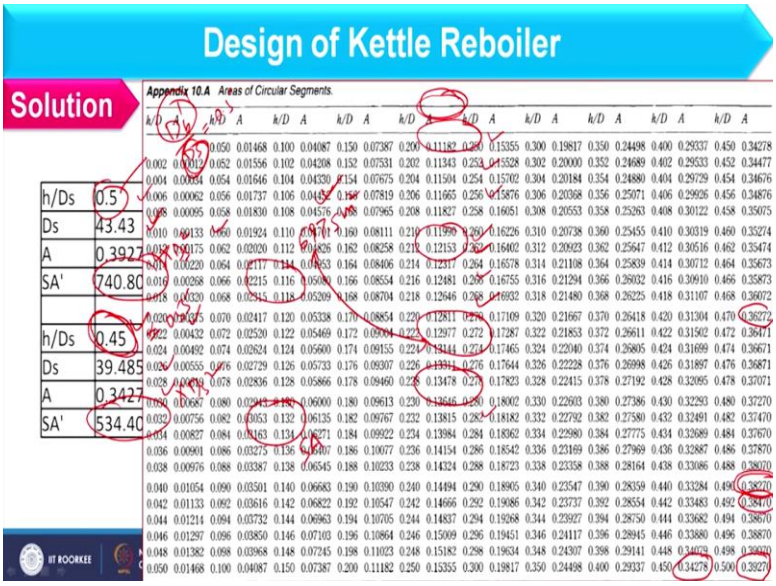

h/Ds	0.5
Ds	43.43
A	0.3927
SA'	740.80
h/Ds	0.45
Ds	39.485
A	0.3427
SA'	534.40

h/D	A	h/D	A	h/D	A	h/D	A	h/D	A	h/D	A	h/D	A	h/D	A	h/D	A	h/D	A
		0.050	0.01468	0.100	0.04087	0.150	0.07387	0.200	0.11182	0.250	0.15355	0.300	0.19817	0.350	0.24498	0.400	0.29337	0.450	0.34278
0.002	0.00012	0.052	0.01556	0.102	0.04208	0.152	0.07531	0.202	0.11343	0.252	0.15528	0.302	0.20000	0.352	0.24689	0.402	0.29533	0.452	0.34477
0.004	0.00034	0.054	0.01646	0.104	0.04330	0.154	0.07675	0.204	0.11504	0.254	0.15702	0.304	0.20184	0.354	0.24880	0.404	0.29729	0.454	0.34676
0.006	0.00062	0.056	0.01737	0.106	0.04452	0.156	0.07819	0.206	0.11665	0.256	0.15876	0.306	0.20368	0.356	0.25071	0.406	0.29926	0.456	0.34876
0.008	0.00095	0.058	0.01830	0.108	0.04576	0.158	0.07965	0.208	0.11827	0.258	0.16051	0.308	0.20553	0.358	0.25263	0.408	0.30122	0.458	0.35075
0.010	0.00133	0.060	0.01924	0.110	0.04701	0.160	0.08111	0.210	0.11990	0.260	0.16226	0.310	0.20738	0.360	0.25455	0.410	0.30319	0.460	0.35274
0.012	0.00175	0.062	0.02020	0.112	0.04826	0.162	0.08258	0.212	0.12153	0.262	0.16402	0.312	0.20923	0.362	0.25647	0.412	0.30516	0.462	0.35474
0.014	0.00220	0.064	0.02117	0.114	0.04953	0.164	0.08406	0.214	0.12317	0.264	0.16578	0.314	0.21108	0.364	0.25839	0.414	0.30712	0.464	0.35673
0.016	0.00268	0.066	0.02215	0.116	0.05080	0.166	0.08554	0.216	0.12481	0.266	0.16755	0.316	0.21294	0.366	0.26032	0.416	0.30910	0.466	0.35873
0.018	0.00320	0.068	0.02315	0.118	0.05209	0.168	0.08704	0.218	0.12646	0.268	0.16932	0.318	0.21480	0.368	0.26225	0.418	0.31107	0.468	0.36072
0.020	0.00375	0.070	0.02417	0.120	0.05338	0.170	0.08854	0.220	0.12811	0.270	0.17109	0.320	0.21667	0.370	0.26418	0.420	0.31304	0.470	0.36272
0.022	0.00432	0.072	0.02520	0.122	0.05469	0.172	0.09004	0.222	0.12977	0.272	0.17287	0.322	0.21853	0.372	0.26611	0.422	0.31502	0.472	0.36471
0.024	0.00492	0.074	0.02624	0.124	0.05600	0.174	0.09155	0.224	0.13144	0.274	0.17465	0.324	0.22040	0.374	0.26805	0.424	0.31699	0.474	0.36671
0.026	0.00555	0.076	0.02729	0.126	0.05733	0.176	0.09307	0.226	0.13311	0.276	0.17644	0.326	0.22228	0.376	0.26998	0.426	0.31897	0.476	0.36871
0.028	0.00619	0.078	0.02836	0.128	0.05866	0.178	0.09460	0.228	0.13478	0.278	0.17823	0.328	0.22415	0.378	0.27192	0.428	0.32095	0.478	0.37071
0.030	0.00687	0.080	0.02943	0.130	0.06000	0.180	0.09613	0.230	0.13646	0.280	0.18002	0.330	0.22603	0.380	0.27386	0.430	0.32293	0.480	0.37270
0.032	0.00756	0.082	0.03053	0.132	0.06135	0.182	0.09767	0.232	0.13815	0.282	0.18182	0.332	0.22792	0.382	0.27580	0.432	0.32491	0.482	0.37470
0.034	0.00827	0.084	0.03163	0.134	0.06271	0.184	0.09922	0.234	0.13984	0.284	0.18362	0.334	0.22980	0.384	0.27775	0.434	0.32689	0.484	0.37670
0.036	0.00901	0.086	0.03275	0.136	0.06407	0.186	0.10077	0.236	0.14154	0.286	0.18542	0.336	0.23169	0.386	0.27969	0.436	0.32887	0.486	0.37870
0.038	0.00976	0.088	0.03387	0.138	0.06545	0.188	0.10233	0.238	0.14324	0.288	0.18723	0.338	0.23358	0.388	0.28164	0.438	0.33086	0.488	0.38070
0.040	0.01054	0.090	0.03501	0.140	0.06683	0.190	0.10390	0.240	0.14494	0.290	0.18905	0.340	0.23547	0.390	0.28359	0.440	0.33284	0.490	0.38270
0.042	0.01133	0.092	0.03616	0.142	0.06822	0.192	0.10547	0.242	0.14666	0.292	0.19086	0.342	0.23737	0.392	0.28554	0.442	0.33483	0.492	0.38470
0.044	0.01214	0.094	0.03732	0.144	0.06963	0.194	0.10705	0.244	0.14837	0.294	0.19268	0.344	0.23927	0.394	0.28750	0.444	0.33682	0.494	0.38670
0.046	0.01297	0.096	0.03850	0.146	0.07103	0.196	0.10864	0.246	0.15009	0.296	0.19451	0.346	0.24117	0.396	0.28945	0.446	0.33880	0.496	0.38870
0.048	0.01382	0.098	0.03968	0.148	0.07245	0.198	0.11023	0.248	0.15182	0.298	0.19634	0.348	0.24307	0.398	0.29141	0.448	0.34079	0.498	0.39070
0.050	0.01468	0.100	0.04087	0.150	0.07387	0.200	0.11182	0.250	0.15355	0.300	0.19817	0.350	0.24498	0.400	0.29337	0.450	0.34278	0.500	0.39270

And A factor you can obtain as 0.3847 so that you can consider over here. SA dash you can obtain as 703.03 which is slightly higher than this. So, we again have 0.8% error, but this is acceptable because it is slightly higher than the required value. If we are able to match SA dash completely with SA so that; will give the perfect design. However, in this case if we are not able to find that we should at least remain at higher side because SA dash can never be less than SA.

However, the value of SA dash equal to 693 will not work where though here we have lesser error. So, error is 0.5%, but still that we cannot consider we will consider this. However, when the h / Ds value is lying between two values where value of A is not available you can simply interpolate between two values to get the exact SA dash value which must be equal to SA.

So, now as far as final shell diameter is concerned that should be 42.749 inch. So, in this way you have to take iterative procedure to find out shell diameter of kettle reboiler. So, here we have end of the example 5 and now we will consider example 6 in which we are going to consider vertical thermosyphon reboiler.

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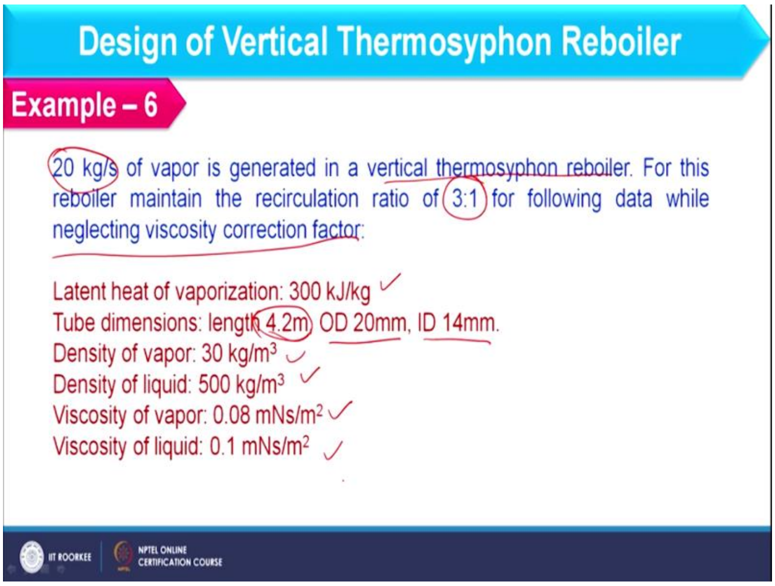

So, this example says that we have 20 kg per second vapour which is to be generated in vertical thermosyphon reboiler and here we are supposed to maintain the recirculation ratio as 3 is to 1 and for this calculation we have to neglect viscosity correction factor. So, you see we are given the latent heat of vapourization and tube dimensions like 4.2 meter length, OD 20 mm and ID 14 mm.

Density of the vapour as 30 kg per meter cube, density of the liquid 500 kg per meter cube, viscosity of vapour and liquid are shown like this. So, we have to maintain the recirculation ratio to generate vapour with the rate of 20 kg per second. So, let us start the solution of this problem.

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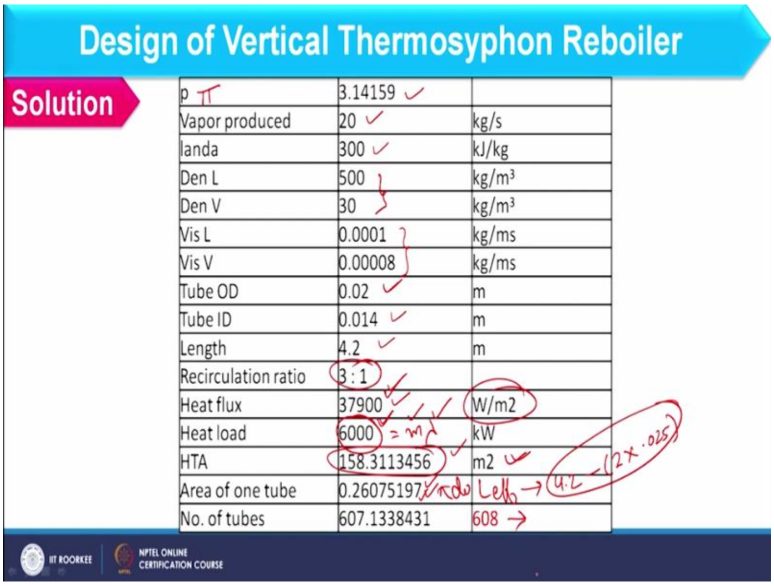

So, here you see we are given p, but this is basically the pi value and pi value I am considering as 3.14159 and as far as vapour production is concerned that is 20 kg per second, lambda we are given as 300 so density values are given like this and similarly we are given the viscosities of liquid as well as vapour, tube OD is given as 20 mm and tube ID is 14 mm, length of the tube is 4.2 meter.

And recirculation ratio we are given as 3 is to 1. So as far as heat flux is concerned, we should consider the maximum heat flux and it is basically 37,900 watt per meter square. So, first of all we have to find out the heat duty and this heat duty will be nothing, but m into lambda. So, 20 kg per second and 300 is the latent heat. So 6,000 kilowatt is the heat duty which is available for this vertical thermosyphon reboiler.

Heat transfer area we can obtain by simply dividing this heat duty by this heat flux. So, 158.311 meter square is the heat transfer area. Further, we can consider area of one tube and that should be pi d 0 L effective. L effective is 4.2 which is the length of the tube and we need to deduct twice into tube sheet thickness and that should be 0.025. So, in this way you can find out L effective and we can have area of one tube as 0.2608.

And division of this with this gives the number of tubes as 607.13 which we can consider as 608. So, in this way you can obtain total number of tubes and as I have told you previously also that number of tubes will be even or odd it is immaterial as far as vertical thermosyphon reboiler design is considered because here we always consider 1-1 pass. So, the next step is we have to find out the desired pressure drop.

And desired pressure drop means pressure drop due to friction in tube side and pressure drop due to static head in tube side. So, till now you must be aware about the procedure to calculate the pressure drop. In tube side, we calculate pressure drop due to friction at entry condition and at exit condition and that should be average to find out pressure drop due to friction inside the tube.

Actually when I am considering that pressure drop due to friction what I am doing basically? I am calculating this at entry point and at exit point. So, when I am considering at entry point I am considering total density of liquid because at that time total feed is in liquid phase. So, that pressure drop I am considering throughout the length. So, what basically I am assuming? I am assuming that in the tube once complete liquid is flowing.

And further in the tube complete mixture is flowing. Therefore, at inlet condition or exit condition we consider total length of the tube. We have not considered perimetry or above area only, we have not considered perimetry or above length or below length like that. We have considered total length therefore we are considering that whatever condition I am saying either it is exit condition or at entry condition, at that condition fluid of that type is flowing throughout the tube.

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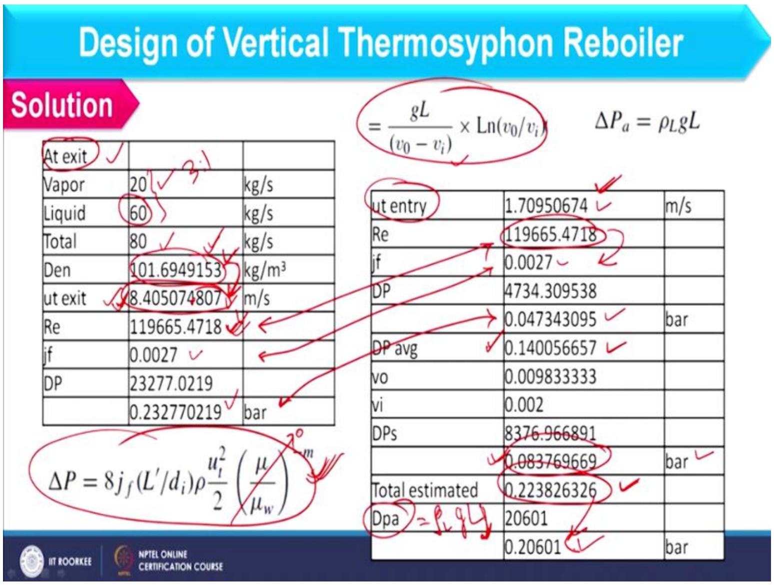

So, at exit condition we have vapour of 20 kg per second 3 is to 1 is the required recirculation ratio. So, liquid value should be 60 kg per second and total of this is 80 kg per second which is the feed. So, at exit condition we have to find out density and that density should be corresponding to the mixture which is coming out as 101.695 kg per meter cube and this calculation is shown in 31st lecture you can refer that.

And further we have to find out ut that is the tube velocity at exit condition and here we are considering this density. So, total mass flow rate you know that will be 80 kg per second. However, density we are considering of mixture. So, velocity at exit condition you can find as 8.405 meter per second. So, once I am having this velocity we can find out Reynolds number considering this velocity as well as density of the mixture and viscosity of the liquid because liquid is available in more amount.

And as far as viscosity is concerned that will be dominant by the viscosity of the liquid. So, we have calculated the Reynolds number accordingly which is coming out as 1.197 into 10 is to the power 5. So, corresponding to Reynolds number this we can find out jf factor from the respective graph and its value comes as 2.7 into 10 is to the power – 3. So, considering this expression and neglecting viscosity correction factor you can find out pressure drop at exit condition which is coming out as 0.233 bar.

Similarly, we can find out pressure drop at entry condition where first of all we have to find out the velocity and considering density of the liquid at entry condition we find out velocity of the liquid as 1.71 meter per second and so the Reynolds number we can obtain which is same as this. So, that is 1.197 and based on that we can find out jf value which is also equal to the jf which we have already seen previously.

So, its value is 2.7 into 10 is to the power – 3 considering this expression and this velocity you can find out pressure drop at entry condition which is basically 0.047 bar. So, now we have to take the average of these two values and it gives the pressure drop due to friction in tube side and the value comes as 0.14 bar and next we have to find out pressure drop due to static head, expression is given here.

And you know v 0 and v i that is the reciprocal of densities. So, considering all these we can find out pressure drop due to static head and it is 0.0838 bar and further we can add this value as well as this value. So, it will give me the total pressure drop in tube side which is coming as 0.22 bar and next we have to find out available pressure drop that would be equal to rho L gL where this L is basically the length of the tube.

So, considering all these parameter we can find pressure drop available in distillation column side as 0.206 bar. So, this value is coming lesser than this value. So, here we can consider that recirculation ratio is not maintained and further we will revise the calculation with the new flux value.

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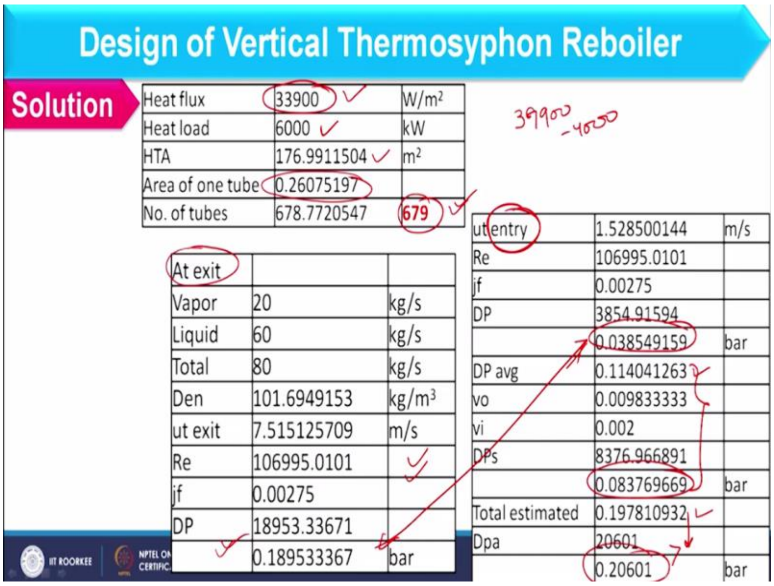

So, now the flux value we are considering as 33,900 previously it was 37,900 and we have reduced 4,000 from this and we can obtain revised heat flux as 33,900 and why it is so? Because if you compare these two values the available pressure drop is not very less in comparison to pressure drop in the tube side. So, we have to reduce small value from the flux. Though we are reducing 4,000, but still it is small.

So, in that case heat load will be same, heat transfer area we can obtain as 176.99 meter square, area of one tube we have already calculated previously and now the number of tubes we can obtain as 679 and this is the odd value, but we can take this as it is and further at exit condition when we calculate pressure drop due to friction we can find the value as 0.1895 bar.

I am not going into detail of this because methods I have already explained previously. So, at entry condition we can find out pressure drop due to friction as 0.0385 bar. So, average of this as well as average of this will give the total pressure drop due to friction in tube side which is coming out as 0.114. Static head will remain same and that should be 0.084 bar and addition of these two will give the total pressure drop in tube side which is coming out as 0.197, available pressure drop will also be same and that should be 0.206.

So, here you can find that available pressure drop is greater than this value and therefore the recirculation ratio of 3 is to 1 can be maintained. So, in this way you have to reduce the flux and maintain the recirculation ratio. So, here we have solved few more examples.

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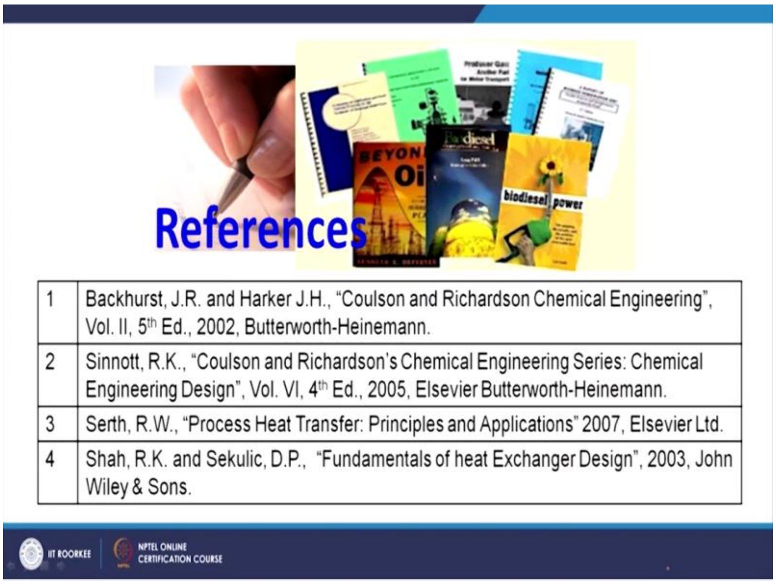

And now we have the references.

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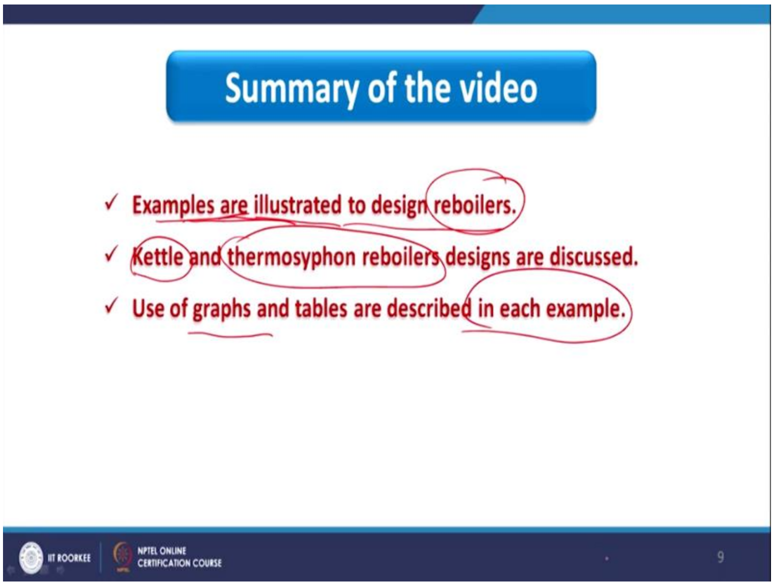

And further I am going to summarize the video and this is the summary of video 31, 32 and 33 lectures. So, here we have considered examples and these examples are solved to illustrate the design of reboilers. And as far as reboilers are concerned we have designed kettle reboiler and vertical thermosyphon reboiler, but not the horizontal thermosyphon reboiler as well as forced circulation reboiler.

And further through these examples, we have discussed the use of graphs and tables in detail and wherever these graphs and tables are appearing. So, that is all for now. Thank you.