

**Process Equipment Design**  
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**Lecture –31**  
**Design of Reboiler-5**

Hello everyone. I welcome you all in 7th week of the course Process Equipment Design. If you remember the 6th week of this course there we have discussed design of reboilers and as far as design is concerned we have considered detailed design of kettle reboiler as well as vertical thermosyphon reboiler and we have classified the reboilers and further we have seen that how to select the proper reboiler according to the operating conditions.

So, in this lecture we will discuss design of reboiler with some example so that you can understand the procedure for designing of these reboilers properly. So, here again we will discuss design of kettle reboiler as well as thermosyphon reboiler. So, let us start with example 1.

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**Design of Kettle Reboiler**

**Example – 1**

Design a kettle reboiler to vaporise chlorine available at  $10^{\circ}\text{C}$  and 5 bar pressure. The boiling point of chlorine is  $10^{\circ}\text{C}$ . The heating fluid is water available at  $50^{\circ}\text{C}$  and to be cooled up to  $30^{\circ}\text{C}$ . The latent heat of chlorine is  $260\text{ kJ/kg}$ . The mass flow rate of chlorine vapor generated is  $15000\text{ kg/hr}$ . Critical pressure of liquid is  $8.54\text{ bar}$ . ✓

Assume  $U$  as  $900\text{ W/m}^2\text{C}$ , ID of tube as  $21\text{ mm}$ , OD of tube as  $25.4\text{ mm}$  U-tube type, length of tube as  $12\text{ m}$ ,  $31.75\text{ mm}$  square pitch, thermal conductivity of chlorine as  $8.9 \times 10^{-3}\text{ W/m}^{\circ}\text{C}$ , density of liquid and vapor chlorine as  $1562.5\text{ kg/m}^3$  and  $16.3\text{ kg/m}^3$ , specific heat as  $0.946\text{ kJ/kg}^{\circ}\text{C}$ , viscosity as  $0.325\text{ cP}$  and surface tension as  $0.13\text{ N/m}$ . ✓

1 inch  
1.25 OD



So, you see in this example we have to design a kettle reboiler to vapourize chlorine which is available at  $10^{\circ}\text{C}$  and which is available at 5 bar pressure. Boiling point of the chlorine is  $10^{\circ}\text{C}$ . So, you see here boiling point of the chlorine as well as chlorine availability both are at same temperature and that is boiling point. What is the meaning of this that when the chlorine is entering into the kettle reboiler no sensible heating is required only the vapourization will take place.

So, to heat the chlorine we use water which is available at 50 degree Celsius and which is cooled up to 30 degree Celsius by providing its heat to the chlorine. So, latent heat of chlorine is 260 kilojoule per kg and mass flow rate of chlorine vapour generated is 15,000 kg per hour. So, you see here we have to generate 15,000 kg per hour of chlorine vapour with the help of water.

Usually we consider steam as a heating media, but in this case because chlorine boiling point temperature is very low so we can use any other heating source and for that purpose water we are using. And as far as critical pressure of the liquid is concerned that is basically 8.54 bar and this is the critical pressure for chlorine. And further we are assuming that initial overall heat transfer coefficient is 900, ID of the tube is 21 mm, OD of the tube is 25.4 mm.

So, if you know this value this is nothing, but 1 inch. And we are using U tubes and length of each tube is 12 meter. So this 12 meter is the total length of the U tube and further we have 31.75 mm square pitch. So, if you see what is the relation in pitch as well as OD. So, if you consider this it is nothing, but 1.25 into OD. So, this is 1.25 OD and arrangement is square. And further we have thermal conductivity of the chlorine as  $8.9 \times 10^{-3}$  watt per meter degree Celsius.

Density of liquid and vapour chlorine are given like this and this. Further, we have specific heat of the chlorine like this, viscosity is given and finally we have the surface tension so you see all properties are given to us. So, let us start the design of kettle reboiler. Now, if you recall the lectures which we have covered in 6th week and if you recall the design procedure for kettle reboiler what is the first step? The first step is obviously to find out heat duty.

In fact, whatever heat transfer equipment we have discussed so far as for a shell and tube heat exchanger is concerned condenser and now we are discussing the reboiler. The first step in each case is to find out the heat duty because complete design depends on that how much heat duty we are dealing with. So, in the case of reboiler heat duty you can find out depending upon how much vapour you are generating.

So, in this problem around 15,000 kg per hour of vapour of chlorine is generated and latent heat of the chlorine is given to us. So, we can simply multiply them to find out heat duty.

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Design of Kettle Reboiler

Solution

$$\text{Duty} = \frac{15000 \times 260}{3600} = 1083.33 \text{ kW}$$

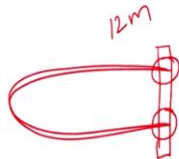
$$\text{LMTD} = \frac{40-20}{\ln\left(\frac{40}{20}\right)} = 28.854^\circ\text{C}$$



$$U = 900 \text{ W/m}^2\text{ }^\circ\text{C}$$

$$A = \frac{Q}{U \times \text{LMTD}} = \frac{1083.33 \times 10^3}{900 \times 28.854} = 41.717 \text{ m}^2$$

$$\text{No. of holes} = \frac{A}{\pi \times d_o \times t} = \frac{41.717}{\pi \times 25.4 \times 10^{-3} \times (6 - 0.0254)} = 87.50 \approx 88$$

$$\text{No. Tubes} = \frac{88}{2} = 44$$



So, if you consider here heat duty is 1083.33 kilowatt where 15,000 kg per hour and that we have converted into seconds and 260 was the latent heat if you recall the example. Further, we have to find out log mean temperature difference because if you consider the temperature profile in chlorine side chlorine is entering at 10 degree Celsius and that is nothing, but the boiling point of the chlorine.

So we have isothermal condition in shell side where boiling is taking place. However, in tube side we have variation in temperature from 50 to 30 where water is available. So, you see in this case we will never come across a situation where temperature cross will take place. So, here only LMTD will work without considering F t correction factor and you know that how to find out LMTD and the value of that LMTD is 28.854.

So, I know the heat duty, I know LMTD value and overall heat transfer coefficient initial guess is given to us as 900 watt per meter square degree Celsius. So, we can simply find out heat transfer area. So, as far as heat transfer area is concerned we can use this expression and putting values of these parameters we can find out heat transfer area as 41.717 meter square. So, once I am having the heat transfer area we should find out the number of tubes.

And for that purpose we can have two procedures. First is if I am considering total length of the tube this is the U tube which enters twice into tube sheet. So, if you see if here tube sheet is there and this is basically the U tube and total length of the U tube is given as 12 meter so

that is the complete length which enters twice into tube sheet. So, if I have to find out effective length we have to deduct thickness of tube sheet into 2 from the total length.

However, you can have a different approach here also like if I consider half length of the tube and that should be 6 meters and if I am considering that length it will enter only once to the tube sheet. So, in that way I have find out the heat transfer area of a single tube and then we can find out number of tubes so let us see. Now as far as area of single tube is concerned that should be  $\pi d_o L_{\text{effective}}$ .

So  $d_o$  is given to us as 1 inch or 25.4 mm and this is nothing, but the effective length where I have considered half of the length and this is basically tube sheet thickness. Usually we consider tube sheet thickness as 25 mm, but here because OD of the tube is more than 25 mm we should consider OD of the tube is equal to tube sheet thickness. So, in this way we have found out tube sheet thickness as 25.4 mm.

So, considering all these values as well as total heat transfer area we can find out number of tubes as 87.5 which should be 88. Now what is this 88 is number of tube or number of holes? If I am considering half of the length that is the length of 1 lakh of U tube it means whatever number of tubes I am considering that is nothing, but the number of holes because so many holes I have to make in tube sheet.

Now, if I consider the number of U tube that should be just half of the number of holes. Otherwise what you could do 12 meter was the total length you should deduct twice of tube sheet thickness from that length and you can find out number of tubes and whatever number of tubes you can obtain just multiply that by 2 to find out number of holes. So, in that way we can carry out the calculation.

Now, once I am having number of tube what is the next step? If you recall the procedure of kettle reboiler we have to find out actual tube count and so the bundle diameter and as far as actual tube count is concerned we have to refer certain standard tables and these tables are table C series which is available in R.W. Serth book in appendix C.

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## Design of Kettle Reboiler

### Solution

$$\text{Duty} = \frac{15000 \times 260}{3600} = 1083.33 \text{ kW}$$

$$\text{LMTD} = \frac{40 - 20}{\ln\left(\frac{40}{20}\right)} = 28.854^\circ\text{C}$$

$$U = 900 \text{ W/m}^2\text{ }^\circ\text{C}$$

$$A = \frac{Q}{U \cdot \text{LMTD}} = \frac{1083.33 \times 10^3}{900 \times 28.854} = 41.717 \text{ m}^2$$

$$\text{No. of holes} = \frac{A}{\pi \cdot d_o \cdot l} = \frac{41.717}{\pi \times 25.4 \times 10^{-3} \times (6 - 0.025)} = 87.50 = 88$$

$$\text{No. Tubes} = \frac{88}{2} = 44$$

Table C.1 Tube Counts for 5/8-in. OD Tubes on 13/16-in. Square Pitch

Shell ID (in.)	TEMA P or S				TEMA U			
	Number of passes				Number of passes			
	1	2	4	6	2	4	6	
8	55	48	34	24	52	40	32	
10	88	78	62	56	90	80	74	
12	140	138	112	100	140	128	108	
13.25	178	172	146	136	180	164	148	
15.25	245	232	208	192	246	232	216	
17.25	320	308	274	260	330	312	292	
19.25	405	392	352	336	420	388	368	
21.25	502	484	442	424	510	488	460	
23.25	610	584	536	508	626	596	562	
25	700	676	618	600	728	692	644	
27	843	812	742	716	856	816	780	
29	970	942	868	840	998	956	920	
31	1127	1096	1014	984	1148	1108	1060	
33	1288	1250	1172	1148	1318	1268	1222	
35	1479	1438	1330	1308	1492	1436	1388	
37	1647	1604	1520	1480	1684	1620	1568	
39	1840	1794	1700	1664	1882	1816	1754	
42	2157	2112	2004	1968	2196	2136	2068	
45	2511	2458	2326	2288	2530	2464	2402	
48	2865	2808	2686	2656	2908	2832	2764	
54	3656	3600	3462	3404	3712	3624	3556	
60	4538	4472	4310	4256	4608	4508	4426	

So, let us see table C 1 first. So, if you focus on table C 1 it is given tube count for 5 / 8 inch OD tubes on 13 / 16 inch square pitch. So, if you see OD of the tube is not 1 inch as we are given in this problem so this table will not work for me.

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## Design of Kettle Reboiler

### Solution

$$\text{Duty} = \frac{15000 \times 260}{3600} = 1083.33 \text{ kW}$$

$$\text{LMTD} = \frac{40 - 20}{\ln\left(\frac{40}{20}\right)} = 28.854^\circ\text{C}$$

$$U = 900 \text{ W/m}^2\text{ }^\circ\text{C}$$

$$A = \frac{Q}{U \cdot \text{LMTD}} = \frac{1083.33 \times 10^3}{900 \times 28.854} = 41.717 \text{ m}^2$$

$$\text{No. of holes} = \frac{A}{\pi \cdot d_o \cdot l} = \frac{41.717}{\pi \times 25.4 \times 10^{-3} \times (6 - 0.025)} = 87.50 = 88$$

$$\text{No. Tubes} = \frac{88}{2} = 44$$

Table C.2 Tube Counts for 3/4-in. OD Tubes on 15/16-in. Triangular Pitch

Shell ID (in.)	TEMA L or M				TEMA P or S				TEMA U			
	Number of passes				Number of passes				Number of passes			
	1	2	4	6	1	2	4	6	2	4	6	
8	64	48	34	24	34	32	16	18	32	24	24	
10	85	72	52	50	60	62	32	44	64	52	52	
12	122	114	94	96	109	98	78	68	98	88	78	
13.25	151	142	124	112	128	129	106	100	128	116	108	
15.25	204	192	166	168	183	168	146	136	180	160	148	
17.25	264	254	228	220	237	228	202	192	238	224	204	
19.25	332	326	290	280	297	286	258	248	298	280	262	
21.25	417	396	364	348	372	356	324	316	370	352	334	
23.25	495	478	430	420	450	430	392	376	456	428	408	
25	579	564	512	498	518	498	456	444	534	500	474	
27	676	648	602	584	618	602	548	532	628	600	570	
29	785	762	704	688	729	708	650	624	736	696	666	
31	909	878	814	792	843	812	744	732	846	812	780	
33	1035	1002	944	920	962	934	868	840	978	928	904	
35	1164	1132	1062	1036	1090	1064	990	972	1100	1060	1008	
37	1304	1270	1200	1168	1233	1196	1132	1100	1258	1200	1152	
39	1460	1422	1358	1320	1365	1326	1264	1244	1390	1336	1290	
42	1703	1664	1578	1532	1611	1560	1498	1464	1632	1568	1524	
45	1960	1918	1820	1800	1875	1834	1756	1708	1882	1820	1770	
48	2242	2196	2106	2080	2132	2100	1998	1964	2152	2092	2044	
54	2861	2804	2682	2660	2730	2684	2574	2536	2748	2680	2628	
60	3627	3476	3260	3200	3295	3245	3228	3196	3420	3340	3286	
66	4292	4228	4088	4044								
72	5116	5044	4902	4868								
78	6034	5964	5786	5740								
84	7005	6934	6760	6680								
90	8093	7998	7832	7758								
96	9203	9114	8956	8884								
108	11696	11618	11336	11268								
120	14409	14378	14080	13984								

So, let us focus on other tables. So, here I am having table C 2 which says that tube OD is 3 / 4 inch and 15 / 16 inch triangular pitch. So, it will also not work for me.

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## Design of Kettle Reboiler

### Solution

$$\text{Duty} = \frac{15000 \times 260}{3600} = 1083.33 \text{ kW}$$

$$\text{LMTD} = \frac{40 - 20}{\ln\left(\frac{40}{20}\right)} = 28.854^\circ\text{C}$$

$$U = 900 \text{ W/m}^2 \text{ } ^\circ\text{C}$$

$$A = \frac{Q}{U \times \text{LMTD}} = \frac{1083.33 \times 10^3}{900 \times 28.854} = 41.717 \text{ m}^2$$

$$\text{No. of holes} = \frac{A}{\pi \times d_o \times l} = \frac{41.717}{\pi \times 25.4 \times 10^{-3} \times (6 - 0.025)}$$

$$= 87.50 = 88$$

$$\text{No. Tubes} = \frac{88}{2} = 44$$

Table C.3 Tube Counts for 3/4-in. OD Tubes on 1-in. Square Pitch

Shell ID (in.)	TEMA P or S				TEMA U			
	Number of passes				Number of passes			
	1	2	4	6	2	4	6	
8	28	26	16	12	28	24	12	
10	52	48	44	24	52	44	32	
12	80	76	66	56	78	72	70	
13 1/4	104	90	70	80	96	92	90	
15 1/4	136	128	128	114	136	132	120	
17 1/4	181	174	154	160	176	176	160	
19 1/4	222	220	204	198	224	224	224	
21 1/4	289	272	262	260	284	280	274	
23 1/4	345	332	310	308	348	336	328	
25	398	386	366	344	408	392	378	
27	477	456	432	424	480	468	460	
29	554	532	510	496	562	548	530	
31	637	624	588	576	648	636	620	
33	730	712	682	668	748	728	718	
35	828	812	780	760	848	820	816	
37	937	918	882	872	952	932	918	
39	1048	1028	996	972	1056	1044	1020	
42	1224	1200	1170	1140	1244	1224	1212	
45	1421	1394	1350	1336	1436	1408	1398	
48	1628	1598	1548	1536	1640	1628	1602	
54	2096	2048	2010	1992	2108	2084	2068	
60	2585	2532	2512	2476	2614	2584	2558	

And then we will focus on table C 3. So, if you see the table C 3 it is for 3 / 4 inch OD and 1 inch square pitch. So, here this also will not work for me.

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## Design of Kettle Reboiler

### Solution

$$\text{Duty} = \frac{15000 \times 260}{3600} = 1083.33 \text{ kW}$$

$$\text{LMTD} = \frac{40 - 20}{\ln\left(\frac{40}{20}\right)} = 28.854^\circ\text{C}$$

$$U = 900 \text{ W/m}^2 \text{ } ^\circ\text{C}$$

$$A = \frac{Q}{U \times \text{LMTD}} = \frac{1083.33 \times 10^3}{900 \times 28.854} = 41.717 \text{ m}^2$$

$$\text{No. of holes} = \frac{A}{\pi \times d_o \times l} = \frac{41.717}{\pi \times 25.4 \times 10^{-3} \times (6 - 0.025)}$$

$$= 87.50 = 88$$

$$\text{No. Tubes} = \frac{88}{2} = 44$$

Table C.4 Tube Counts for 3/4-in. OD Tubes on 1-in. Triangular Pitch

Shell ID (in.)	TEMA L or M				TEMA P or S				TEMA U			
	Number of passes				Number of passes				Number of passes			
	1	2	4	6	1	2	4	6	2	4	6	
8	42	40	26	24	31	26	16	12	32	24	24	6
10	73	66	52	44	56	48	42	40	52	48	40	
12	109	102	88	80	88	78	62	68	84	76	74	12
13 1/4	136	128	112	102	121	106	94	88	110	100	98	32
15 1/4	183	172	146	148	159	148	132	132	140	136	136	
17 1/4	237	228	208	192	208	198	182	180	206	188	182	70
19 1/4	295	282	258	248	258	250	228	220	266	248	234	90
21 1/4	361	346	318	320	324	290	276	276	330	316	296	120
23 1/4	438	416	382	372	400	384	352	336	400	384	356	
25	507	486	448	440	450	442	400	392	472	440	424	160
27	592	574	526	516	543	530	488	468	554	528	502	224
29	692	668	632	604	645	618	574	556	648	616	588	274
31	796	774	732	708	741	716	666	648	744	716	688	328
33	909	886	856	812	843	826	760	740	852	816	788	378
35	1023	1002	942	920	950	900	858	856	974	932	908	
37	1155	1124	1058	1032	1070	1052	992	968	1092	1056	1008	460
39	1277	1254	1194	1164	1209	1184	1122	1096	1224	1180	1146	530
42	1503	1466	1404	1372	1409	1378	1314	1296	1434	1388	1350	620
45	1729	1690	1622	1588	1635	1608	1536	1504	1652	1604	1560	718
48	1964	1936	1870	1828	1867	1842	1768	1740	1894	1844	1794	816
54	2519	2466	2380	2352	2399	2366	2270	2244	2426	2368	2326	918
60	3065	3004	2904	2828	2981	2940	2832	2800	3006	2944	2884	1020
66	3709	3722	3618	3576								1112
72	4302	4448	4324	4280								1212
78	5009	5252	5126	5088								1312
84	6162	6398	6264	6200								1412
90	7103	7540	7408	7360								1512
96	8052	8476	8344	8296								1612
108	10040	10206	9992	9940								1812
120	12731	12848	12450	12336								1912

I will focus on table C 4 and it is for 3 / 4 inch OD and 1 inch square pitch. So, obviously this will also not work for me.

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## Design of Kettle Reboiler

### Solution

$$\text{Duty} = \frac{15000 \times 260}{3600} = 1083.33 \text{ kW}$$

$$\text{LMTD} = \frac{40 - 20}{\ln\left(\frac{40}{20}\right)} = 28.854^\circ\text{C}$$

$$U = 900 \text{ W/m}^2\text{ }^\circ\text{C}$$

$$A = \frac{Q}{U \cdot \text{LMTD}} = \frac{1083.33 \times 10^3}{900 \times 28.854} = 41.717 \text{ m}^2$$

$$\text{No. of holes} = \frac{A}{\pi \cdot d_o \cdot l} = \frac{41.717}{\pi \times 25.4 \times 10^{-3} \times (6 - 0.02)}$$

$$= 87.50 = 88$$

$$\text{No. Tubes} = \frac{88}{2} = 44$$

**Table C.5** Tube Counts for 1-in. OD Tubes on 1.25-in. Square Pitch

Shell ID (in.)	TEMA P or S				TEMA U			
	Number of passes				Number of passes			
	1	2	4	6	2	4	6	
8	17	12	8	12	14	8	6	
10	30	30	16	18	30	24	12	
12	52	48	42	24	44	40	32	
13 1/4	61	56	52	50	60	48	44	
15 1/4	85	78	62	64	80	72	74	
17 1/4	108	108	104	96	104	100	100	
19 1/4	144	136	130	114	132	132	120	
21 1/4	173	166	154	156	172	168	148	
23 1/4	217	208	194	192	212	204	198	
25	252	240	230	212	244	240	230	
27	296	280	270	260	290	284	274	
29	345	336	310	314	340	336	328	
31	402	390	366	368	400	384	372	
33	461	452	432	420	456	444	440	
35	520	514	494	484	518	504	502	
37	588	572	562	548	584	576	566	
39	661	640	624	620	664	644	640	
42	776	756	738	724	764	748	750	
45	900	882	862	844	902	880	862	
48	1029	1016	984	972	1028	1008	1004	
54	1310	1296	1268	1256	1320	1296	1284	
60	1641	1624	1598	1576	1634	1616	1614	

And further we have table C 5 where OD is 1 inch and 1.25 inch square pitch is given. So, as per the specification this table is suitable for me. So, let us see the actual tube count in this table. Here, I am having U tube and number of tubes we have obtained as 44 and passes are 2. So, if you see here I am having 44 tubes. So, in this case whatever number of tubes we have calculated the same number of tube is available in standard table.

Otherwise what you could do whatever number of tubes you will obtain just take next value which is available in this table. In this table means table C series. So, here I am having 44 tubes and corresponding to this 44 tube shell ID is given as 12 inches and as you remember the last week lectures the bundle diameter should be slightly lesser than the shell dia and for that purpose we usually deduct 0.25 inches from this shell ID.

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## Design of Kettle Reboiler

### Solution

$$\text{Duty} = \frac{15000 \times 260}{3600} = 1083.33 \text{ kW}$$

$$\text{LMTD} = \frac{40 - 20}{\ln\left(\frac{40}{20}\right)} = 28.854^\circ\text{C}$$

$$U = 900 \text{ W/m}^2\text{ }^\circ\text{C}$$

$$A = \frac{Q}{U \cdot \text{LMTD}} = \frac{1083.33 \times 10^3}{900 \times 28.854} = 41.717 \text{ m}^2$$

$$\text{No. of holes} = \frac{A}{\pi \cdot d_o \cdot l} = \frac{41.717}{\pi \times 25.4 \times 10^{-3} \times (6 - 0.0254)}$$

$$= 87.50 = 88$$

$$\text{No. Tubes} = \frac{88}{2} = 44$$

Take 1-2 pass

P = 1.25 for square pitch

P = 31.75 mm Shell id = 12 in

Bundle dia =  $12 - 0.25 = 11.75$  in

≈ 298.45 mm



So, considering this we can find out bundle diameter as 12 inch – 0.25 so that is 11.75 inches conversion you can make in mm. So, in this way we can find out bundle diameter. So, next step is to find out heat transfer coefficient in shell side as well as in tube side. So, if you remember the heat transfer mechanism that is nothing, but the pool boiling. So, we will consider nucleate boiling correlation over here and in this problem we are given the critical pressure. So, accordingly we will choose the expression.

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**Design of Kettle Reboiler**

**Solution**

$$h_{nb} = 0.014 (P_c)^{0.69} (q)^{0.7} \left[ 1.8 \left( \frac{P}{P_c} \right)^{0.17} + 4 \left( \frac{P}{P_c} \right)^{1.2} + 10 \left( \frac{P}{P_c} \right)^{10} \right]$$

$$h_{nb} = 0.014 (8.54)^{0.69} \left( \frac{1083.33 \times 10^3}{41.717} \right)^{0.7} \left[ 1.8 \left( \frac{5}{8.54} \right)^{0.17} + 4 \left( \frac{5}{8.54} \right)^{1.2} + 10 \left( \frac{5}{8.54} \right)^{10} \right]$$

$$m\lambda = mC_p dT$$

$$(1/3600) \times 15000 \times 260 = m_w \times 4.187 \times 20$$

$$m_w = 12.958 \text{ kg/sec}$$

$$\text{Tube cross sectional area} = \frac{\pi}{4} \times (21 \times 10^{-3})^2 \times 44 = 0.01524 \text{ m}^2$$

$$\text{Velocity} = \frac{12.958}{10^3 \times 0.01524} = 0.85 \text{ m/sec}$$

$= 2133.3 \text{ W/m}^2\text{°C}$

So, here we have the expression depending upon the critical pressure as well as the operating pressure along with the flux. So, what is this flux? This flux is nothing, but the heat duty divided by the heat transfer area. In this case whatever number of tubes you have obtained the same number of tube you can find in standard table C. However, if it will not happen then what you have to do?

If whatever number of tube you will see in table C that number of tubes are more than whatever you have calculated, so in that case you have to find out revised area. Revised area how you can find out because you know the area of one tube into number of tubes. So, based on that revised area you should consider and accordingly you have to find out the flux. Flux calculation is very simple heat duty divided by heat transfer area.

So, here I am having flux as 1083.33 into 10 is to the power 3 watt divided by the heat transfer area. So, this is the simple calculation for flux. Critical pressure for chlorine is given to us and operating pressure also. So considering these parameters you can find out  $h_{nb}$



value which should come as 2133.3 watt per meter square degree Celsius sorry I forget to write the value over here, but you can see the value as like this.

Now once you have the heat transfer coefficient in shell side we have to find out heat transfer coefficient in tube side where water is flowing. So, a particular expression related to water is known to you, you have to find out velocity and for that you have to find out area per pass and then you can find out heat transfer coefficient in tube side. So, let us start the calculation for that.

And here first of all we have to find out the flow rate of water and that we can find out by making energy balance simply. So, mass flow rate of water you can obtain as 12.958 kg per second and tube cross sectional area how you can find out you already know the internal diameter of the tube and  $\pi / 4$  into  $d_i$  square should be the cross sectional area of one tube into number of tubes you already know.

So, area per pass is like 0.01524 meter square. Now once you have this mass flow rate you can find out volumetric flow that should be divisible by area per pass and then you can find out velocity as 0.85 meter per second. So, here whatever velocity you will obtain just take this value as it is. We should not meet that in a permissible limit because we are dealing with 1-2 pass.

And usually in kettle reboiler passes are 1-2 if you recall the design procedure. So, in this way we can find out the velocity.

**(Refer Slide Time: 17:56)**

**Design of Kettle Reboiler**

**Solution**

$$h_i = \frac{4200 (1.35 + 0.02 \cdot 40) \cdot 0.85^{0.8}}{21^{0.2}} = 4312.996 \frac{\text{W}}{\text{m}^2 \text{ } ^\circ\text{C}}$$

$$\frac{1}{U_0} = \frac{25.4}{21} + \frac{1}{4312.996} + \frac{1}{2133.3} + \frac{25.4 \cdot 10^{-3} \ln\left(\frac{25.4}{21}\right)}{2k_w}$$

$$U_0 = 1334.76$$

$$\% \text{ Error} = \frac{1334.76 - 900}{900} = 48.3\%$$

Repeat all steps by taking  $U_0 = 1334.76 \text{ W/m}^2 \text{ } ^\circ\text{C}$

$$q_{cb} = k_b \left( \frac{p_t}{d_o} \right) \left( \frac{\lambda}{\sqrt{N_t}} \right) [\sigma g (\rho_L - \rho_v) \rho_v^2]^{0.25}$$

$$q_{cb} = 0.44 \left( \frac{81.75}{25.4} \right) \left( \frac{260 \cdot 10^3}{\sqrt{88}} \right) [0.13 \cdot 9.81 (1562.5 - 16.3) 16.3^2]^{0.25} = 410117.22 = 410.117 \text{ kW}$$

And so I can find out heat transfer coefficient in tube side considering this expression and so the value comes out as 4312.996 watt per meter square degree Celsius. So, as you have the value of  $h_i$  as well as  $h_o$  you can find out overall heat transfer coefficient calculation and in this problem dirt factors of two fluids are not given to us along with this thermal conductivity of tube material is also not known to me.

So, we will eliminate the three terms considering dirt factor as well as thermal conductivity of the material. So, based on these two term which includes  $h_i$  as well as  $h_o$  we can find out overall heat transfer coefficient value as 1334.76 watt per meter square degree Celsius and when you compare this with the initial guess you can find error as 48.3% which is more than plus minus 30%.

So, ideally we should take a repetition of all values depending upon  $U$  value as 1334.76, but for now we are considering the same problem and we are proceeding further because this is the repeat calculation and I hope you can do that calculation on your own, but in ideal case we should take the repeat. So, for now we are considering same value of  $U_0$  as we have obtained and next step is to check critical flux value.

So, to find critical flux value we will use this expression where  $q_{cb}$  is the critical flux in kettle reboiler and here you see all parameters so  $k_b$  value should be 0.44 and  $p_t$  is the pitch and  $d_o$  is the OD of the tube, values you know already and here we have to see that what is the  $N_t$ ?  $N_t$  is usually we represent for number of tubes, but here I am considering  $N_t$  as number of holes.

So, here  $N_t$  value should be 88 as you can see here. So, considering all these values we can find out critical heat flux as 410.117 kilowatt per meter square also.

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Design of Kettle Reboiler

Solution

$q < 0.7 (410.117)$  ✓  
 $\therefore q < 287.0819$  ✓  
 $q = 25.968$  ✓

$VL = 2290 \rho_v \left( \frac{\sigma}{\rho_l - \rho_v} \right)^{0.5}$  ✓

$VL = 2290 * 16.3 \left( \frac{0.13}{1562.5 - 16.3} \right)^{0.5} = 342.264$  ✓

$SA = \frac{\dot{m}}{L * VL} = \frac{15000}{3600 * (6 - 0.0254) * 342.264}$  ✓  
 $SA = 2.0376 * 10^{-3} m^2$  ✓

$D_b' = D_b + 4 \text{ in}$   
 $= 11.75 + 4 = 15.75 \text{ in}$   
 $= 400.05 \text{ mm}$

$\frac{h}{D_s} = 0.4$

$D_s = \frac{D_b'}{0.6} = \frac{15.75}{0.6}$   
 $D_s = 26.25 \text{ in} = 666.75 \text{ mm}$

$\frac{h}{D_s} = 0.4$   
 $A = 0.29337$

And what is the criteria for critical heat flux that the system heat flux should be less than 70% of critical heat flux. So, we should find out critical heat flux limit and that should be 0.7 into 410.117 so 287.0819 and system flux is this which is 25.968 kilowatt per meter square. So, you see the condition is satisfied here and next step is to find out the shell dia of kettle reboiler because here I am using special kind of shell.

And to design the shell diameter we have to first find out that how much vapour we are considering and how much segment area we want and to find out the segment area we also have to compute the vapour loading. So, first see the calculation of vapour loading. As far as the expression is concerned it is like this. And considering surface tension, densities of liquid and vapour and density of vapour over here we can find out vapour loading as 342.264 kg per second meter cube that is the unit of vapour unit VL.

So, once I am having the VL value we can find out the segment area as  $\dot{m} / L$  into VL. So  $\dot{m}$  you know already that is 15,000 kg per hour of chlorine vapour we are generating so that should be converted into per second also. And here we have this L is basically L effective and here you should also keep in mind that L is basically the length of tube bundle this is not the length of tube because for U tube length is 12 feet. But here we are considering only 6 meter because that is the length of the bundle.

So in SA you should consider  $L$  effective as length of the bundle not the length of the tube. So, in this case  $L$  effective should be  $6 - 0.0254$  and vapour loading we can consider to find out segment area which comes as  $2.0376$  into  $10$  is to the power  $-3$ .

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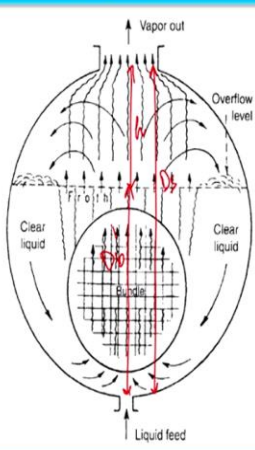
Design of Kettle Reboiler

**Solution**

$q < 0.7 (410.11)$   
 $\therefore q < 287.081$   
 $q = 25.968$

$VL = 2290 \rho_v \left( \frac{\rho}{\rho_v} \right)$   
 $VL = 2290 * 16.$

$SA = \frac{\dot{m}}{L * VL} = 2.0$





$D_b' = D_b + 4 \text{ in}$   
 $= 11.75 + 4 = 15.75 \text{ in}$   
 $= 400.05 \text{ mm}$

$\frac{h}{D_s} = 0.4$  ✓

$D_s = \frac{D_b'}{0.6} = \frac{15.75}{0.6}$  ✓  
 $D_s = 26.25 \text{ in} = 666.75 \text{ mm}$

$\frac{h}{D_s} = 0.4$   
 $A = 0.29337$

So, if I ask you that what is the segment area in kettle reboiler that we can understand with a schematic as shown here. If you see this is the bundle and this is basically the shell diameter and SA is the area of this section. Now, if you focus on this schematic SA can be computed after weir height and for now I only know the bundle diameter so how I can find out weir height.

Weir height can be obtained by adding 4 inches to bundle dia that is the thumb rule. So, this height we can find out and this we represent as  $D_b$  dash. So  $D_b$  dash you can find out as  $11.75 + 4$  inches so  $15.75$  inches you can convert that into mm. Now, to find out shell diameter we have to carry out iterative procedure. And for that purpose we initially assume that the height of segment section divided by the shell dia should be 40% or in other word we can say the height of the segment section is at least 40% of shell dia that is the initial guess.

So, if you consider height segment section so that we represent as  $h$  and this is nothing, but the  $D_s$ . So  $h / D_s$  should be 0.4. Now, if I ask you what should be  $D_b$  dash /  $D_s$ ? Obviously the value will be 0.6 only because  $h + D_b \text{ dash} = D_s$ . So, we can find out shell dia from this that is  $15.75$  divided by  $0.6$  so  $26.25$  inches is the shell dia. So, we have to find out revised segment area and for that purpose we have to find out segment area factor.

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### Design of Kettle Reboiler

**Solution**

$q < 0.7 (410.1)$   
 $\therefore q < 287.08$   
 $q = 25.968$

$VL = 2290 \rho_V$

$VL = 2290 \times 1$

$SA = \frac{\dot{m}}{L \cdot VL}$   
 $= 2$

$h/D$	$A$	$h/D$	$A$	$h/D$	$A$	$h/D$	$A$
11182	0.250	0.13355	0.300	0.19817	0.350	0.24498	0.400
11343	0.252	0.13528	0.302	0.20000	0.352	0.24689	0.402
11504	0.254	0.13702	0.304	0.20184	0.354	0.24880	0.404
11665	0.256	0.13876	0.306	0.20368	0.356	0.25071	0.406
11827	0.258	0.14051	0.308	0.20553	0.358	0.25263	0.408
11990	0.260	0.14226	0.310	0.20738	0.360	0.25455	0.410
12153	0.262	0.14402	0.312	0.20923	0.362	0.25647	0.412
12317	0.264	0.14578	0.314	0.21108	0.364	0.25839	0.414
12481	0.266	0.14755	0.316	0.21294	0.366	0.26032	0.416
12646	0.268	0.14932	0.318	0.21480	0.368	0.26225	0.418
12811	0.270	0.15109	0.320	0.21667	0.370	0.26418	0.420
12977	0.272	0.15287	0.322	0.21853	0.372	0.26611	0.422
13144	0.274	0.15465	0.324	0.22040	0.374	0.26805	0.424
13311	0.276	0.15644	0.326	0.22228	0.376	0.26998	0.426
13478	0.278	0.15823	0.328	0.22415	0.378	0.27192	0.428
13646	0.280	0.16002	0.330	0.22603	0.380	0.27386	0.430
13815	0.282	0.16182	0.332	0.22792	0.382	0.27580	0.432
13984	0.284	0.16362	0.334	0.22980	0.384	0.27773	0.434
14154	0.286	0.16542	0.336	0.23169	0.386	0.27969	0.436
14324	0.288	0.16723	0.338	0.23358	0.388	0.28164	0.438
14494	0.290	0.16905	0.340	0.23547	0.390	0.28359	0.440
14666	0.292	0.17086	0.342	0.23737	0.392	0.28554	0.442
14837	0.294	0.17268	0.344	0.23927	0.394	0.28750	0.444
15009	0.296	0.17451	0.346	0.24117	0.396	0.28945	0.446
15182	0.298	0.17634	0.348	0.24307	0.398	0.29141	0.448
15355	0.300	0.17817	0.350	0.24498	0.400	0.29337	0.450
15528	0.302	0.17999	0.352	0.24689	0.402	0.29533	0.452
15702	0.304	0.18182	0.354	0.24880	0.404	0.29729	0.454
15876	0.306	0.18365	0.356	0.25071	0.406	0.29925	0.456
16051	0.308	0.18548	0.358	0.25263	0.408	0.30122	0.458
16226	0.310	0.18732	0.360	0.25455	0.410	0.30319	0.460
16402	0.312	0.18916	0.362	0.25647	0.412	0.30516	0.462
16578	0.314	0.19100	0.364	0.25839	0.414	0.30712	0.464
16755	0.316	0.19284	0.366	0.26032	0.416	0.30910	0.466
16932	0.318	0.19468	0.368	0.26225	0.418	0.31107	0.468
17109	0.320	0.19652	0.370	0.26418	0.420	0.31304	0.470
17287	0.322	0.19836	0.372	0.26611	0.422	0.31502	0.472
17465	0.324	0.20020	0.374	0.26805	0.424	0.31699	0.474
17644	0.326	0.20204	0.376	0.26998	0.426	0.31897	0.476
17823	0.328	0.20388	0.378	0.27192	0.428	0.32095	0.478
18002	0.330	0.20572	0.380	0.27386	0.430	0.32293	0.480
18182	0.332	0.20756	0.382	0.27580	0.432	0.32491	0.482
18362	0.334	0.20940	0.384	0.27773	0.434	0.32689	0.484
18542	0.336	0.21124	0.386	0.27969	0.436	0.32887	0.486
18723	0.338	0.21308	0.388	0.28164	0.438	0.33086	0.488
18905	0.340	0.21492	0.390	0.28359	0.440	0.33284	0.490
19086	0.342	0.21676	0.392	0.28554	0.442	0.33483	0.492
19268	0.344	0.21860	0.394	0.28750	0.444	0.33682	0.494
19451	0.346	0.22044	0.396	0.28945	0.446	0.33880	0.496
19634	0.348	0.22228	0.398	0.29141	0.448	0.34079	0.498
19817	0.350	0.22412	0.400	0.29337	0.450	0.34278	0.500

So, to find this we have to focus on this particular table and if you see this table here I am having  $h / D$  that is nothing but  $h / D$  s and  $A$  factor. So, if I focus on  $h / D$  as 0.4  $A$  value should be 0.29337. So, this value you can note down over here.

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### Design of Kettle Reboiler

**Solution**

$AD_s^2 = (SA)_{calc} = 0.29337 \cdot (666.75 \cdot 10^{-3})^2$   
 $= 0.1304 \text{ m}^2$

$(SA)_{calc} > SA$

Assume next value of  $h/D_s$

$\frac{h}{D_s} = 0.1$

$D_s = \frac{D_b'}{0.9} = \frac{400.05}{0.9} = 444.5 \text{ mm}$

$A = 0.04087$

$AD_s^2 = 0.04087 \cdot 0.4445^2$   
 $= 8.07 \cdot 10^{-3} \text{ m}^2 > SA$

$\frac{h}{D_s} = 0.044$

$D_s = \frac{D_b'}{0.956} = \frac{400.05}{0.956} = 418.46 \text{ mm}$

$A = 0.01214$

$AD_s^2 = 2.125 \cdot 10^{-3} \text{ m}^2$

$\frac{h}{D_s} = 0.042$

$D_s = \frac{D_b'}{0.958} = \frac{400.05}{0.958} = 417.588 \text{ mm}$

$A = 0.01133$

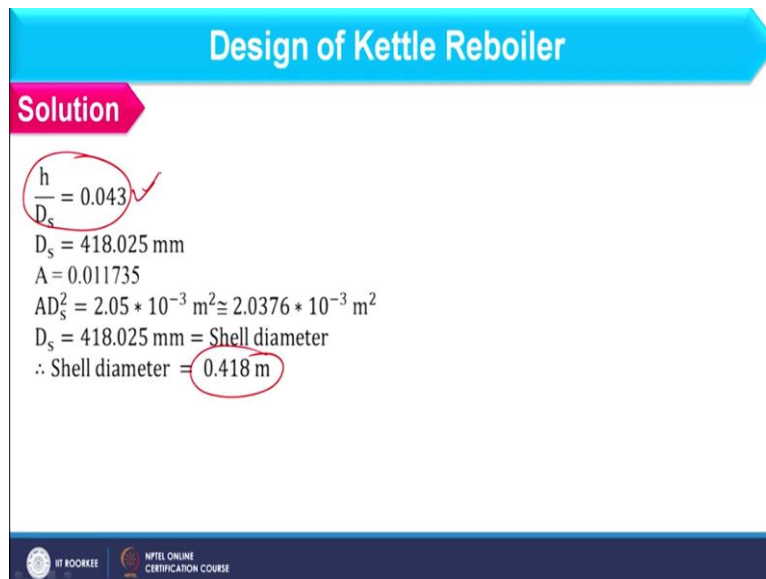
$AD_s^2 = 1.975 \cdot 10^{-3} \text{ m}^2$

And further we can find out revised area as  $A$  into  $D_s$  square. So, area we can obtain as 0.1304 that I am considering as  $SA$  calculated or you can simply consider that  $SA$  prime. So, in this case  $SA$  prime or  $SA$  calculated is very high in comparison to segment area. So, what we have to do further? We have to reduce the value of  $h$ ? So, now we will consider slightly lesser ratio of  $h / D_s$ .

So, further I am having value 0.1 and if  $h / D_s$  is 0.1  $D_b \text{ dash} / D_s$  should be 0.9. So, considering this we can find out shell dia as 444.5 mm for this ratio  $h / D_s$  as 0.1 we can find out segment area factor as 0.04087. So, you can see value over here SA calculated you can find as 8.07 into 10 is to the power - 3 and that is again more than SA. So, further we have to reduce  $h / D_s$  ratio.

And we should carry out this iterative procedure till I am getting SA calculated should be equal to SA that will be the perfect design. Otherwise, we should obtain slightly larger value than SA. SA calculated will never be less than SA perfect design and for perfect design these two areas should be equal. So, iterative procedure you can see.

**(Refer Slide Time: 27:59)**



**Design of Kettle Reboiler**

**Solution**

$$\frac{h}{D_s} = 0.043 \checkmark$$

$$D_s = 418.025 \text{ mm}$$

$$A = 0.011735$$

$$AD_s^2 = 2.05 \times 10^{-3} \text{ m}^2 \cong 2.0376 \times 10^{-3} \text{ m}^2$$

$$D_s = 418.025 \text{ mm} = \text{Shell diameter}$$

$$\therefore \text{Shell diameter} = 0.418 \text{ m}$$

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And we can obtain final diameter of shell as 0.418 and that is corresponding to  $h / D_s$  value as 0.043. Now, if you recall the table 10 A where we have area sector factor. So, in that case only even values are available as far as  $h / D_s$  is concerned so here we have to interpolate to find out the correct value for odd value of  $h / D_s$ . So in that way you can design the kettle reboiler.

**(Refer Slide Time: 28:38)**

## Design of Kettle Reboiler

### Example – 2

A 1-2 pass kettle reboiler is used to produce 100000 kg/h vapor at 5 bar, which has critical pressure as 30 bar. The feed and saturated steam enters the reboiler at 60°C and 130°C, respectively. The reboiler has U-tubes of 19.05mm OD, 15mm ID and 7.5m total length and tubes are arranged in 25.4mm square pitch. The tubes are made of material having  $k$  as 50 W/m°C. Assuming initial value of  $U_o$  as 800 W/m<sup>2</sup>°C and steam condensing coefficient as 5500 W/m<sup>2</sup>°C calculate  $U_o$  of reboiler. Carry out only one iteration for  $U_o$ . Also compute shell diameter of kettle. Check the actual flux condition.

Parameters given:  $\rho_v = 15 \text{ kg/m}^3$ ,  $\rho_L = 800 \text{ kg/m}^3$ ,  $\sigma = 0.095 \text{ N/m}$ ,  $\lambda = 531 \text{ kJ/kg}$ ,  $h_{fd} = 2500 \text{ W/m}^2\text{°C}$ ,  $h_{cd} = 3500 \text{ W/m}^2\text{°C}$ .

And here I am having second example which I will cover quickly. So, here you see 1-2 pass kettle reboiler is used to produce 1 lakh per hour of the vapour at 5 bar and critical pressure is 30 bar, feed and saturated steam enters the reboilers at 60 degree Celsius and 130 degree Celsius. So, in this case you see both are isothermal conditions. So, temperature difference should be difference of these two values.

So, mean temperature difference should be difference of these two values. So, for reboiler we are using U tubes with OD of the tube as 19.05 mm so that should be 3 / 4 inches, ID of the tube is 15 mm, total length of the tube is given as 7.5 meter and tubes are arranged in 12.5 mm square pitch. So, if you consider this pitch it is basically 1 inch and tubes are made with the material for  $k = 50$  and for initial value of  $U_0$  as 800 is given to us.

Condensing coefficient of steam is given as 5.5 kilowatt per meter square degree Celsius. We have to find out overall heat transfer coefficient for the reboiler and for that we have to perform only one, iteration and also compute shell diameter for the kettle and check the flux conditions.

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## Design of Kettle Reboiler

### Solution

Vapor produced	100000	kg/h
Latent heat	531	kJ/kg
Pressure	5	bar
Pc	30	bar
Tf	60	
Ts	130	
OD	0.01905	0.75
ID	0.015	
Total length	7.5	m

Square pitch	0.0254	25.4
kw	50	W/mC
Uo	0.8	kW/m <sup>2</sup> C
hi	5.5	kW/m <sup>2</sup> C
row v	15	kg/m <sup>3</sup>
row L	800	kg/m <sup>3</sup>
sigma	0.095	N/m
hid	2.5	kW/m <sup>2</sup> C
hod	3.5	kW/m <sup>2</sup> C

So just see the solution of this problem quickly and here we have the known values here as well as here and dirt factors are also given to us as you can focus on this line.

(Refer Slide Time: 30:42)

## Design of Kettle Reboiler

### Solution

$$h_{nb} = 0.104(P_c)^{0.69}(q)^{0.7} \left[ 1.8 \left( \frac{P}{P_c} \right)^{0.17} + 4 \left( \frac{P}{P_c} \right)^{1.2} + 10 \left( \frac{P}{P_c} \right)^{10} \right]$$

Duty	14750	kW
LMTD	70	
Area	263.393	
Area of one tube	0.446	
No of tubes	590.75	592
Actual tubes	648	
No of holes	1296	
Ds	0.7874	31
Db	0.78105	
Revised area	288.92	

Flux, q	51052.41	51.05 ✓	kW/m <sup>2</sup>
hnb	3850.318	3.85 ✓	kW/m <sup>2</sup> C ✓

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o \ln \left( \frac{d_o}{d_i} \right)}{2k_w} + \frac{d_o}{d_i} \times \frac{1}{h_{id}} + \frac{d_o}{d_i} \times \frac{1}{h_i}$$

1/Uo	1.2844	
Uo	0.7786	kW/m <sup>2</sup> C
%diff	-2.68 ✓	

So, let us start the solution of this problem. Here, I have to find out heat duty that will be nothing but m lambda LMTD or we can say the mean temperature difference is 70 degree which is the difference of two temperatures only. Heat transfer area I can find out, area of one tube I can find out as we have discussed previously and number of tubes we can obtain as 592.

(Refer Slide Time: 31:10)

## Design of Kettle Reboiler

**Solution**

$$h_{nb} = 0.104(P_c)^{0.69}$$

Duty	14750	kW
LMTD	70	
Area	263.393	
Area of one tube	0.446	
No of tubes	590.75	592
Actual tubes	648	
No of holes	1296	
Ds	0.7874	31 - 0.25
Db	0.78105	
Revised area	288.92	

**Table C.3 Tube Counts for 3/4-in. OD Tubes of 1-in. Square Pitch**

Shell ID (in.)	TEMA P or S				TEMA U			
	Number of passes				Number of passes			
	1	2	4	6	2	4	6	
8	28	26	16	12	28	24	12	
10	52	48	44	24	52	44	32	
12	80	76	66	56	78	72	70	
13 1/4	104	90	70	80	96	92	90	
15 1/4	136	128	128	114	136	132	120	
17 1/4	181	174	154	160	176	176	160	
19 1/4	222	220	204	198	224	224	224	
21 1/4	289	272	262	260	284	280	274	
23 1/4	345	332	310	308	348	336	328	
25	398	386	366	344	408	392	378	
27	477	456	432	424	480	468	460	
29	554	532	510	496	560	548	530	
31	637	624	588	576	648	636	620	
33	730	712	682	668	748	728	718	
35	828	812	780	760	848	820	816	
37	937	918	882	872	952	932	918	
39	1048	1028	996	972	1056	1044	1020	
42	1224	1200	1170	1140	1244	1224	1212	
45	1421	1394	1350	1336	1436	1408	1398	
48	1628	1598	1548	1536	1640	1628	1602	
54	2096	2048	2010	1992	2108	2084	2068	
60	2585	2532	2512	2476	2614	2584	2558	

And actual tube count we can find from this table where if you see table C 3 there OD of the tube is 3 / 4 inch and 1 inch square pitch is given. So, this is as per the problem given to us. Now the number of tubes is 592 if you see 592 is not available next value is 648. So this would be the actual tube count and corresponding to this 31 is the shell dia and Db is basically 31 – 0.25 inches as we have discussed in previous example.

So, in that case because number of tube are changing now we have to find out revised area multiplying this number of tube with the area of one tube. So, in this way we can find out the revised area and we can find out the heat flux q depending upon the revised area and heat transfer coefficient. We can find out considering this expression and the value comes as 3.85 kilowatt per meter square degree Celsius.

Condensing side heat transfer coefficient dirt factor thermal conductivity of the material you know. So, we can simply calculate overall heat transfer coefficient and the value comes as 778.6 watt per meter square degree Celsius so we can have error around 2.5% so which is acceptable. Further, we have to check the critical heat flux condition.

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## Design of Kettle Reboiler

Solution

$$q_{cb} = K_b \left( \frac{p_i}{d_o} \right) \left( \frac{\lambda}{\sqrt{N_i}} \right) [\sigma g (\rho_L - \rho_v) \rho_v^2]^{0.25}$$

$$VL = 2290 \rho_v \left( \frac{\sigma}{\rho_L - \rho_v} \right)^{0.5}$$

$$VL = 377.88 \quad \checkmark$$

$$SA = \frac{\dot{m}_v}{L \times VL} \quad \checkmark$$

$$SA = 0.0197 \text{ m}^2$$

Critical heat flux			
Kb	0.44		
qcb	174298.8936	174.299	kW/m2
		122.009	kW/m2
	51.05241087	< 122.009	Satisfied

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This is the expression which we have already discussed in the last example. So, I am simply giving the value of 70% of  $q_{cb}$  and that comes as 122.009. System flux we have already calculated in the last slide and condition is satisfied in this problem. So, next we have to focus on shell diameter calculation and for that we should consider VL calculation and then SA.

So, VL you can obtain as 377.88 and segment area you can consider as 0.0197 meter square and how to use this expression that I have already explained in previous example.

(Refer Slide Time: 33:43)

## Design of Kettle Reboiler

Solution

**Appendix 10.A Areas of Circular Segments**

	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$	$k/D$	$A$
Db	0.78105		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
Db'	0.88265		0.000	0.00012	0.052	0.01556	0.102	0.04308	0.152	0.07531	0.202	0.11343	0.252	0.15528	0.302	0.20000	0.352	0.24680	0.402	0.29533
h/Ds	0.4		0.006	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
Ds	1.47108		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
A	0.29337		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
SA'	0.63487		0.010	0.00133	0.060	0.01924	0.110	0.04701	0.160	0.08111	0.210	0.11990	0.260	0.16228	0.310	0.20738	0.360	0.25455	0.410	0.30319
			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
h/Ds	0.2		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
Ds	1.10331		0.016	0.00258	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
A	0.11182		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
SA'	0.13611		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
			0.022	0.00432	0.072	0.02530	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
h/Ds	0.1		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	0.26865	0.424	0.31699
Ds	0.98072		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
A	0.04087		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
SA'	0.03930		0.030	0.00687	0.080	0.02945	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	0.32295
			0.032	0.00759	0.082	0.03053	0.132	0.06125	0.182	0.09767	0.232	0.13815	0.282	0.18182	0.332	0.22792	0.382	0.27580	0.432	0.32491
h/Ds	0.05		0.034	0.00827	0.084	0.03163	0.134	0.06277	0.184	0.09922	0.234	0.13984	0.284	0.18362	0.334	0.22980	0.384	0.27775	0.434	0.32689
Ds	0.98072		0.036	0.00901	0.086	0.03258	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
A	0.04087		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
SA'	0.03930		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	0.28339	0.440	0.33284
			0.042	0.01133	0.092	0.03616	0.142	0.06822	0.192	0.10547	0.242	0.14656	0.292	0.19086	0.342	0.23737	0.392	0.28534	0.442	0.33483
h/Ds	0.025		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
Ds	0.98072		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
A	0.04087		0.048	0.01382	0.098	0.03958	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
SA'	0.03930		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

So, if you carry out the shell diameter calculation you have to find out Db dash and that should be 4 inches plus Db. So, Db dash you can obtain like this  $h/Ds$  initial guess as 0.4 factor A is like this as we have already seen in the last example and you can find out SA dash

as 0.634 which is very high in comparison to whatever SA is required. So, we have to reduce  $h / D_s$  ratio.

So here I am having  $h / D_s$  as 0.2 SA dash we can obtain like this which is still very high and further we have to reduce  $h / D_s$  and further I am finding larger value of SA dash in comparison to SA and how to use this table that is appendix 10 A that I have already explained in the last example and I am not going into detail of that assuming that you know the use of it.

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Design of Kettle Reboiler				
Solution				
$h/D_s$	0.05 ✓			
$D_s$	0.929	m		
A	0.01468			
SA'	0.0127	m <sup>2</sup>	35.78%	✓
$h/D_s$	0.06 ✓			
$D_s$	0.939	m		
A	0.01924			
SA'	0.01696 ✓	m <sup>2</sup>	14.04%	
$h/D_s$	0.066			
$D_s$	0.94502	m		
A	0.02215			
SA'	0.01978 ✓	m <sup>2</sup>	-0.24%	

So, let us see further calculation  $h / D_s$  I am now considering as 0.05 SA dash you can obtain as 0.127 and the error you can see. Now the error becomes positive, so you have to increase SA dash value. To increase that we should increase  $h / D_s$  so now I am considering 0.06. So, SA dash you can obtain like this which is still less than the SA and further we have to increase  $h / D_s$ .

And finally we can obtain SA dash which is equal to 0.01978 which is slightly higher than SA, but comparable also. So, you can consider this value as final shell diameter. So, bundle diameter is 781 mm and shell diameter you can find as 945 mm. So, in this way you can design the kettle reboiler and here I am stopping this lecture. We will solve a few more examples in subsequent lectures. So that is all for now. Thank you.