**Process Equipment Design**
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**Lecture –28**
**Design of Reboiler-2**

Hello everyone. Welcome to the 28th lecture of the course Process Equipment Design and here we are going to discuss design of reboiler and this topic I have started from the last lecture that is 27th where we have discussed different types of reboiler, what is the application of reboiler and how the heat transfer mechanism is taking place inside the reboiler and respective correlations.

So, let us start the design of boiler and first of all in this category I will focus on kettle reboiler. So, some points about the kettle reboiler we have already discussed in the last lecture and here we will revise a few and we will discuss few more points before going to design part.

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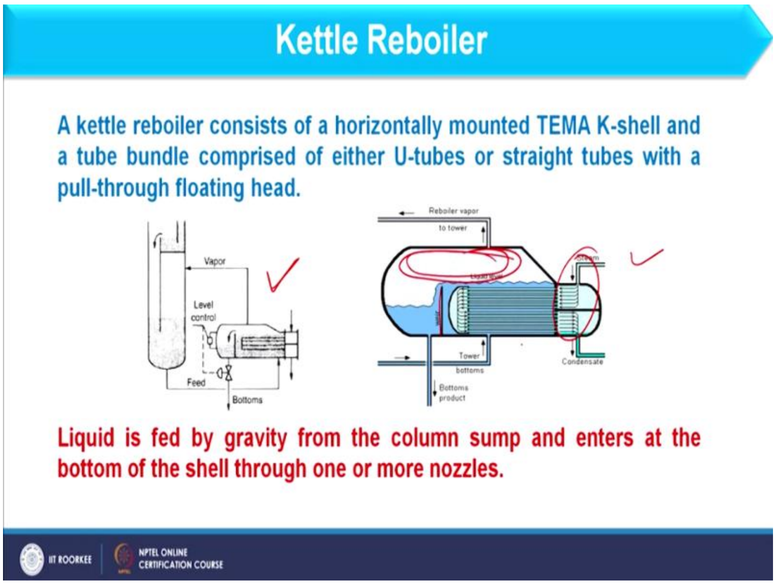


So as far as you know that kettle reboiler is always placed horizontally it will never be placed vertically and it contains TEMA K-shell and K derives from kettle. So, this is a specific type of shell which is used only for kettle reboiler because apart from bundle it also includes the space for vapour liquid separation. So, this reboiler includes the bundle which may have U tube or which may have straight tubes.

So, this schematic we also have seen in the last lecture along with this. So, as far as design is concerned we have different parameters to count. First is the bundle itself second is this weir and third is this vapour liquid separator. So, if you see what we do usually if I decide the length of the tube I automatically fix the length of the shell, but in this case bundle and shell are not related to each other.

If you see the complete length of the shell that is much more than the length of the tubes. So, length of the shell is again a parameter to be considered in design. So, in this way the movement of liquid from bottom of the distillation column to the reboiler is through gravity that point we also have discussed in the last lecture.

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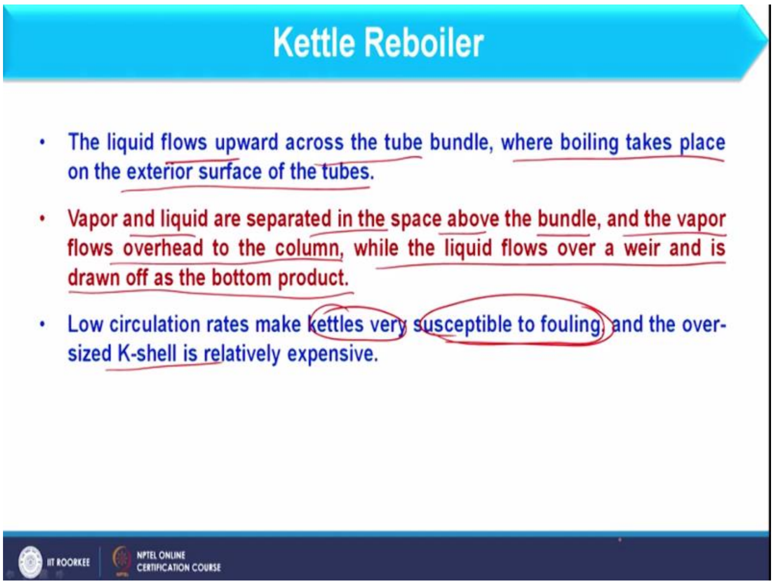


So, liquid flows upward across the bundle where boiling takes place on the exterior surface of the tubes because this is the reboiler which is always placed horizontally and secondly boiling will take place on outer surface that is in shell side always. There is no combination of kettle reboiler for vertical positioning as well as tube side boiling and further we can see that vapour and liquid are separated in the space above the bundle.

And vapour flows overhead to the column while liquid flows over a weir and is drawn off as bottom product. So, bottom product of the distillation column is collected from kettle reboiler not the column. So, low circulation of kettle reboilers makes it more susceptible to fouling and oversized K shell gives higher cost to such type of reboilers in comparison to thermosyphon and forced circulation.

So, how I can reduce the cost of kettle reboiler? When I am inserting the bundle in the column only that we also called as internal reboiler if you remember the last lecture. So, in that case shell is not required only bundle is there which is inserted in the distillation column and which is completely merged in the liquid, but it has some limitations that also we have discussed in last lecture.

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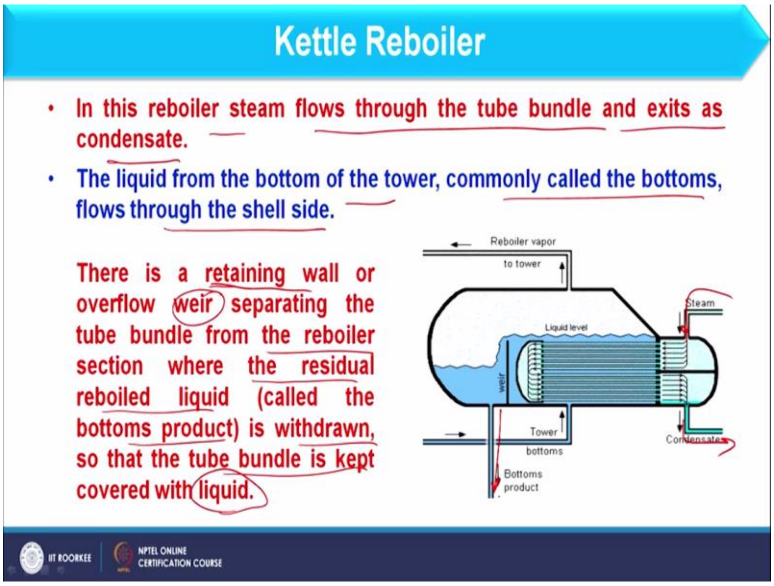


So, in this type of reboiler steam flows through the tube bundle and exits as condensate. So, that you can understand that heating media is always available in tube side as you can see from here and condensate exits from this side. Liquid from the bottom of the tower commonly called as the bottom flows through the shell side. So, in this case only shell side boiling is considered.

There is a retaining wall or we call that as weir it is used to separate the tube bundle from the reboiler and where the residual reboiled liquid which we called as the bottom product is withdraw so that the tube bundle is kept converted with the liquid all the time. So, you can see from here we can get the bottom product. So, as far as kettle reboiler is concerned it has more residence time because it coverts liquid into vapour and also separates vapour and the liquid.

So, it has two operation which is taking place in a single unit and therefore liquid should be there for longer time and because of that it is more prone to fouling. So, what is the limitation of kettle reboiler? It is like it should use clean fluid not the fluid has high fouling tendency.

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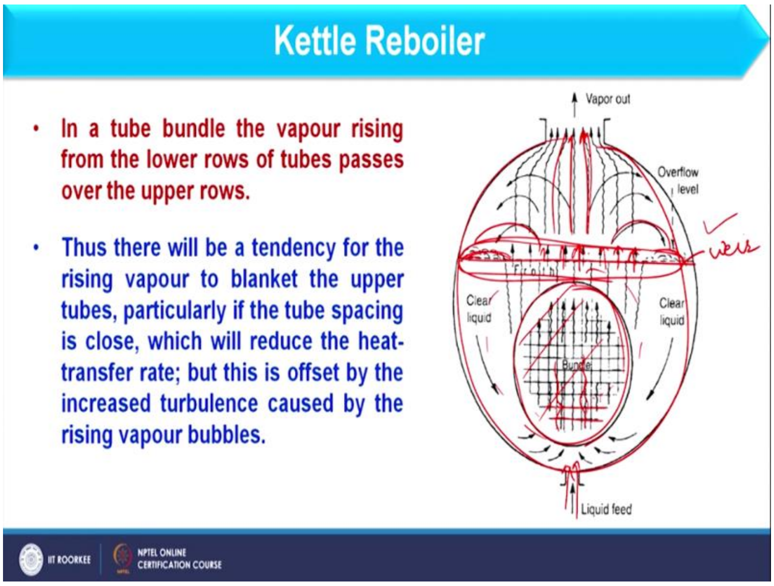


Now, if you see this schematic this is basically cross sectional view of kettle reboiler and if you see bundle is very small in comparison to shell, shell dia is this much and from bottom we get the liquid from the distillation column and when this liquid come in contact with the tubes at outer surface of the tubes boiling will take place and here you see continuously liquid is coming, continuously vapours are formed and the moment of the vapour will be upward.

So, what will happen over here when the vapour moves up it forms a bubble and then only it is called a vapour. So, when it moves upward within the bundle it joins other bubbles, it joins with other bubbles and bubble size increases and sometime the size of that bubble is so large that it covers the space between two tubes which I am saying as the open space for liquid to move.

That space is usually covered by the bubbles of vapour. However, it will not retain there because whatever liquid is moving from the bottom or whatever vapour is moving from the bottom to upward it create sufficient turbulence and break that blanket. So, continuously vapour is formed, it blocks the tubes and continuously breaking of these bubbles is also going on. So, the phenomena is very much complicated over here.

And if you see in this diagram we have this line and this line is nothing, but the weir this is weir and this ensures that bundle should always be available in liquid and in this case because bundle is in the liquid we call this as pool boiling and when the vapour is formed and moves upward it also carry some liquid droplet with it and here therefore at this location of the reboiler we continuously have froth as well as foam.

So, after vapour liquid separation this froth separates and whatever foam is there that is also separate and completely vapour moves upward like this and liquid is taking to another side of the weir and exits from that side as the final product. So, as far as design of reboiler is concerned we have to keep in mind all these point like bundle weir and shell dia. So, in this way we can understand that mechanism of kettle reboiler as far as boiling is concerned is not easy.

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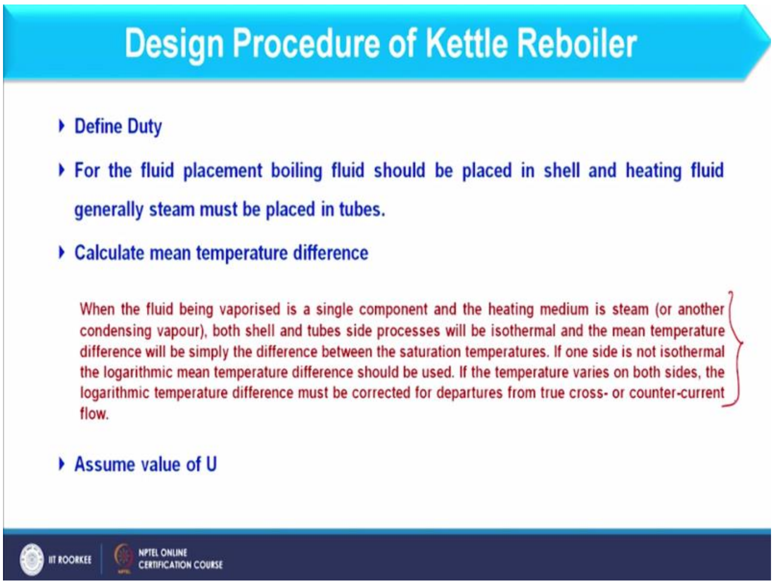


And we have to start now the design procedure for kettle reboiler and if I ask you what should be the first step because my purpose is what? My purpose is to convert certain amount of liquid into vapour. So, the first step of this reboiler is that what is the heat load of the reboiler and how I calculate that heat load? I should calculate that based on the amount of vapour. So, the first step is to define duty.

So, you already understand that how much vapour you need to generate and you know the mechanism of generation of vapour and that is through boiling it means latent heat is involved over here and what happens further when the liquid from the distillation column exits and enters into the reboiler it passes through a certain pipe and this pipe has certain length. So, some heat loss may take place.

And when the liquid entering into the reboiler is it possible that it will reach less than boiling point of the component because in distillation column bottom liquid is at boiling condition or it is at boiling point. However, it may not happen when the liquid is entering into the kettle reboiler. So, if this is the case we have to provide the heat for sensible heating to reach the liquid to the boiling condition.

And then after that we should consider vapour formation, but here as far as duty is concerned it is entirely based on how much vapour I am generating. So M into lambda you should consider over here. Next step is for the fluid placement boiling fluid should be placed in shell and heating fluid generally steam should be placed in tube. So, here you should not bother about the allocation of the fluid, boiling fluid should always be in shell side.

So, in this way you allow the fluid to move to shell side or tube side and next we should calculate the mean temperature difference. Now, here we will have three different cases. Number one, if I am saying that steam is used as a heating media and in most of the cases steam only works as a heating media. So, if steam is available it condenses and then transfer its heat to liquid.

So, what is the meaning of that? In tube side we have isothermal operation. Now what will happen in boiling side which is the shell side? Let us say, if I am having pure component. So its boiling point will be one temperature and if the fluid is entering at the boiling point only vaporization will take place and that will again an isothermal process because it is a pure component.

And formation of vapour at particular temperature and that is the boiling point of the fluid. So, in this case liquid which is available in shell side it is also at particular temperature so isothermal conditions can be obtained in both side of the reboiler. So, if this is the case difference of these two temperature will give me delta T mean. Second condition is what when I am having the steam as a heating media.

So, there we have isothermal condition so the components available in that mixture has different boiling temperature. So, what is the meaning of that? Vapour will take place at different temperature once the component reaches at boiling condition. It means in boiling side or shell side we have non isothermal condition and which is like this. So, if this is the case LMTD you have to calculate because here I am having continuous variation of temperature difference.

Now third case maybe when I am having any other heating media than the steam and if I am dealing with mixture of compound as a feed to reboiler. In that case, both temperature profiles are non isothermal and if this is the case you should consider LMTD along with F t correction factor. So, you see the problem and accordingly find out mean temperature difference.

So, if you see this text it is basically explaining the same thing which I have already explained and after that we need to assume overall heat transfer coefficient value.

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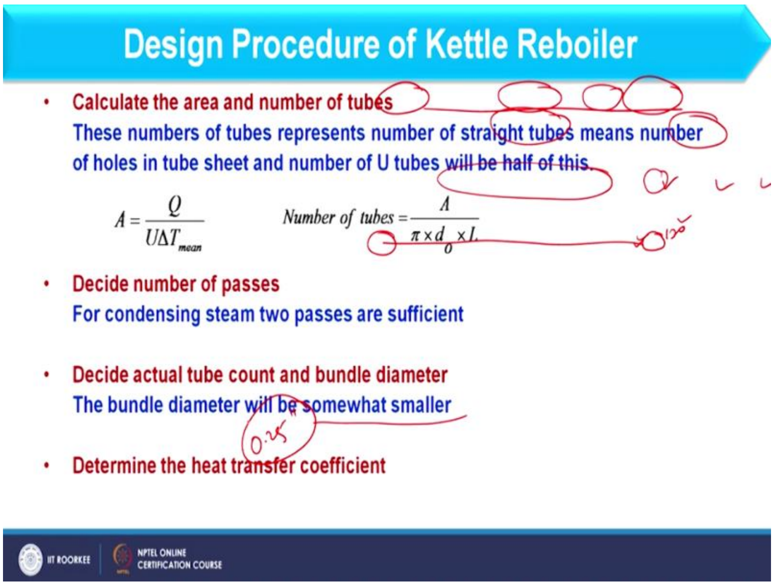


Now once I am having the heat duty U value and mean temperature difference I have to find out area and number of tubes. So, if you remember kettle reboiler includes straight tubes or U tubes. So, we have to find out number of tubes accordingly. So, as far as area is concerned that you can find out using this usual expression of heat transfer A = Q / U delta T mean. So, once I am having this area which is basically the heat transfer area I can find number of tubes as A should be divided by pi d 0 L as we keep on doing in previous equipment.

So, here again you have to consider L effective instead of L now here some points you have to keep in mind if I am considering straight tube how you find out L effective? L effective will be L – twice of tube sheet thickness. However, what will happen when I am having straight tube usually tube sheet is available only at one side because in between we have baffle which works as a support plates.

And second tube sheet is not available because I do not have to separate vapour and liquid mixture through the second tube sheet. It can be done through first tube sheet only so in that case L effective should be calculated accordingly if one tube sheet is there you have to reduce the thickness of tube sheet once only. Now, what will happen in U tube? If you consider this is the tube sheet and this is basically U tube.

And if you know that length of U tube is let us say 10 meter so this is the complete length of the U tube until and unless it is not mentioned that it is half of the U tube. So, if total length you are considering what is the meaning of that? That total length enters twice to the tube sheet. So, if I am considering half of the U tube it is basically called as one leg and it will enter to tube sheet only once.

So, L effective you have to find out carefully if it is total length of the U tube you should deduct twice of tube sheet thickness from L to find out L effective otherwise it should be deducted only once if one leg of U tube is given. Now, further if I ask you and what should be the number of holes? If you are considering single length of U tube or the straight tube this should be number of holes not the tubes.

In that case if you are considering U tube number of tube should be half of the number of holes because only half number will enter in this section and second half will enter to this section and if you are considering total length of the U tube whatever value you will obtain that would be only number of tubes and number of holes would be just double to that. So, I hope these things are clear to you and after that we have to decide the passes.

So, as far as passes are concerned kettle reboiler includes only 1-2 pass. So, there is no much choice about that and further we have to find out bundle diameter and here slight difference in approach is there to find out bundle diameter first of all you have to find out actual tube count because if you remember the last lecture we have discussed that pitch of kettle reboiler varies then 1.25 into d 0.

So, according to the pitch and according to the number of tubes you decide the bundle diameter.

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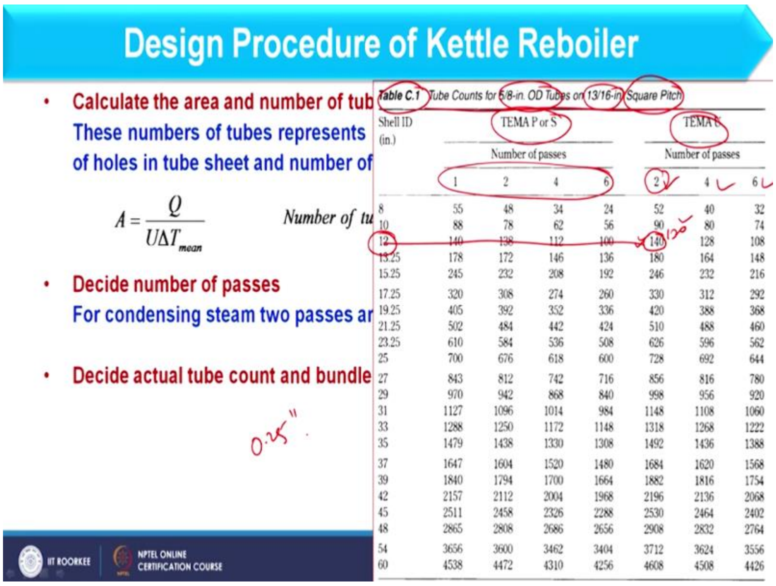


Table C.1 Tube Counts for 5/8-in. OD Tubes on 13/16-in Square Pitch

| 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 |

And the procedure is like you have to refer these standard tables. So, if you see here I am having table C 1 these tables are available in appendix C of R. W. Serth book and if you see the title of this table is tube counts for 5 / 8 inch OD tubes on 13 / 16 inch square pitch. So, here OD of the tube is mentioned and pitch is given. It is not always 1.25 into d 0 and type of arrangement of tubes is also given.

So, in this way you can find out the suitable table as per your requirement. If U tube is given you can consider this section where passes are 2, 4 and 6 and here P and S it is basically the split ring as well as pull through. So, according to the number of passes you can tally the tubes. Now what will happen? You can decide OD of the tube as we have discussed in previous lectures and you can decide the pitch and arrangement also.

So, depending upon all these three parameter you will find correct table. In Serth book table up to 8 that is C 8 table is available depending upon different OD arrangement as well as pitch. So, let us say I am considering two passes of U tube and number of tubes whatever you have calculated let us say that is 120. So, actual tube count in this case should be 140 whatever number of tubes available more than whatever you have calculated that you have to consider as actual tube count.

Now, if you see 140 is the actual tube count you will consider this as shell ID. This is shell ID as per this table, but this is actually not the shell ID for kettle reboiler. So, in this way we consider the shell ID and you should understand that bundle diameter is slightly lesser than the shell diameter. So, we usually deduct 0.25 inches from shell ID to find out bundle dia I hope it is clear.

And if the pitch is given as 1.25 into d 0 it is triangular or square you can find out bundle diameter based on the usual approach we have discussed in previous lectures, but however if pitch is different than 1.25 into d 0 you have to refer these table to find out actual tube count and corresponding to that the actual bundle diameter. So, bundle diameter will be somewhat smaller to count that we simply reduce 0.25 inches from the shell diameter which we have seen in tube count and after that we have to find out heat transfer coefficient.

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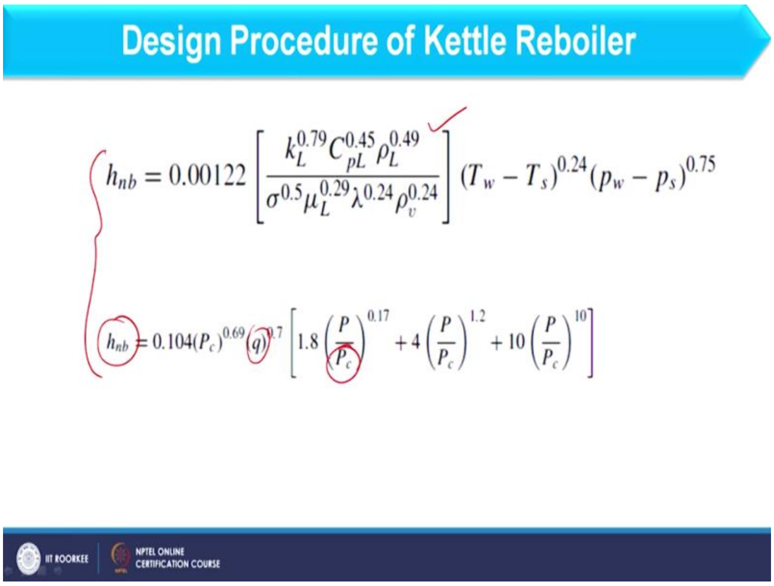


So, as far as heat transfer coefficient is concerned we have already discussed this in last lecture in heat transfer mechanism where for pool boiling we can use these two expressions. If properties are available to you in detail you can use this expression otherwise you can use this expression based on the flux as well as critical pressure. So, in this way you can find heat transfer coefficient in shell side because boiling is occurring in shell side.

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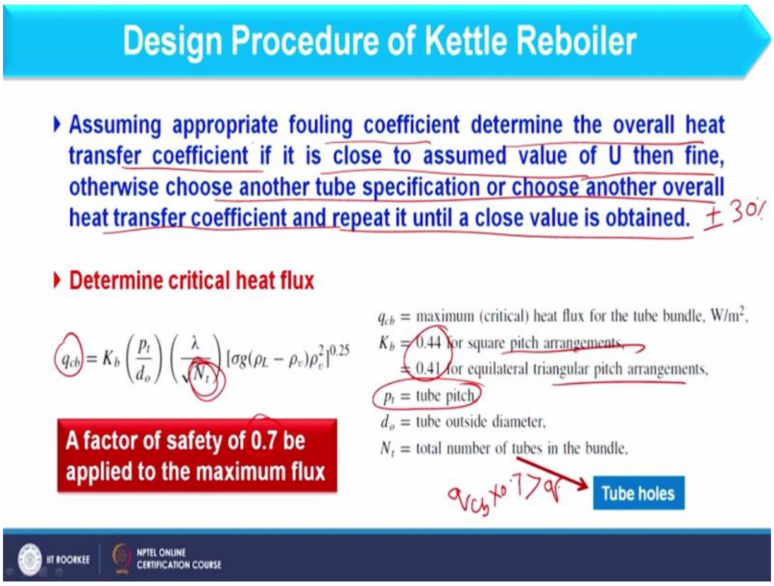


Next step is assuming appropriate fouling coefficient, determine the overall heat transfer coefficient if it is close to the assumed value of U then fine otherwise choose another tube specification or choose another overall heat transfer coefficient and repeat it until a close value is obtained and that close value should be within plus minus 30%. So, till now you have only calculated heat transfer coefficient in shell side, what about tube side?

In tube side, we usually have steam where steam is condensed and supply its heat. So, in that case you can consider a specific value like 8,000 which is the heat transfer coefficient for condensation of steam otherwise you can simply apply the condensation rules in tube side so that will be horizontal placed condenser and condensation is occurring in tube side. So, in that way you can find out heat transfer coefficient of tube side then you can find out overall heat transfer coefficient considering fouling coefficient.

Now, once I am having the overall heat transfer coefficient within the permissible limit next we have to check about the critical heat flux because if you remember the last lecture there we have discussed that critical heat flux is very important as when we have more flux than the critical because when we go beyond the critical heat flux heat transfer coefficient reduces drastically.

And we should not enter into that region therefore the flux should be less than the critical heat flux. So, as far as calculation is concerned you can find out critical heat flux using this expression where different parameters are given like K b value depending upon the arrangement. So, you can choose the value accordingly p t is the tube pitch and here N t is basically number of holes.

If I am having straight tube we can consider number of tubes = number of holes, but if I am having U tube so number of tubes into 2 will be the number of holes so this N t you should count very carefully. So, here you have to check whether system flux is less than or not. So, what is the criteria? The criteria is a factor of safety of 0.7 be applied to the maximum heat flux.

So, whatever q c b we have obtained into 0.7 and that should be more than the system flux. System flux you can calculate because you already know the heat duty as well as area. So, q will be fixed and that should be less than 70% of q c b so this condition you have to satisfy and now we will find out the shell dia.

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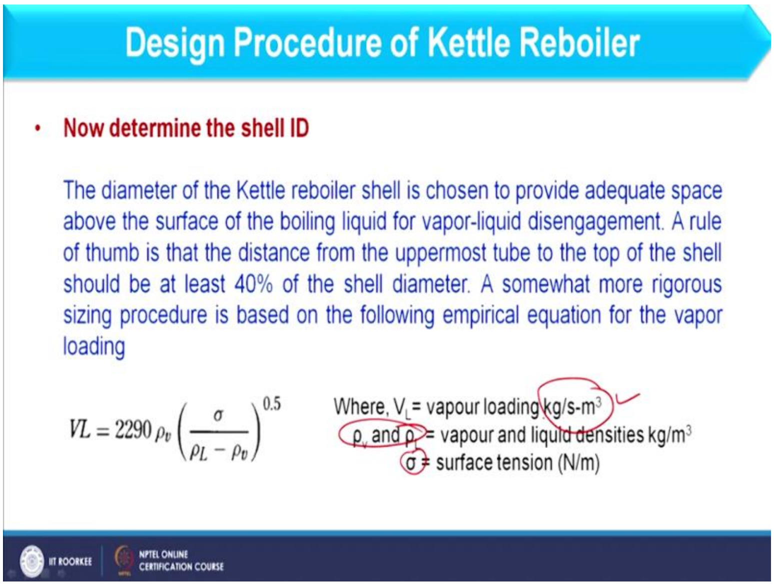


So, as far as shell ID is concerned it based on some thumb rules and if you consider usually this shell ID will depend on how much vapour we have to generate because that much vapour should be separated from the liquid in vapour liquid separating section and then the vapour should enter into the distillation column. So, in this case we usually consider some assumption and that assumption is the distance from upper most tube to top of the shell should be at least 40% of the shell diameter.

What is the meaning of this if I am having this shell and this bundle and let us say this is weir height. So, this section this height which we usually call as small h this height should be 40%

of D s, but that is only an initial guess. If you follow Richardson Coulson Volume 6 their shell ID is computed based on this factor only. However, if you follow Serth book there we have different method to find out shell ID that how much vapour you need to generate accordingly you have to provide vapour liquid separating section.

So, you see h is equal to 40% of the D s and that is only the initial guess. So, instead of doing this we need more rigorous procedure to size the shell and for that purpose we compute vapour loading. So, that vapour loading you can find out using this expression it is also available in Serth book, but it is not in Volume 6. So here VL is basically the vapour loading rho v and rho (()) (30:10) vapour liquid densities and sigma is basically the surface tension. So, if you see the unit of VL is kg per second meter cube.

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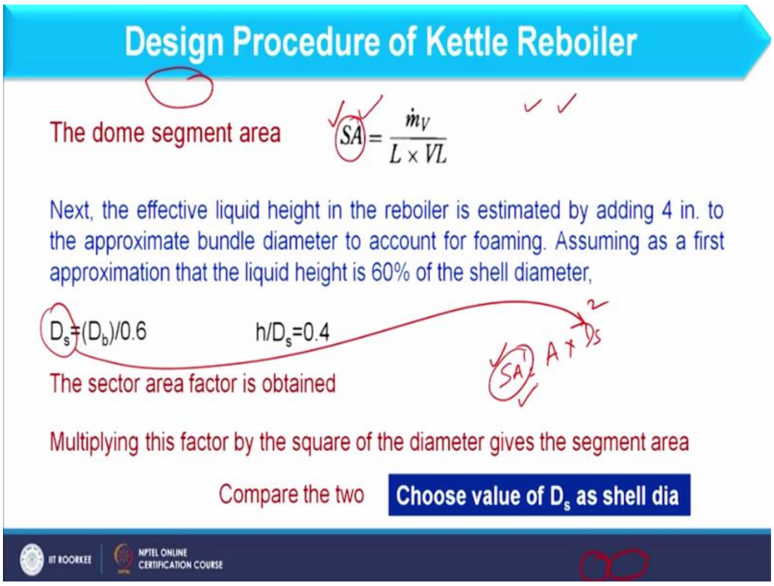


So, further we have to find out dome segment area, what is dome segment area? If I considering shell and here I am having the bundle and this is the weir this section we call as dome segment area and it will depend on how much vapour you need to generate which you can calculate by this expression where m dot v we can consider that how much vapour is to be generated and L and VL.

So, in that case you can find out SA in meter square and this L should be L effective of tube because only that section is available for transfer of heat. However, length of the shell is significantly high than the tube length. Now, if you are having dome segment area we should follow a rigorous method. Initially, we will also consider that this h is 40% of shell ID because you do not know the shell ID so here just I am taking an assumption.

And further if you focus on this schematic here h I have taken from this weir height. So, what should be this height? This height should be more than the bundle diameter and that we can obtain as bundle dia plus 4 inches we simply add 4 inch to bundle dia to find the height of weir. So, above that we have h and this section this height we are representing as D b dash and if I am asking you what should be the shell diameter that should be equal to h + D b dash.

So, if I am having h / D s as 40% then D b / D s should be 60% I hope that point you can understand. So, here I am having that D s which is equal to D b dash / 0.6. So here you should consider D b dash if I am having h / D s as 0.4. So, we have to find out area sector factor, so from where we can find it out?

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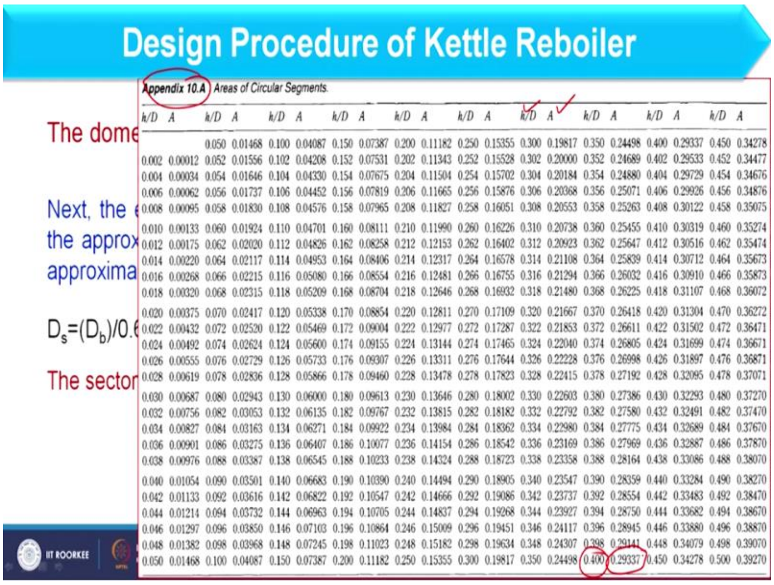


Appendix 10.A Areas of Circular Segments.

| 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 |

We can find out area sector factor from this table and it is also available in Serth book you can see Appendix 10 A. So, according to the h / D ratio this is basically h / D s we can find out different factor. So, let us say h / D is 0.4 at present so factor A should be 0.29337. So, we can consider that factor and then we can find out segment area that is SA dash and that SA dash would be A into D s square.

So, D s you will obtain from here and A value we have just seen from the table. So, next what you have to do you have to compare this SA dash and SA. So, this SA dash should be equal to this. We do not have to play with it we have to play with this. So, you have to choose h / D s ratio in such a way so that SA should be equal to SA dash. So, what you can do let us say SA dash is more than SA so what is the meaning of this?

You need to require lesser space for vapour liquid separation. In that case you have to provide less value of h. So, now another assumption you can take that h / D s should be 0.6. So, in that case you consider h / D s ratio as 0.2 so once you are having h / D s as 0.2 you can consider D b dash / D s as 0.8. So, in each iteration as you keep on changing h D s value will keep on changing.

And we can obtain different factors from the table which we have seen just now and then you can find out SA dash and that should be compared with SA. The value of diameter of shell at which SA should be equal to SA dash that value of D s should be considered as final diameter of shell. So, in that way you can find out shell ID and here I am stopping this lecture. I will continue design of kettle reboiler in the next lecture also and that is all for now. Thank you.