

Process Equipment Design
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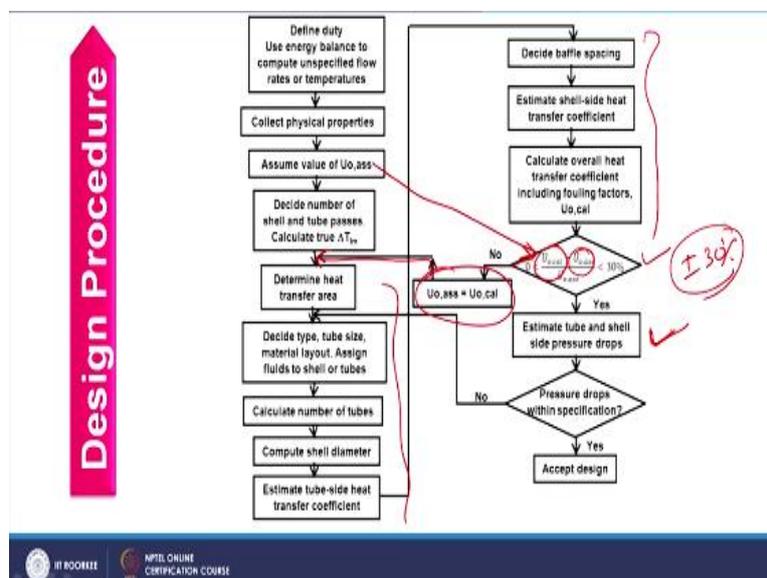
Lecture –14
STE Design- Kern’s Method-3

Hello everyone. Welcome to the 4th lecture of week 3 of the course Process Equipment Design. This is 14th lecture of this course where I am continuing design of shell and tube heat exchanger using Kern’s method. So, if you consider the second lecture and third lecture of this week there, we have started design of shell and tube heat exchanger and we have covered some steps and some steps are left which I am going to cover in this particular lecture.

So, let us start the design of shell and tube heat exchanger using Kern’s method. So, in the last lecture we have discussed how to calculate heat transfer coefficient of tube side and shell side. What are the different steps involved in that, that we have discussed? So, next to that we have to find out overall heat transfer coefficient because I have already calculated tube side heat transfer coefficient and shell side heat transfer coefficient.

I have already allocated the fluid to respective side either tube side or shell side it means I already know the dirt factor of each fluid. So, considering dirt factor inside and outside heat transfer coefficient that is tube side and shell side and thermal conductivity of the material of the tube.

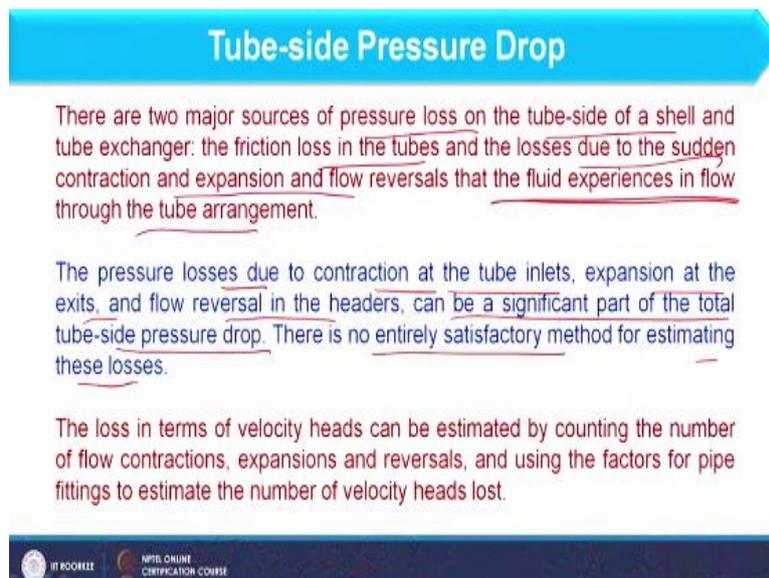
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We can consider this expression to find out overall heat transfer coefficient. So, all these parameters are known to me and then I can find out the coefficient and after that next step is to compare the overall heat transfer coefficient calculated with the assumed value which we have done over here. So here you should find the difference between the two. If this difference is lying plus minus 30% your design is accepted.

Otherwise what you have to do? You have to replace the assumed value with calculated value and start with heat transfer area calculation. So, all these steps you have to repeat to bring the overall heat transfer coefficient value within plus minus 30%. If it is within plus minus 30% next, I have to calculate the pressure drop of shell side and tube side.

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Tube-side Pressure Drop

There are two major sources of pressure loss on the tube-side of a shell and tube exchanger: the friction loss in the tubes and the losses due to the sudden contraction and expansion and flow reversals that the fluid experiences in flow through the tube arrangement.

The pressure losses due to contraction at the tube inlets, expansion at the exits, and flow reversal in the headers, can be a significant part of the total tube-side pressure drop. There is no entirely satisfactory method for estimating these losses.

The loss in terms of velocity heads can be estimated by counting the number of flow contractions, expansions and reversals, and using the factors for pipe fittings to estimate the number of velocity heads lost.

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So, let us start with tube side pressure drop. There are two major sources for pressure loss on tube side of a shell and tube heat exchanger. The frictional loss in the tube and the losses due to sudden contraction and expansion and flow reversal that the fluid experiences in a flow through the tube arrangement. Now what is the meaning of this? If I consider the pressure drop either in shell side and tube side what basically I am considering?

I am considering the frictional loss when the fluid is moving from one side to another side and that frictional loss causes pressure drop in the exchanger in tube side or shell side. Now when I am considering tube side what will happen over here though tube is straight, but when fluid is entering into this it come across with contract or with lesser area that we consider as the contraction.

And when the fluid leaves the tube it comes across larger area which we consider as the expansion. So, when the fluid is moving in the tube it is entering or exiting the tube it has friction loss due to wall, it has frictional loss due to sudden contraction and expansion and if I am considering the tube passes so what will happen? Fluid exits the tube then reversed and then enters to another tube.

It means 180 degrees reversal of the flow is made when it is flowing in tube side. So that will again cause a pressure drop. Further, pressure losses due to contraction at the tube inlet, expansion at the exit and flow reversal in headers can be a significant part of total tube side pressure drop. There is no entirely satisfactory method for estimating these losses. Now in chemical engineering course in second year you must have done the fluid mechanics lab or maybe second semester of first year.

So in that lab you have done the experiment on pipe fittings where you have consider flow through straight pipe where pipe diameter are changing one pipe is of smaller diameter, one pipe is of larger diameter and then when flow is passing through this you have studied the manometer reading which is basically located at the inlet and outlet of the pipe. In the similar line you have also studied the fittings in that like elbow, valve like that you have studied.

Along with that you have studied sudden contraction and expansion. So, whatever you have studied there that you are applying in calculating pressure drop in tube side.

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Tube-side Pressure Drop

For two tube passes, there will be two contractions, two expansions and one flow reversal. The head loss for each of these effects is: contraction 0.5, expansion 1.0, 180° bend 1.5, so for two passes the maximum loss will be

$2 \times 0.5 + 2 \times 1.0 + 1.5 = 4.5$ velocity heads
 $= 2.25$ per pass

$$\Delta P_t = N_p \left[8j_f \left(\frac{L}{d_i} \right) \left(\frac{\mu}{\mu_w} \right)^{-n} + 2.5 \right] \frac{\rho u_t^2}{2}$$

N_p = number of tube passes
 L = tube length
 u_t = tube-side velocity, m/s

So, when you are calculating the pressure drop in tube side you have to consider different friction losses which is occurring in the tube side. For that purpose, if I am considering passes in tube side. So here I am having pass partition plate and if tube is available like this or like this then what will happen. When fluid is entering into this it come across sudden contraction because here area is more, here area is less.

Sudden contraction and here we have sudden expansion and after that we have complete reversal of the flow and again, I am having sudden contraction here and sudden expansion here and from this nozzle the fluid exits. So, what will happen if I consider 1-2 pass at two points contraction will occur at two, point expansion will occur and at one point 180 degree reversal is there.

So as far as head losses are concerned in these conditions, contraction consider head loss as 0.5, expansion consider head loss as 1 and 180, degrees bend consider head loss as 1.5. So, for two passes maximum loss can be obtained as 2 into 0.5 that is for contraction, 2 into 1 that is for expansion and 1.5 because 180 degrees bend is there. So, total 4.5 velocity heads are there when I consider 1-2 pass so 2.25 head loss is there per pass.

So, researchers have given a complete number that is instead of 2.25 they have mentioned 2.5. Now further if I focus on pressure drop in tube side I use this expression where N_p is the number of passes and each pass if you consider each pass will have 2.5 head loss and this is the expression where $8 j f$ I am considering capital $L / d e$ and this is the viscosity correction factor and here we have the velocity in tube side as well as density of the fluid.

So, you can use this expression to find out pressure drop in tube side. Now in this expression what you have to keep in mind you have to consider total length of the tube. If you see here, I am having capital L so capital L is what total length of the tube and if you remember the calculation of number of tubes there, we have considered effective length and here I am considering total length.

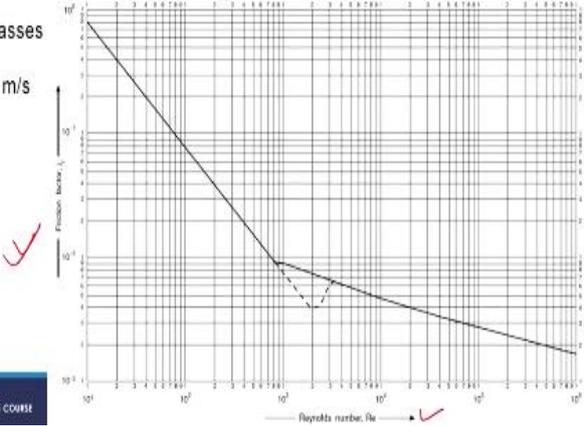
And the reason is very simple because though tubes are inserted in tube sheet, but flow will occur from that section also. So, when I am calculating pressure drop of tube side, I have to consider total length of the tube as capital L .

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Tube-side Pressure Drop

$$\Delta P_t = N_p \left[8 j_f \left(\frac{L}{d_i} \right) \left(\frac{\mu}{\mu_w} \right)^{-m} + 2.5 \right] \frac{\rho u_i^2}{2}$$

N_p = number of tube passes
 L = tube length
 u_i = tube-side velocity, m/s



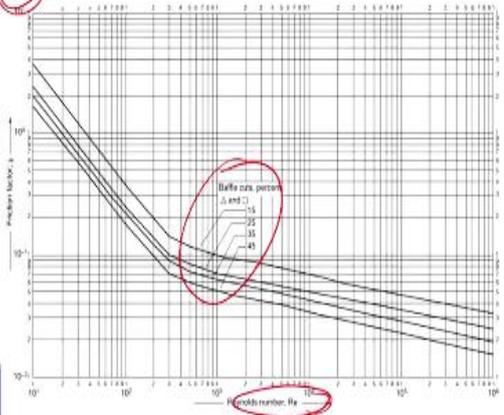
So here we have the expression which just we have discussed about pressure drop in tube side and j f factor that is the frictional factor you can compute using this curve. So that will also depend on the Reynolds number and once you have j f value you can find out pressure drop considering this expression. I hope this method is clear to you.

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Shell-side Pressure Drop

$$\Delta P_s = 8 j_f \left(\frac{D_s}{d_e} \right) \left(\frac{L}{l_B} \right) \frac{\rho u_s^2}{2} \left(\frac{\mu}{\mu_w} \right)^{-0.14}$$

L = tube length.
 l_B = baffle spacing.
 (L/l_B) = the number of times the flow crosses the tube bundle = $(N_b + 1)$
 N_b = number of baffles



And next we will discuss the shell side pressure drop. So, if you see here, we have the expression to calculate the shell side pressure drop j f is again the frictional factor which you can see from this graph it will depend on the baffle cut. So, whatever baffle cut you are considering based on that you can see the j f factor depending upon the Reynolds number and here we have D_s / d_e so d_e is the equivalent diameter that we have calculated in heat transfer coefficient calculation in shell side.

D_s is the shell dia capital L is the tube length because I have already told you that once I am fixing the tube length, I am fixing the shell length also. So that capital L is basically the tube length over here, but here this L should be $L_{\text{effective}}$ because the portion of tube inside the tube sheet is not creating any friction in shell side that will create friction in tube side that we have already considered while taking complete length of the tube in ΔP_t calculation.

But here whatever is inside the tube sheet it will not participate in any friction or in pressure drop. Therefore, in shell side pressure drop we will consider $L_{\text{effective}}$. These are some small things, but you have to consider these things in designing to carry out the effective design of shell and tube heat exchanger and u_s that we have already calculated considering cross flow area that is A_s and this is the viscosity correction factor that we know already.

And once I am having this L / l_B this is nothing, but the number of times the flow crosses the tube bundle and that should be equal to number of baffles + 1. So, in that way we can calculate pressure drop in shell side as well as in tube side.

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Shell-side Pressure Drop

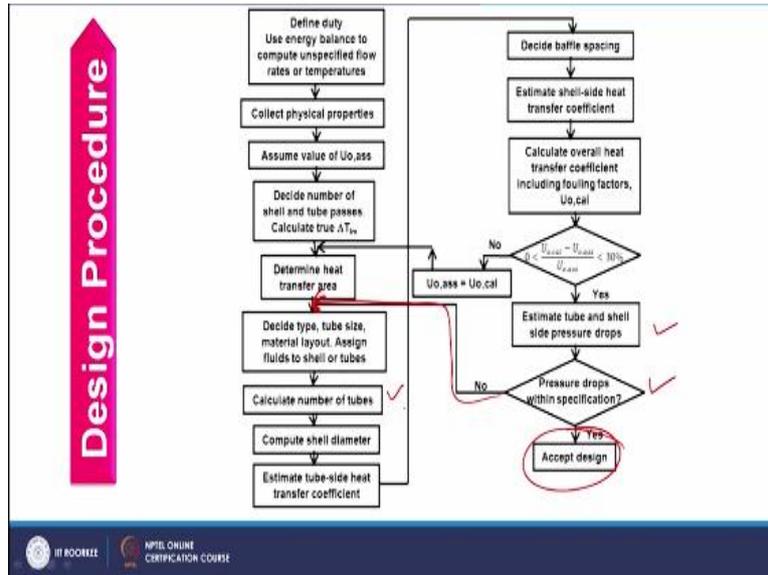
Shell nozzle-pressure drop

The pressure loss in the shell nozzles will normally only be significant with gases. The nozzle pressure drop can be taken as equivalent to 1.5 velocity heads for the inlet and 0.5 for the outlet, based on the nozzle area or the free area between the tubes in the row immediately adjacent to the nozzle, whichever is the least.

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Now let us discuss the pressure drop in shell nozzle. So, pressure loss in shell nozzles will normally only be significant with gases. If I am considering the gases then we should consider this the nozzle pressure drop can be taken as equivalent to 1.5 velocity heads for the inlet and 0.5 for the outlet based on nozzle area or the free area between tubes in a row immediately adjacent to the nozzle whichever is the least. So, depending upon that you can consider shell nozzle pressure drop.

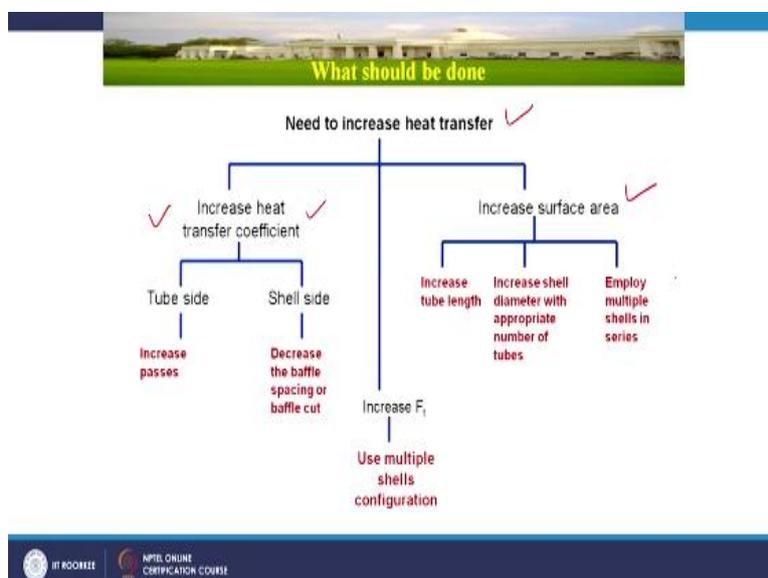
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Now once I am having this estimation of tube side and shell side pressure drop I can compare that pressure drop within the permissible limit and if it is falling within the permissible limit we can accept the design otherwise we have to change the parameters and then we start the calculation from this step where will relocate the fluid and calculate number of tubes in this way.

So, these are different steps which we can use to find out shell side heat transfer coefficient and so these are different steps which we can use to design shell and tube heat exchanger considering Kern's method. Now next we will discuss that if the heat transfer coefficient and pressure drop will not lie within the specified range what change we have to do.

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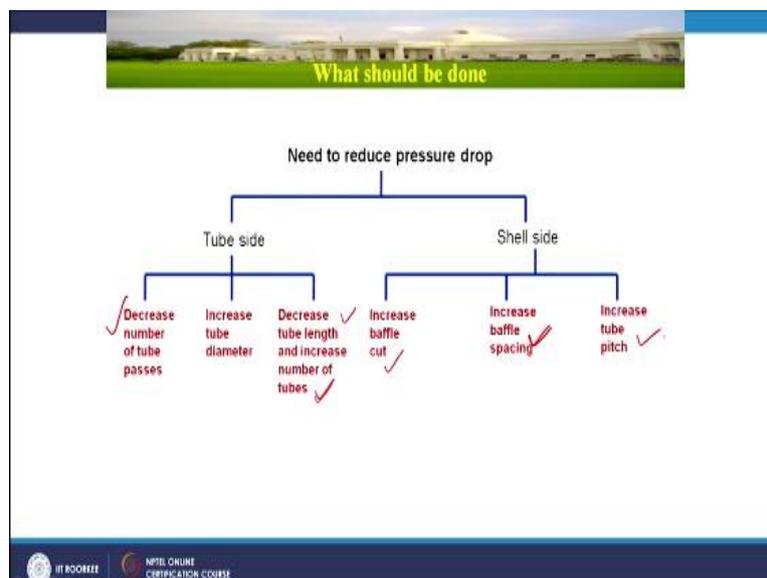


So, the next topic is what should be done? So, let us see here if I need to increase the heat transfer how I can increase that? Either I can increase heat transfer coefficient or I can increase the surface area. So, if I need to increase the heat transfer coefficient, we have different options like in tube side what we can do we can increase the passes because what will happen when I increase the pass, I am basically reducing number of tubes per pass.

And mass flow rate remains same so more flow is occurring in less number of tube in that case more velocity can be obtained so I can have more heat transfer coefficient in tube side and in shell side what we can do? We can decrease baffle spacing and baffle cut because baffle cut or baffle spacing basically decides the flow of the fluid in shell side. So, if I am reducing that section either baffle spacing or baffle cut, I am basically creating more and more turbulence.

And so, the heat transfer coefficient will be increased. Further, if I need to increase surface area what I can do. I can increase the tube length which will give me more surface area, increase shell diameter with appropriate number of tubes and employ multiple shells in series. So, all these will give me more surface area and if I need to increase the F_t correction factor, I can increase the passes in shell side and I can use multiple shells in series configuration. So that is the option.

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And second is if I need to reduce pressure drop because I should increase the heat transfer coefficient, but at the same time I should reduce the pressure drop. So, what we have to do to reduce the pressure drop. So, if I am doing this in tube side what should I have to do and

when I am doing that to shell side what should I have to do. So, let us first focus on tube side. If I need to reduce the pressure drop in tube side, I have to decrease the passes.

So there maybe contradictory thing, you have to increase the pass to increase heat transfer coefficient, but at the same time it will give more pressure drop. So, you have to reduce the pressure drop by decreasing the passes, but it will reduce heat transfer coefficient as well so you have to make the balance. How you make the balance you have to reduce the pass, but it should not be like very less heat transfer coefficient you can obtain.

However, if your pressure drop is very near to the permissible limit it should be less, I am not saying it should be high it should be less, but if it is close to the permissible limit or slightly less than the permissible limit you can consider those passes if it is giving you high heat transfer coefficient. So, you have to make the balance, you have to adjust the passes in such a way.

Next option is you can increase the diameter of the tube because more diameter will give more space to flow and so the less pressure drop can be obtained, but at the same time all these things will affect the heat transfer coefficient also, but heat transfer coefficient is mostly affected by passes. So, if you are changing the diameter heat transfer coefficient will not differ significantly.

But all these changes like changing the diameter etcetera you can make slight change in calculations, but when you are changing these things like diameter of the tube, pressure drop and heat transfer coefficient change will be very less. So, if less variation is required then only you should proceed for that otherwise passes will be the better option. I hope I am clear and second is decrease tube length and increase number of tubes.

Considering this you can reduce the pressure drop in tube side. However, how I can reduce pressure drop in shell side considering more baffle cut when baffle cut will be more, more space will be provided you can have less pressure drop, but at the same time it will reduce heat transfer coefficient as well and second option is we have to increase the baffle spacing and then we can increase the tube pitch also.

So, if pressure drop will be more you can switch to square pitch from triangular pitch. So, you can change the pitch, you can change the baffle spacing or baffle cut in shell side whether increment or decrement is required that will depend on the pressure drop and heat transfer coefficient, but try to make the balance because one thing you will change other things will definitely be affected.

And another thing you have to keep in mind that whatever change you are doing you should keep in mind that what parameters are associated with that change in previous calculation so you have to repeat all. To given an example if you are considering shell side and if you are trying to bring the pressure drop within permissible limit you should first change the baffle cut or baffle spacing because it will only affect the calculation in shell side.

However, if you are changing the pitch let us say from triangular pitch to square pitch so what you have to do? You have to restart from bundle diameter calculation. So, it will affect the tube side, heat transfer coefficient and pressure drop along with shell side heat transfer coefficient and pressure drop. So, in that way you have to think that what parameter you have to vary so that previous calculations should not change much.

So that when you will solve one or two problems on shell and tube heat exchanger the methods will be more clear to you. So here I am completing the design of shell and tube heat exchanger using Kern's method. In the next lecture, we will illustrate this design with the help of example so that different steps will be clear to you.

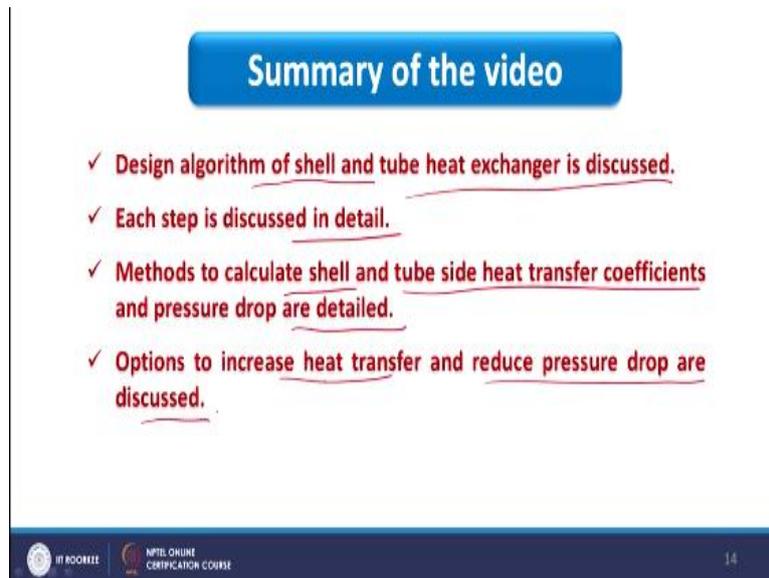
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1	Backhurst, J.R. and Harker J.H., "Coulson and Richardson Chemical Engineering", Vol. II, 5 th Ed., 2002, Butterworth-Heinemann.
2	Sinnott, R.K., "Coulson and Richardson's Chemical Engineering Series: Chemical Engineering Design", Vol. VI, 4 th Ed., 2005, Elsevier Butterworth-Heinemann.
3	Serth, R.W., "Process Heat Transfer: Principles and Applications" 2007, Elsevier Ltd.
4	Shah, R.K. and Sekulic, D.P., "Fundamentals of heat Exchanger Design", 2003, John Wiley & Sons.

So here I am having the references and the complete method you can take from Richardson's Coulson Vol 6 and in Serth book also the detail method is available.

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Summary of the video

- ✓ Design algorithm of shell and tube heat exchanger is discussed.
- ✓ Each step is discussed in detail.
- ✓ Methods to calculate shell and tube side heat transfer coefficients and pressure drop are detailed.
- ✓ Options to increase heat transfer and reduce pressure drop are discussed.

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So here I have the summary of the video and as you know that I have completed the design of shell and tube heat exchanger using Kern's method in three different lectures that is second, third and fourth lecture of week 3. So, this is the summary of all these lectures. So, in these videos design algorithm of shell and tube heat exchanger is discussed, each step is discussed in detail.

And methods to calculate shell and tube side heat transfer coefficient and pressure drops are detailed and options to increase heat transfer and reduce pressure drops are discussed. So that is all for now. Thank you.