Process Equipment Design
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Lecture –12
STE Design- Kern's Method-1

Welcome to the 12th lecture of the course Process Equipment Design and here we are in third week of this course and in this lecture we will start design of shell and tube heat exchanger and if you see we have already discussed some standards as well as codes, but these codes and standards are available for mechanical design of shell and tube heat exchanger, but process design we do not have any standard, but we have some definite method.

The very first method which is used to design of shell and tube heat exchanger is the Kern's method and if we consider this is the basic method also, whatever methods developed after that it is based on Kern's method only. So, let us start the design of shell and tube heat exchanger using Kern's method and this particular topic I will cover in three lectures lecture 12, lecture 13 and lecture 14.

And after that we will see the design of shell and tube heat exchanger through some examples.

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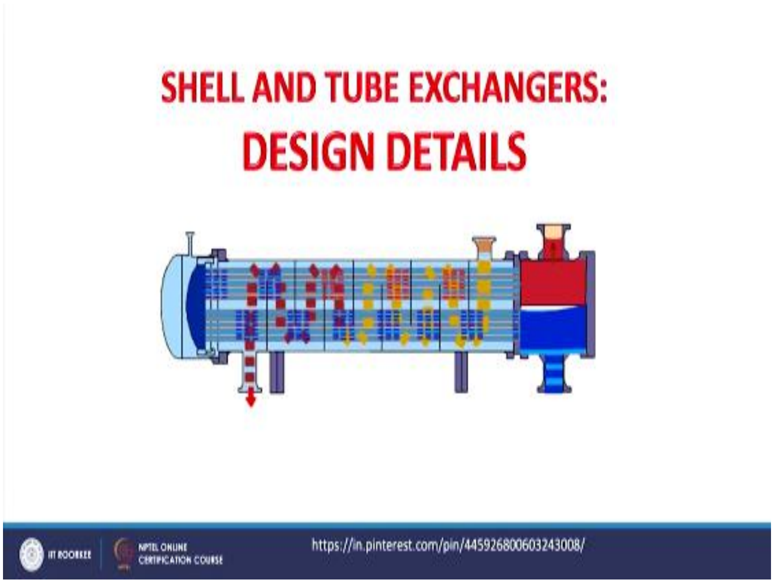

So, let us start the design of shell and tube heat exchanger and now we are going to discuss the design details. We have already covered the constructional details and all those sections or accessories which we have discussed in constructional details here you have to obtain that through proper designing, designing means through proper calculations.

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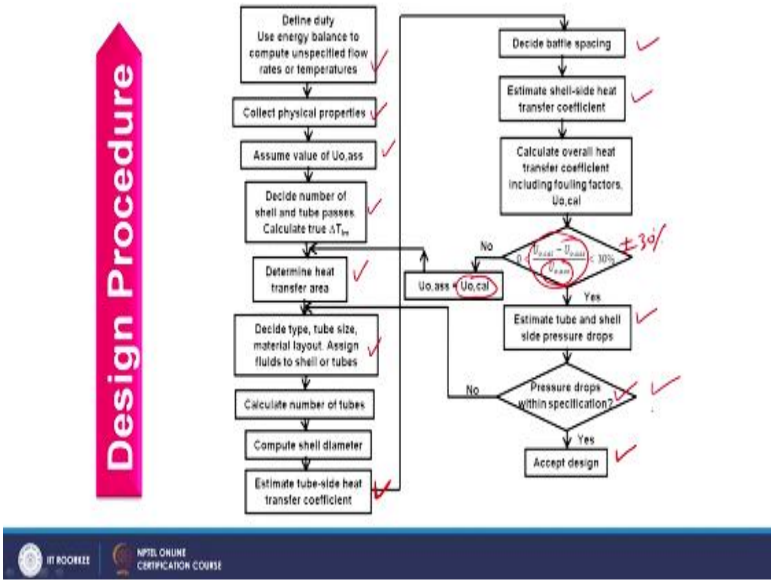

Let us see the procedure for design of shell and tube heat exchanger and what are the steps involved this one by one. So, the very first step is to define heat duty of the exchanger and use energy balance to compute unspecified flow rates or temperature. So, if you see here we have unspecified flow rates and temperature, what is the unknown parameter and what are the known parameter that we will discuss in details of this design.

Here, I am only focusing on the steps. So, first of all you have to compute the heat duty and find the unknown parameter after that we have to collect the physical property. Now if you see we have to define the heat duty. For heat duty what parameter we need or what property we need is the specific heat? So you have to collect the specific heat depending upon the temperatures of the fluid and then you have to calculate the heat duty.

So, in this way first of all you have to collect C p then calculate heat duty and then you have to find out other properties and after that the third step is we have to assume overall heat transfer coefficient because until and unless you will not assume any overall coefficient you cannot find out the area and once you find out the area then only you can proceed for heat transfer coefficient calculations.

So, here you have to assume first the overall coefficient based on outer surface. So here we have named this as Uo, ass that is the assumed overall heat transfer coefficient based on outer surface of the tube and after that we have to decide the number of shell and tube passes and calculate true LMTD because you may need to find out F t correction factor here and after that once I am having heat duty overall coefficient and mean temperature difference.

I can calculate heat transfer area and once I am having the heat transfer area we have to decide type, size, material layout, assign fluids to tube or shell side and after that we have to find out number of tubes because I already know the tube dimensions and the total heat transfer area. So, you can calculate number of tubes over here. Once you have the number of tubes you can find out shell diameter.

And to calculate the shell diameter you consider first the bundle diameter and the clearance. All these steps we will discuss in details in subsequent slides and once you have the shell diameter we can calculate tube side heat transfer coefficients and here we will discuss the empirical correlation used to calculate the tube side heat transfer coefficient. After that we will proceed towards the shell side and here first of all we have to decide the baffle spacing.

After baffle spacing we can calculate shell side heat transfer coefficient and here also we will discuss the equations or the empirical correlations involved in this estimation and once I am having this we can calculate overall heat transfer coefficient depending upon the shell side and tube side coefficient and dirt factor and thermal conductivity of the material. We also have discussed this expression in double pipe heat exchanger design.

So same expression we will use over here. Now here whatever overall heat transfer coefficient you will obtain we can name that as Uo, cal that is calculation. So, this is basically calculated overall heat transfer coefficient based on outer surface. So now you have assumed value of overall heat transfer coefficient as well as calculated value of overall heat transfer coefficient so we will compare these two.

How we will compare? We will compare based on assumed value. So here you can consider Uo, ass that is the assumed value as denominator and the value of this expression should be in plus minus 30%. Here, it is shown as + 30%, but it should be plus minus 30% if this difference lies between plus minus 30% your design is okay you can proceed further. If it is not then you have to consider calculated overall heat transfer coefficient as the assumed value.

And then you have to restart from heat transfer area calculation. So, all steps whatever you have calculated from heat transfer area you have to repeat that with calculated value of overall heat transfer coefficient and if this difference is lying within plus minus 30% you should proceed further and calculate tube side and shell side pressure drops. Now once you have this shell side and tube side pressure drop you have to compare this with the permissible limit.

Like how much pressure drop is permissible in shell side and how much is permissible in tube side. If it is lying within the range then your design can be accepted or design is valid. If it is not then you have to make some changes in tubes and other parameters and repeat whole calculation till you will find your pressure drop within the acceptable limit. So, here you can repeat that.

And if it is lying within the specified range we can accept your design can be accepted or we can say that design is valid. So, you have to carry out thorough calculations to complete the design of shell and tube heat exchanger. So from here onwards, we will discuss each step one by one in detail.

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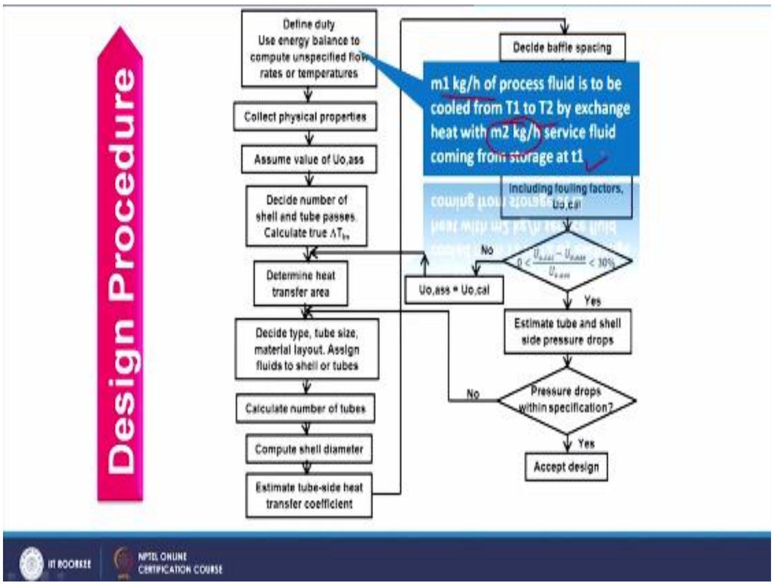

So, let us start with the first step that is define the duty. Now to define this duty we should understand that what are the known parameters to me. So, the problem of shell and tube heat exchanger design goes as m 1 kg per hour of the process fluid is to be cooled from T 1 to T 2.

So, if it is cooled it means this is the hot fluid. By exchange heat with m 2 kg per hour of service fluid which is coming from the storage at temperature T 1.

Now how many parameters are given to you? You are given m 1 which is the flow rate capital T 1 and capital T 2 which are the terminal temperatures of one fluid for which flow rate is m 1. So, for one fluid you know the flow rate, you know the terminal temperature and for second fluid either you know both temperature or you have to calculate flow rate or flow rate and one temperature and another temperature is unknown to you.

So in this way the problem is given to you and you have to define the duty. So how you can define that duty? For one fluid you know the terminal temperature. So, how you can calculate the duty? First of all you have to find out specific heat of the fluid. So, fluid is known to you, its flow rate is known to you, its terminal temperatures are known to you. So, first of all you have to consider average temperature.

And that average temperature you have to see the specific heat of the fluid and once the specific heat will be known to you, you can calculate the heat duty considering mCpdT. So, once you have the heat duty of one fluid you can calculate the unknown parameter of another fluid. Now how you will calculate the unknown parameter because to calculate unknown parameter you should also know the C p of another fluid I hope you are getting that.

So both are unknown both means the unknown temperature as well as specific heat and specific heat at what temperature you have to see? You have to see that at average temperature so both things are unknown. So here we should use trial and error method. How? First of all, you have to assume a C p value of a fluid and then you have to calculate the unknown temperature by making energy balance with the first fluid for which all parameters are known to you. So, you will calculate the unknown temperature of second fluid.

Now once you have the unknown temperature of second fluid you can calculate average temperature of second fluid and at that average temperature you can see the value of specific heat and at that average temperature of second fluid you can see the value of specific heat and at that specific heat again you have to make the balance and calculate the unknown temperature.

So, whatever would be the specific heat you have assumed or you have calculated is it equal or not that you have to ensure. If it is equal well and good if it is not what you have to do you have to consider calculated C p as the final C p and then you have to calculate the unknown temperature then calculate average temperature and then see the value of specific heat from the graph and then compare the two specific heat.

So this trial and error method should be continued till you find two consecutive C p value should be equal. So, this trial and error method becomes slightly easier when you have second fluid as water because water C p you usually know. So, in this way you have to calculate the unknown parameter of another fluid. Now once you have all temperatures of both fluids you can proceed to collect the physical properties.

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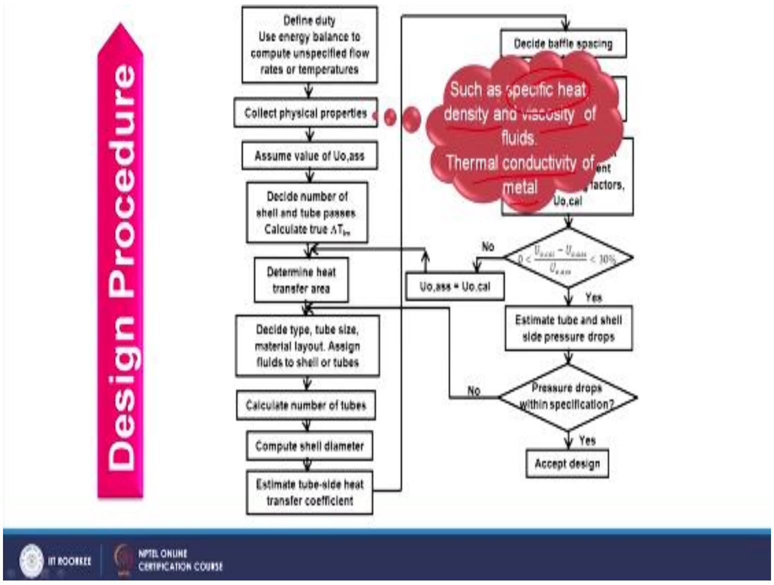

And physical properties such as density, viscosity of the fluid, thermal conductivity of the metal and for the fluid because specific heat you have already calculated and how you have to calculate this and how you have to collect the physical properties which we have already discussed in double pipe heat exchanger design just I am giving an overview.

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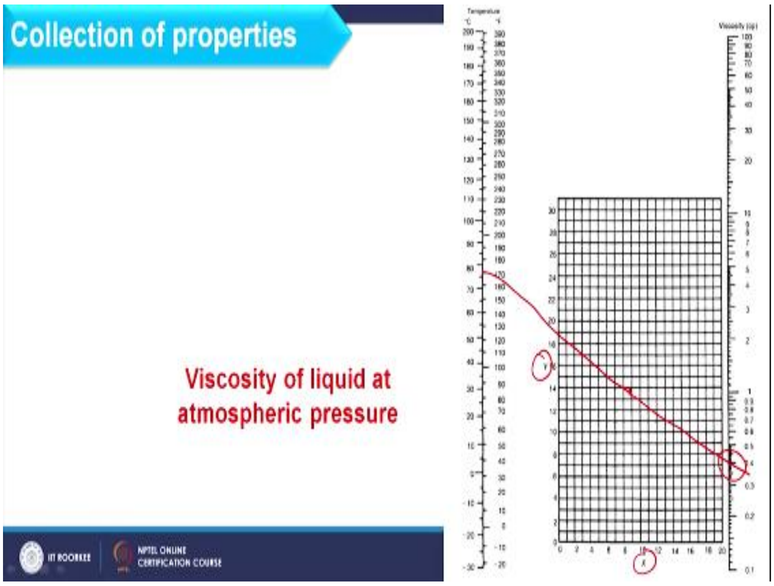

Here you can see the viscosity data and X and Y are given to you. So these X and Y you can find from these tables we have discussed all these in detail in double pipe heat exchanger. So, according to the X and Y value you can place a mark in this and depending upon the average temperature whatever it is you can simply make a line crossing that point and wherever it is cutting the right axis that value you can note as the viscosity of the fluid.

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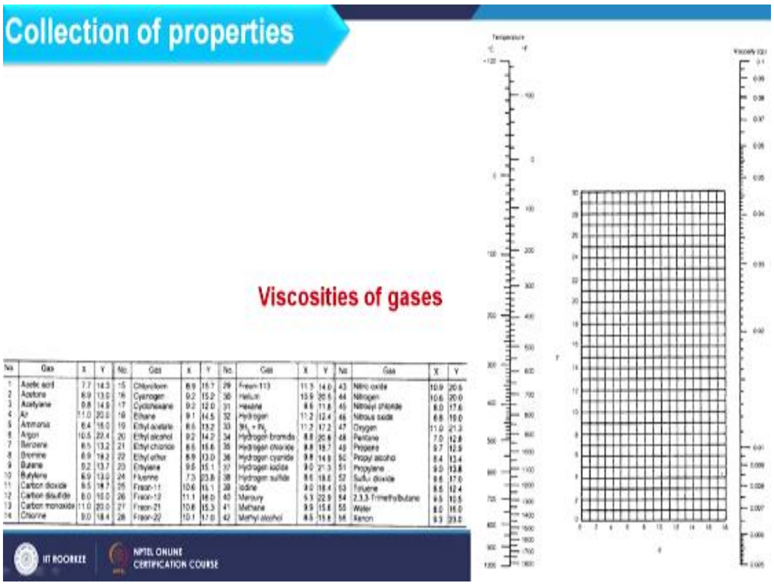

And here we can consider the viscosity of the gases depending upon X and Y values using the same method which just I have explained.

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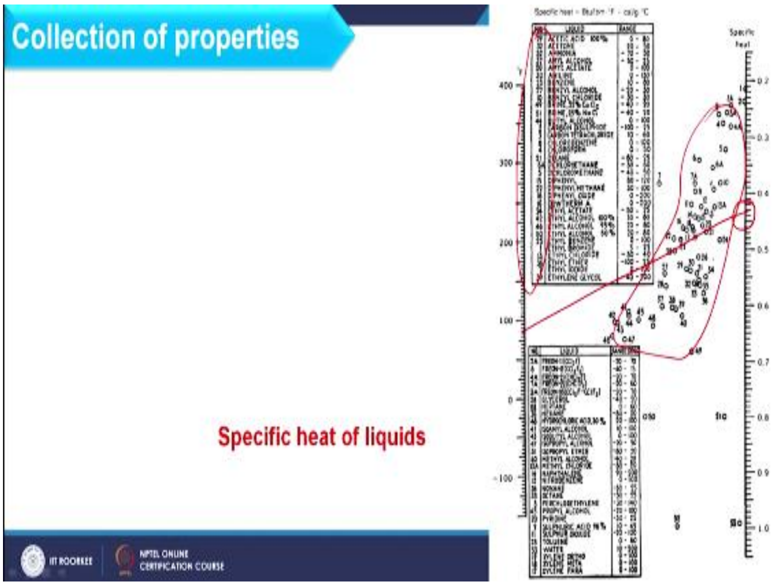

And here we have the specific heat of the liquids where for each liquid the number is given and these numbers are available in this bunch you can locate that, you can find the average temperature and then you can simply draw a line crossing that block and wherever it is cutting this right side you can consider specific heat of the fluid.

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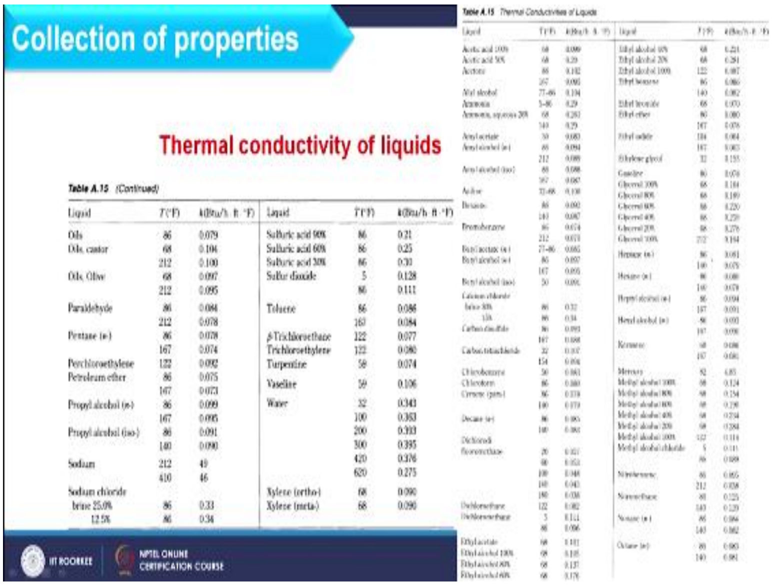

Table A.15 (Continued)

Liquid	T(°F)	k(Btu/h · ft · °F)	Liquid	T(°F)	k(Btu/h · ft · °F)
Oils	86	0.079	Sulfuric acid 90%	86	0.21
Oils, castor	68	0.104	Sulfuric acid 60%	86	0.25
	212	0.100	Sulfuric acid 30%	86	0.30
Oils, Olive	68	0.097	Sulfur dioxide	5	0.128
	212	0.095		86	0.111
Paraldehyde	86	0.084	Toluene	86	0.086
	212	0.078		163	0.084
Pentane (n-)	86	0.078	β-Trichloroethane	122	0.077
	167	0.074	Trichloroethylene	122	0.080
Perchloroethylene	122	0.092	Turpentine	59	0.074
Petroleum ether	86	0.075	Vaseline	59	0.106
	167	0.073			
Propyl alcohol (n-)	86	0.099	Water	32	0.343
	167	0.095		100	0.363
Propyl alcohol (iso-)	86	0.091		200	0.393
	140	0.090		300	0.395
Sodium	212	49		420	0.376
	410	46		620	0.275
Sodium chloride			Xylene (ortho-)	68	0.090
brine 25.0%	86	0.33	Xylene (meta-)	68	0.090
12.5%	86	0.34			

And from this table you can find out thermal conductivity of the liquids depending upon the temperature and density this we have already discussed in double pipe heat exchanger where I have discussed example 1 before that I have discussed the density, data depending upon the liquids. So, by now you have all properties, you have heat duty and all unknown parameters and after that we have to assume overall heat transfer coefficient value.

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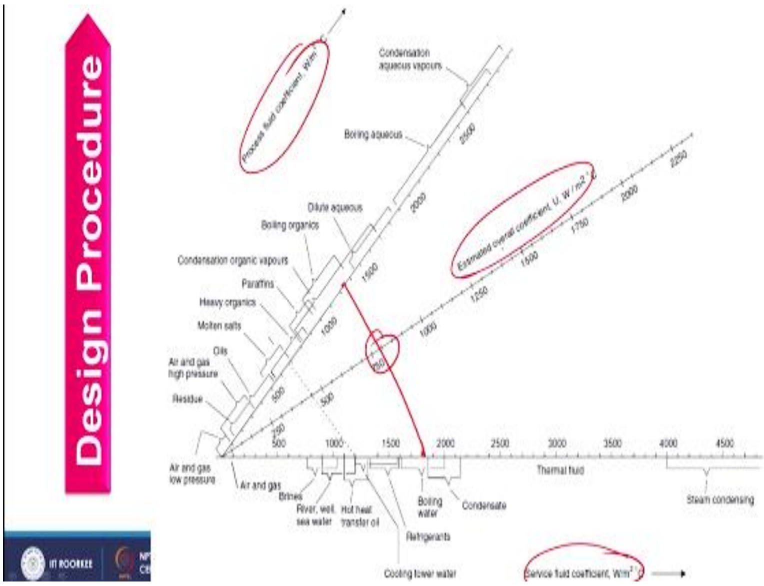

Now how I have to assume this that you can do through this graph which I have already discussed in basic design parameters. So here I am having the process fluids and here I am having the service fluids depending upon the process fluid and service fluid you can consider the center of these ranges whatever fluids you are considering and just draw a line between the two.

And wherever it is cutting this middle line which is basically estimated overall coefficient which I am saying as assumed overall coefficient. So, this value you can choose as assumed overall heat transfer coefficient.

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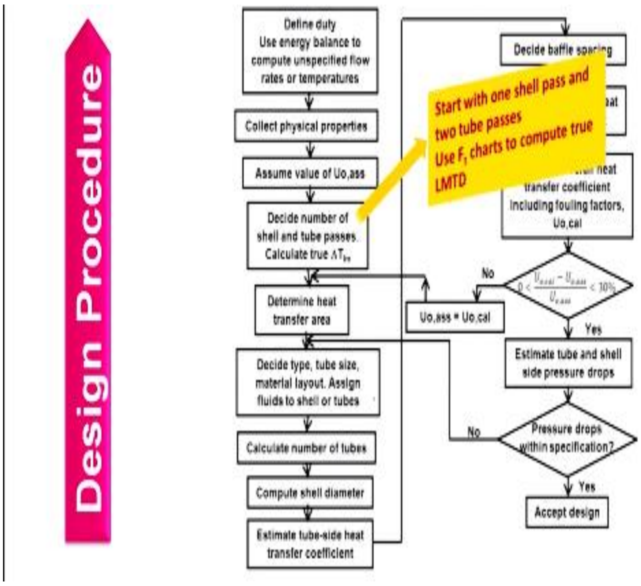

Now once you have this overall heat transfer coefficient. Next, you have to decide the shell and tube passes. Now to decide that the basic design says that the passes should be 1, 2 for initial guess. So, initially you will assume one shell and two tube pass and if criteria will not met you have to increase the passes either shell side or tube side or both. So, once you will have one shell and two tube pass you will find that F t correction factor and then you can calculate true LMTD.

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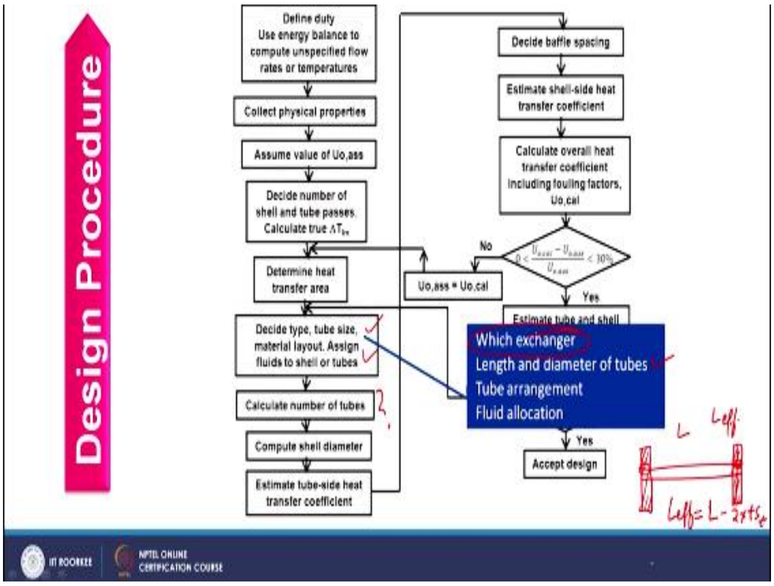

And once you have this overall heat transfer coefficient which is obviously the assumed value heat duty and true LMTD you can simply calculate heat transfer area. So, that is basically the total heat transfer area of the exchanger and after that you need to decide the following parameters such as decide type, tube size, material layout, assign fluid to shell side or tube side. So which exchanger you have to choose how you can decide that?

There are different parameters first is if temperature is less than 90 degree. If the maximum temperature available in the system is less than 90 degree you can choose fixed tube sheet. If fluid is clean in nature and temperature is more than 90 degree you can use U tube and if temperature is more than 90 degree and fluid is not clean it means dirt factors are given or toxic nature of the fluid is mentioned you should use internal floating head.

And if temperature is high and fluid tendency is not toxic you should choose external floating head. So, based on these guidelines you can choose the type of heat exchangers and then you can decide the length and diameter of the tubes. How we have to decide this that we have already discussed in constructional details where we have discussed tubes and after that we have to decide the tube arrangement whether it is triangular pitch or square pitch.

But in most of the cases triangle pitch gives satisfactory results so you can consider triangle pitch as initial guess and after that you have to allocate the fluid and what are the criteria to allocate the fluid that we have already discussed. So, depending upon the priority table you can locate the fluid to shell side as well as tube side. So, in that case if I consider the tube side there first of all you should consider about the corrosion where more corrosive fluid is there that it should be allocated to tube side.

If water fluid is there that should be allocated to tube side, if fouling tendency fluid is there it should be allocated to tube side. In the similar line if you are dealing with vapors and vapor is noncorrosive that should be allocated to shell side and if vapor is corrosive in nature that should be allocated to tube side. So here you should keep one thing in mind that if something bad is there with the fluid that fluid should be allocated to tube side not the shell side.

So in this way you can decide the type of exchanger, you can decide the length and diameter of the tube and then tube arrangement and after that allocating the fluid you can proceed to calculate the number of tubes. Now to calculate number of tubes how we can calculate this number of tubes? That will be very easy. So, how I can calculate number of tube that is very easy like total heat transfer are you have already calculated, but now you have to calculate area of one tube.

Division of these two will give the number of tubes. Now the point is how you will calculate area of one tube? Your answer should be very simple that pi d 0 L should be the area of one tube. So if I say that this is not the correct expression you should consider pi d 0 L effective instead of L. Now what is this L effective? Let us see if you are having this much of the tube and here the tube is inserted in tube sheet.

Now, if I consider the particular thickness of this tube sheet. So, that section of the tube which is inside this tube sheet it will not participate in heat transfer. So, instead of total L you should consider L effective and what is L effective is total length of the tube minus twice of tube sheet thickness. So, how you have to choose the thickness of tube sheet that we have discussed in exchanger shell that is just previous lecture than this.

So, there you can find that if OD of the tube is less than 25 mm or so tube sheet thickness should be at least 25 mm and if OD of the tube is more than 25 mm the tube sheet thickness should be equal to OD of the tube. So, in this way you can calculate L effective and once you know the L effective you can find out area of one tube and then division of total area by area of one tube will give the number of tubes.

And whatever number of tubes you will find it will also depend on the passes because whatever number of tube you have obtained if next value is even that is fine because passes are at least two pass. So, number of tube should be even so that each pass must have the complete number and if it is coming odd like total number of tubes you have calculated and found that as odd value you have to make that even and then you have to consider tubes in each pass I hope it is clear.

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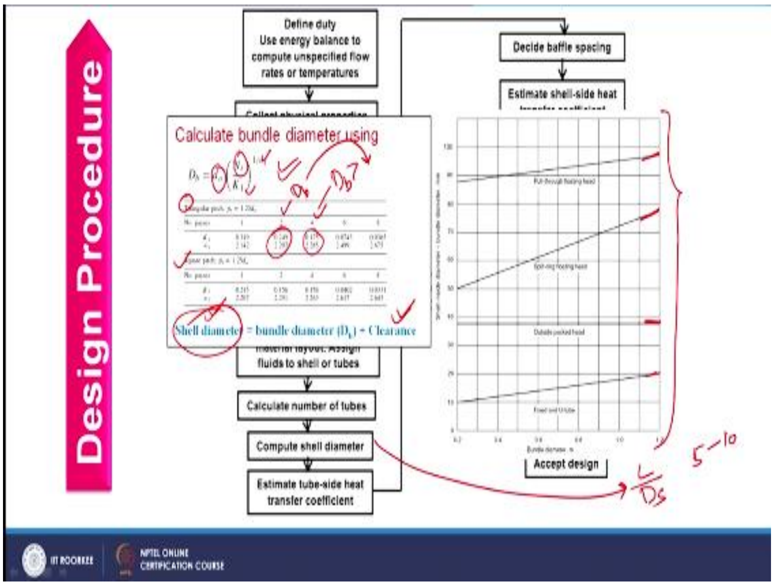

And after that you have to find out shell diameter and to calculate the shell diameter you first need to calculate the bundle diameter which you can calculate from this expression where d 0 is the outer diameter of tube N t is total number. So it will not depend on the passes whatever number of tubes you have obtained just check that it should be even number so that N t you can consider over K 1 and N 1 will depend on the passes as well as the pitch.

So, initially you have to assume the required pitch and then you have to consider the number of passes and depending upon this you can find out bundle diameter. Now if you consider the passes in one pitch let us say instead of 2 we can consider 4 passes also. So K 1 and N 1 values are arranged in such a manner so that you can obtain more bundle diameter in comparison to bundle diameter you will obtain here.

So bundle diameter will also depend on the passes along with number of tubes as well as the arrangement. Now, once you have the number of passes you can calculate shell dia considering clearance and clearance you can see from this graph where the type of heat exchanger you are using that you can locate and calculate the clearance. The type of heat exchanger you are using that you can locate and find out the clearance value and then you can calculate the shell dia.

Now here you have to do one more thing because when you have decided the tube dimension there you have considered tube diameter as well as length of the tube and I have told you previously that length of the tube means length of the shell. So, that would be basically depending upon the heat transfer whatever length of the exchanger is required that is basically the length of tube.

So here you have to ensure about the L / D ratio. L / D ratio should be what? It should be within 5 to 10 value. So length of tube you have decided that should be divided by shell diameter which you have just calculated over here and that should lie between 5 to 10 if it is not lying within 5 to 10 then what you have to do? You have to change the length in such a way so that it should fall within 5 to 10 ratio.

Here you can argue that we can change the shell diameter also. Shell diameter how you can change? You can change the bundle dia and how you can change the bundle dia? By changing the dimension of tube like diameter of the tube because you cannot have much choice in exchanger type. If fluid is fixed your heat exchanger is almost fixed or you can have very little room there to play with.

However, you have a range in tube diameter, but when you are changing the tube diameter your bundle diameter will not affect much and therefore the shell diameter will not affect much. However when you change the length of the tubes. If let us say, you have considered length as 12 fit. If L / D is coming more than that what you have to do? You have to reduce the length of the tube so next length then 12 is available as 8 fit.

So, you can see the difference over here such large difference you will not find in tube diameter. I hope I am clear. So you have to change the L / DS ratio so that you can bring this ratio to 5 to 10. If slight difference is there, then definitely you can change the tube diameter otherwise you should change the length of the tube. I hope it is clear. So, here I am stopping this lecture, we will continue this design in the next lecture and so that is all for now. Thank you.