Process Equipment Design
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Lecture - 10
Exchanger Tubes

Hello everyone, welcome to the fifth lecture of week two and this is basically 10th lecture of the course Process Equipment Design and here we are going to discuss exchanger tubes, okay. Now before we start design of shell and tube heat exchanger, it is very important for you to understand its constructional details, okay.

So how the tubes are arranged, what are the sizes of tubes; sizes means its diameter, its length, and what should be the details in shell side, right. So first of all we will focus on constructional details and then we will focus on design details of shell and tube heat exchanger. So let us start with construction details.

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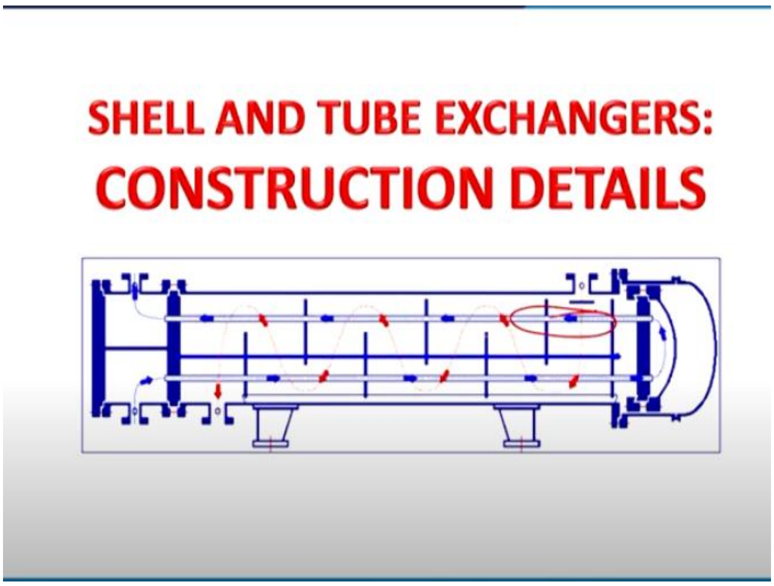

And here we will first focus on the tubes, okay.

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So let us start with the tube. But before starting that we will briefly discuss the heat exchanger standards and codes which are available and this we have also discussed in the last lecture that we have some standards, okay depending upon different countries, fine? So as far as these codes are concerned, these are specifically used for mechanical design.

So mechanical design features, fabrication, material of construction and testing of shell and tube heat exchanger is covered by British Standard BS 3274. So for each category, for each application, we have different standards and for shell and tube heat exchanger mechanical design we have British Standard BS 3274, right.

Along with that we have some standards from American also which is basically American Tubular Heat Exchanger Manufacturers Association that is the TEMA standard which we have also discussed in the last lecture and these are used in other countries also.

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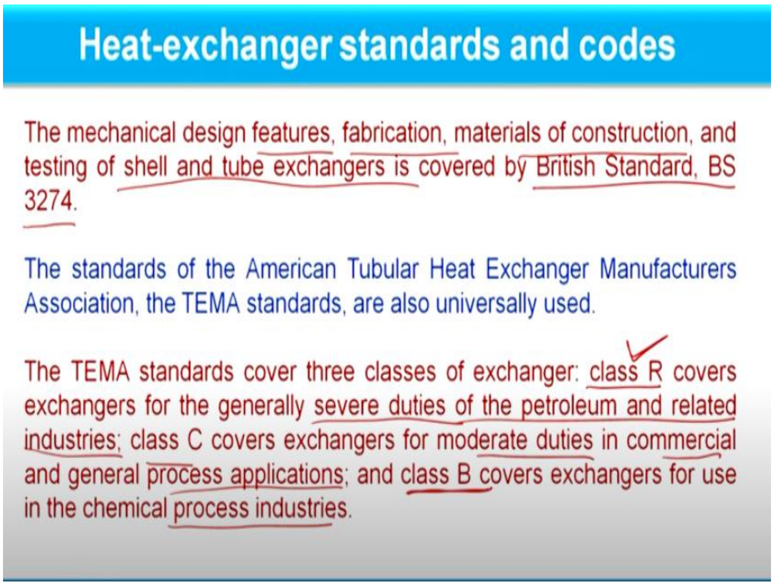

So as far as TEMA standards are concerned these standards basically cover three classes of exchanger. First is the class R, okay. It covers exchangers of generally severe duties of petroleum and related industries, okay. So when the duty is very large, we go for large, we go for class R exchangers. Class C covers the exchangers of moderate duties in commercial and general purpose application.

And similarly Class C and similarly Class B covers exchanger for use in chemical process industries. So in chemical industry, we usually use Class B as shell and tube heat exchanger, okay.

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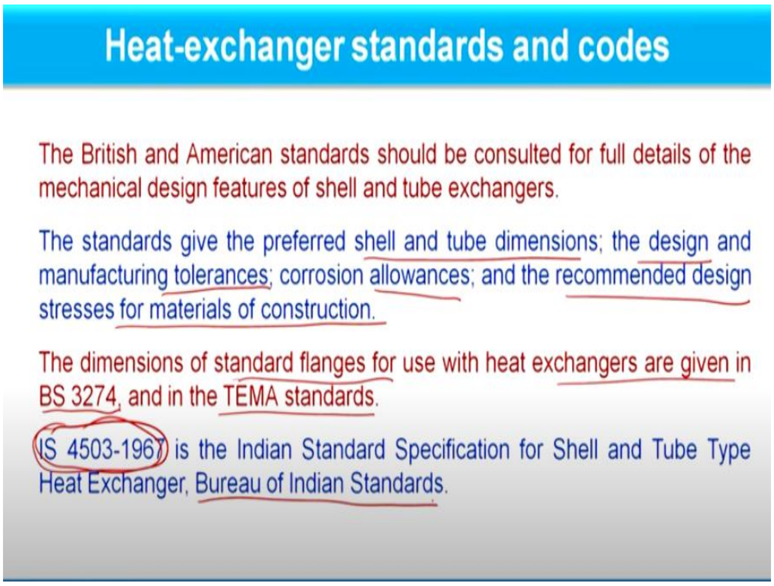

So British and American standards should be consulted for full details of mechanical design feature of shell and tube exchanger. So if you see all these codes, which are available, it is basically for mechanical design. Process design is not covered in these codes or standards, right. So standard gives, so the standard give the preferred shell and tube dimensions, the design and manufacturing tolerance, corrosion allowance and the recommended design stresses for material of construction.

So whatever would be the stresses, you can choose the material of construction, you can choose the thickness of shell thickness of the tube, but that comes under mechanical aspect, but that comes under mechanical aspect, okay. So dimension of standard flanges, further dimension of standard flanges for use in heat exchangers are given in BS 3274 and in TEMA standards also.

So if you consider the flanges, what these flanges are? This we have already discussed in our course on equipment design mechanical aspect where detailed design of flanges are considered. So these flanges are used to cover shell and tube heat exchangers also and its dimension you can calculate as per BS 3274 and TEMA standards.

In fact, India also has one standard which is extensively used to design shell and tube heat exchanger and that is IS 4503-1967, okay. So that you can use and it is given by Bureau of Indian standards. So these are basically the heat exchanger standards and codes depending upon different countries.

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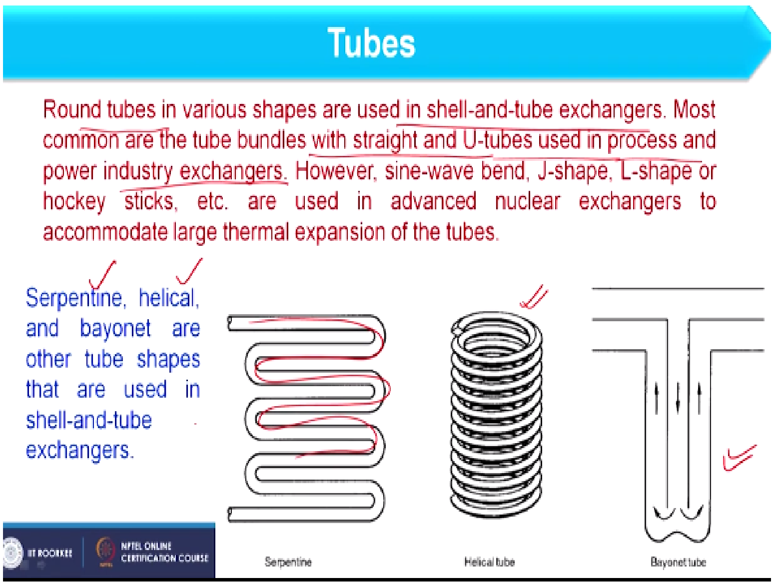

And now we will focus on tubes, okay. So first of all as far as constructional details of heat exchanger, as far as constructional details of shell and tube heat exchanger is concerned we will focus on tubes, right. So generally we consider round tubes of various shapes in shell and tube heat exchangers. Most common are tube bundle with straight and U-tubes used in process and power industry exchangers.

So mostly we use straight tubes as well as U-tubes also and for some special purposes such as nuclear exchanger also we use other type of tubes such as sine wave bend. Sine wave means the tube is like this, okay tube is like this, okay. So that is basically the sine wave bend. J shape or L shape or hockey stick. So if you consider hockey stick is like this. So this type of tubes are also used in special applications, right.

And if you see this schematic here we have serpentine that is of this shape, okay. We have helical tubes like this. And this we also have discussed in classification where pipe coils were discussed. And we have bayonet shape also as you can see from this image.

And these are some other tube shapes that are used in shell and tube heat exchangers along with straight U-tube, sine wave bend, and J shaped tubes, right. So here we have different shapes.

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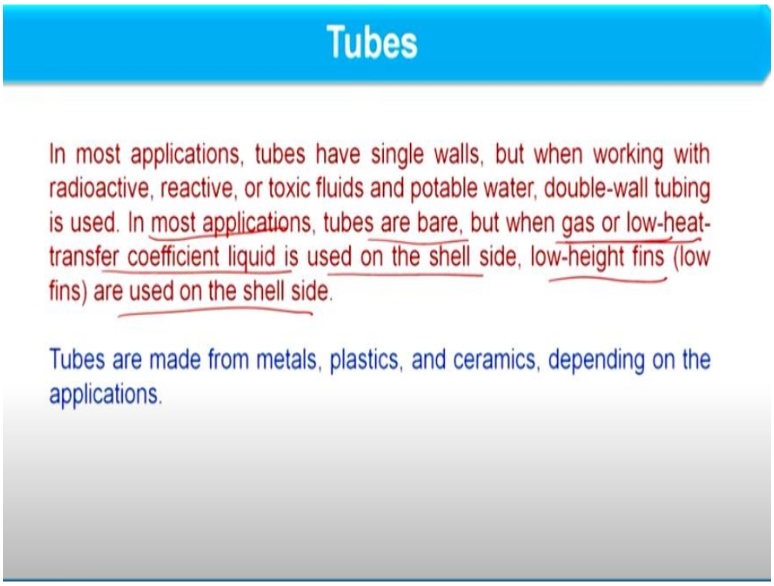

In most applications, in most of the application, we usually consider tubes with single wall, but for special consideration where I am dealing with radioactive material, I am dealing with where I am dealing with radioactive material, I am dealing with toxic fluids, we should we can use double walled tubes also, okay. So tubes are both single wall as well as double walled. And in most of the application tubes are bare.

It means we use tubes as it is which do not have any other design over it. However, in some of the application like extended surfaces, when we are dealing with gas or low heat transfer coefficient liquid in shell side, we should use low-height fins in shell side or that so that is basically attached over the tube. So these are basically tubes with fins, okay.

And further if we consider the material of construction, tubes are usually made from metal, plastic, ceramic and it depends on the type of application where the shell and tube heat exchanger will be used. So these are basically some general information about tubes. Now we will decide the tube dimension. Tube dimension if I am speaking I am speaking about tube diameter and tube length.

So what are the standards available and how we should choose the right tube dimension that we can use to design shell and tube heat exchanger, okay.

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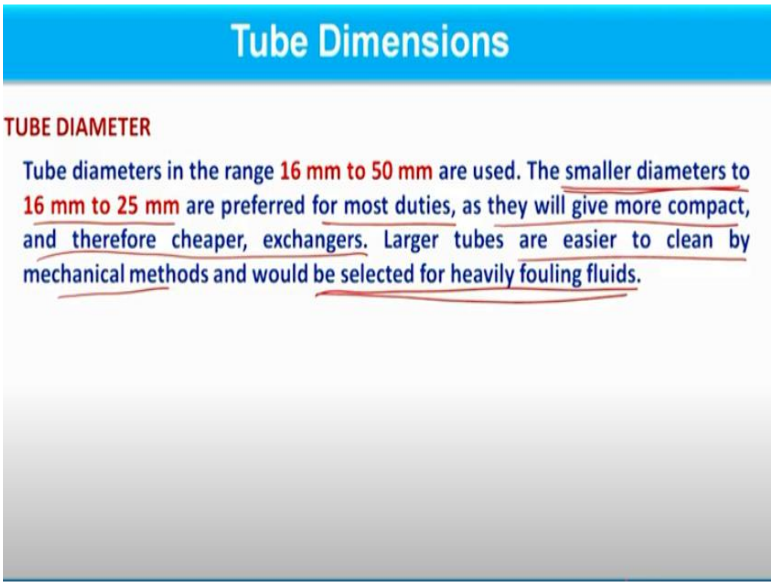

So first of all we will focus on tube diameter. Now as far as tube diameter is concerned the complete range of tube diameter is 16 mm to 50 mm, right. So up to 50 mm you can use the tube dimension or the tube diameter, okay. So up to 50 mm you can use tube diameter. The smaller diameter we can also used. So complete range is 16 to 50 mm.

However, in most of the application we consider tube diameter as 16 mm to 25 mm as optimum value, right. So smaller diameter like 16 mm to 25 mm are preferred for most duties as they will give more compact and therefore cheaper exchangers. Now if I ask you what is the parameter which decides or which enhances the cost of shell and heat exchanger.

That parameter is the diameter of shell, right. So when I am considering compact design or compact design is possible when I am having smaller diameter tubes, right. So compact design gives cheaper exchanger as it has less diameter shell in comparison to wide exchanger not the compact.

So larger tubes are easier to clean by mechanical methods and would be selected for heavily fouling liquid. So what is the main point over here is the optimum range of tube diameter is from 16 mm to 25 mm. However, you can choose any dimension from 16 to 50, okay. If I am saying any dimension what is the meaning of this?

Any dimension which is available in standard, not the any random number like 16 mm if I am saying you cannot use 17 mm if that is not available in standard, fine? So what is the main point? If I am considering tube diameter and if I am saying that you have to use smaller diameter tube, okay. And if area is fixed, where I have to focus on further?

I have to focus on the length because if I am reducing the tube dimension because if I am reducing the tube diameter, I am basically increasing the length, okay. But larger tube it means more length of the tube is good for mechanical method instead of small length and more number of tubes, right. So we can use fouling fluids also in large diameter. So now we are going to decide the dimension of the tube.

If I am saying dimension of the tube what is the meaning of that? I am deciding diameter as well as length of the tube, right. Now if I focus on the complete range of tube diameter, the complete range varies from 16 mm to 50 mm. So up to 50 mm you can consider as tube diameter. However, the smaller diameter tubes such as 16 mm to

25 mm are preferred for most duty as they will give more compact and therefore cheaper exchangers, okay.

Now if I ask you, what is the parameter which increases or enhances the cost of shell and tube heat exchanger. That parameter is the diameter of shell. So if I am using smaller diameter tube, it will give more compact heat exchanger. It means it will give lesser diameter shell it means it gives cheaper exchanger, fine?

On the other hand if I am considering larger diameter tubes, these are easy to clean by mechanical method and we can go for heavily fouling fluids and we can handle heavily fouling fluids in larger tube diameter easily, okay. However, the optimum range should be 16 mm to 25 mm. So you have to choose the diameter accordingly, okay.

Now if I ask you that complete range is 16 mm to 50 mm can you choose any number between this? The answer is no. Because there are standards and depending upon those standards only you can choose the tube diameter because in market tubes are available depending upon that standard only okay, not as per your choice. So what these standards are, let us discuss that.

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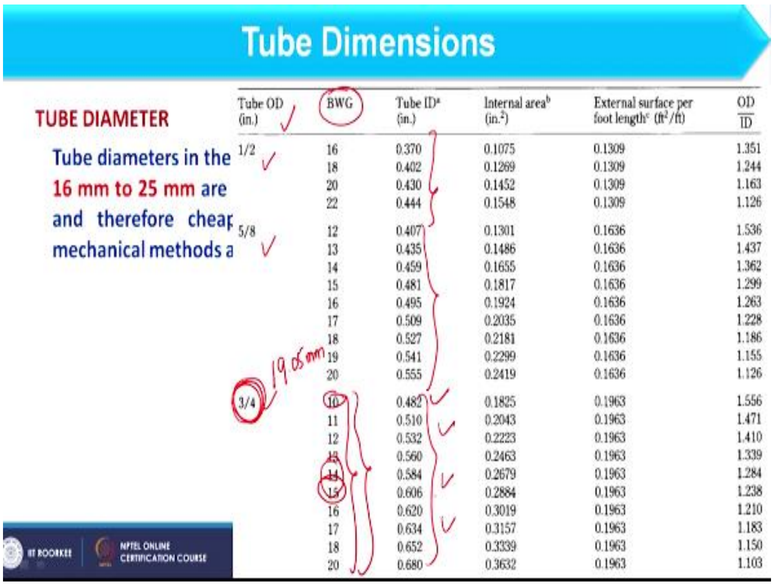

Tube OD (in.)	BWG	Tube ID[a] (in.)	Internal area[b] (in.^{2})	External surface per foot length[c] (ft^2/ft)	OD/ID
1/2	16	0.370	0.1075	0.1309	1.351
	18	0.402	0.1269	0.1309	1.244
	20	0.430	0.1452	0.1309	1.163
	22	0.444	0.1548	0.1309	1.126
5/8	12	0.407	0.1301	0.1636	1.536
	13	0.435	0.1486	0.1636	1.437
	14	0.459	0.1655	0.1636	1.362
	15	0.481	0.1817	0.1636	1.299
	16	0.495	0.1924	0.1636	1.263
	17	0.509	0.2035	0.1636	1.228
	18	0.527	0.2181	0.1636	1.186
	19	0.541	0.2299	0.1636	1.155
	20	0.555	0.2419	0.1636	1.126
3/4	10	0.482	0.1825	0.1963	1.556
	11	0.510	0.2043	0.1963	1.471
	12	0.532	0.2223	0.1963	1.410
	13	0.560	0.2463	0.1963	1.339
	14	0.584	0.2679	0.1963	1.284
	15	0.606	0.2884	0.1963	1.238
	16	0.620	0.3019	0.1963	1.210
	17	0.634	0.3157	0.1963	1.183
	18	0.652	0.3339	0.1963	1.150
	20	0.680	0.3632	0.1963	1.103

So here I am having, so here if you see here I am having the tube OD. So you see here I am having the tube dimensions and tube parameters as we have the parameters for pipe, right. So here I am having tube OD and this tube OD is given in inches. So half inch is there, 5 by 8 inch is there and 3 by 4 inch is there, okay. There is complete length. There is further dimensions also. So this table is not complete.

Just I am putting a part of that and the complete table is available in appendix B 1 of R.W. Serth book. So you can refer that, okay. Now this tube OD is given and after that we have BWG value, okay? And depending on the BWG value, we can have tube ID, okay. We can have tube ID like this, okay. So OD is fixed. However, depending upon BWG value we can choose different tube ID, right.

So what is BWG value? BWG value is basically Birmingham Wire Gauge, okay. This is Birmingham Wire Gauge. So this is a number a standard number which decides the thickness of the tube, okay. It does not mean that if number is given 10 as so the thickness is like 10 mm or something, it is not like that. But for 10 we have some specific thickness, okay.

And if I deduct twice of that thickness from the OD, I can find out internal diameter of the tubes, fine? Because we have to focus on internal diameter and outer diameter while considering shell and tube heat exchanger designing, okay. So that diameter is given by the BWG value. It does not mean that there is any relation between BWG value and tube thickness, tube wall thickness right.

Like there is a linear relation, there is nonlinear relation, it is not like that. Simply BWG a number corresponding to that wall thickness is mentioned. You cannot calculate wall thickness based on these number, okay. So this BWG number is the same as we have schedule number in pipe, okay. Schedule number also gives the thickness of the pipe and BWG value also gives the thickness of tubes.

That is the main difference only. But depending upon the BWG value you can choose the tube ID. Now as we have already discussed that optimum diameter should be within 16 mm to 25 mm, right. So if you consider 3 by 4 inches and if you convert it you will find 19.05 mm fine? So here you can choose 3 by 4 inch OD of the tube as starting guess okay because this is falling within the range.

5 by 8 if you convert, it will not fall within the range. However 3 by 4 and beyond that if value is falling within 16 to 25 mm you can definitely choose. But better start is 3 by 4 inches, okay. And you have different BWG value. So better to start the BWG value from the middle, from the center because it will give the internal diameter in such a way so that it will require least iterations, okay.

However, there is no criteria that you should use the middle one, you can use any number between this. But middle number will give the better value of tube ID. And betterment I am saying because less iterations is required as far as different examples have been seen, right? So in this way, you can choose the tube diameter.

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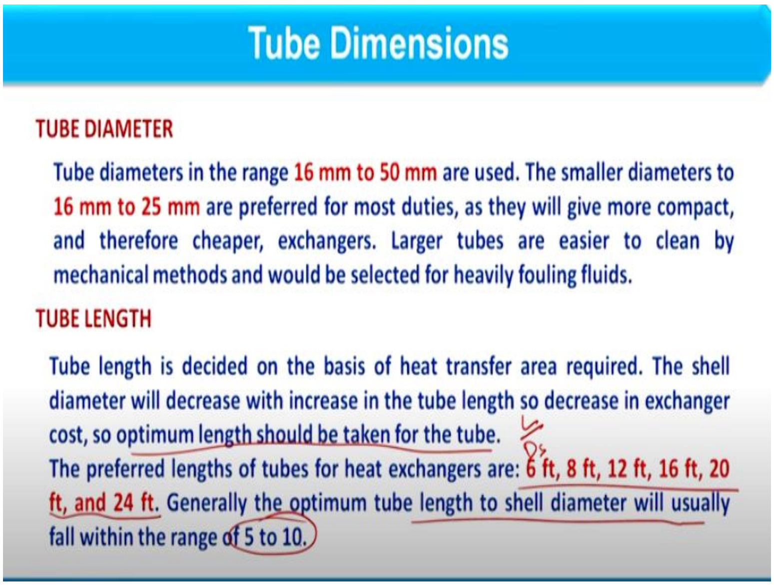

Now let us focus on tube length, okay. So what is the purpose of tube length? Tube length when I am saying basically I am fixing the length of heat exchanger, okay. If I say that 5 meter is the length of tube, 5 meter will be the length of shell also, fine? So that length, so the tube length basically decides the shell length also as far as heat transfer area is concerned.

However, complete length can be obtained by adding this tube length and tube sheet thickness and the cover size also. So accordingly the complete exchanger length can be finalized, but as far as heat transfer is concerned tube length will be equal to the shell length, right. So as we have discussed previously that the optimum diameter falls between 16 mm to 25 mm so it will give compact heat exchanger.

Now if I have the fixed area I can have the more, now if I have the fixed area, I can increase the length of tube because I am reducing the diameter of the tube. In that case what will happen? In that case we have compact heat exchanger and longer heat exchanger. But length means what? There must be some limitation, okay. So the limitation is optimum length of the tube can be taken as per L by D ratio.

And this D is basically shell diameter, okay. So this is a part of design that we will discuss. Now first we should focus on how to choose the correct length, okay. So there are standards also because when you have the standard it means you have to decide the length and diameter from that standard only. You can not choose any random value between this.

So as far as standard of tube lengths are concerned we have 6 feet, 8 feet, 12 feet, 16 feet, 20 feet, and 24 feet. So this is the complete range of tubes which are available in the market and we have to choose these length in such a way so that length to shell diameter should fall within the range and that range varies from 5 to 10, right. So length and so tube length and shell diameter should be within 5 to 10 ratio, okay.

If it is within this we can consider that your length and diameter are fixed. If we have this ratio then we can say that the length and diameter which you have chosen is correct, right. But here you should keep in mind that I am taking the ratio of shell dia not the tube dia, okay. And what is the reason behind this that we will discuss because the number of tubes will depend on the diameter of the tube right and length of the tube, okay.

And number of tubes will give the shell diameter, okay. So I am not taking the tube diameter, I am directly taking the shell diameter. So l by d ratio should be 5 to 10 that you have to ensure while designing, right.

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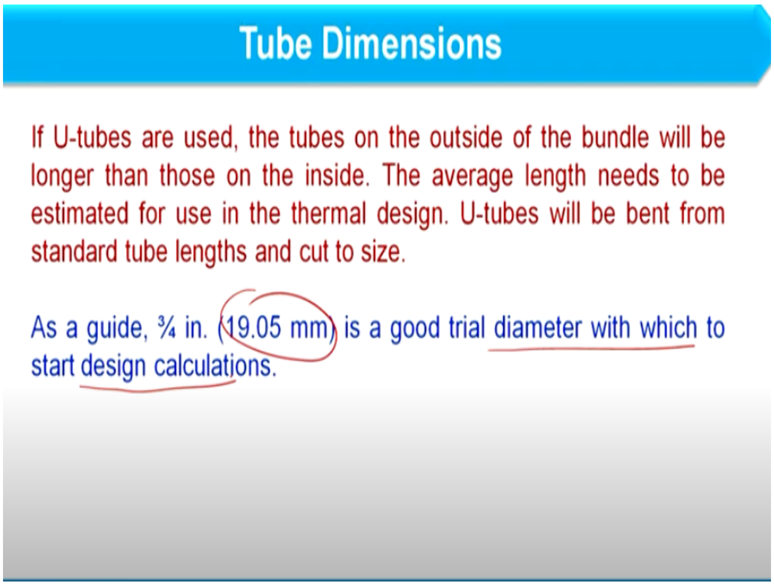

Now if we use U-tubes, so what will happen? In that case tubes on the outside of the bundle will be longer than those of the inside and that is very obvious.

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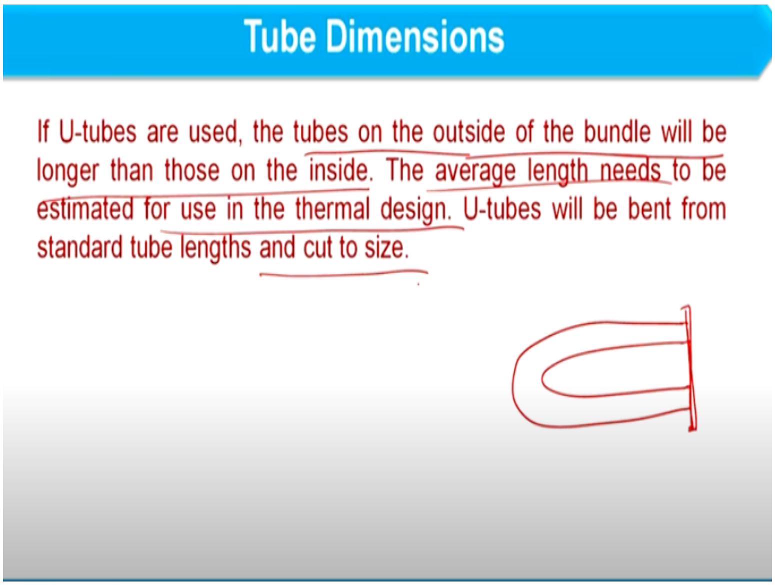

If I am having tube sheet like this, okay. Here I am having inner tube and if I am considering outer tube, it means outer tube dimension or size is very large in comparison to inner pipe, right. So the average length needs to be estimated for the use in thermal design, okay. So U-tube will be bent from the standard tube length and cut to the size. So in this way we usually consider the U-tube.

If I say the U-tube is a particular, if I say that U-tube is of particular length, it means that length is of average pipe, okay. Or this is basically the average length of the U-tube. And in the complete bundle less length tube and large length tube than the average will be available, right. So as a guide 3 by 4 inches that is 19.05 mm is a good trial diameter with which we can start the design calculations.

So which we have already discussed that it will fall in 3 by 4 inches. So that you can choose as a starting value.

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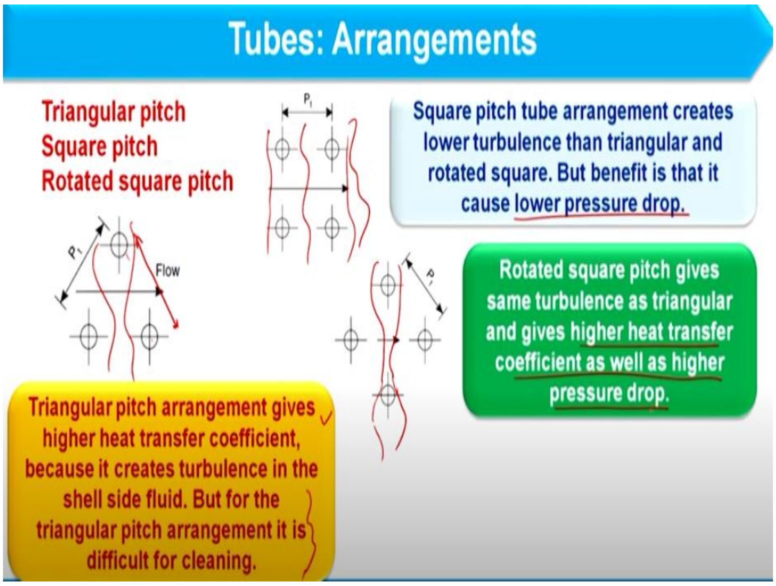

Now next we will discuss the tube arrangement, how tubes are arranged, okay. The first one is the triangular tube, the first one is the triangular pitch. So this is the schematic of triangular pitch. Now what is the pitch? Pitch is basically the distance between center to center line of two consecutive pipes, okay center to center lines of two consecutive pipe. So that is basically the pitch.

If I consider triangular pitch, because in triangular pitch what will happen flow will occur like this, flow will occur like this and further I am finding a tube over here so this flow will split, okay. Therefore, the triangular pitch arrangement gives high heat transfer coefficient because it creates more turbulence in shell side and turbulence as I have already discussed as the flow will pass through the gap and then over the tube.

So it will create more turbulence. However, at the same time it gives difficulty in cleaning because space between tube is very less in triangular pitch as compared to other pitch, okay. So the next pitch we have is the square pitch and in this square pitch you can find that the flow is very smooth. So because of that turbulence will not be created and therefore, it will have lesser heat transfer coefficient.

However, the benefit is it has low pressure drop as well, okay. And next we have the rotated square pitch. So if I rotate this arrangement it is basically called as rotated square pitch. So when the fluid is falling over here it is again spread over this tube and then it will fall like this, fine? So what is the meaning of that? It is basically creating more turbulence in comparison to square pitch, okay.

However, it will give high heat transfer coefficient at the same time it gives high pressure drop. So if you need to increase the pressure you should choose triangular pitch or rotated pitch. However, if you need to reduce the pressure drop, you have to choose the square pitch. And similarly, you can choose the condition as required to meet heat transfer coefficient values, right.

So here we have discussed three most commonly used arrangement of the tubes. However, among this triangular pitch and square pitch are used most commonly, right. So recommended tube pitch means that distance between center to center line of two consecutive tubes, this length we consider as P t and its value is 1.25 into D naught. So you see in this way we can arrange the tubes.

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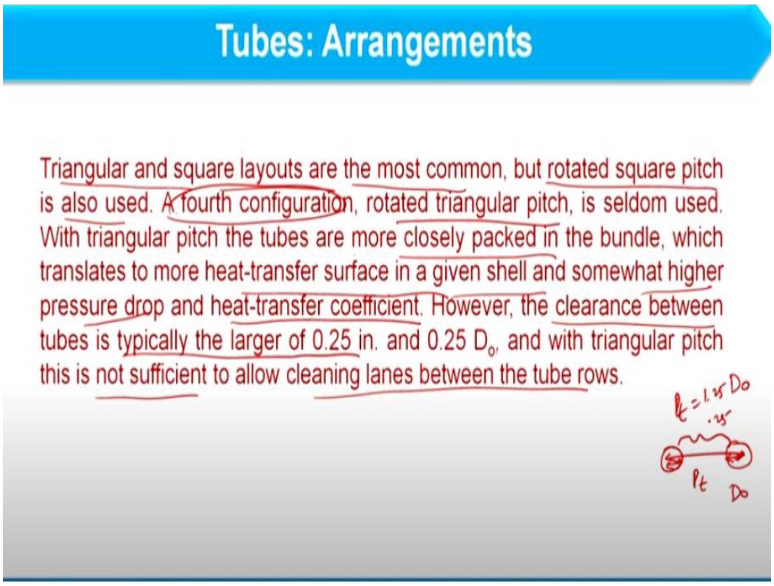

As we have already discussed that triangular and square layout or arrangement are most common. However, we can consider rotated square pitch also, okay. Further we have fourth configuration and that configuration is rotated triangular pitch and this is not very commonly used. So fourth configuration we have where I am considering rotated triangular pitch which is rarely used, but it is in the use, okay.

So with triangular pitch the tubes are more closely, so in the triangular pitch tubes are more closely packed in a bundle which translates to more heat transfer in a given shell and somewhat higher pressure drop and high heat transfer coefficient. So you can understand that tube, so you can understand that triangular pitch is more compact. It gives more heat transfer coefficient and more pressure drop, right.

At the same time cleaning becomes very complicated in triangular pitch okay because the clearance between tube is typically the large of 0.25 inch and 0.25 OD okay because complete P t is 1.25 into D naught. So if I am having tube, two tubes like this, so this is basically the P t okay. And if you consider this distance and this distance this combinely gives D naught. So the available distance is 0.25 only, right.

So in this way, this is the clearance and with triangular pitch this is not sufficient to allow cleaning lanes between tube rows. So in that case mechanical cleaning is difficult. However, we can carry out chemical cleaning, fine? Or in other words what we can do? If cleaning is required, what we can say that the formation of a scale or whatever problem is there in shell side that will be due to the proper that will be because of less gap in the tubes in shell side, right.

So that is the problem in shell side not in tube side. So how I can address that? I can provide less fouling tendency fluid to shell side. If you remember the order of priority by which we are allocating the fluids to shell side or tube side you should see there that if corrosion is more, fouling is more that fluid we allocate to tube side and the reason is this only.

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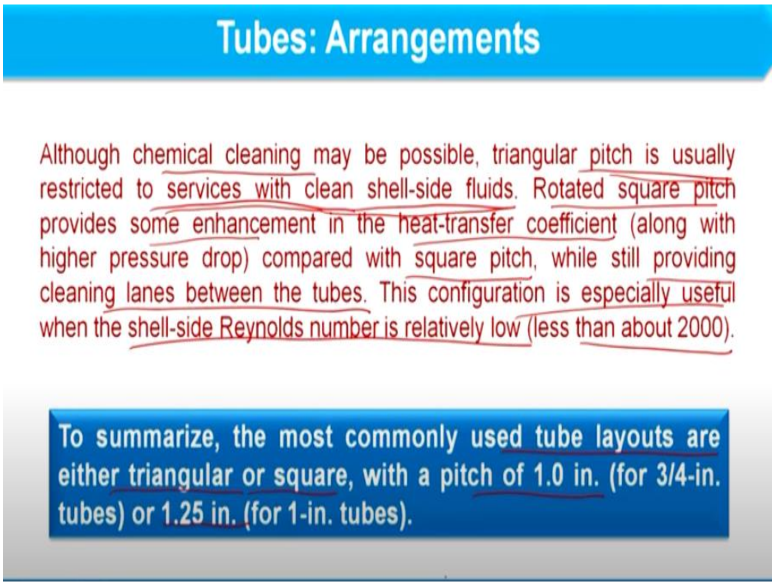

Because gap is very less and cleaning is very difficult in shell side, right. So we should allocate clean fluid to the shell side. So although chemical cleaning may be possible in triangular pitch, triangular pitch is usually restricted to services with clean shell side fluid, that we have already discussed.

Now rotated square pitch provides some enhancement in heat transfer coefficient compared to square pitch, but it is still providing cleaning lanes between the tubes, okay. So triangular pitch the main problem is the cleaning. That problem can be solved by putting rotated square pitch. Because in square pitch gap is more.

However, due to the rotation we can find larger heat transfer coefficient as required along with the larger pressure drop or higher pressure drop. So this configuration is especially useful when shell-side Reynolds number is relatively low and that is less than 2000. So in that way you can consider different arrangement in the tube side in shell and tube heat exchanger.

Now to summarize, the most commonly used tube layout are either triangular or square with a pitch of one inch for 3 by 4 inch tubes and 1.25 inch for one inch tubes. So you can see if I consider this, this is nothing but 1.25 into tube OD, okay. So that pitch we can consider.

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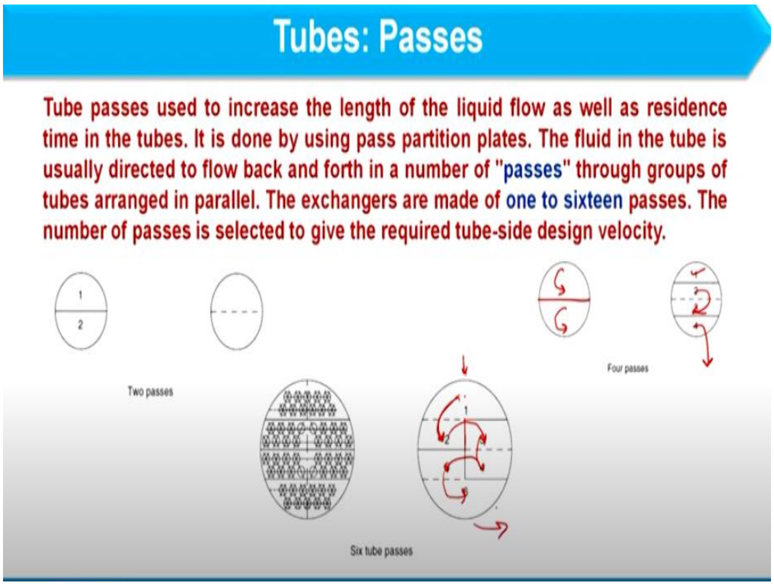

And now we will focus on the passes, okay. If I consider tube pass, what is the meaning of this? Basically I am dividing the fluid okay which is entering in the tubes and let us say if I am having 100 tubes, the complete mass flow rate of fluid which is allocated to tube side will be entered to 100 tubes in single time, okay. Now if I consider tube pass and if I consider one tube pass, what is the meaning of that?

We are addressing the complete mass flow rate of fluid which is allocated to tube side to 50 number of tubes, fine? So tube passes used to increase length of liquid flow as well as residence time in the tubes, okay. It is done by putting pass partition plate, okay. Now what will happen?

If you remember the type of shell and tube heat exchanger and fixed tube sheet heat exchanger in cover when the fluid is entering into the tube there was a plate, there was a horizontal plate. That plate is basically called as partition plate which divides the liquid in tube side in equal number of tubes, right. Either it is 2, 4, 6 like that.

So fluid in tubes is usually directed to flow back and forth in number of passes through groups of tube arranged in parallel, okay. So up to 1 to 16 pass we can use as the total number of passes. Now what is the purpose of increment? Now what is the purpose of use different passes, okay.

The purpose is, when I am considering the example of 100 tube in one to pass, we are addressing the complete fluid to 50 tubes. Now what I am doing basically? I am putting fluid to less number of tubes. It means I am increasing the velocity, okay. So if I have to increase tube side design velocity, I should increase the number of passes, fine?

So as I have already discussed that passes are up to 16 feet, passes are up to 16 number, we can see some example of these passes. Let us say if I am having two passes, okay.

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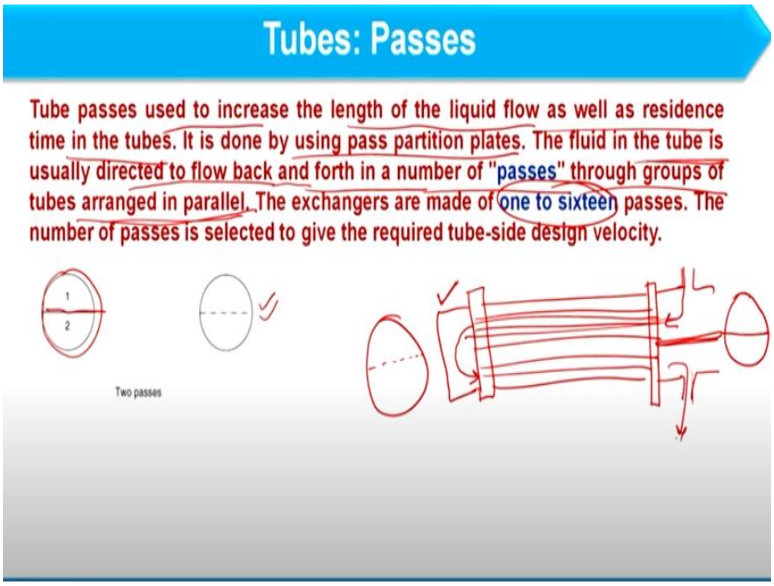

So if this is the complete cross section of the shell, and this we have divided into part and if I see the dotted line, dotted line shows that on another side of heat exchanger, we have the pass. To give an example if this is the fixed tube sheet, okay. This is the heat exchanger. And let us say here I am having the cover, right. And here I am having the tubes, okay. And pass partition plate is available here.

So whatever fluid is coming, it will be addressed to the tubes available in this region, fine? So liquid will flow in this tube and here I am not having any and in this side I am not having any partition plate. So whatever fluid is coming it will definitely go to this direction, there is no other direction, okay. So this dotted line shows that partition plate is available on another side.

Like here I am considering the partition plate. So here we should consider cross sectional view like this and here I am considering cross sectional view like this, right. So in this way we consider the two passes. So fluid will enter from here then reverse back and then it exits from here, right. So this is basically the simple pass one two pass. Now here we have the four passes.

Obviously the two partition plate will be available in one side of the exchanger or we can see the front side and rear side we have one partition plate. So fluid will enter from here, reverse from this. Then it comes to 2 and then reverse from this to 3 from the front side only and then from here it will enter to fourth and then it exits from here right in this way. In the similar line we can consider 6 tube passes.

The fluid will enter from here, the fluid will enter to here from back side. Then it will go from here, then it will go to here and from next side because solid line is there. The partition plate is available over here. From next side, it is entering to 3 and then to 4 and then to 5 and then to 6 and from here it exits from another side right. So in this way we can have 6 passes, okay.

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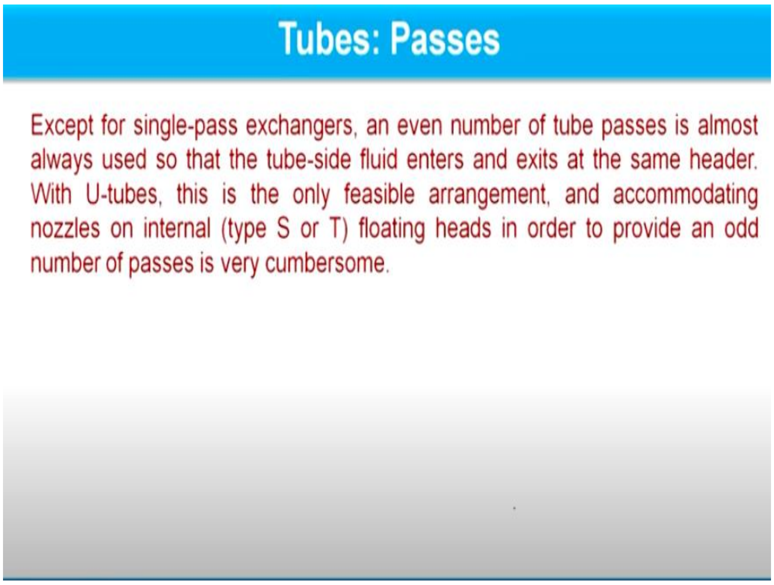

So one point I have to tell you that, if I consider the total number of passes, the passes are usually even in number, it is not odd. Because, what will happen? We usually consider inlet and outlet at one side only, that is the front side. At rear side if you consider the heat exchanger, there are different assemblies like we have to provide the movement of thermal expansion and contraction, we will have the U-tube.

So this is not possible to put the exit nozzle from second side or from the rear side, fine? So in common heat exchanger or like fixed tube sheet you can put the exit nozzle at rear side also. So there we can have the odd number of passes also. But usually we consider at one side only, inlet and outlet.

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And therefore standard we follow as we have to consider even number of passes in tubes, right. And here we have some of the references which you can go through for details of the tubes.

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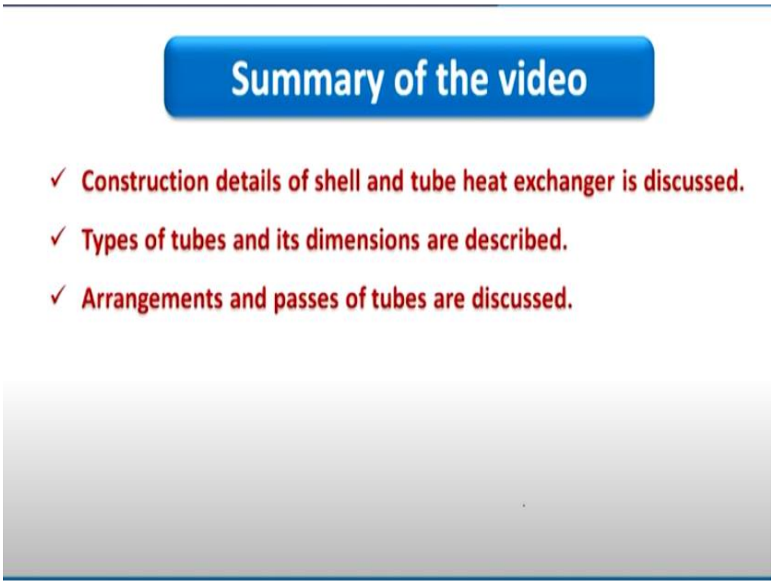

And let me summarize this video. Here we have discussed construction details of shell and tube heat exchangers. Type of tubes and its dimension are described. And then we have discussed arrangement and passes of tubes in this video. And that is all for now. Thank you.