Process Equipment Design
Prof. Shabina Khanam
Department of Chemical Engineering
Indian Institute of Technology - Roorkee

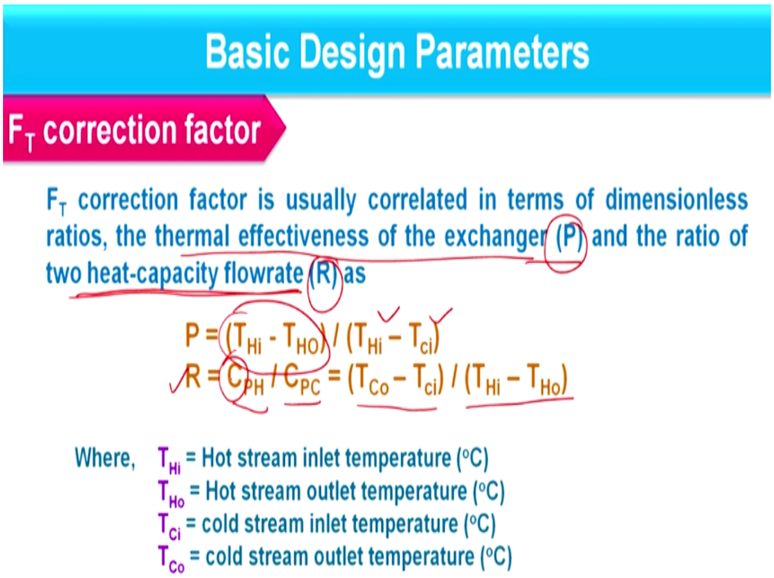
Lecture – 5
Basic Design Parameters - II

Hello everyone, welcome to the fifth lecture of week 1 of the course process equipment design and here we are discussing basic design parameters, and this topic I have started in previous lecture that is lecture 4 where we have discussed different parameters which are involved in basic design equation of heat transfer that is Q = UA delta T lm. So, we have discussed overall heat transfer coefficient, different terms involved in that and the mean temperature difference that is LMTD.

So, what happened when I am designing shell and tube heat exchanger, I consider FT correction factor in log mean temperature difference and that log mean temperature difference corresponds to the counter current flow. So, FT factor considers the mix flow because in shell and tube heat exchanger, we have co-current, counter-current as well as crossflow.

All three pattern will occur simultaneously and therefore we have to consider that through a mathematical term and that is FT correction factor. So, in this lecture we will cover FT correction factor, its proper value, how to choose the right value of FT and what is the consideration while choosing FT factor and after that we will discuss fluid allocation to shell side and tube side and then we will discuss some velocity as well as pressure drop limitations in shell and tube heat exchanger. So, let us start with FT correction factor.

(Refer Slide Time: 02:12)



So as far as ft correction factor is concerned, we consider that considering two different parameters. First parameter is thermal effectiveness of exchanger and that we represent with P and the ratio of two heat-capacity flowrate that is R. So, here we have two parameters P and R and depending upon these two values, we will consider FT factor value. So, what is this P and R? P is the thermal effectiveness of the exchanger.

It means how effectively the heat transfer take place in an exchanger. So, obviously it will depend on the temperature difference okay. So, if I consider expression of P, P is basically THi – THo okay and THi – TCi. Now, if I consider this THi – Tho that is the temperature difference of one fluid that is the hot fluid okay and this THi – Tci what is this? THi – TCi is nothing but maximum driving force or maximum temperature difference available in a heat exchanger.

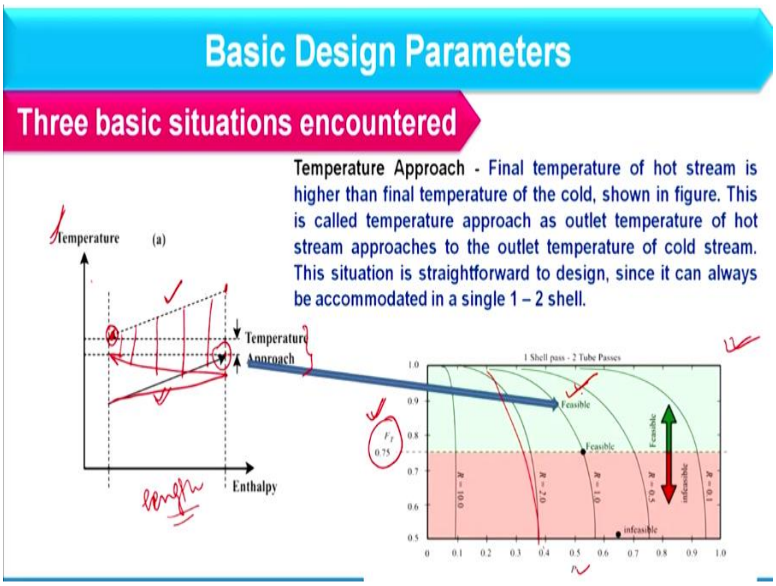
Because highest temperature will be when hot fluid is entering that is THi and lowest temperature would be when cold fluid is entering that is TCi. So that is the maximum temperature difference available in the system and THi – THo is basically temperature difference of one fluid that is the hot fluid. So, what I can say over here that the maximum value of P should be 1 okay.

Maximum value of P should be 1 because in this case no driving force will be close to THi – TCi and further if I speak about heat capacity flow rate that is R, so that is CPH by CPC. So, TCo – TCi by THi – THo. So, this capital CP, this is not a small c, this capital CP is heat capacity flow rate and that is the multiplication of m into specific heat fine of hot fluid as well as of cold fluid. Now, this is basically the combination of P and R okay.

If I consider P as THi – THo can I consider P as TCo – TCi divided by THi –Tci. Instead of hot fluid temperature difference, can I take four cold fluid temperature difference? Definitely I can, fine, but in that case the combination will be for R we have CPC by CPH, right. So, whatever would be the numerator of P, the same would be the denominator of R that would be the proper combination.

So, in some books you can find different terms of P and R like TCo – TCi divided by THi – TCi, but in that case R would be CPC by CPH okay. So, this I am repeating because you have to keep in mind that this is not only the correct expression, other expressions are also there, but that should be in combination and what is the combination that I have already explained, fine.

(Refer Slide Time: 06:10)



Now, I will speak about that how we should consider FT correction factor. To explain that I have to consider another parameter and that we call as temperature approach, fine. So, considering temperature approach we usually have three basic conditions. The first condition is when we have sufficient temperature approach value. Now, what is temperature approach? Temperature approach you can see in this diagram where I am having this is the hot fluid where temperature decrease is there.

And this is the cold fluid where temperature increment is there. So, temperature approach is basically the difference between outlet temperature of hot fluid minus outlet temperature of cold fluid, difference of this, difference of this okay that is basically the temperature approach as you can see here. Now, if this is the case, then I can represent FT factor in this diagram, this is the FT factor graph.

You all must be aware with this where on X axis we have P value and we have different curves for R value as shown over here and we have given one factor that is the FT factor. If it is equal to 0.75 or more we consider that design is feasible, right. Now, how I can consider that design is feasible? Fine, feasibility means what? When I am considering heat transfer what is the meaning of feasibility?

Feasibility means whatever would be the cold stream or whatever would be the temperature of cold fluid that temperature will be less than the temperature of hot fluid all the time, then only natural heat transfer will take place because it will definitely move from high temperature to low temperature. So, cold fluid temperature should always fall below hot fluid temperature, fine.

So, if you consider this diagram, here I am having a hot fluid, this is the hot food and this is cold fluid. So, at each point we have cold fluid lesser than the hot fluid, this much temperature difference is always there fine. So, this is basically the proper temperature difference and heat transfer can occur easily, right. So, what is the point that if I consider counter current flow at every point cold fluid temperature will be less than hot fluid temperature.

Now, what will happen in 1-2 shell and tube heat exchanger. If let us say instead of enthalpy if I am considering here length, if length is there and here I am having temperature also. So, if 1-2 shell and tube heat exchanger is there what I can say that terminal temperature should not change because whatever temperatures are available for hot fluid and cold fluid that I cannot play with.

So if I consider 1-2 shell and tube heat exchanger and if hot fluid is moving in shell side, so shell side because one flow is there, so it will enter here and exit at this, right. Now, what will happen with cold fluid? Cold fluid will move in tubes and that is to pass, but outlet temperature of cold fluid will remain at this point only. So, how this movement will occur along the length, first it will move like this and then it will move like this, right.

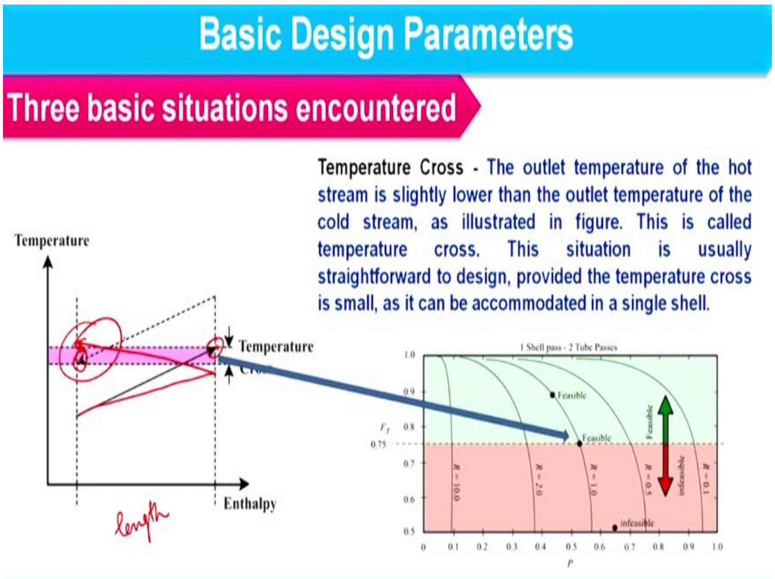
So, along the length in 1-2 shell and tube heat exchanger the movement is like this and further what I can say that at each point cold fluid temperature is less than the hot fluid temperature. It means at each point heat transfer becomes feasible. So, if this is the case FT factor will lie in feasible zone where FT factor will be greater than 0.75. Now why I have put the bar of 0.75?

Because when I am considering LMTD for counter-current flow we multiply that with FT correction factor right and that FT correction factor reduces the temperature driving force, reduces the mean temperature difference. So if temperature difference will be reduced, area will increase manifold, right. So, to put a bar on area we put a bar on ft correction factor because I cannot change LMTD, temperature I cannot play with.

I can make a bar or put a bar on FT value and that value that thumb rule is that it should be greater than 0.75. It does not mean that if FT correction factor reduces, then 0.75 heat transfer will not occur, heat transfer will occur but the area will increase manifolds so that we consider as infeasibility, right. So, if this is the case where temperature approach is sufficient, we can counter or we can consider proper heat transfer in 1-2 heat exchanger also.

Therefore in that case FT correction factor will be more than 0.75 okay. If you calculate it will definitely come more than 0.75 because temperatures are like that okay.

(Refer Slide Time: 12:41)



Now further if I consider another situation and another situation means what, when I am considering temperature cross okay. Now what is temperature cross? Let us discuss with this temperature cross is basically when hot fluid exit temperature is lesser than the cold fluid exit temperature. In that case what will happen? In that case if I consider counter-current flow or if you focus on this diagram, at every point cold fluid is lesser than the hot fluid.

So, feasibility is maintained, but as far as counter-current flow considers. Now if I consider1-2 shell and tube heat exchanger and hot fluid is available in shell side. So, exit temperature of hot fluid will remain as it is, right. Now what will happen with cold fluid? Cold fluid exit temperature is this. Now if 1-2 shell and tube heat exchanger I am considering and I am considering length on X axis then this temperature should be allocated here.

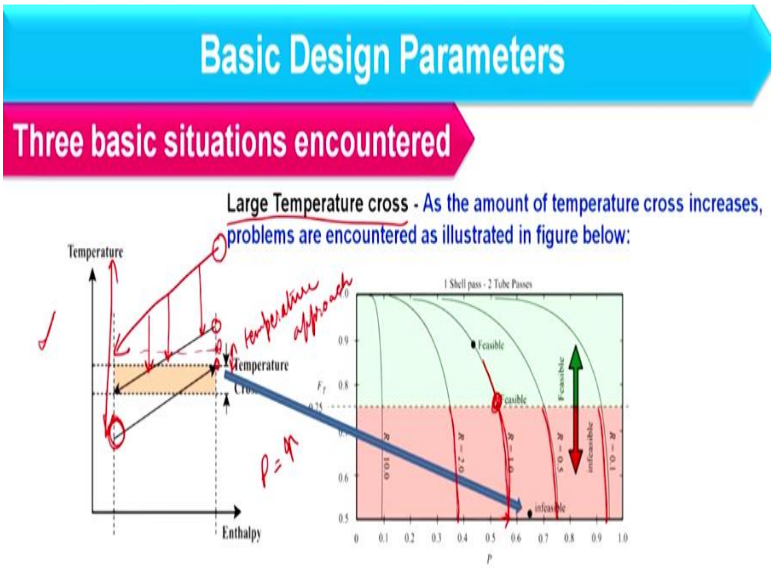
So, in that case what will happen? This for first moves like this and then it will move like this. So, what will happen in this region? Here we have higher temperature of cold fluid than the hot fluid temperature, which is not feasible okay. However, we can consider some amount of temperature cross. In that case if this situation arises, then what will happen? FT factor will be equal to 0.75, fine.

So, what I can say that up to 0.75 little bit temperature cross is occurring that is fine. Now what will happen in temperature cross? Is it possible that cold fluid temperature increases then hot fluid temperature? In some cases you can argue that because there is a mix flow counter-current co-current flow, so in some cases is it possible, but usually what will happen it will not reach up to the desired temperature.

Cold fluid will not reach up to the desired temperature. It means a desired heat transfer is not possible and therefore I am saying that temperature cross must be avoided. So as temperature cross increases, FT correction factor falls rapidly which is the infeasible design because we should not allow temperature cross. So, I hope you understand that 0.75 is a bar, is a thumb rule to control the increment in heat transfer area okay and that will be due to the temperature cross.

So, if we want to avoid the infeasible design, we have to avoid the temperature cross and for that purpose FT factor should always be or equal to more than 0.75 okay.

(Refer Slide Time: 16:24)



Now, next is if I am considering more temperature cross then what will happen? Let us see. If you see this graph here we have more temperature cross, up to this much temperature crosses there. So, as far as counter-current flow is considered, I am again saying that no feasibility is occurring. However in 1-2 shell and tube heat exchanger, we have this kind of flow. So, sufficient temperature cause will be there and this we are considering as large temperature cross.

So, what will happen in that case? In that case the FT correction factor falls rapidly and it will lie in a region of infeasible design. Now, my point is why this FT factor decreases? To explain that let us compare temperature approach and temperature cross. Now, what will happen if I consider this diagram temperature approach is what? Temperature approach is basically this value if I consider hot fluid temperature.

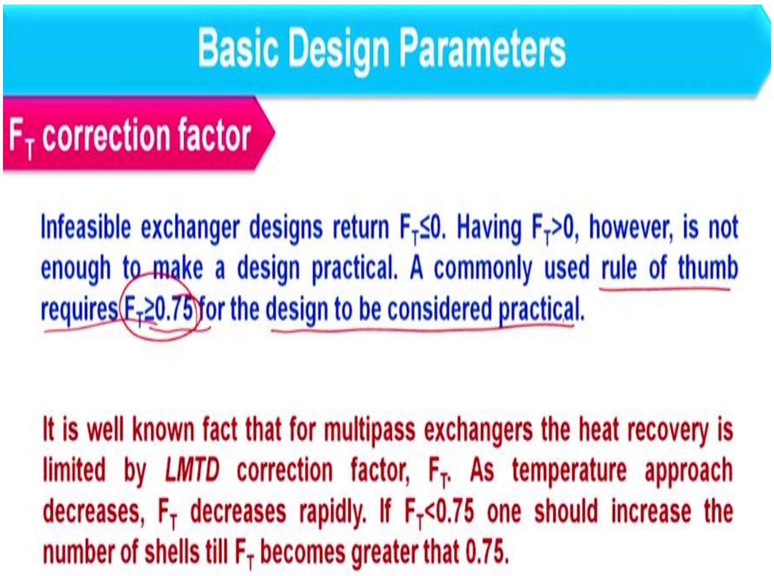
So this is the outlet temperature of hot fluid and this is the outlet temperature of cold fluid. So, this difference is basically temperature approach, right. Now, if temperature approach is there what is the P value? P value if you remember that is basically the inlet temperature of hot minus inlet temperature of cold. So, the difference is around this much, fine. However, if I am considering temperature cross then what will happen?

This line will fall up to this level okay and now P value will be what? This minus this. So, what will happen? As temperature cross increases, P value will increase because denominator value will decrease. Now, what will happen if I am considering same R? Let us say this R I am considering and if temperature cross increases P value will increase. So, if I am operating over here and temperature cross occurs, so P value will increase, so slight increase.

Let us say slight increase in P reduces FT correction factor rapidly because now it is falling in this asymptotic lines. So, as temperature cross increases, FT factor decreases rapidly which we should avoid. So, we will also discuss that what we have to do when FT correction factor falls less than 0.75 okay, but first of all you should understand that what will happen when FT factor reduces then 0.75.

So, in that case temperature cross increases which we should avoid okay. Temperature cross basically cold fluid increases than hot fluid. So, what will happen at that point? Local reversal of heat transfer will take place from cold fluid to hot fluid or in some cases cold fluid will not reach up to the desired exit temperature. So, all these infeasibility will occur when I am considering temperature cross, so that we should avoid okay.

(Refer Slide Time: 20:17)

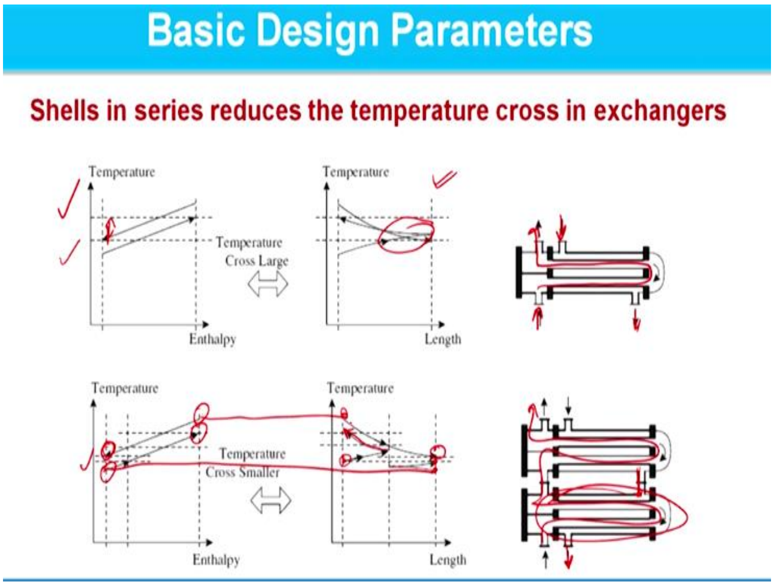


So, FT correction factor says that the rule of thumb is what FT factor should be greater than 0.75 to consider practical design. So, if I am considering 0.75 that is I have to do that fine, now how I will do that? If FT factor comes less than 0.75 because I have already told you before that I cannot change the terminal temperatures, whatever would be the temperature cross I should not change the inlet and outlet temperatures.

Then how I can improve FT factor? FT factor can be improved by considering more shell passes okay. Here what I have considered one shell and two tube pass okay and if one shell will remain there and I will keep on increasing tube passes, so hot fluid will pass only the shell once. So, no change will occur in fluid which is flowing in shell side. So, if I have to improve the temperature cross, I have to improve the shell passes.

Now, I will discuss one example with the flow pattern inside the heat exchanger so that you can get the idea that if I increase the shell passes, how FT correction factor can be improved. Because whatever FT factor graph you have seen till now that is only for 1-2 shell and tube heat exchanger. If I consider 1-4 shell and tube heat exchanger, FT correction factor graph will be different than this. So, there we can find for the same terminal temperature FT should be more than 0.75 that is the advantage.

(Refer Slide Time: 22:32)



Now, I will show the pattern that how the shell passes improves temperature cross and so the FT correction factor okay. So, here I am explaining that with the help of this example. Here you see we have temperature and enthalpy profile where temperature cross is large, this much is the temperature cross. Now, if I draw that in 1-2 shell and tube heat exchanger, so you can understand here we have the schematic where fluid enters 1-2 shell and exits.

And in tubes fluid will enter from here it will pass through this and then it will exit from here. Now what will happen? It will pass twice in tubes, fine. So, that you can understand from this graph that here we have temperature as well as length. So, in shell pass fluid moves once only and in tubes it moves twice. So, here I am having the temperature cross, so this condition I should avoid okay. So, I will increase the shell passes, fine.

Here we have the same condition like this. These two graphs are same and here what will have been instead of one shall we consider two shells. Here fluid enters in one shell, exits, and then enters to second shell and then exits from second shell and if I am considering two shell I have to consider four passes in tubes. Once tube will be like this and then tube movement will be like this, right. So, here we have this kind of condition.

Now what will happen? I cannot change the terminal temperature, this temperature, this, this, all these temperature will remain same. So when the fluid is entering, this temperature will be equal to this, you see this is, okay and then once it will exit the first shell it will enter the second shell and then finally it will exit. So this temperature and this temperature will remain same.

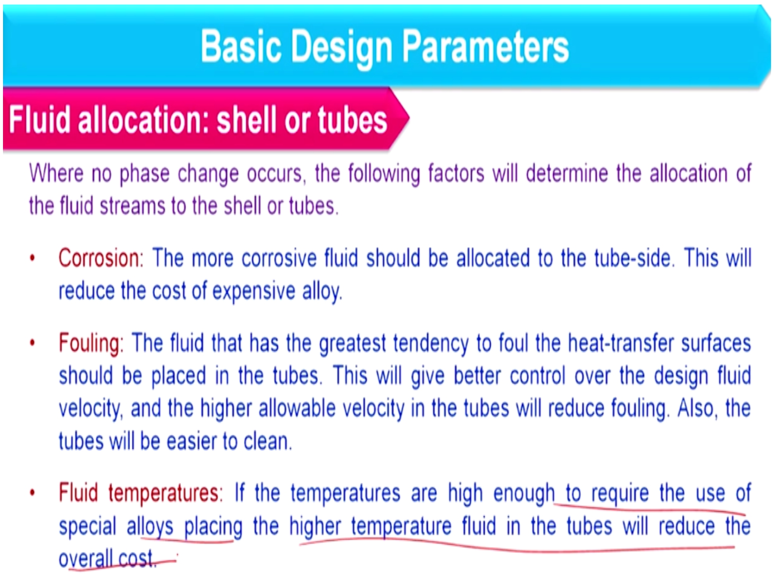
Now what will happen with tube side fluid? Tube side fluid this is the inlet temperature, which is equal to this temperature. So, the fluid starts from here and then exits in first shell which is basically this shell and then at this temperature it will enter to the second tube at this temperature okay you see and then it will move like this and then it will move like this. So what I can say that when I am increasing the shell passes, the movement of fluid will be like it will never cross the hot fluid because its path will change, fine.

So, that is the advantage of increasing the number of shells. So, when I am increasing the number of shells, I am avoiding temperature cross, I am increasing FT correction factor. So, when FT correction factor you have found less than 0.75, immediately you have to increase the number of shells. So, that is the basic design parameters. Now, we will consider another point that is how I should allocate the fluids to shell or tube side.

Now, before considering this allocation, one thing you should keep in mind that whatever verse you are doing okay whatever verse you are doing that you should do with tubes, not shell, you have to keep that in mind okay. What is the meaning of that? If I have come across with some bad conditions that condition I should allocate, I should consider in tube side, not in shell side because tube side maintenance is very easy in comparison to shell side and tube side.

What I am saying if I consider the cost also, so tube's cost will be very less in comparison to shell because shell diameter is significantly larger than the tube diameter. So that you should keep in mind and then let me start with the factors based on that we can allocate the fluid to shell side or tube side. The very first factor in that category is the corrosion. What is corrosion?

(Refer Slide Time: 28:07)



Corrosion is the phenomena when the reaction will take place between fluid and the material, tube material or shell material or we can say the metal. So, there we have the rust formation, etc. So it will weak the material, it will weak the equipment. So, how I can consider that corrosion? Corrosion can be removed, corrosion can be eliminated considering special alloys. So if you are finding that fluid is highly reactive to the material, allocate that fluid to tube side.

What I have told that whatever verse you are doing just do it with the tubes. So, high corrosion fluid should be located to tube side and reason is very simple that to avoid that corrosion we can use special alloys and the cost of that material is very expensive. So, when I am preparing tubes with that material it becomes cheaper in comparison to preparing a shell with that material. So high corrosion, fluid should be allocated to to tube side.

Next is fouling okay. How fouling will takes place that I have already explained. It will depend on temperature and the solubility, so I am not going into detail of that. So, you should understand that the fluid is having either high tendency of fouling or low tendency of fouling okay. How you can ensure that? You can see the dirt factor table which is with you in volume 6. So the point is when you are dealing with high fouling fluid that should be allocated to tube side.

Because what will happen when you are considering the tube side, you can consider more velocity there and when you are increasing the velocity, it will take the scaled material with it okay which we also call as erosion, but erosion of the metal should not occur, erosion of scaled material should occur. So that we can control with increasing the velocity in tube side. Secondly, tube side cleaning is very easy in comparison to shell side because tube side we have the straight pipes only.

So straight pipe cleaning you can do easily in comparison to zigzag space which is available in shell side okay and when you carry out the design of shell and tube heat exchanger, you will see that space in between two tubes in shell is sometime lesser than the tube ID. So, you can see the high fouling tendency fluid should be allocated to tube side and reason I have already explained.

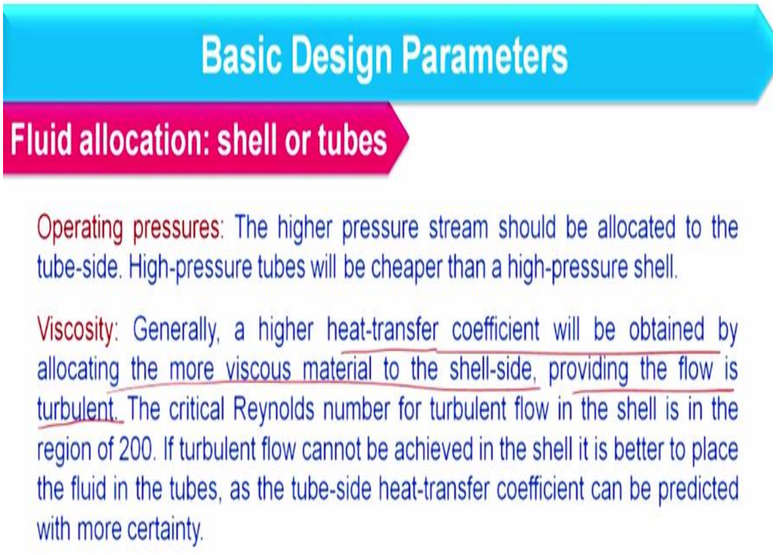
Fluid temperature, if fluid temperature is high that should be allocated to tube side. So, if temperature are high enough to require use of special alloys placing the high temperature fluid in tube side will reduce the overall cost because of the same reason. So, how I am considering reduction in overall cost when I am considering tube or shell? So, what will happen when this material will play a role, it will play a role by making the tube or shell.

It means whatever would be the material involved in tube or shell directly it will give the cost. So, what will happen? When I am saying the material involvement it means the thickness of the material or thickness of the shell or thickness of the tube and how that thickness will occur? Again the same expression which I have discussed in previous lectures also that T = p d0 by 2 fj + p.

So here if I am considering same pressure and if I am considering diameter, so tube is having lesser dia, so it will have lesser thickness in comparison to shell. So, material cost involved in tube manufacturing is very less in comparison to shell. So, we can use costly material and alloys easily in tubes or in less price in tubes in comparison to shell. So, high fluid temperature should be allocated to tube side.

Similarly, high operating pressure that should be allocated to tube-side because high operating pressure or we can say high pressure shell is very costly in comparison to high pressure tube. In the same line as I have explained just now that because pressure is constant, so thickness will be directly proportional to the diameter and shell dia is very large in comparison to tube dia, so high operating pressure should be allocated to tube-side.

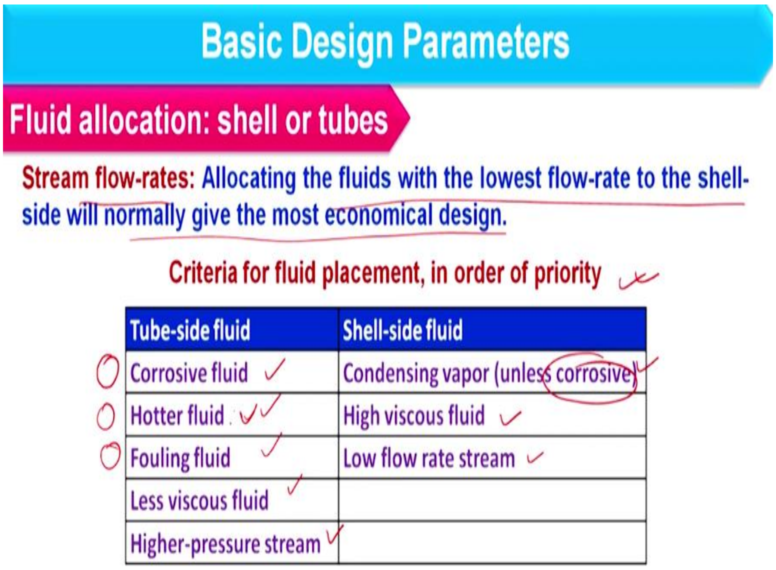
(Refer Slide Time: 32:46)



Now, what will happen if I consider viscosity? So, generally the higher heat transfer coefficient will be obtained by allocating more viscous fluid to shell-side, but this is with the condition that it should provide turbulent flow in shell-side, and in shell-side flow is not as straight because we have different arrangement of the tube, so continuously zigzag motion will occur in shell-side. So, turbulence in shell-side is obtained at lesser Reynolds number in comparison to tube-side.

Tube-side is basically a straight pipe and when Reynolds number exceeds 4000 it comes under turbulent flow zone. However, in shell-side critical Reynolds number is around 200. If Reynolds number exceeds than that, we consider that as a turbulent condition. So, you have to consider the viscosity of the fluid which must give Reynolds number more than the critical Reynolds number in shell-side and if this is occurring, you should allocate the fluid to shell-side, otherwise tube-side okay.

(Refer Slide Time: 34:20)

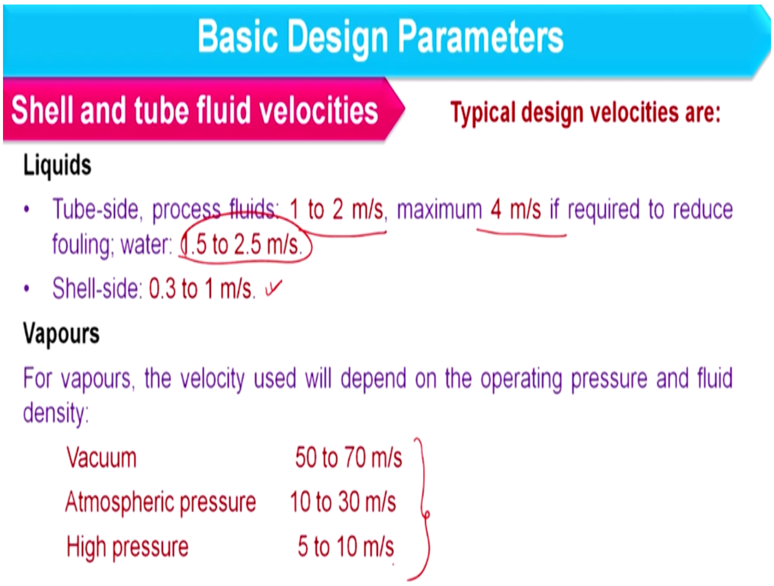


So, our next point we have about the stream flow-rates. So, allocating fluid with lower flow rates to shell side will normally give more economical design. So, lower flow-rate in shell-side means at low flow rate it gives the turbulent and it will give better heat transfer coefficient. So, lesser stream flow-rate should be located to shell-side. So, based on this discussion we have this order of priority to allocate the fluid.

So, tube-side corrosive fluid should be allocated, hot fluid should be allocated, fouling fluid should be allocated, less viscous fluid should be allocated and high pressure fluid should be allocated and in the shell-side condensing vapor until unless it is not corrosive, high viscous fluid and low flow rate stream should be allocated to shell-side. So, what is the meaning of this priority?

It means I have to first consider corrosive fluid and then hotter fluid and then fouling fluid like that we have to arrange, fine. So, let us say if corrosive fluid has lesser temperature okay, then only I should allocate that to tube-side and then in that case hot fluid will be allocated to shell-side but that will work because more problem is with corrosiveness than the hot or cold temperature. So, I have to decide according to this priority table.

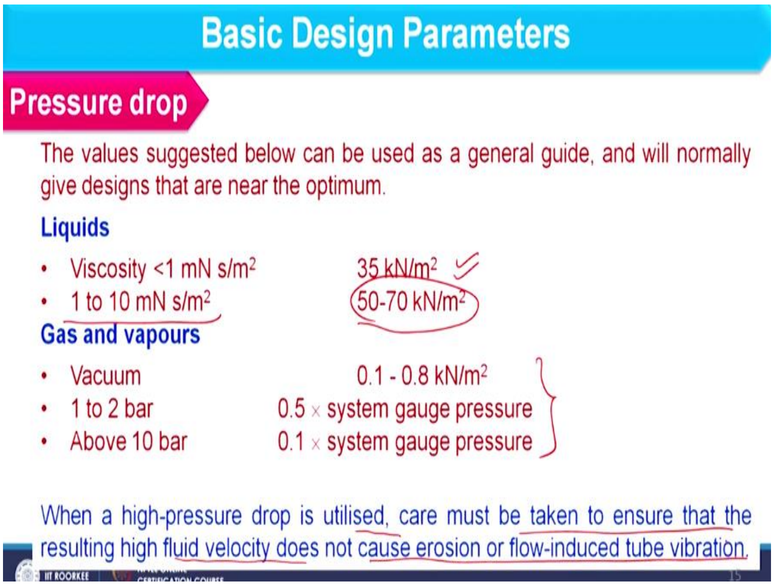
(Refer Slide Time: 36:05)



Now, we will consider some velocity and pressure drop conditions in shell-side and tube-side. So, typical design velocities in shell-side and tube-side are when I am considering liquid tube-side flow rate should be 1 to 2 meter per second, maximum 4 meter per second and if I am considering water it is 1.5 meter to 2.5 meter per second.

Similarly, in shell-side it should be 0.3 to 1 meter per second okay, and if I am considering vapor we have to consider the velocity in these ranges. So, these are some permissible limits to handle the liquid and vapor in shell-side and tube-side.

(Refer Slide Time: 36:45)



In the similar line I can consider the pressure drops in shell-side as well as in tube-side okay. So, that pressure drop limits are as per the optimum design. For liquid if viscosity is less than 1 million Newtons second per meter square maximum pressure drop should be 35 kilonewton per meter square and similarly if viscosity changes up to 10 million Newtons second per meter square we can consider this much as the pressure drop range.

In the similar line we can consider gas and vapor pressure drops, right. So, when a high pressure drop is utilized care must be taken to ensure that resulting high fluid velocity does not cause erosion or flow-induced tube vibration. So, we have to take care about that that vibration should not occur in tubes. So, permissible limit of pressure drop must be maintained along with the velocity okay.

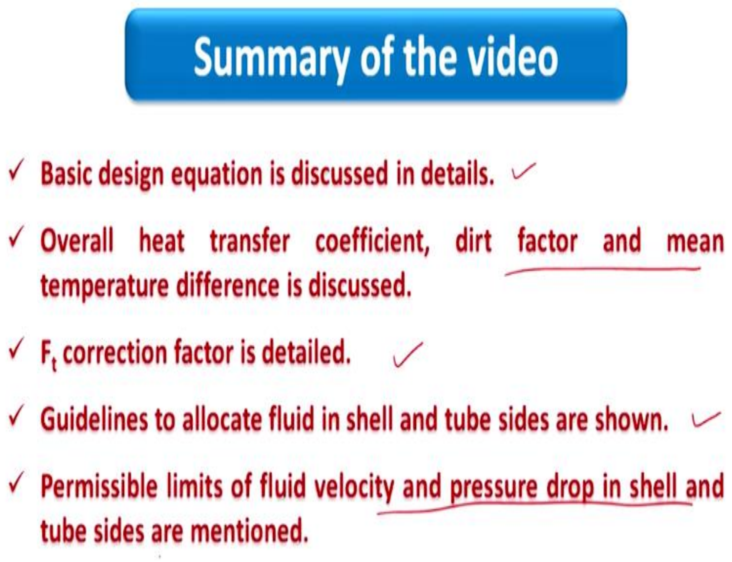
So, these are some of the guidelines about the design and all these guidelines we will consider in design of shell and tube heat exchanger.

(Refer Slide Time: 37:55)

1	Backhurst, J.R. and Harker J.H., "Coulson and Richardson Chemical Engineering", Vol. II, 5th Ed., 2002, Butterworth-Heinemann.
2	Sinnott, R.K., "Coulson and Richardson's Chemical Engineering Series: Chemical Engineering Design", Vol. VI, 4th 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.

These are some references, you can go through about detailed study of the basic design parameters.

(Refer Slide Time: 38:07)



Here we have the summary of the video and this summary is of lecture 4 as well as this lecture also okay. So, in these 2 lectures we have discussed basic design equation in detail, overall heat transfer coefficient, dirt factor and mean temperature difference We have discussed FT correction factor in detail and then guidelines to allocate fluid to shell-side and tube-side we have discussed

And after that finally we have discussed permissible limits of fluid velocity and pressure drop in shell-side and tube-side. So, that is all for this lecture. Thank you.