Principles and Practices of Process Equipment and Plant Design

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Module - 03
Lecture - 41
Design of Heat Transfer Processes- Introduction

Good day to you all. I am going to start your module 3 which is on the Design of Heat Transfer Processes and today is a Introductory class. What I intend to cover is basically the fundamentals first and they shall be followed by design of different equipment.

Mostly, we shall be covering the different types of heat exchangers, starting with the double pipe heat exchanger, followed by the different types of shell and tube heat exchangers. And you definitely will be doing which is a very important topic of the day, heat exchanger network synthesis or analysis whatever you may call it.

So, I start now, thank you.

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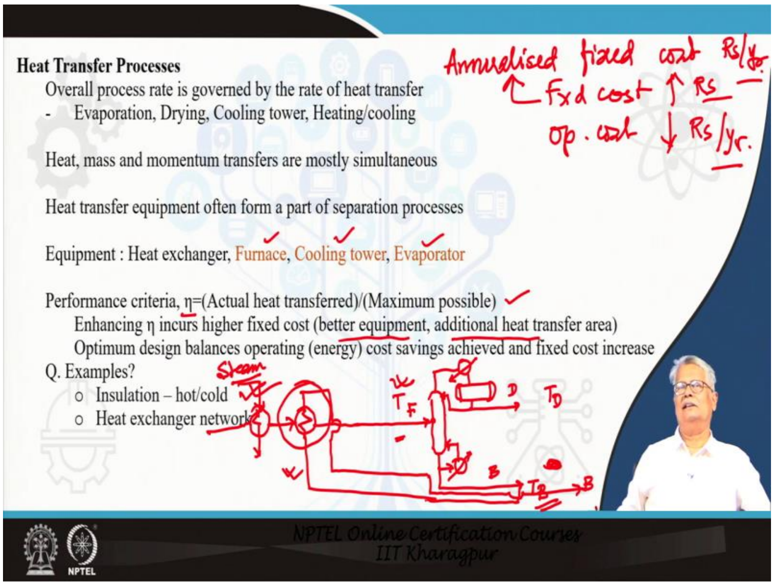

Heat Transfer Processes

Overall process rate is governed by the rate of heat transfer
- Evaporation, Drying, Cooling tower, Heating/cooling

Heat, mass and momentum transfers are mostly simultaneous

Heat transfer equipment often form a part of separation processes

Equipment : Heat exchanger, Furnace ✓, Cooling tower ✓, Evaporator ✓

Performance criteria, η=(Actual heat transferred)/(Maximum possible) ✓

Enhancing η incurs higher fixed cost (better equipment, additional heat transfer area)

Optimum design balances operating (energy) cost savings achieved and fixed cost increase

Q. Examples?
- Insulation – hot/cold
- Heat exchanger network

Annualised fixed cost Rs/yr.
↑ Fxd cost ↑ Rs
Op. cost ↓ Rs/yr.

Let us look at the heat transfer processes. If we see a process, we will always find that heat mass and momentum transfers are mostly simultaneous. That means, hardly ever you will find only a single process is taking place. Often we say that it is not a heat transfer process and we consider a particular process by analyzing it in an isothermal fashion, but that is an approximation in most cases. Why most? Almost in all cases.

So, one thing is true that all the tray transfer processes are usually simultaneous. An example of this could be if we talk about distillation, on the tray you have movement of the liquid which is definitely a mass transfer process and you got to design your tray based on the tray hydraulics which is basically a momentum transfer process.

The mass transfer decides the number of stages required or the enrichment or the efficiency on the tray. And definitely the vapor coming in and the liquid coming in from the top, they are mixing on this, but they come at different temperatures. So, there is heat transfer as well.

So, the question now comes that what exactly is a heat transfer process and that what we are looking for. When we say that a particular process is a heat transfer process, what we really mean is the rate, the overall rate of the process is governed by the rate of heat transfer.

Now, let us look at a few things. For example, if we are drying a solid and if we supply more amount of heat the drying will be faster, quicker and the rate will be higher. If you are talking about a cooling tower and evaporative cooling tower, – if more amount of heat is supplied to the cooling tower or more amount of air is supplied to the cooling tower there will be more amount of vaporization of the part of the water which is the liquid and which is evaporating in a cooling tower and here cooling will be faster.

Similarly, for example, we have evaporators for concentrating inorganic solutions or sometimes organic even, but very common is your caustic soda evaporation, which is done in multiple stage evaporation. And more heat we supply, faster is a removal of water from that particular solution and that governs or that decides the drying rate. Obviously, apart from these we have the standard case of heating or cooling a particular material.

It could be in a continuous system, it could be in batch or it could be a mix of both. That means, you will also notice that whenever we are talking about continuous systems or even batch systems whenever something is heating there is a cooling of the other stream. So, the heat exchange involves both heating as well as cooling.

Now you definitely must have noticed that heat transfer equipment often form a part of the separation processes. Which all separation processes have you done? You have done scraper, you have done absorbers, you have done distillation columns. Whenever we talked about distillation columns typically you had an overhead condenser for generating the liquid reflux to the column top.

So, naturally the condenser was there which was a heat transfer equipment. It also had a reboiler at the bottom to generate the reboiled vapor and feed it back to the column. So, naturally in almost every distillation column you will always find a reboiler and a condenser. So, at least 2 heat exchangers are there. There may be more number also depending on the configuration of the column.

So, one thing is true. Let us look at the equipment where heat exchange is involved. The first is definitely the heat exchangers where you have heating or cooling. If you heat something by combustion of a particular fuel, it is a furnace. And in case of cooling tower, the hot water is cooled by vaporizing part of the liquid itself, part of the water itself, so that is in the cooling tower. In case of evaporator, we supply heat often in the form of steam or some other heating fluid.

So, we see that what these heat transfer processes are. In case of any equipment there has to be a performance criteria and we do normally try to improve or enhance that particular performance. So, we can define this performance criteria as eta or efficiency whatever way you may call, is the actual heat transfer in the equipment divided by the maximum possible amount of heat that can be transferred.

So, it is something very similar to efficiency and we are using the same connotation of eta to define it. Now let us see what exactly we mean by this. I am using a very specific word enhancing. Enhancing eta incurs higher fixed cost. That means, if it is; that means, what it simply means for the maximum possible amount of heat that can be transferred if that remains same, the actual heat transfer is more.

Now, if it is more, then your eta increases, but specifically I have been using the word enhancing, because there are certain applications in which enhancement means reduction in eta, we will see that. But one thing is true if we are heating something and we would like to transfer the heat there, possibly we could go for a better equipment, we could also go for a bigger equipment. The bigger equipment means additional heat transfer area and a better equipment means a different type of heat exchanger possibly with a higher efficiency or effectiveness.

That means in order to enhance eta, I need to invest; I need to invest in a fixed cost. So, if my eta gets enhanced it gets enhanced due to some additional fixed cost investment. Now if I do that what benefit do I get? In most of the cases it is a saving in the energy. Now you will notice one thing your energy is a part of the operating cost. That means, what happens when you enhance, you have a fixed cost which goes up and you have a component of the operating cost which comes down.

Now, you will notice one thing your fixed cost unit is rupees, your operating cost is rupees per year. So, how can we balance these? There is no question of balancing it directly, but one thing we will see as we have done in case of optimizing the heat exchangers this fixed cost we will be converting to annualized fixed cost; annualized fixed cost which will again become rupees per year.

Now, it is possible for us to look at the sum of the annualized fixed cost and the operating cost which we try to minimize. Now I had two examples with me; the first is that of insulation. Why do we insulate? We want to reduce a heat loss. That means, in this case my performance criteria for the insulation is better insulation performance or enhanced performance of the insulation, i.e. reduction in the heat transfer. So, this is the case in which efficiency comes down, I mean the eta value comes down, but it gets enhanced.

So, what by insulation more, by adding either an insulation material with a lower thermal conductivity or increasing the thickness of the insulation what we do? We add fixed cost. What we save? We save energy. If it is a hot fluid and if it is a cold insulation, then we save cold. That means, the cold losses are less.

Now we have another example here, this is a typical process industry example that I am going to give you. Suppose I have a heat exchanger here, I have its overhead vapor coming in going to a condenser, it is coming to the reflux drum and from there it is reflux. I am just showing the schematic. So, I have the reflux here. And I have a conventional reboiler which generates the vapor and puts it back to the column and I take my bottoms from here. This is my bottom steam and this is my distillate steam.

Now, I have the feed coming in somewhere. Now it is possible; in this particular case which temperature will be higher; the distillate temperature or the bottom temperature? Obviously, the bottom base contain the heavier component and bottom temperature is going to be higher than the distillate temperature TD. And it is also true that in my feed the feed is going to enter somewhere in between. That means, my temperature here is TF and TF is lower than bottom temperature TB.

So, it is possible for me to put a heat exchanger here by investing something definitely. Take this steam, preheat my feed and then send it out as bottoms. So, what I have done is, I have invested in my heat exchanger here. But what happens earlier in order to obtain TF, I had one more exchanger here which was using steam as a heating medium.

Now I am getting part of the heat for attaining this TF from somewhere else. So, what happens now? I can reduce my steam. So, what I read what I save in this particular case by investing on a new exchanger which is here new preheat exchanger or an additional preheat exchanger is, the quantity of steam that I will be using now.

So, here I have an example where possibly the balance between the two is going to give us an optimum design. The balance is between what? It is between the fixed cost and the operating cost. And fixed cost naturally has to be converted to the annualized fixed cost based on the interest rate of the bank or whatever you feel like a financial interest rate and then can be added in order to minimize this.

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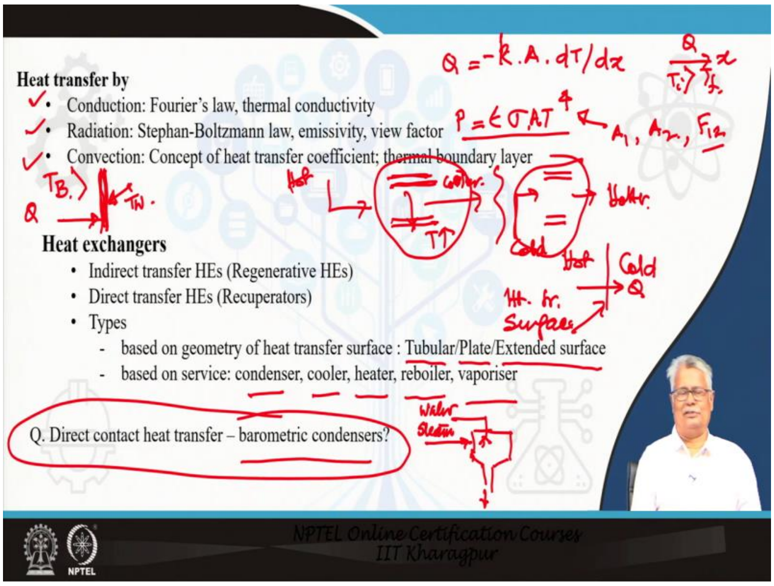

Heat transfer by

- Conduction: Fourier's law, thermal conductivity
- Radiation: Stephan-Boltzmann law, emissivity, view factor
- Convection: Concept of heat transfer coefficient; ~~thermal boundary~~ layer

Heat exchangers

- Indirect transfer HEs (Regenerative HEs)
- Direct transfer HEs (Recuperators)
- Types
  - based on geometry of heat transfer surface : Tubular/Plate/Extended surface
  - based on service: condenser, cooler, heater, reboiler, vaporiser

Q. Direct contact heat transfer – barometric condensers?

$Q = -k.A.dT/dx$

$P = \epsilon \sigma A T^4$

Now we look at the basics. We know always from the fundamental in our school days that the modes of heat transfer are conduction, convection and radiation. The fundamental laws are; for conduction it is Fourier's law and it is based on the definition of thermal conductivity. That means, this Q which is the heat transfer rate in case of conduction is equal to minus K the heat transfer area is A or rather the conduction area is A into dT/dx.

The negative sign appears definitely because T decreases along the increasing x. That means, my Q goes from the higher temperature to a lower temperature and this is my direction of this, and this is definitely my direction of X as well. In case of radiation what happens the radiation does not require any in between medium for heat transfer.

So, what you have there you the governing law is the Stephan-Boltzmann law which says the power which is emitted by radiation is proportional to there is a constant which is a Stephan-Boltzmann constant multiplied by T to the power 4. And if there is an emissivity of the surface which is the surface characteristics, this is going to be the power emitted by radiation from a particular surface. And if I have the surface area, it is going to be multiplied by the surface area also.

So, I could also write here the heat exchange between two surfaces with an area A1 and A2 by using this particular thing. And in that case we also need a few exchange factor which is between 1 and 2 surface which is F 1 2. You already have done this, so I am not going to repeat it here. Now, what we have is a convection we look at the convection; and we need to have or recapitulate the concept of heat transfer coefficient and thermal boundary layer also.

We know that in case of convection what happens is, basically there is bodily movement of the fluids. In fact, if I have a medium which is in contact with a wall. This is the temperature of the wall and this is the temperature of the bulk medium itself, it is a liquid or it is a fluid and temperature of the bulk medium TB is greater than temperature of the wall TW, the heat will get transferred from here to here (fluid to wall). So, that will be my direction.

So, what is the driving force? The driving force in this case is the TB minus TW. So, TW is basically this particular wall temperature or surface temperature. Now what we do is we look at the heat exchangers, what are the different types of heat exchangers and before doing that we know it pretty well that these heat exchangers they have lot of applications. In fact, all the separation processes that we have come across so far they all involve heat transfer. So, you require either to heat something or cool something or preheat something or even the equipment has to be heated in many different cases.

Now there are two ways you can transfer heat from one fluid to another. It could be a continuous, it could be a batch system also. First we talk of a very simple arrangement where say I have a grid. May be a ceramic grid and I have a hot fluid. I have a hot fluid which passes through this and what happens is, the heat gets accumulated in this, so its temperature rises.

Now what I do is, then I take the cooled fluid which has to be heated; what I do in that case is I simply take this and I pass my cold fluid. So, what happens? This gets cooled this gets cooler now, this will get hotter. So, what happens is the same grid gets heated up by the hot fluid and later cooled by the colder fluid.

So, there is a periodic change in the medium through which the heat exchange takes place and basically this is called a regenerative exchanger principle. Now what do you also have, that it is possible to have direct heat transfers. Now when you are talking about directory transfers in most of the cases we would not like the two fluids to come in direct contact. That means they may be immiscible, they may not be immiscible, they may react they may not.

So, what you have in most of the cases a heat transfer surface in between. So, what you have is a heat transfer surface. In one side you have the hot fluid and one side you have the cold fluid. Quite naturally the heat flows from the hot to the cold side across the heat transfer surface.

Now depending on the geometry of the heat transfer surface which could be a tubular section. You have tubular heat exchangers, if it is a flat plate it is a plate heat exchanger. If you have or add extended surfaces on the tube or on the plate it becomes an extended surface heat exchanger.

Now definitely you must have noticed that the heat exchangers in the separation processes you have used for many applications. In some case you condense a vapor, it is a condenser you call it a condenser, you cool a steam of liquid you call it a cooler. If you heat a steam of liquid you call it a heater; no phase change of course, in that case then what you have if you look at the reboiler at the bottom of the distillation column to generate vapor it is a reboiler, and if you are going to vaporize a liquid steam entirely to a vapor then it is a vaporizer. So, depending on the service there are classifications as well.

Now I just draw your attention to one specific case. We have talked about surface heat exchangers, but there are certain situations in which you need not have a surface and you can allow mixing of the hot and the cold fluid. An example of this is the barometric condensers.

In a barometric condenser what you have? You basically have a chamber you basically have a chamber in which you have a liquid spray and you have a leg. This could be water and it could be steam. What will happen? This steam will come in contact with the cold water it will condense and both will come out. This is used in case of creating vacuum in many systems, it is used in evaporators, it is also used in distillation columns which operate under vacuum.

So, I suggest that you look up the book by Kern process heat transfer and find out for yourself what exactly is a barometric condenser? It is needless to say right now that direct contact heat transfer is a most efficient method in which since you have directly the hot and the cold fluid mixing you have the highest level of efficiency of heat transfer.

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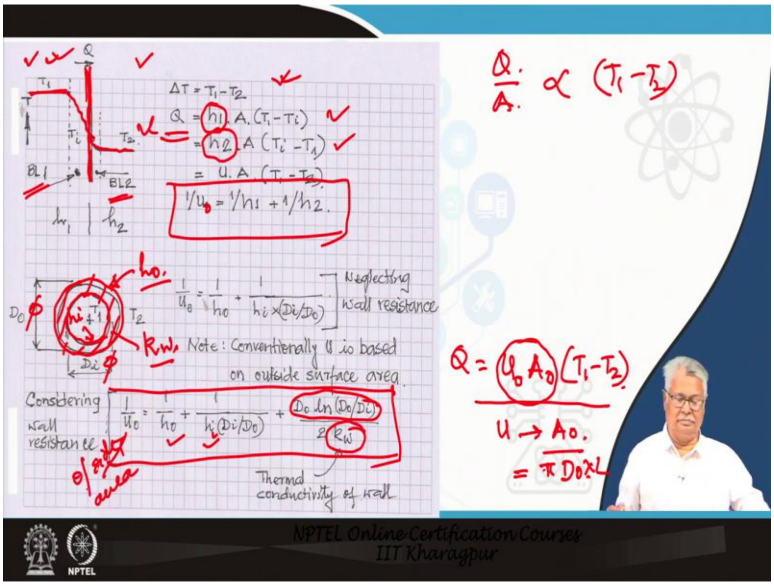

$\Delta T = T_1 - T_2$

$Q = h_1 . A . (T_1 - T_i)$

$= h_2 . A (T_i - T_1)$

$= U . A (T_1 - T_2)$

$1/U_0 = 1/h_1 + 1/h_2.$

$\frac{1}{U_0} = \frac{1}{h_o} + \frac{1}{h_i \times (D_i/D_o)}$ Neglecting wall resistance

Note: Conventionally U is based on outside surface area

Considering wall resistance $\frac{1}{U_0} = \frac{1}{h_0} + \frac{1}{h_i(D_i/D_o)} + \frac{D_o \ln(D_o/D_i)}{2 K_w}$

0/s area

Thermal conductivity of wall

$\frac{Q}{A} \propto (T_1 - T_2)$

$Q = U_0 A_0 (T_1 - T_2)$

$U \rightarrow A_0.$

$= \pi D_0 \times L$

But often we are unable to do it because such mixing possibly from the process angle may not be acceptable.

Now, look at the convection equations. Convection is the most common thing because most of the process industries are going to use fluids; it will be either liquid, it will be gas, it will be vapor. What is the difference between the gas and vapor? Gas is basically above its critical temperature, vapor is below the critical temperature, otherwise the everything is same.

Now what we have here is a schematic. I have here a fluid 1 to the left a fluid 2 to the right. The fluid 1 bulk temperature if we note is T1 the interface temperature is Ti and the right-side temperature is T2. I had mentioned about at least I have it written the word boundary layer in the first slide itself. You will notice in the bulk; in the bulk if it is fairly well mixed the temperature is pretty well mixed and the temperature is pretty uniform which is more or less T1.

The transfer is from T1 to the interface temperature Ti and you will find a very sharp temperature which happens in a very narrow zone close to the interface. This is called the boundary layer. So, it is a boundary layer 1 to the left and it is a boundary layer 2 to the right side.

You will also notice one more thing. In fact, these are called thermal boundary layers which; how is it defined? It simply is defined by - I will say it is more or less a hypothetical assumption that the thickness after which the temperature becomes 99 %; 99 % of your bulk temperature is the end of the boundary layer practically.

So, what you have is a temperature variation around the interface of two fluids or rather two fluids like this. I will add one more thing also; suppose these two fluids are separated by a metal which has got very high thermal conductivity. In that case it could be the wall of a heat exchanger.

So, I if it is having a very high thermal conductivity as compared to the thermal conductivity of the liquids which are being used here, what will happen? The wall left side and the right side will be more or less at the same temperature. So, your interface temperature will be practically the wall temperature.

So, here the net driving force is the difference between T 1 and T 2 which is here the delta T. And the concept of heat transfer says that the heat flow rate or the heat flux Q upon A is proportional to the driving force. So, it is proportional to T 1 minus T 2. And what is h 1 of the heat transfer coefficient? It is the constant of proportionality. So, quite naturally what we expect to find, we can find there will be one heat transfer coefficient to the left, another heat transfer coefficient to the right.

Now, I do a little bit of mathematical jugglery and eliminate T i from this one and this one. So, what I get, I could very well write 1 by u is equal to 1 by h1 plus 1 by h2. This happened because the A cancels off along with T i, it also gets eliminated. I look at another case in which I have a tube and the heat transfer is taking place from the inside to the outside. Well if it is from outside to the inside the analysis will be the same only the direction of Q will be different.

In this case you could also define exactly in the same way. But since the heat transfer area from here and here they are different and they are proportional to the diameter. Di and Do the two diameters (inner and outer diameters) will also come into the expressions here. Now I just add one thing here.

If I say the heat transfer coefficient inside is h i and if I say the heat transfer coefficient here is h o; I could also say that my heat transfer is proportional to u A. Now, the question is if I say A o; that means, outside area it will mean the u o into T 1 minus T 2.

So, you will also notice that the way I am defining my overall heat transfer coefficient has a reference to the area through which the heat is getting transferred. If the convention is to define for such tubes the heat transfer coefficient u, even if I do not say anything specifically it will refer to the area outside or A o which is nothing but pi into D o into the length of the tube itself.

There is one more thing which is also there. Well if I have a wall with a thermal conductivity k w, the thermal conductivity of the wall is k w in that case this gets slightly modified and this is basically the term which relates u o which is same as u or u o whatever you may say. And it relates to the thickness of the tube intern which is defined by D o and D i, the thermal conductivity of the wall itself, the inside heat transfer coefficient h i, the outside heat transfer coefficient h o. By convention, this h o is based on outside area.

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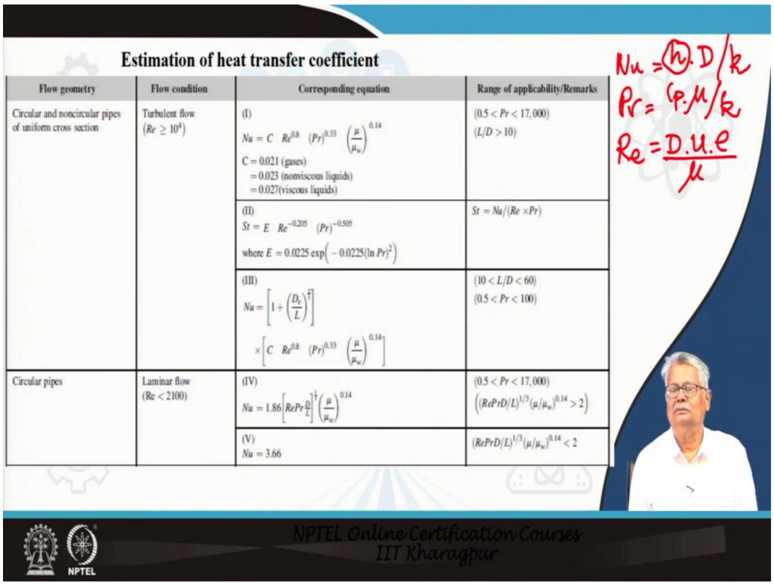

Estimation of heat transfer coefficient

Flow geometry	Flow condition	Corresponding equation	Range of applicability/Remarks
Circular and noncircular pipes of uniform cross section	Turbulent flow ($Re \geq 10^4$)	(I) $Nu = C\ Re^{0.8}\ (Pr)^{0.33}\ \left(\frac{\mu}{\mu_w}\right)^{0.14}$ C = 0.021 (gases) = 0.023 (nonviscous liquids) = 0.027(viscous liquids)	$(0.5 < Pr < 17{,}000)$ $(L/D > 10)$
		(II) $St = E\ Re^{-0.205}\ (Pr)^{-0.505}$ where $E = 0.0225 \exp\left(-0.0225(\ln Pr)^2\right)$	$St = Nu/(Re \times Pr)$
		(III) $Nu = \left[1 + \left(\frac{D_e}{L}\right)^{\frac{2}{3}}\right] \times \left[C\ Re^{0.8}\ (Pr)^{0.33}\ \left(\frac{\mu}{\mu_w}\right)^{0.14}\right]$	$(10 < L/D < 60)$ $(0.5 < Pr < 100)$
Circular pipes	Laminar flow (Re < 2100)	(IV) $Nu = 1.86\left[RePr\frac{D}{L}\right]^{\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{0.14}$	$(0.5 < Pr < 17{,}000)$ $\left((RePrD/L)^{1/3}(\mu/\mu_w)^{0.14} > 2\right)$
		(V) $Nu = 3.66$	$(RePrD/L)^{1/3}(\mu/\mu_w)^{0.14} < 2$

$Nu = \boxed{h}.D/k$

$Pr = C_p.\mu/k$

$Re = \frac{D.u.\rho}{\mu}$

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Now I have introduced you to h i and h o. The question comes that whenever you have to do such calculations you will be requiring to find out or have a value of h i and h o. Now there are few things which are there, you will notice there are certain non-dimensional numbers which relate to heat transfer.

What are these numbers? First is the Nusselt number which is h_D upon k, the thermal conductivity of that fluid. Then the you have a property group which is a Prandtl number; which is what, it is Cp into mu μ upon the k which is the thermal conductivity of the liquid.

What else you have? You have the Reynolds number which is what; which is D multiplied by velocity of the fluid multiplied by ρ, upon μ which is again the viscosity of your liquid or fluid whatever you have.

So, you will find that the Nusselt number involves h. There are correlations which involve these three numbers and they depend on the length of the tube or another dimension capital L which is typically the length of the tube. There are certain correlations for heating, cooling, your turbulent flow, laminar flow, condensation and similar things.

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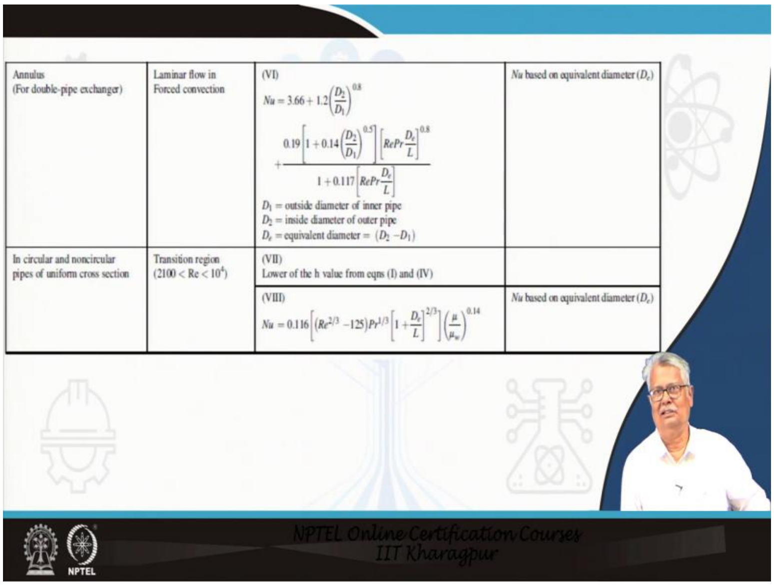

Annulus (For double-pipe exchanger)	Laminar flow in Forced convection	(VI) $Nu = 3.66 + 1.2\left(\frac{D_2}{D_1}\right)^{0.8} + \frac{0.19\left[1 + 0.14\left(\frac{D_2}{D_1}\right)^{0.5}\right]\left[RePr\frac{D_e}{L}\right]^{0.8}}{1 + 0.117\left[RePr\frac{D_e}{L}\right]}$ D_1 = outside diameter of inner pipe D_2 = inside diameter of outer pipe D_e = equivalent diameter = $(D_2 - D_1)$	Nu based on equivalent diameter (D_e)
In circular and noncircular pipes of uniform cross section	Transition region $(2100 < Re < 10^4)$	(VII) Lower of the h value from eqns (I) and (IV)	
		(VIII) $Nu = 0.116\left[(Re^{2/3} - 125)Pr^{1/3}\left[1 + \frac{D_e}{L}\right]^{2/3}\right]\left(\frac{\mu}{\mu_w}\right)^{0.14}$	Nu based on equivalent diameter (D_e)

So, these are nothing but a set of data which is given to you which are the empirical correlations. These are all compiled from different sources and what we intend to do is, to supply you with a document which will contain almost all practically required such correlation using which you can estimate the value of the individual surface heat transfer coefficients h for condensation, vaporization everything together.

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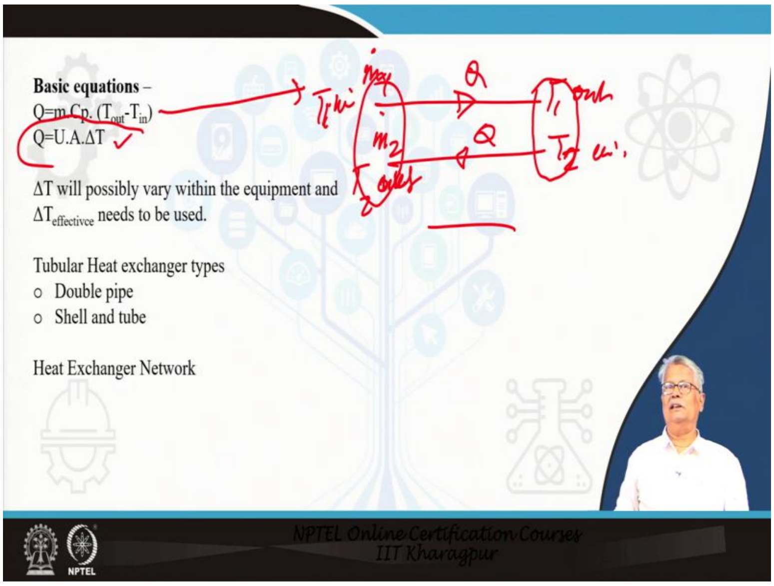

Basic equations –

$Q = m.Cp.(T_{out} - T_{in})$

$Q = U.A.\Delta T$ ✓

ΔT will possibly vary within the equipment and $\Delta T_{effectivce}$ needs to be used.

Tubular Heat exchanger types

- Double pipe
- Shell and tube

Heat Exchanger Network

Now what we do is, your basic equation is the energy balance. What is it? It is basically mass, means mass flow rate, into Cp into delta T in case of the continuous fluid flowing in and flowing out of your heat exchanger. And in case of the heat exchanger the same Q is equal to U which is the overall heat transfer coefficient multiplied by the heat transfer area A multiplied by the driving force delta T.

There is something which is important now. If you are talking about a heat exchanger, I am more than sure that you are aware of the tubular exchangers in which two fluids flow with flow rates m 1 dot and m 2 dot. This is T 1 in and this is T 2 in. This is T 1 out and this is T 2 out. Quite naturally I could I have to write the this equation and this will be the same Q here and here.

The heat transfer between these two will be given by this. If you notice at this end of the exchanger the differences between these two temperatures and this end it is different. So, within the exchanger the delta T varies. This happens with most equipment. So, what is required to be used is not that just any delta T to the left or to the right of your system or any part of your system, it has to be an effective or an averaged out delta T.

Now, what you do is basically there are different types of tubular exchangers. Tubular exchangers are in fact, more common, you can have double pipe which we will be covering next. This will be followed by the shell and tube heat exchangers. And finally, you will be covering the heat exchanger network.

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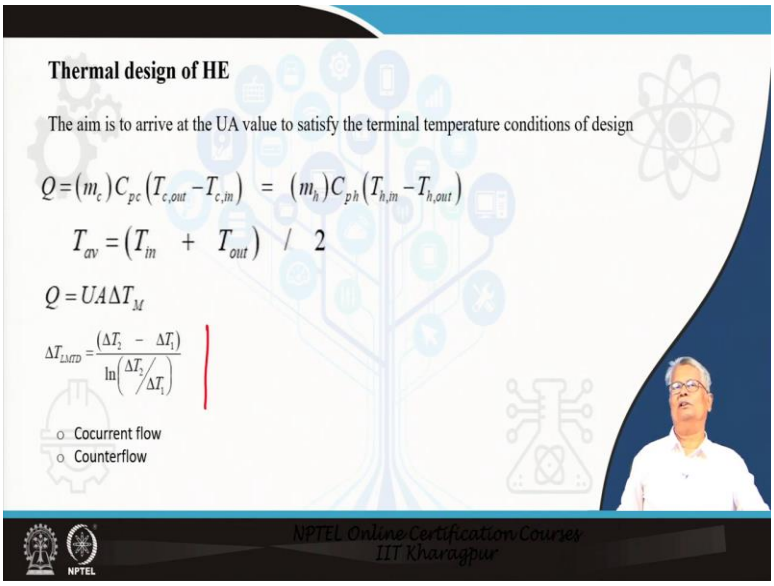

Thermal design of HE

The aim is to arrive at the UA value to satisfy the terminal temperature conditions of design

$$Q=(m_c)C_{pc}(T_{c,out}-T_{c,in}) = (m_h)C_{ph}(T_{h,in}-T_{h,out})$$

$$T_{av}=(T_{in} + T_{out}) / 2$$

$$Q=UA\Delta T_M$$

$$\Delta T_{LMTD}=\frac{(\Delta T_2 - \Delta T_1)}{\ln\left(\Delta T_2/\Delta T_1\right)}$$

- Cocurrent flow
- Counterflow

This is about the thermal design and we have given you just an expression of the LMTD, the Log Mean Temperature Difference which is usually taken as the effective temperature difference to be used. And when you come to the other configurations of may be the multi pass exchangers you will find that its delta T LMTD is not enough it requires further corrections.

In tubular exchangers, you can have co current flow or you can have counter current flow. Normally the delta T LMTD is defined specifically for counter flow, but there are certain situations in which co current flow is also desirable. All these will be dealt with when you are dealing with the different type of exchangers.

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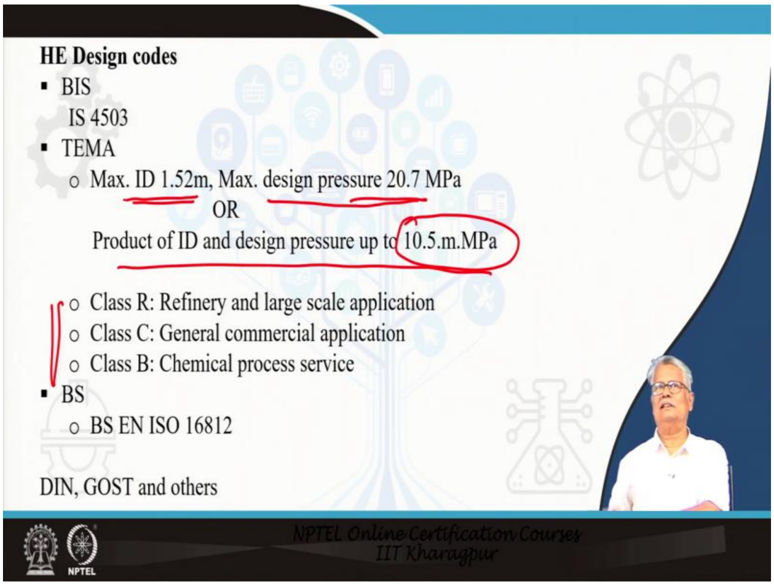

HE Design codes

- BIS
  IS 4503
- TEMA
  - Max. ID 1.52m, Max. design pressure 20.7 MPa
    OR
    Product of ID and design pressure up to 10.5.m.MPa
  - Class R: Refinery and large scale application
  - Class C: General commercial application
  - Class B: Chemical process service
- BS
  - BS EN ISO 16812

DIN, GOST and others

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Regarding the code which is followed for designing, the first is the Bureau of Indian Standard which is the IS 4503. The world over the Tubular Exchanger Manufacturers Association or TEMA; class R class C and class B codes. These three codes are almost universal, it is used over the world. Now let us look at the applicability of the TEMA you will notice one thing very interesting.

TEMA is applicable for heat exchangers, naturally it is a tubular exchanger manufacturers association. So, next which is an American entity of course, and it deals with maximum shell ID of 1.52 or 60 inches. And a corresponding maximum design pressure of 20.7; in fact, this is not the corresponding value. The maximum design pressure is 20.7 megapascals. There is another way they have defined the applicability of the cold which is the product of the ID in metres, and the corresponding design pressure and which is given into the maximum limit of this is 10.5 meter megapascal.

So, you can say rather I leave it to you to think why they have defined it this way. That means, smaller diameters you can go for a larger pressure rating or larger design pressure. For larger diameters you will be going for the lower limit of your design pressure. Just think over it.

Possibly we will be covering a little bit of shell and tube exchangers later on when we may discuss this as well. You have the British Standard; the British standard is basically 168 IS I mean EN ISO 16812 and there are German Standards like DIN and GOST and few others are also there. I think with this I will stop here.

Thank you.