Thermal Operations in Food Process Engineering: Theory and Applications
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Lecture - 31
Heat Transfer by Convection (Contd.)

Good morning. We have been dealing with Convection Heat Transfer if you remember and we have given some of the very important non-dimensional parameters which are very useful. Your heat transfer typically convectional many empirical as well as experimental both relations are available because as you have seen that the Newton's law of cooling their Q was equal to (h A ΔT), 'right'.

Now, the problem is this h that is the function of many parameters. So, it cannot be identical for any and every purpose for conduction heat transfer that Fourier law when you are using that minus Q is minus k dt dx a. So, that time you are knowing that if area is fixed if material is fixed and conductivity does not change then here you know the Q, but here in convection if your area is also fixed, if your delta t is also fixed, but for different system of transfer of heat h will be different for which that q also is different. That is why very straightforward relation with h is very difficult, 'right'.

So, today we will try to give you some ideas, not only ideas some relations which are very helpful and to determine the h, heat transfer coefficient some problems also we will try to solve. Only the problem could be that the solution I could not check beforehand because when I was doing these slides because I did it first in the word and then converted into that. So, I could not make the systematic way. However, we will do that and many such correlations we will try to bring about, 'right'.

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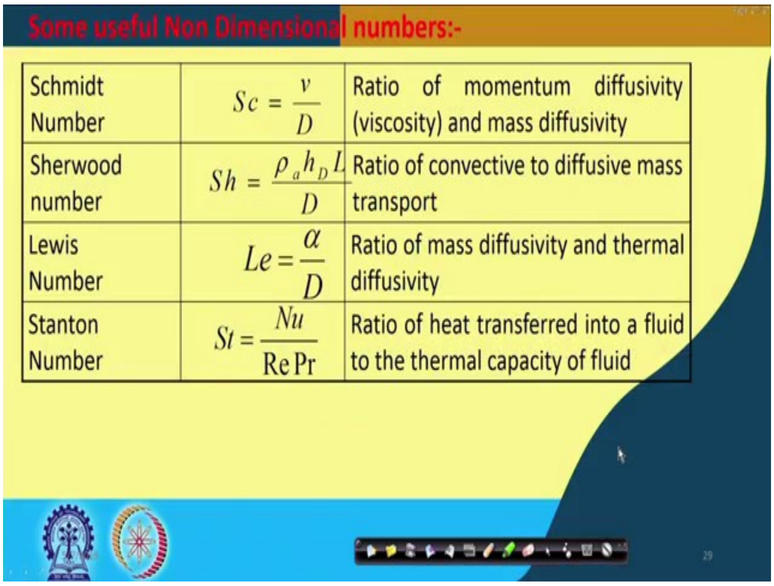

So, in our 31st class of Heat Transfer by Convection it is a continued one. We have already given many numbers of non-dimensional numbers and these numbers are very very helpful. Some of them we have said Reynolds number, Prandtl number, then earlier we have also perhaps given the Nusselt number, 'right' and we have Biot number.

So, there also we said if you remember that the Biot number or Biot number and Nusselt number both are having the same expression hl/K; l is the characteristic length, h is the heat transfer coefficient, convective heat transfer coefficient and k for Biot number it is the conductivity of the material through which it is being conducted whereas, in Nusselt number it is the conductivity of the fluid through which heat is being conveyed, 'right'.

So, this is the major difference between Nusselt number and Biot number and most of these students make this mistake. That is why emphatically I am highlighting on this that take care of this fine. Some more numbers which are very useful like Schmidt number it is not necessarily that all of them are for only heat transfer some could also be utilized in mass transfer. And, heat and mass transfer analogy if you go into there you will see these non-dimensional parameters are very helpful, 'right'.

So, Schmidt number is Sc that is defined as υ/D that is the ratio of momentum diffusivity or viscous diffusivity to the mass diffusivity, 'right'; υ/D. This D is not the diameter, this D is the division coefficient, 'right' or mass diffusivity. That is why in the definition we are saying it. Sherwood number this is also mass transfer related non-dimensional parameter, 'right'. Sherwood number is $Sh = \frac{\rho_a h_D L}{D}$ that is ratio of convective to diffusive mass transport, 'right'; ratio of convective to diffusive mass transport.

Similarly, Lewis number this is useful for heat transfer also heat transfer rather this is $\frac{\alpha}{D}$ again this is ratio of mass diffusivity and thermal diffusivity, 'right' $\frac{\alpha}{D}$; α is the thermal diffusivity or diffusion coefficient, D is the mass transfer diffusion coefficient. So, it is ratio of mass diffusivity and thermal diffusivity.

Stanton number or it is written as St, it is also related with non-dimensional numbers other and there $\frac{Nu}{Re \times Pr}$ that is Nusselt number over product of Prandtl number and Reynolds number and significance is it is the ratio of heat transferred into a fluid to the thermal capacity of the fluid. I repeat ratio of heat transferred into a fluid to the thermal capacity of the fluid, 'right'.

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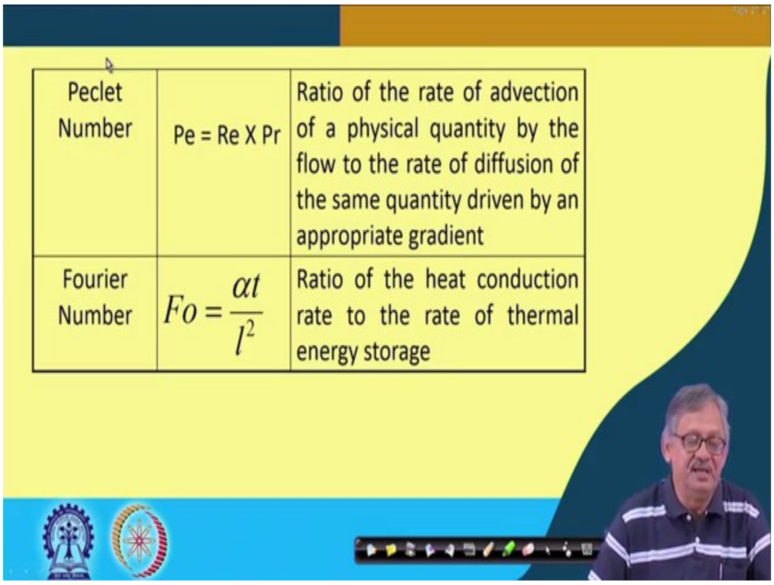

Similarly, some other numbers could be Peclet number, 'right'. This is also very useful in both; in this is majorly in heat transfer and that is Pe, Peclet number is product of Reynolds number and Prandtl number, 'right' or N_{Pr} and N_{Re}; N_{Re} times N_{Pr}. So, this can be defined as ratio of the rate of advection of a physical quantity by the flow to the rate of diffusion of the same quantity driven by an appropriate gradient. I repeat ratio of the rate of advection of a physical quantity by the flow to the rate of diffusion of the same quantity driven by an appropriate gradient, 'right'.

And, perhaps the last number which we are telling you there are some more also, 'right' there are some more also, but I do not like to bring all to you because may or may not be you will be utilizing all of them at least many of them will be utilized or are being utilized in this heat transfer course. But, some of them may not be in the heat transfer course or may be required for mass transfer if it is not in this class in other classes, but should be known also, 'right'.

Like this one we have already used Fourier number Fo that is $\alpha t/l^2$. I hope you remember that when we were using Heisler chart, that Heisler chart we had typically used this Fourier number in the x-axis, 'right' this is called non dimensional time parameter, 'right'.

Fourier number is a non-dimensional time parameter $\alpha t/l^2$ 'right' which is the ratio of the heat conduction rate to the rate of thermal energy storage. Repeat, ratio the heat conduction rate to the thermal energy storage. This time that is alpha t perhaps till now, whatever you have seen in none of them directly we had time as one of the parameter, 'right'.

So, far we have seen in non-dimensional units or non-dimensional numbers in none of the numbers you have used time as one of the variable, but in Fourier number only it is $\alpha t/l^2$ and that is why this is also known as non-dimensional time, 'right'. So, non-dimensional time because time is second minute or hour whatever be the unit, but here in Fourier number you do not have any unit it is also non-dimensional $\alpha t/l^2$,'right'. So, like that you have many numbers which we have say said. Now, let us utilize them, 'right', ok.

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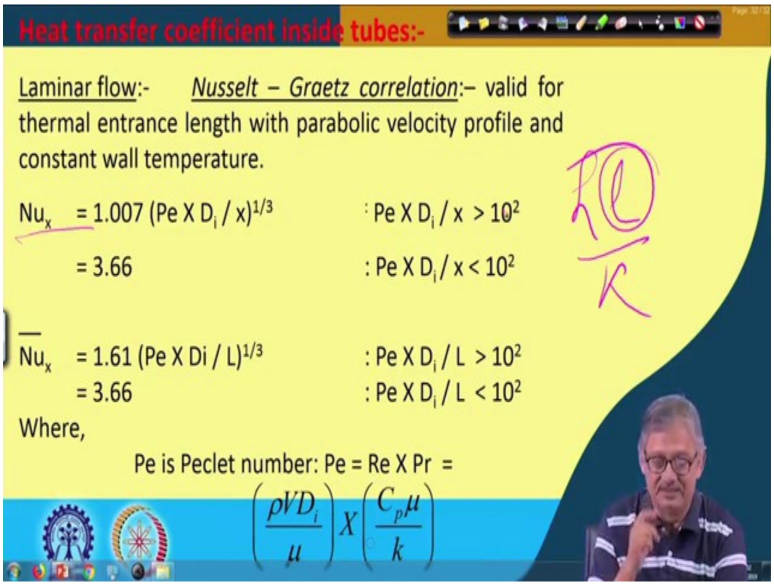

Some of them are utilized in this way as I said that there are many relations or correlations available for heat transfer typically convective heat transfer, 'right'. And that is valid for different regime different conditions; flow either flow conditions or boundary conditions etcetera. So, heat transfer coefficient inside tube, 'right'.

So, we would like to find out the heat transfer coefficient inside tube. What condition? Condition is laminar flow 'right' and this is called Nusselt-Graetz correlation. Nusselt Graetz correlation, 'right' that is valid for thermal entrance length with parabolic velocity profile and constant wall temperature, 'right'. This is valid for thermal entrance length with parabolic velocity profile and constant wall temperature.

So, Nu_x is given like that $1.007(Pe \times D_i/x)^{1/3}$,'right' and this is valid that is why I said that regime; the word regime I utilized that it is valid between $Pe \times D_i/x > 10^2$, 'right'. So, this is valid for that whereas, this Nusselt number x; x means at any position because Nusselt number is hl/K, 'right'. So, this is x at any position that is 3.66 when $Pe \times D_i/x < 10^2$, 'right'.

Similar, other relations average Nusselt number this is localized Nu_x. So, this is average Nusselt number x is anyway x rather $1.61(Pe \times D_i/L)^{1/3}$ valid for $Pe \times D_i/L > 10^2$ where as it is 3.66 when Pi into Di sorry $Pe \times D_i/L < 10^2$ where of course, Peclet number

Pe is the Peclet number as we have already defined equal to Reynolds number times Prandtl number which is again nothing, but $\left(\frac{\rho V D_i}{\mu}\right) \times \left(\frac{C_P \mu}{K}\right)$, 'right'.

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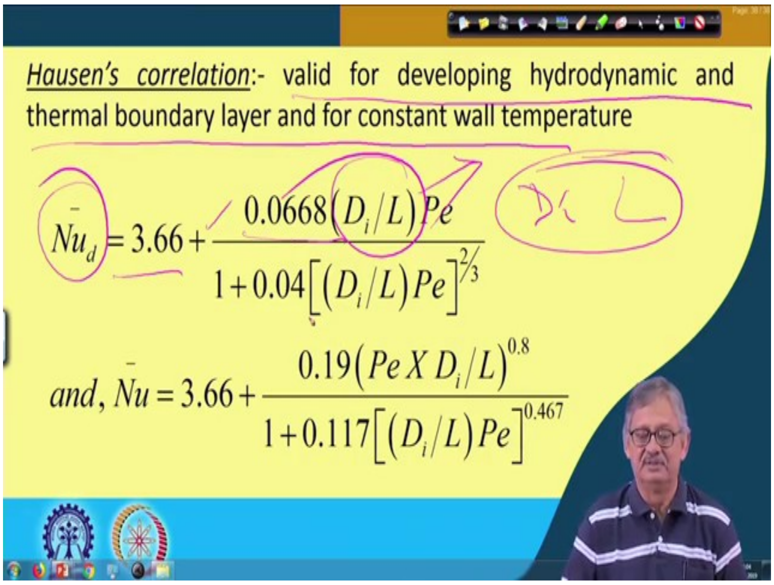

So, like this some more correlations we look into like Hausen's correlations. Hausen's correlation is valid for developing hydrodynamic and thermal boundary layer and for constant wall temperature. So, again it is a $\overline{Nu}_d = 3.66 + 0.0668(D_i/L)Pe$. Of course, these nomenclatures are normal like D_i meaning internal diameter; L meaning length.

So, these are implicit, 'right', over $1 + 0.04[(D_i/L)Pe]^{2/3}$. This is with respect to Nu_d, 'right' in terms of diameter whereas, average Nu this is a

$$\overline{Nu} = 3.66 + \frac{0.19(Pe \times D_i/L)^{0.8}}{1 + 0.117[(D_i/L)Pe]^{0.467}}$$, 'right'.

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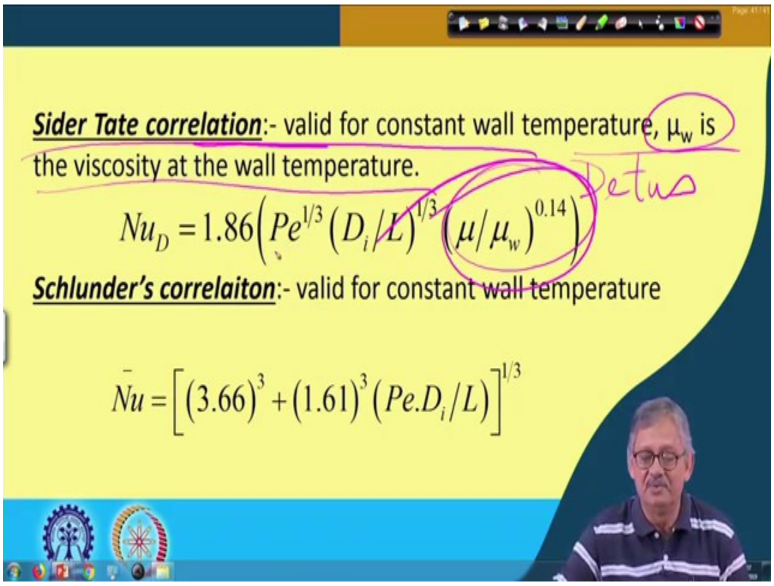

So, let us look into some other relations. This is very useful particularly when you are doing food handling and or liquid food or liquid fluid handling through pipes, 'right'. Obviously, flow in conduit and open flow they are quite different. That is the difference between that maybe your land and water and food and chemical. So, where mostly it is under bounded condition whereas, in land and water it is open, 'right'.

However, but many basic things are common it has to be. So, they do not use this one Sider Tate because normally this is for the conduit. So, Sider Tate equation is this is valid for constant wall temperature mu w is the viscosity at the wall temperature, 'right'. In many cases you will see there is I do not know whether it is with me or not that is called Detus Voltars equation, 'right'.

In one case that this is called viscosity correction factor that is mu over mu w this is called viscosity correction factor. How it is coming, 'right'. Maybe in all the cases it will not be possible for us to explain because of the time constraint, but when it has come let us say that you have a pipe, 'right' and this is the central axis, 'right' and a fluid is flowing, 'right'.

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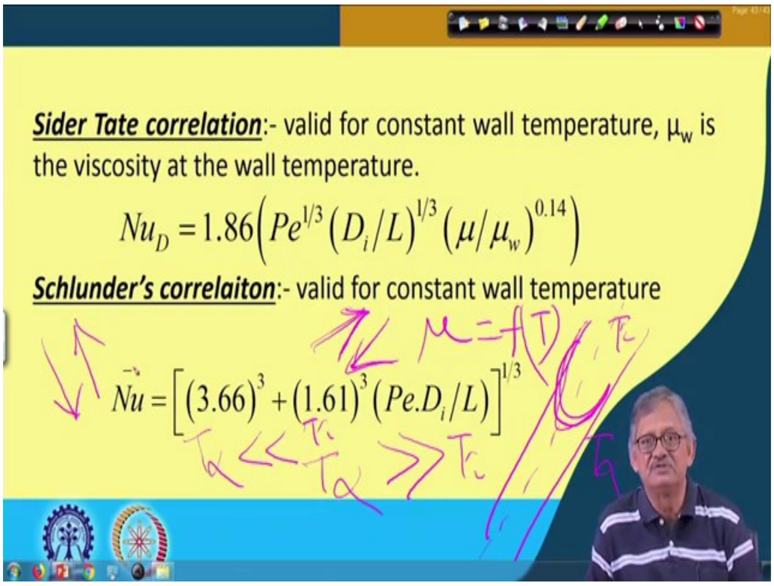

And your pipe it has say outside temperature is T_∞ whereas, this fluid as a temperature of say T_i and obviously, T_∞ is may be much greater than T_i or less than how does it matter? It does not matter, T_∞ will be much less than T_i, 'right'. In one case one it will have a have one type in other case it will be just inverse or reverse, 'right'. So, when it is coming as we know that viscosity mu is a function of temperature, 'right'.

In most of the cases without exception, in most of the cases the viscosity is a function of temperature that is true, but as the temperature increases viscosity decreases, 'right', this is by enlarge happening. As the temperature is increasing viscosity is decreasing or that vice versa as the temperature is decreasing viscosity is increasing it is becoming more and more viscous; viscosity increasing when more and more viscous, 'right'.

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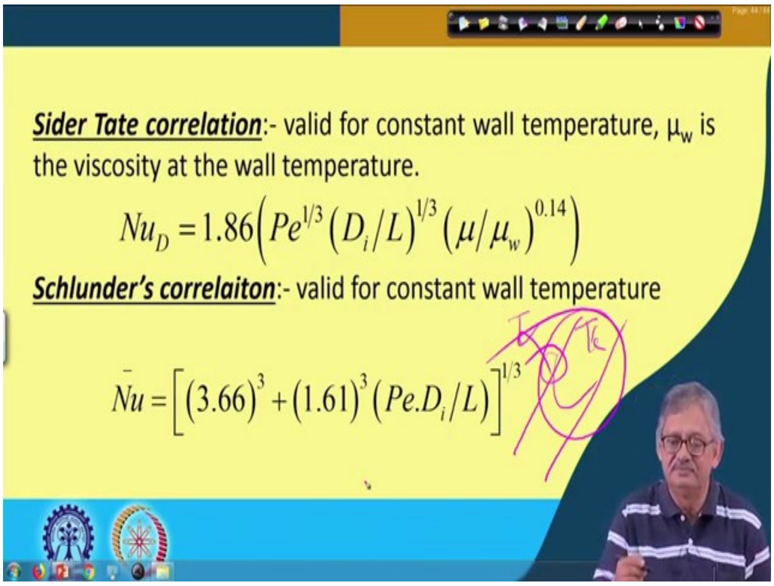

So, when we had this flow. So, the viscosity at the wall which was T_∞ around and viscosity at the center which is say T_i around, 'right' are quite different. So, unless you take care of this viscosity correction then you will have some error. So, that is what the Sider Tate correlation has incorporated that.

So, valid for constant wall temperature and mu w is the viscosity at the wall temperature. Then Nusselt number in terms of diameter is $1.86\left(Pe^{1/3}\left(D_i/L\right)^{1/3}\left(\mu/\mu_w\right)^{0.14}\right)$. This is in many cases through pipe flow are utilized, 'right'.

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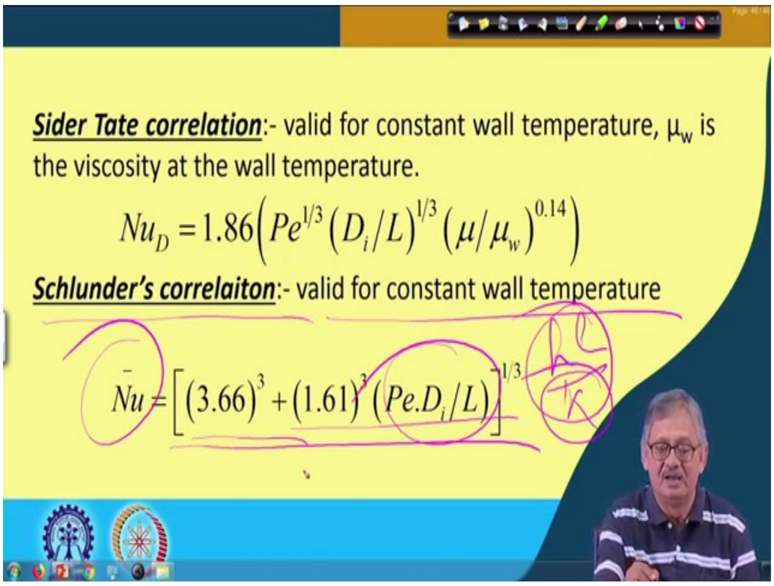

Similarly, some other like Schlunder's correlation it is valid for constant wall temperature and the average Nu is 3.66; Nu is Nusselt number. Again h_l / k do not forget that this k is the conductivity of the fluid or the medium. So, $[(3.66)^3 + (1.61)^3 (Pe.D_i / L)]^{1/3}$, 'right'.

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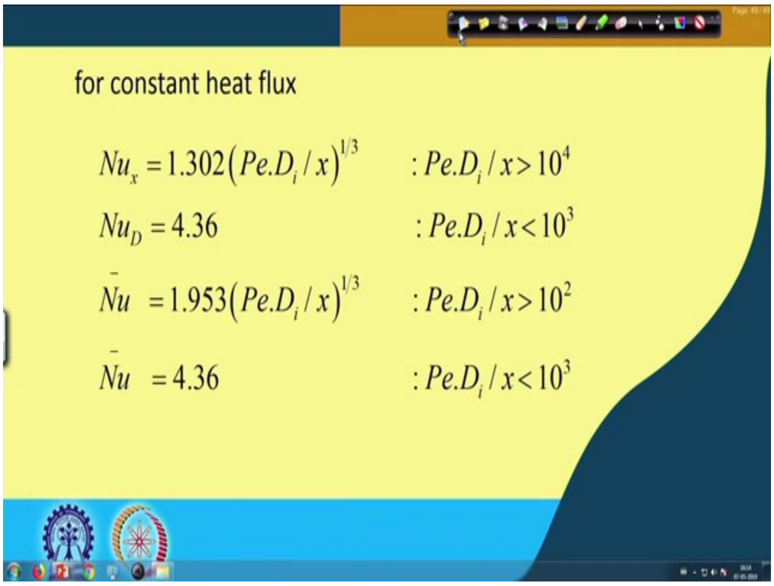

So, if this is true then for constant heat flux, again under different conditions for constant heat flux $Nu_x = 1.302(Pe.D_i / x)^{1/3}$, where $Pe.D_i / x > 10^4$. Whereas, Nu_D is means Nusselt number in terms of diameter is 4.36. This is also valid for P_i into D_i sorry $Pe.D_i / x < 10^3$. Average Nusselt number is $1.953(Pe.D_i / x)^{1/3}$ that is $Pe.D_i / x > 10^2$.

Similarly, for average Nusselt number is 4.36 if $Pe.D_i / x < 10^3$ 'right'. So, this type of many correlations are there, perhaps some more will also bring in because as and when you will have different situations of your system, that time you may need to utilize it, 'right'. And, these are collections from different resources that is why I preferred that I should share with you so that in future when you are doing your either master or post doc or doc that time you may be required, 'right'. So, with this let us stop today here and.

Thank you.