Thermal Operations in Food Process Engineering: Theory and Applications
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Lecture - 30
Heat Transfer by Convection (Contd.)

So, good evening again, we are now on the class lecture number 30, where we are doing convection heat transfer. And we have done already with a lot with the help of Heisler chart also and subsequently now we will do the convective heat transfer for the normal other things also.

Like we have already said what we mean by convection, how many types of convections are also there in what way etcetera. We have also shown that, how we can find out center temperature, how we can find out surface or any other temperature, how we can find out the time required to reach the center or surface temperature etcetera from Heisler chart, but there are cases where it is not so, easy that this can directly be put into Heisler charts or into the lumped system. So there it may be required that some other solutions or some other equations which may be useful, 'right'. So, now let us go some a little deep into the convection, 'right'.

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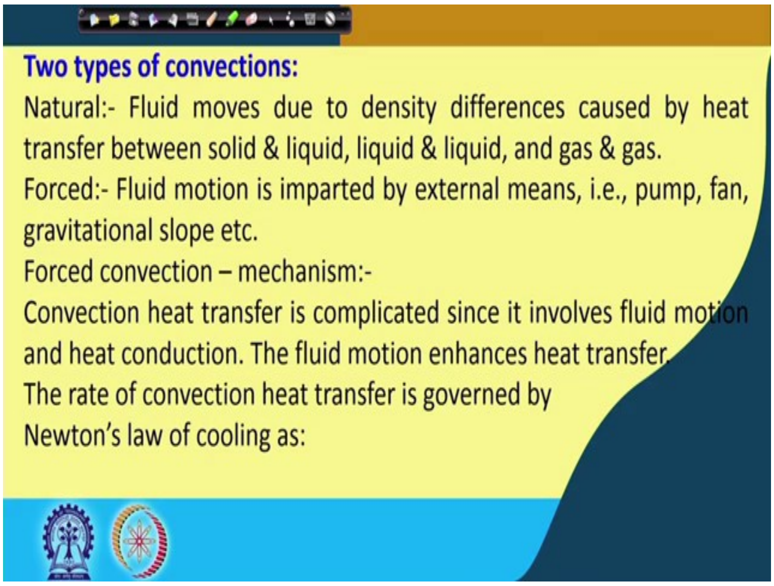

So, whatever we have already done we can skip them and perhaps now, we have come to this that there are two types of convections, 'right'; one is natural which you have said and the other one is forced convection, 'right'. So, fluid in the natural convection it can be said that the fluid moves due to density differences caused by how caused by heat transfer between solid and the liquid or liquid and liquid or gas and gas, 'right'. So, in that way heat is getting transferred or it can be forced where fluid motion is imparted by external means that is by pump or by fan or by some gravitational slope etcetera, 'right'.

So, the mechanism of first convection is like this; convection heat transfer is complicated since it involves fluid motion and heat conduction both, 'right'. The fluid motion enhances heat transfer the rate of conviction heat transfer is governed by; obviously, we have said earlier also that Newton's law of cooling and that Newton's law of cooling can be written in this form.

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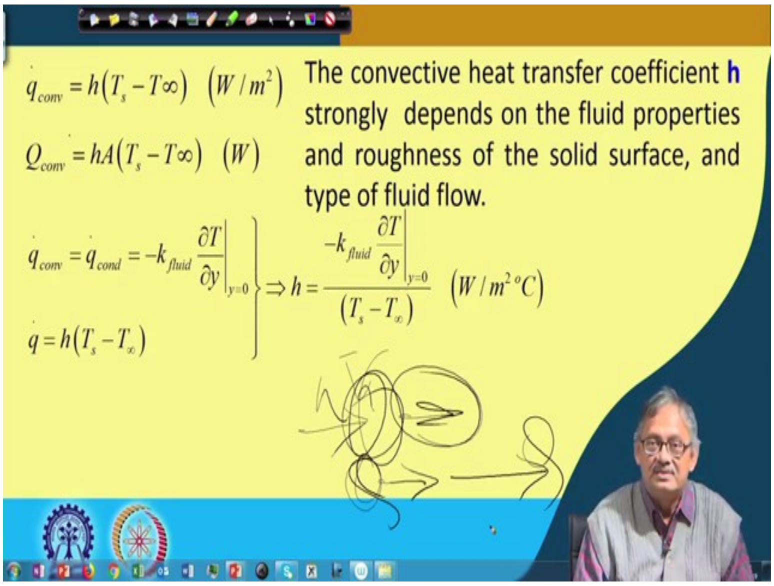

That $\dot{q}_{conv} = h(T_s - T\infty) \quad (W/m^2)$; 'right' or it can also be written that Q convection capital Q convection in any case small q refers to per unit m^2, 'right'; that is flux that heat flux is $\dot{q}_{conv} = h(T_s - T\infty) \quad (W/m^2)$ and Q capital is $\dot{Q}_{conv} = hA(T_s - T\infty) \quad (W)$

The convective heat transfer coefficient h strongly depends on the fluid properties and roughness of the solid surface. And also the type of the fluid which is flowing, 'right' that is the type of the fluid flow not the fluid properties only, but the flow of the fluid that also will all dictate the value of h, 'right'. So, h is very important in convective heat transfer because that will dictate how good or how bad the heat transfer will take place, 'right'.

And from where the earlier we have done that fin so whether you need the fin in addition or not that is also dependent on this value of h. So, h is a very important parameter in convective heat transfer and this heat transfer coefficient may be required to either calculate or predict or determine whatever.

So, it is having a very significant role on the heat transfer, 'right'. So, we can say that $q_{convective}$ is equal to $q_{conductive}$ it is under; obviously, under steady state that whatever q is coming through convection. So, if this is a body; if this is a body. So, whatever q is coming due to h and T_∞ at this place is conducted by the body, 'right'.

So, that is only possible and the same Q is; same Q is coming into this and going out from there, 'right', this is only possible under steady state. So,

$$\left.\begin{array}{l} \dot{q}_{conv} = \dot{q}_{cond} = -k_{fluid} \left.\dfrac{\partial T}{\partial y}\right|_{y=0} \\ \dot{q} = h\left(T_s - T_\infty\right) \end{array}\right\} \Rightarrow h = \frac{-k_{fluid} \left.\dfrac{\partial T}{\partial y}\right|_{y=0}}{\left(T_s - T_\infty\right)} \quad \left(W/m^2\,{}^oC\right)$$

And this is true because $\dot{q}_{conv} = h\left(T_s - T\infty\right)$, 'right'. So, this conductive by this thing; we have divided so much Watt per meter square h, theoretically we are able to find out, 'right'. So, let us look into some other aspects of this convection, 'right'.

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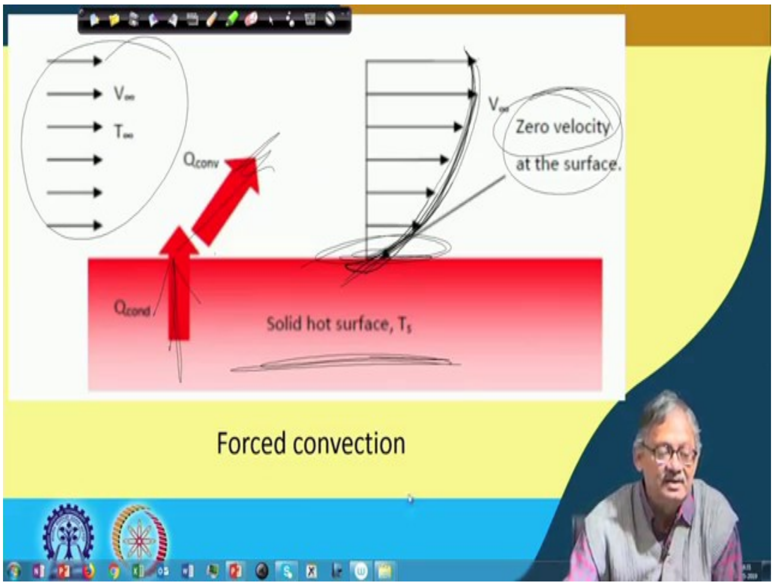

So, solid if we have a hot solid, 'right' we if we have a hot solid surface like that this is the hot solid surface. So, this is through conduction coming to this and then by convection it is going and this is the V velocity of the surrounding medium, 'right'. So, zero velocity at this surface; we know that the fluid which is in contact with the solid, so that is it is called clinging to the surface, 'right'.

It is clinging to the surface that fluid clinging to the surface; that means, the velocity at that surface is zero that is what is shown, 'right'. We have a velocity profile like this is called parabolic velocity profile, 'right'. So, velocity profile is whatever be; so environmental for velocity of the fluid is like that and this is what is the reality of the convective heat transfer, 'right'.

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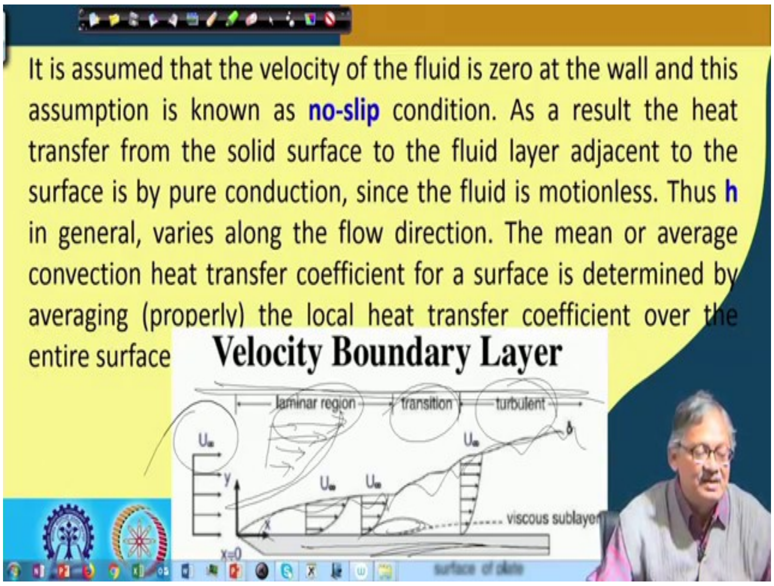

Now if we look at; it is the assumed that the velocity of the fluid is zero at the wall and this is assumption and this assumption is known as no slip condition, 'right'. No slip condition means clinging there is not slipping no slip condition, 'right'; it is assumed that the velocity of the fluid is zero at the wall and this assumption is known as no slip condition.

As a result of the heat transfer from the solid surface to the fluid layer adjacent to the surface is by pure conduction since the fluid is motion less there. Thus h in general varies along the flow direction; this means that the mean or average convection heat transfer coefficient for the surface is determined by averaging; properly averaging the local heat transfer coefficient over the entire surface, 'right' this is called velocity boundary layer, 'right' this is called velocity boundary layer.

So, this is also in the previous or thing we had shown that we have velocity profile which is like this called parabolic, 'right'. So, we have this is x is 0s; that is the viscous sub layer here ok, then laminar region is here, then transition region is here and then turbulent region is here depending on the flow pattern of the fluid; the boundary layer is becoming different, 'right'.

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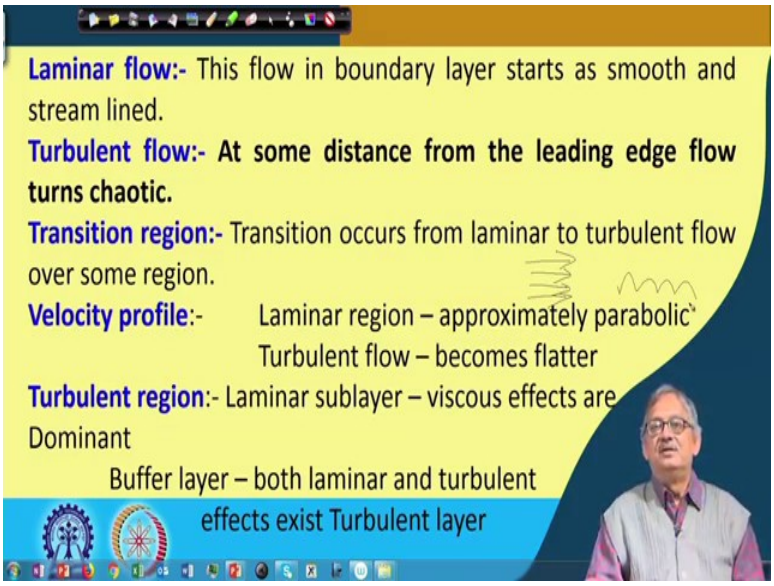

So, let us look into that laminar flow; this flow in boundary layer starts at smooth and streamlined, 'right'. So, boundary layer in the laminar flow it is; obviously, that is streamlined like that all the layers are parallel; there is no mingling intermingling of the layers, 'right'; so that mixing of the layers are not possible in laminar. Turbulent flow at some distance from the leading edge flowed turns chaotic, 'right'.

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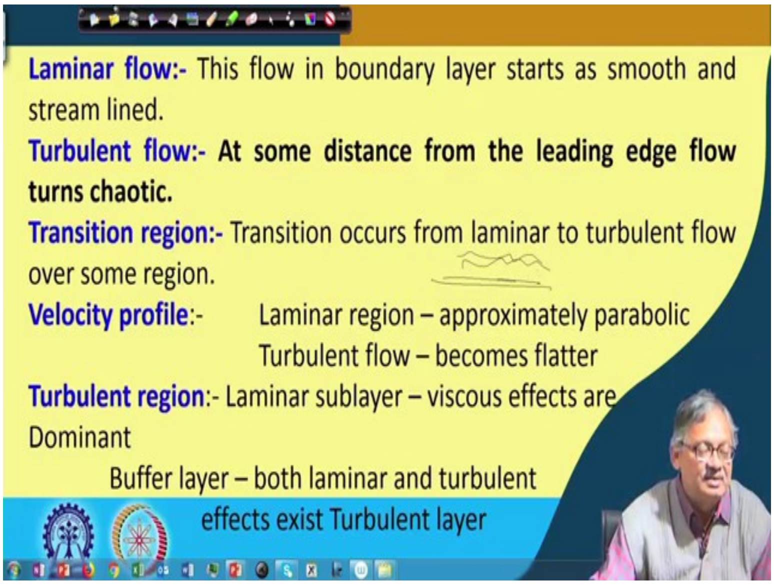

So, this was the surface; so here it was laminar. So, after some time heat started making turbulent, 'right' the flow became mix the, 'right' or the layers became mixable and this is called the turbulent flow. Then the transition region where it is neither mixing, nor it is this fully under in under full mixing that situation is not there; in between this region is called transition region, ‘right’ at some distance from there ok.

Transition occurs from laminar to turbulent flow and over some region. Now velocity profile if we look at in the laminar region; approximately parabolic, in the turbulent flow heat it becomes flatter, ‘right’. Because in the laminar region it is approximately parabolic like this, but in the turbulent region; it becomes more or less flatter.

And in the turbulent region laminar sub layer viscous effects are also dominant laminar sub layer is possible there, but viscous effects are also dominant, ‘right’. Now buffer layer is also there were both laminar and turbulent effects exist in the turbulent layer, ‘right’.

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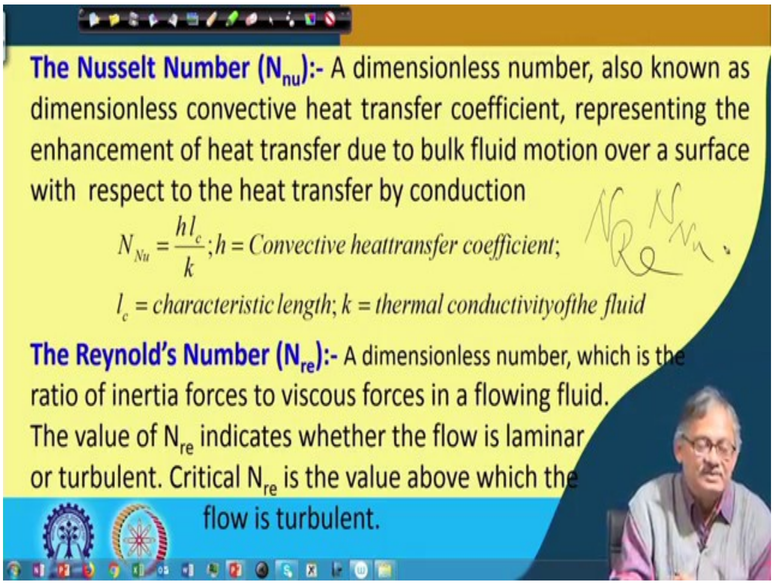

So, now after understanding all these; let us define some of the dimensionless parameters which has very important in convective heat transfer. And this dimensionless parameters as we have seen in the earlier even in the graphical method; that is Heisler chart that dimensionless parameters are important, here also for finding out the heat transfer coefficient basically there are different correlations with this dimensionless parameters and some are empirical, some are experimental.

So, different very pronounced or effective here relations are there for convective heat transfer with the help of dimensionless numbers; so, these numbers also are important. So, let us know some of them that the Nusselt number first is that Nusselt number or normally called N_{Nu}, 'right'. As we said earlier that numbers are said with N like Reynolds number N_{Re}, similarly the Nusselt number is said N_{Nu}, 'right'.

So, there it is said that a dimensionless number also known as dimensionless convective heat transfer coefficient representing the enhancement of heat transfer due to bulk fluid motion; over a surface with respect to the heat transfer by conduction.

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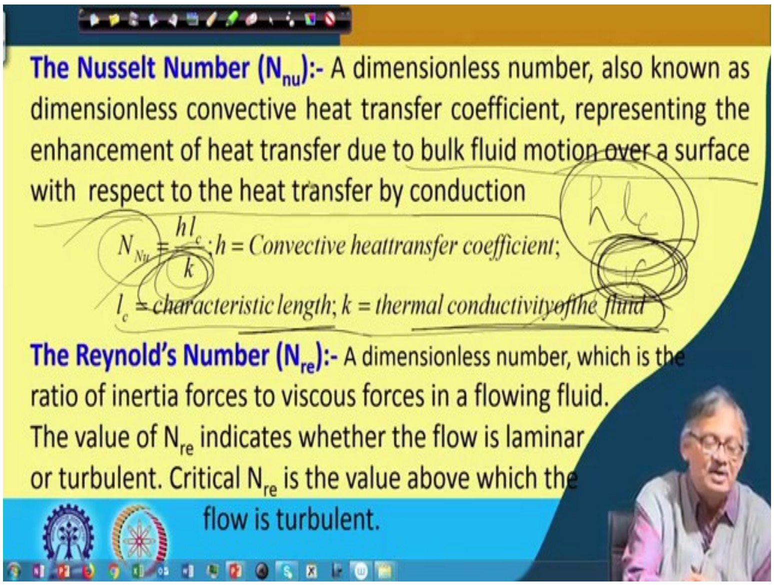

So, N_{Nu} is You remember

$$N_{Nu} = \frac{h\,l_c}{k}; h = Convective\ heattransfer\ coefficient;$$

$$l_c = characteristic\ length; k = thermal\ conductivityofthe\ fluid$$

when we were discussing Biot number; I said that this is also very important to remember that hl by k this; the same terminology or the same notations are used for other case, only the difference the property values, 'right'. So, in the Nusselt number; it is also the number wise or the representation wise same as Biot number hl/k, but h is written coefficient.

It was also there in Biot number heat transfer coefficient, l or characteristic length where whatever nomenclature you use l, lc whatever you use that is characteristic dimension parameter and divided by k; now in that Biot number this k was the conductivity of this solid through each it is being conducted and here it is the conductivity of the fluid by which heat is being convective, 'right'.

So, this is the difference primarily or most of these cases this is ignored or the mistakes are made. So, this k is the conductivity of the fluid; not the material, conductivity of the fluid that is what is Nusselt number. Reynolds number we know by this time many of us because Nusselt number being in heat transfer could be new, but necessary Reynolds number; since we know the fluid flow hopefully we know Reynolds numbers.

But still it is a dimensionless number which is the ratio of inertia forces to the viscous forces in flowing fluid the value of N re indicates that the flow is laminar or turbulent. Critical Reynolds number is the value above which the flow is turbulent; that is called critical Reynolds number. The Reynolds number; the value of which above which is the flow is turbulent that is called critical Reynolds number, 'right'; so, some more non dimensional parameters.

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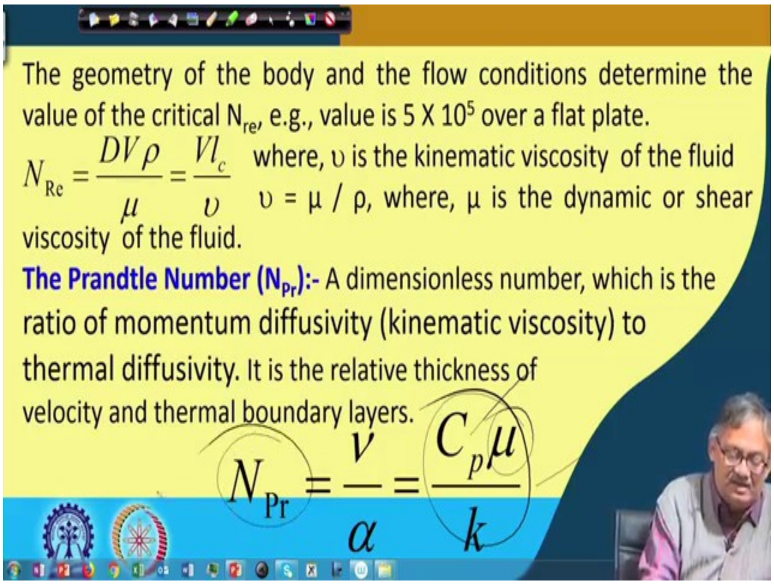

The geometry of the body and the flow conditions determine the value of the critical Reynolds number. For example value is 5×10^5 over a flat plate, 'right'. So, N_{Re} is $N_{Re} = \frac{DV\rho}{\mu}$ or it can also be written as $\frac{Vl_c}{\upsilon}$; where υ is the kinematic viscosity of the fluid. And υ is μ/ρ where, c μ is the dynamic viscosity or shear viscosity of the fluid, 'right'.

Then Prandtle number; N_{Pr}, 'right', Prandtle number normally denoted as N_{Pr}, this is a dimensionless number which is the ratio of momentum diffusivity; kinematic viscosity to thermal diffusivity. And it is the relative thickness of velocity and thermal boundary layers; it is the relative thickness of velocity and thermal boundary layers. So, N_{Pr} is can be written as nu by alpha which can be simplified as C p mu over k; normally not in this form, but in this form N_{Re} or N_{Ps} or rather N_{Pr} is known that Prandtle number is

$$N_{\mathrm{Pr}} = \frac{\nu}{\alpha} = \frac{C_p \mu}{k}$$

, 'right'.

Obviously, C_p is the medium specific heat, μ is the medium viscosity, k is also the medium conductivity..

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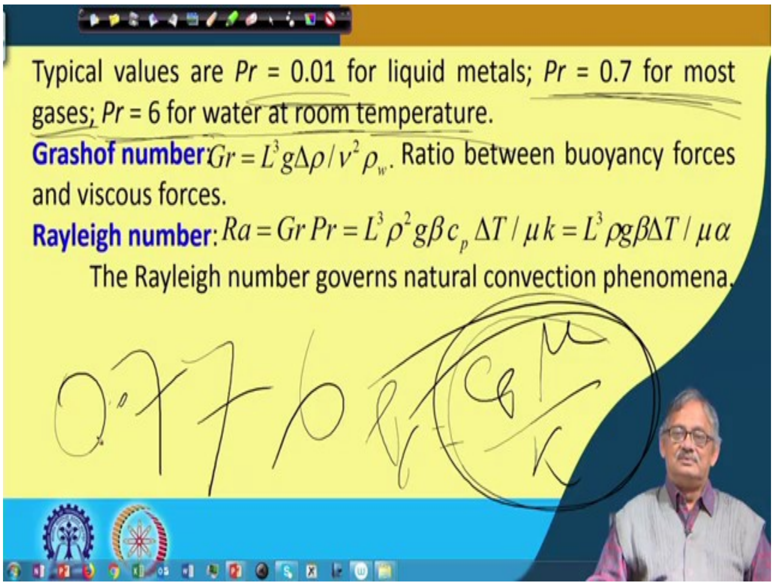

Then we see typical values of N_{Pr} are 0.01 for liquid metals; 0.7 for most gases and Prandtle number is 6 for water at room temperature. That means, you have different situations and Prandtle numbers are quite different; in liquid metals Prandtle number is very low 0.01 whereas, Prandtle number is 0.7 for most of the gaseous.

Like air oxygen or most of the gases Prandtle number is 0.7; whereas, Prandtle number is very high 6, for water at room temperature, ‘right’. And you use as I said that N_{Pr} is equal to $\frac{C_p \mu}{k}$. So, all these property values are for that medium, ‘right’. So, when it was 7 or 6 for water; the all the values C_p, μ, k are for water only, ‘right’.

Similarly, when it was 0.7 for gases; say air then C_p, μ, k all are for air only, ‘right’ for liquid materials it is 0.01; again that C_p, μ, k were all for the liquid metal only, ‘right’.

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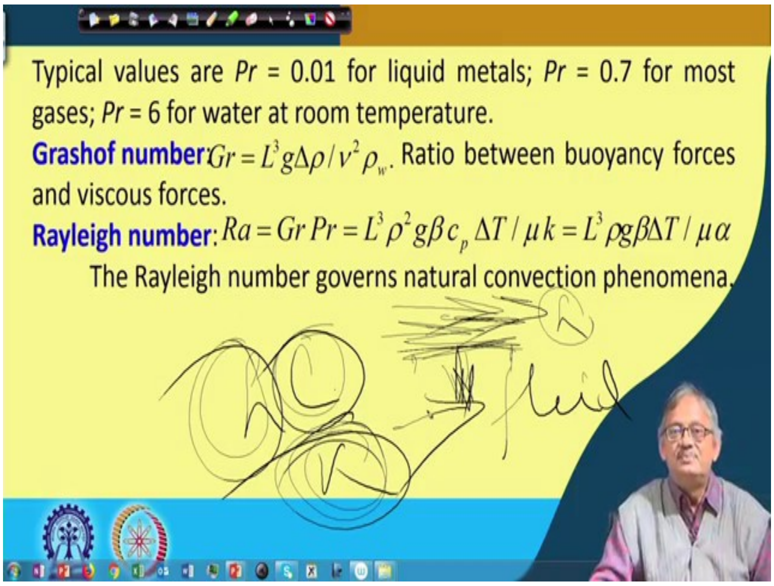

So, unlike that Nusselt number which was hL/k and this L characteristic dimension, h is heat transfer coefficient, but this k for Nusselt number was for the medium or fluid, ‘right’. Because this Nusselt number means this surface we have; over it there is a flow of fluid and that fluid has heat transfer coefficient of h. And the characteristic length through which heat is being transferred is L; then this k was for this medium.

But the same is not true for the Biot number, where h is same, but L was as we were saying that characteristic length, but this k was the conductivity through which the material is being conducted; the heat is being conducted through the material, ‘right’. So, the property values are very important and it should be also known that which property is being used, ‘right’.

So, for which dimensionless parameter which property is being used that should be very much known, ‘right’. So, again and again we are; I am highlighting that do not confuse with the; with the Biot number and the Nusselt number, ‘right’. Because in a convective heat transfer Nusselt number is very commonly used and perhaps is one of the; one of the non dimensional parameters which is correlated with some other non dimensional parameters, in most of the relations subsequently when we will come across we will see, ‘right’.

So, be careful that you must differentiate between Nusselt number and Prandtle number; Nusselt number and Biot number. In both the cases the expression is same hL/k; h you cannot make any mistake because that is a convective heat coefficient. L you cannot make any mistake because that is also the characteristic dimension; like maybe length or whatever you say one dimension that is characteristic dimension of heat transfer.

And k for Nusselt number this k is for the medium through which heat is being convicted and for Biot number this k is the; this k is the conductivity of the material through which heat is being conducted, ‘right’. So, these two differences are very fundamental and most of the cases students do mistake; may not be the today it is being read; so we will be remembered. But in most of the cases, we have seen during viva we see this mistake is being occurred by majority of the students.

So, that is why I am highlighting repeatedly that you do not make this mistake, ‘right’. So, another and as also you see that Prandtle number; we have shown given some typical numbers typical values for different cases that for liquid it is 0.01, for liquid metals of course, for most of the gases it is 0.7 and for water at room temperature it is 6; so wide.

Then another non dimensional number is Grashof number which is normally used for natural convection, ‘right’. It is the ratio between buoyancy forces and viscous forces, ‘right’; this is the ratio between buoyancy forces and this viscous forces. And can be expressed in other form also it can be expressed maybe today time is going up. So, you may not be able to in some other day; we will also show that it can be expressed in some other way also. So, here we are writing that it is expressed as L cube g; delta rho over nu square into rho w, ‘right’ or rho w, ‘right’ at the wall.

So, Grashof number is $Gr = L^3 g\Delta\rho / \nu^2 \rho_w$. So, for the last for today it is Reynolds Rayleigh number; Rayleigh number is the number that governs natural convection phenomena, 'right'. Both Grashof number and Rayleigh number are associated with natural convection whereas, Nusselt number is normally with force convection by enlarge, 'right'.

So, Grashof number and Rayleigh number are for natural convection and Rayleigh number is nothing, but a product of Grashof number and Prandtle number. So, Grashof number into Prandtle number is the Rayleigh number and Rayleigh number is designated as Ra. So, that is equal to. $L^3 \rho^2 g\beta\, c_p\, \Delta T / \mu\, k = L^3 \rho g\beta\Delta T / \mu\, \alpha$. So, some of the non dimensional parameters we have come across. There are few many more and there are many relations between them for different cases for different situations. So, in the next class, we will do that, 'right', today time is over. So, let us now stop it and.

Thank you.