Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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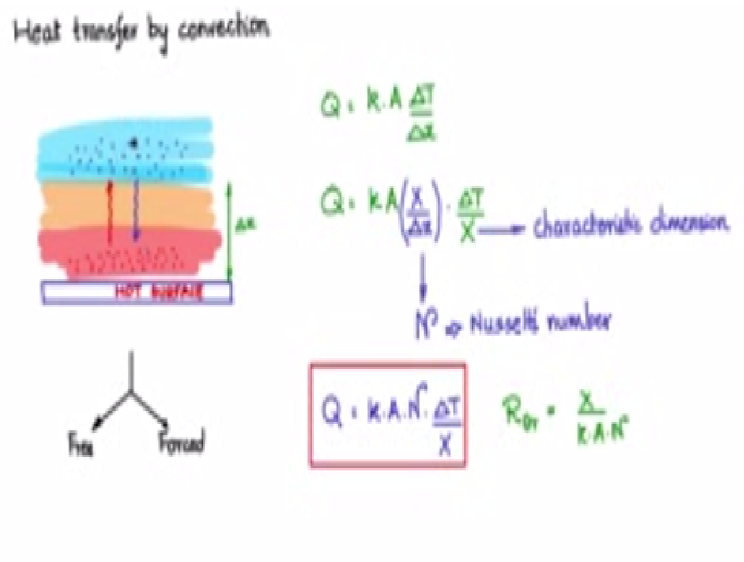

Heat transfer by convection, it is a heat transfer mechanism where heat flow occurs between solid and a fluid. So let us consider a solid that is hot and it is dissipating heat and where is heat flow vertically up. So how does this come about, if you see the immediate environment of the solid there are layers of molecules. So you will have the immediate neighborhood becoming hot by diffusion the molecules become hot by diffusion.

And it progressively decreases and the temperature of the molecules quite far away from the solid will not have that high temperature as the ones close to it. So if you consider the fluid molecules close to this solid they will be hot, and the fluid molecules away from the solid they will not be as hot.

So the hotter molecules those will start travelling up, moving up, because they are less dense. And the colder, heavier molecules will start moving down, so there is a circulation of the fluid naturally and this is the convection movement, and this is called the natural or the free convection. You can also have forced convection where you are forcing the molecules to move carrying the heat away with them by putting a sand here.

So let us now see how we obtain the relationship for the heat flow, so this is the hot surface and I will, measurement called a di X. Now Δx is the thickness of the fluid, see when we consider the solid block we said Δx was the thickness of the block in conduction, and it was easy for us to measure the di x. But in the case of the fluid what is the thickness of the fluid, now that is an uncertain quantity.

Now anyway let us put down the equation, we know that $Q=Ka\Delta t/\Delta x$, this is the heat fluorite equation. Now everything is known, you know the thermal conductivity, you know the area of cross-section across which the heat is flowing, orthogonally Δt the temperature of hot surface, the temperature of external ambient and the Δx is the thickness of the fluid. Now this is uncertain quantity.

So normally what is done commonly done is that lot experimentation as been done and then different geometries of solids have been characterized so slight modification a variant of that is I multiply and divided by a variable x now what this x is let me tell you in a short movement so ΔT/ that variable x now this is a characteristic x now this $x/\Delta x$ this is called the Nusselt number up to the work done by Nussle on heat flow this is called the Nusselt number.

And this upper case x is called the characteristic dimension of the solid so it could be in a length or it could be the breath or it could be the high of the cylinder or diameter of the cylinder so depending up on the way the solid object is positioned and it is geometry characteristic dimensions of the solids have been identified for various solids by experimentation.

So we will use that characteristic dimension to arrive at the value of the Nusselt number now let us say you have these Nusselt number by some means I will discuss how we calculate how we determine the Nusselt number but let us say we have the Nusselt number then we have this relationship kA Nusselt number into Δt / characteristic dimension x, the thermal resistance R thermal and convection they use the subscript v so thermal resistance convection is given by characteristic dimension x/ thermal conductivity A of cross section Nusselt number.

So this is the important equation for convection that you should remember and use remember that there are two variants in convection one is the free convection the natural convection and the force convection is if you put a fan or a blower and speed up the molecules that are in contact with the solid that is called force convection free convection the natural convection is the natural circulation that is attained by the movement of the molecules due to the density movement.

When a option of the molecules become hotter than the other set of molecules which are for removed from the surface which are colder, so it should be noted that the nosselt's number is not the same for free conviction and force convection nosselt's number is different for free convection and different for force convection, how do we what calculating nosselt's number have will just now shortly discuss.

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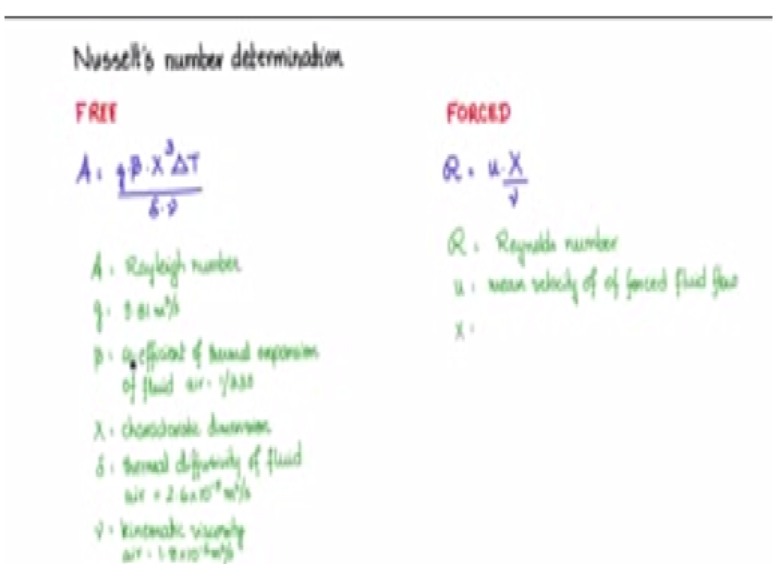

Now let us see how we determine the results number or various solids various geometries this is by series or empirical relationship, now to determine the nosselt's number as said that the nosselt's number is different for free convection and for force convection so for free convection we have the relationship of another number this is called the rally number okay where were each of this or is the rally number g is the acceleration due to gravity 9.8 $1m^2/s$ ß is the coefficient of thermal expansion of the fluid.

So this is given in science tables and for air I will tell you it is 1/330 x is the characteristic dimension which I will have to discuss ΔA is the thermal diffusivity again this is a property of the fluid which is given in science tables and for air it is 2.6 $10^{-5m2/s}$ no is kinematic viscosity and again it is given in science tables not to worry and for air I am writing it down 1.8 and $10^{-5m2/s}$ because we most of our experiments will have the air has the fluid medium so we apply these values here.

X characteristic dimension I will tell you how to get that ΔT is the temperature difference you will get rally number and nosselt's numbers can be expressed in terms of the rally number for free convection I will tell you how to express the nosselt's number in terms of the rally number, now for the forced convection part another number call the Reynolds number is used U into X/nosselt's number ue is that mean velocity of the forced fluid, see of you are using a fan blowers some such device.

Than the air flow what is the man velocity of the air flow that you are forcing is how what is needed and that is u you can get that value x again the characteristic dimension I will discuss that and Nu is the kinematic viscosity just like as I have indicated here.

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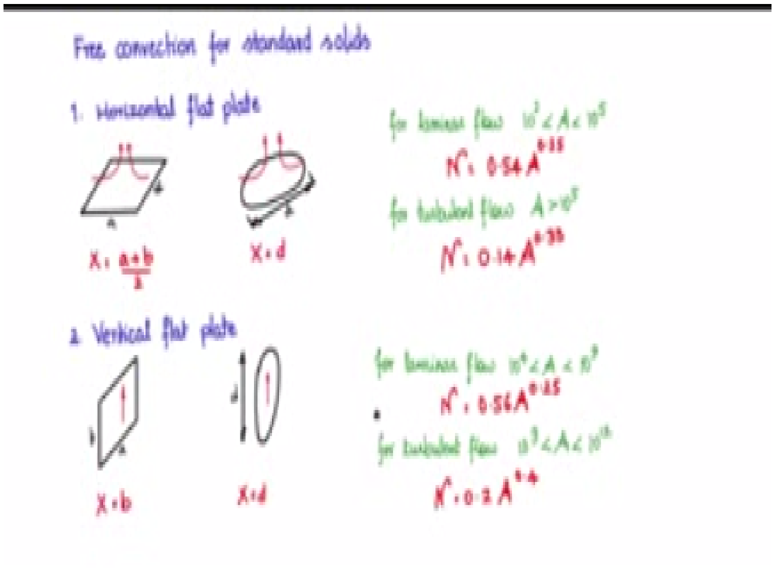

So now consider the free conviction for standard solids and first we, first important one is horizontal flat plate, so many of the heat sinks or flat plates let us say horizontal flat plate it can be cubiod, it can rectangular or it can be circular so if it is rectangular it has two important dimensions A and B and it is place flat the fluid flow is up like that, and if it is circular you have a dimension D diameter and the fluid flow is like that.

So X the characteristic dimension for the rectangular flat plate is a+b/2 and X is d that is the diameter for a circular flat plate. Now if the floor is land in all that you can find out from the rally number if it is lying between 10^{-2} and 10^{-5} and then Nussle's number is given by this empirical relationship $0.54A^{0.25}$. For turbulent and flow where the rally number turns out to be greater than 10^{-5} Nussle's number is given by $0.14A0^{.33}$.

So this way you can find out the Nussle's number for horizontal flat plate likewise for the vertical flat plate also you can find out they are based on the experimental results and the empirical relationships you have the vertical plate a and b and you have the fluid flow up in this fashion, and likewise for a circular vertical plate of diameter D you have a fluid flow up X=b only the vertical dimension is taken and X=d in the case of the circular.

So for the laminar flow which is between 10^{-4} and 10^{-9} Nussle's number is given by $0.56A^{0.25}$, for turbulent flow which is between these limits Nussle's number is given by $0.2A^{0.4}$, so in this way you can obtain and Nussle's number for horizontal and vertical flat plate higher the result

Nussle's number lower will be the thermal resistance and better it is for heat conduction for removal of the heat.

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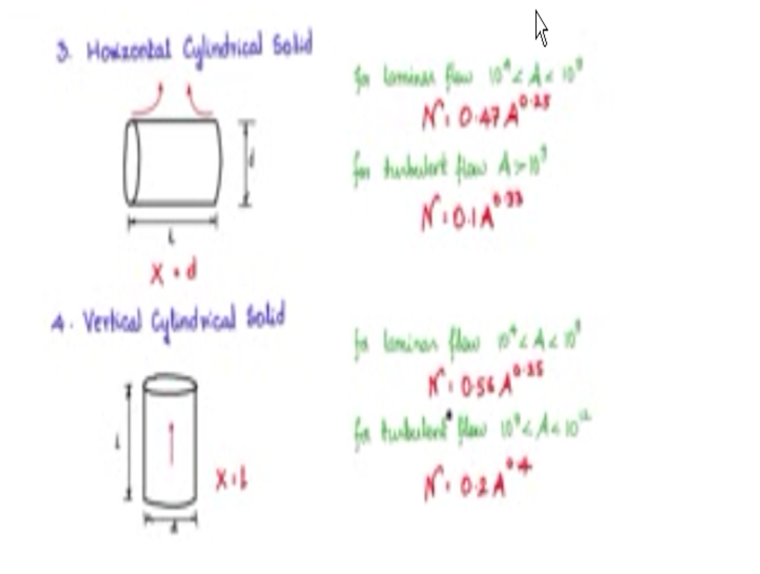

Another commonly used solid is as cylinder the solid cylinder so consider horizontal solid cylinder in this fraction which as a length of L diameter D like this as shown and you will have the fluid flow moving up like this so far this the X is D the characteristics dimension is D fro laminar flow were the rally number is between 10^4*10^9 Nusselt number is given by 0.7 rally number to the power of .25.

And for turbulent flow were the rally number is greater than 10^9 Nusselt number is given by 0.1 rally number to the power of .33 now the same cylinder you can keep it vertical, vertical solid cylinder and you can get slightly different results number characteristics you have the length L and the diameter D the flow is up and X is the characteristics dimension is L in this case.

And the laminar flow is Nusselt number is given by .56 rally number to the power of .25 and for turbulent flow the results given by 0.2 rally number to the power of .4

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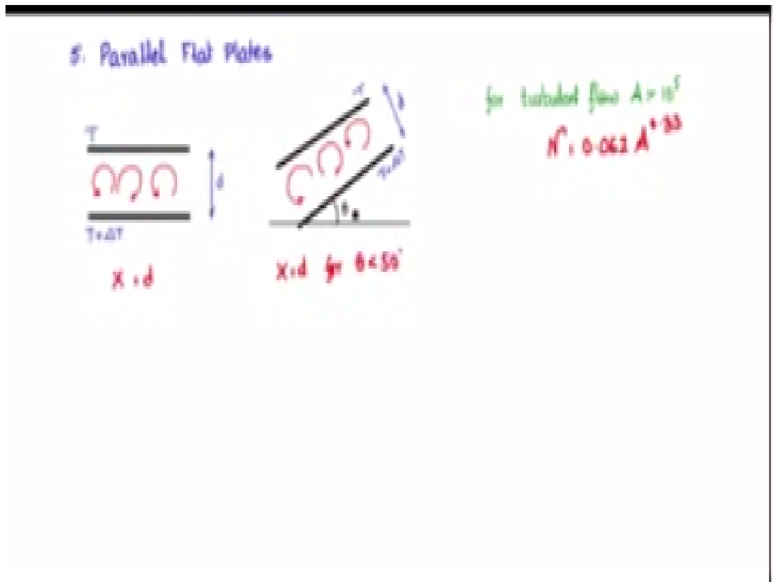

Another commonlu used solid configuration is the apparels flat plat so parallel flat plates can be placed in this fashion were plate 1 could be the temperature T and the other plate could be at a slightly different temperature T+ΔT and they could be separated with the distance d and there could be the flow within or the parallel plate can be placed at an angel to the horizontal angel θ and then you have T + ΔT for the 2 plate temperatures, separated by distance d and you can flow within like this.

So here the characteristics dimension is d in both the cases as long as the $\theta<50^0$. Now only turbulent flow is found out for this rally number > 10^5 and the results number is 0.062, 0.33. So in this way most of the geometry fall in this fashion if it is not, if it cannot fit standard geometry in a particular experiment, or a for a particular solid, then it is better to experimentally find out what is the nusselt number or what is the thermal resistance for that particular solid

For the case of force convention, let us consider 2 geometry for the solution, one as the flat plate and the other as the cylinder and if we put a fan consider this as flat rate and if you put a fan in this fashion where there is the flow of the fluid along the length of the flat plate which is having the dimension A like this I have shown then the characteristics dimension is A now for such a configuration for laminar flow Reynolds number less than 5.10^5 the noise number is given by 0.664 Reynolds number to the power o.5 kinematic viscosity by diffusivity of the fluid.

To rise to power of 0.33 for turbulent flow where the Reynolds number is greater than 5 is given 0.37 Reynolds number to the power of 8 and viscosity by diffusivity raised to the power of 0.33

the other solid configuration is the cylindrical kept vertical like this with that diameter of D and I have the fan position in this fashion and you have the continuous fluid flow shown like that x for this is given as D.

Now for this also the lamina flow where Reynolds number is between 0.1 and 1000 is given in this fashion and for turbulent flow where Reynolds number is from 1000.10^5 you have number given like this so these are the number value that you have to use for the various solid geometries in the thermal resistance equation that is thermal resistance given by x characteristic dimension by thermal conductivity K number k/kan now that is how you go about calculating the thermal resistance for convection.