Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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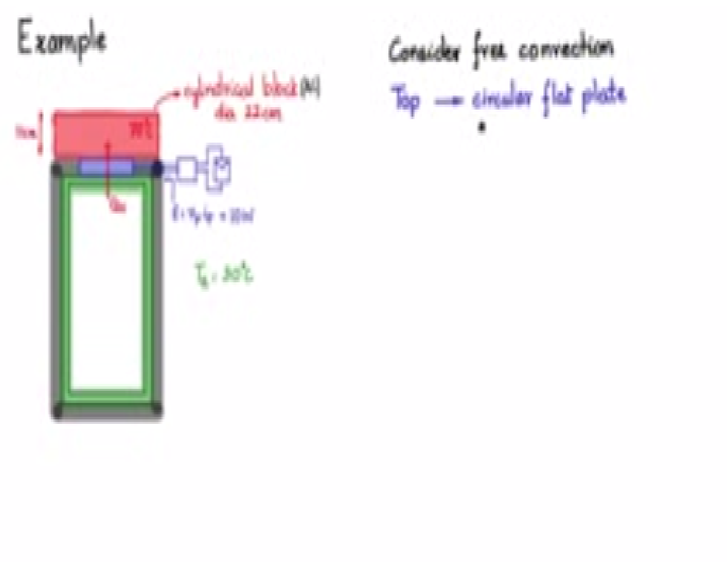

Free convection and force convection are two of the common mechanisms of heat transfer that is used for removing heat from heat sinks and components, hot bodies. Let us now consider an example to crystallize our understanding of this free and forced convection. Let us take an example of refrigerating the volume of box. So consider this cylindrical box, I will take a cylindrical box like this, and we would like to cool the chamber inside.

So now this cylindrical box is covered all round by thermocol let us say. So the cylindrical box is tightly packed with thermocol, there is no way of heat coming out into the atmosphere or from the external ambient within the box. Now let us make small opening there on the top of the box, so the top of the box what I will do is, cut open an opening such that a peltier element can directly just fit in there.

So let us place a peltier element there, and the terminals of the peltier element will bring it out through the thermocol and then there I will terminate it with the appropriate electronics DC-DC converter and I will power it up with photovoltaic panel of the module externally in this fashion. So the peltier junction is getting its electric power, job of the peltier junction is to remove the heat which is there, whatever heat is there out into the external ambient such that once the heat is removed from this chamber, this chamber starts becoming cold.

So that becomes something like the refrigerator, a container which is a refrigerator. Now this portion will be the cold portion and that will be the hot portion of the peltier element. Now on top of the hot portion I will place a heat sink, I will just place a block of aluminum and this block of aluminum, because this is a cylindrical box, I will take a cylindrical shape block and then place it on top of this aluminum like this.

On top of the hot part, hot plate of the peltier element in this fashion. So this is the aluminum block which will act like a heat sink. It will remove the heat from the hot site of the peltier junction and put it out into the external ambient. Now all this portion which is in contact call this metal body of the box which is in contact with the cold junction of the peltier element will conduct the heat into this cold portion and the heat from the cold portion into the hot junction will be pumped by means of this electric power that we are giving to this peltier element.

So the heat flow will be like this, QC amount of heat from this chamber will be pushed into the aluminum block which is acting as the heat sink by the peltier heat pump now let us say this aluminum block is having a 11 cm high and it is having a tier it is a cylindrical block aluminum cylindrical block it is having a diode of 22cm now let us say that we would like to maintain this aluminum block at 70^0 now let us say that after one or two hours of working it has reached a steady state of 70^0 and during that time the ambient temperature outside was 30^0.

So now this is the situation so this is the refrigerator that is working now let us try analysis it and understand it from the point of view of force convection because when you are putting Qc amount of heat into the heat that much amount of heat + the heart that is put from the electrical side flow peltier junction E the electrical power both those should be put out into the ambient so let us calculate that values and let us see how we go about doing that for this example let me say that I am measuring the input power from the electrical side.

So I am measuring PB the thermal voltage across the peltier element and IP the current flowing through the peltier element so after measuring I will calculate VB into IP and I am finding it around V 10 racks just for an example here, so there is no force cooling I will not place any fan anywhere so it is a case of a free convection so considering this as free convection problem and this cylindrical block being aluminum block let us find out how much amount of heat is going out of this another aluminum block.

So in this aluminum block there are only two possible surface one is the top surface from the top surface you can have heat going out and on the side surface so it is a cylinder so the entire side surface there also the heat can go out into the ambient, so those are the only two surfaces where the heat can go remember that we have place thermocol every where so there is no chance of heat going for any other direction.

The heat can transact with the atmosphere with the external and then only through this peltier element everything else is covered up with thermocol and once it has gone into the hot body which is the heat sink it can go out into the ambient only through the top and through the sides so let us find out how much amount of heat is going out from the top and the sides then we will have an idea of how much of Qc is going out through the peltier element so the top is a circular flat plate so it is like a circular flat plate and we had studied about these circular flat plate while considering while studying discussing 3 convection.

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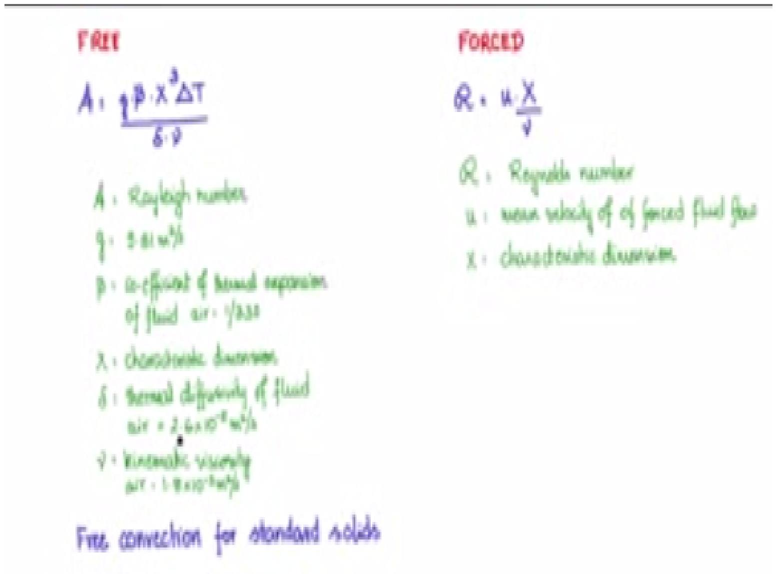

Recall that we had discussed about this while studying 3 convection for standard solids the circular horizontal flat plate where the diameter will become the characteristic dimension and then we have the calculation for the nosslet's number depending upon whether it is lamina flow or turbulent flow and to calculate nosslet's number we need the rally number so the rally number we had calculated we had given a formula, formula like this for free convection and we had list down all these pyramids what, what it is like so let use these formulas so find out the nosslet's number and there by then later on the thermal resistance.

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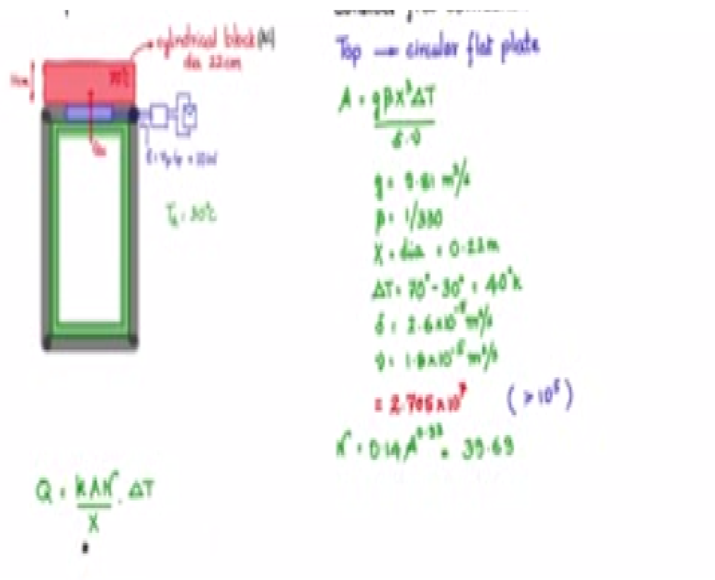

So the rally number is given by this equation gß^{x3x3} ΔT/ the Δ and nosslet's here so this is the diffusivity and nosslet's is viscosity and kinematic viscosity, so the values g is 9.81m2/s ß for air this is the coefficient of thermal expansion for air 1/330 for every degree Kelvin x is the characteristic dimension the characteristic dimension for a flat horizontal plate circular is the diameter d which is in this case 22cm or 0.22m ΔT will be 70^0 for the hot aluminum block external ambient 30.

So it will be 70 – 30 that would be 40^0 ΔT 40^0k then you have the thermal diffusivity for air and mentioned 2.6 x 10 $^{-5m2/s}$ and the kinematic viscosity 1.8 10 $^{-5m2/s}$ all these data available in scientific tables ß Δ nosslet's are all available in scientific tables, so now if you substitute all these into this and calculate you will get 2.7 into 10^7 now this is a value that is > 10^5 and therefore I will use the nosslet's number corresponding to the turbulent flow equation corresponding to the turbulent flow 0.14 rally number to the power of 0.33.

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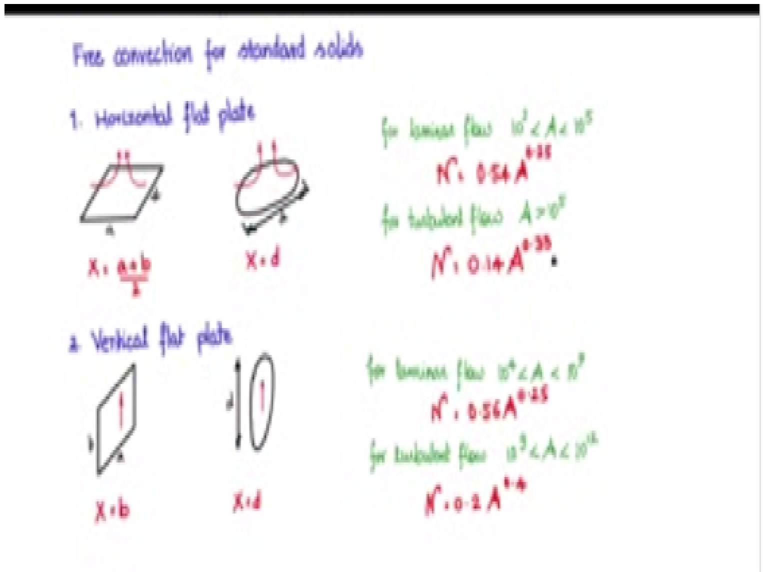

Rea call that what are blend flow horizontal flat plate for rally number > 10^5 we use nosslet's number given by this relationship, so if you substitute for rally number you can find out the nosslet's number and it will work out to be 39.69 so next let us try to find what is the our heat that is flowing out heat flow in watts that is flowing out of the tope plate so we have the heat flow equation which is conductivity a area of cross section orthogonal to heat flow nosslet's number by x.

Let me by x into ΔT so this is the heat flow equation now we know everything we know the thermal conductivity of air we know the area of cross section of the circular plate on top nosslet's number is known X is known which is the dia point 22 ΔT is 40°K, so if we substitute let me do that if we substitute this values thermal conductivity for air I mentioned is 0.026 W/°K/m, area of the circular plate $\pi/4.d^2$ which is 0.22^2 Nussle's number 39.69x40°K as the ΔT/X which is 0.22, so this works out to be around this 7.13W. So this 7.13 amount of watts is the heat flow out of the top of the aluminum block cylindrical aluminum block we will call it one as Qtop per now.

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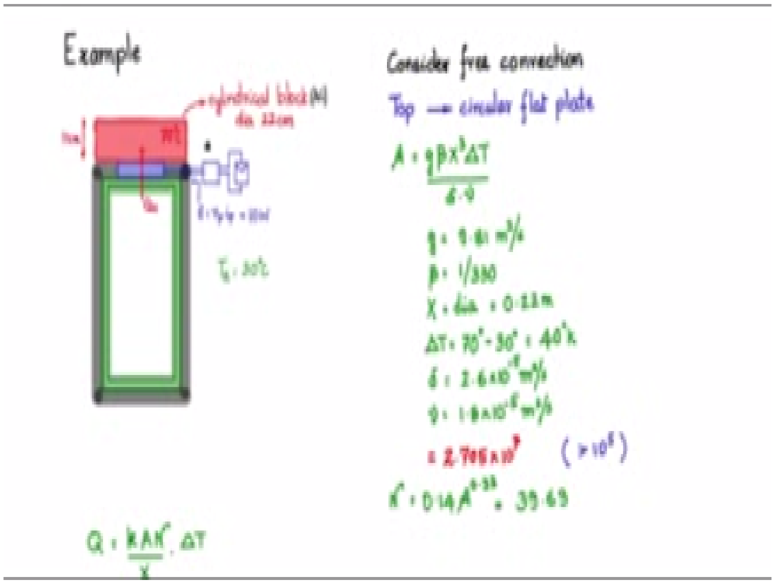

So now let us calculate what is the heat flow out of the sides of the aluminum block.

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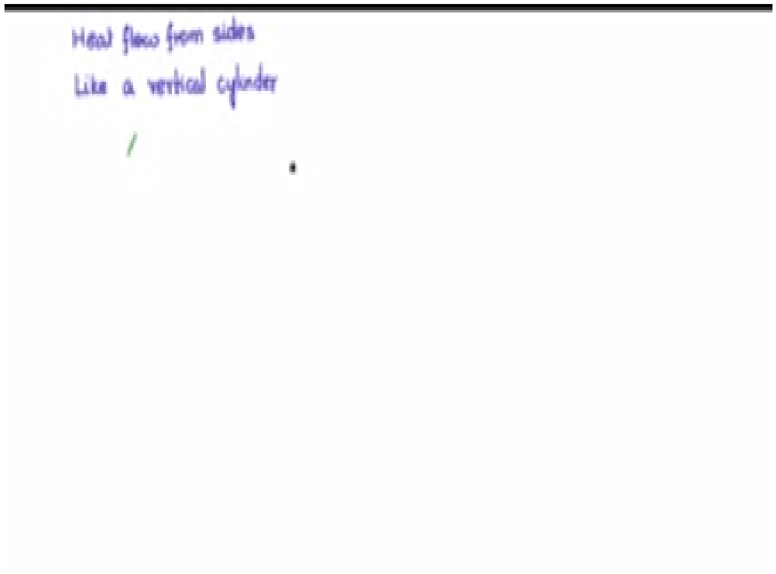

So let us now find out the heat flow from the sides of the aluminum block, so from the sides if you see it is like a vertical cylinder so a vertical cylinder.

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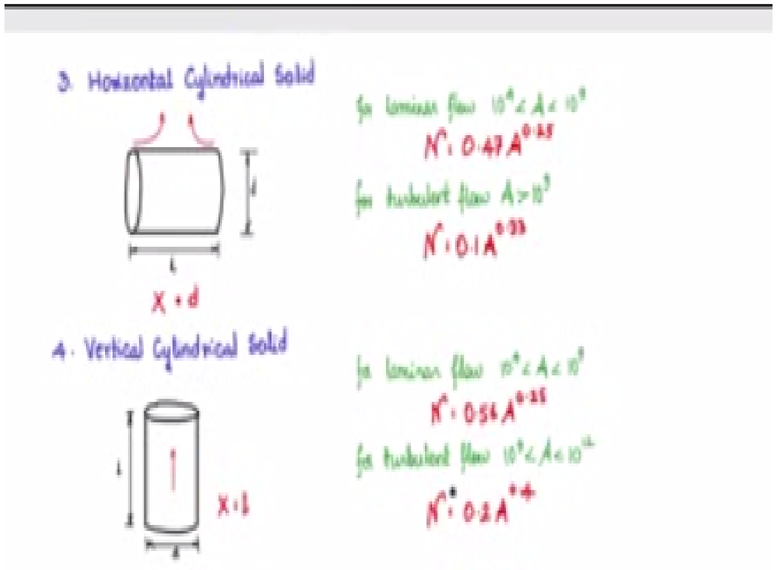

Is something like this we had discussed about the vertical cylindrical solid and the heat flow when it is placed in this fashion and we know that the characteristic dimension is l which is the height of the cylinder and for laminar flow and the turbulent flow the relationship for the Nussle's number with respect to the rally number is given in this fashion.

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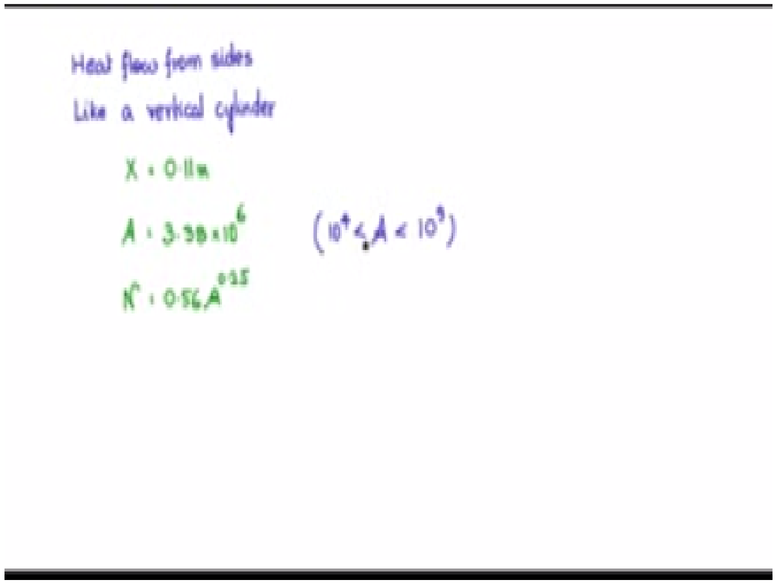

So X is 0.11m which is the height of the cylindrical block the rally number is given by $3.38x10^{6}$ here it is the same thus it is the same relationship that we use for the top the only difference is in X it was the diameter before it was 0.22 and here it is the height which is 0.11 substituting you have this relationship this value so this value is between 10^{4} and 10^{9} so we will use the Nussle's number equation which is appropriate for the laminar flow.

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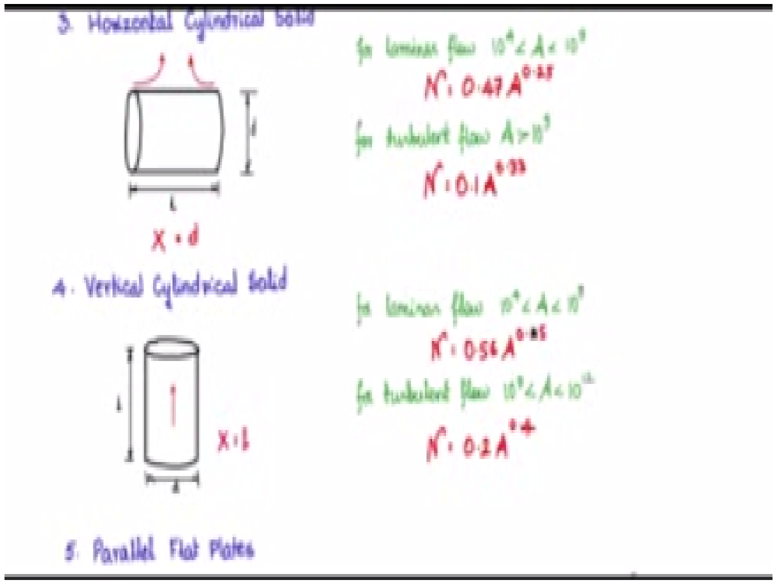

Recall that for the vertical cylinder laminar flow and the rally number is between 10^4 and 10^9 we use the Nussle's number relationship here which is given that $0.56A^{0.25}$ so that is what we will be using.

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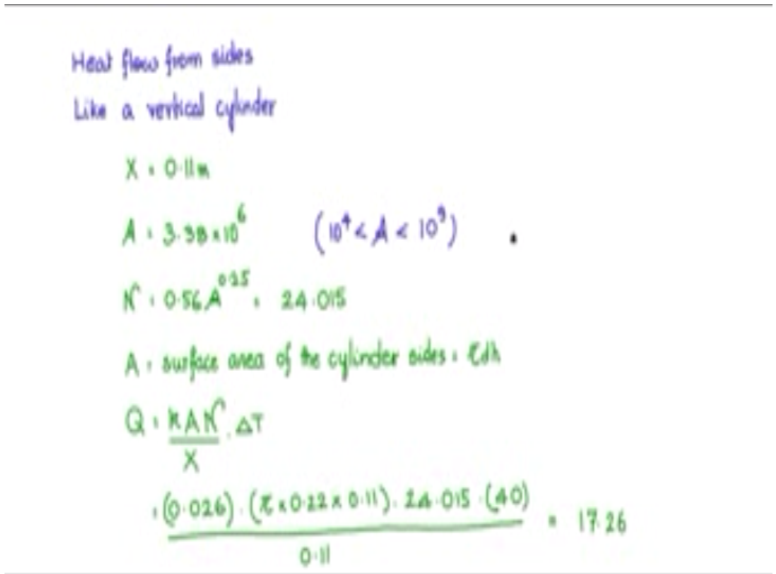

Substituting rally number value you get the value of the Nussle's number as 24.015 the area of the side cylindrical surface, surface area of the cylinder on the sides is πdh or 2πrxh this πdh so now we are ready to find the Q the heat flow from the sides given by K a Nusselt number by X into ΔT all this values or known we can substitute 0.026 per year thermal conductivity a is area of the sides of the cylinder πdh/*0.22*0.11 the Nusselt number 24.015*ΔT so this is 40^{o} Kelvin/ X again 0.11 so this works out to 17.26.

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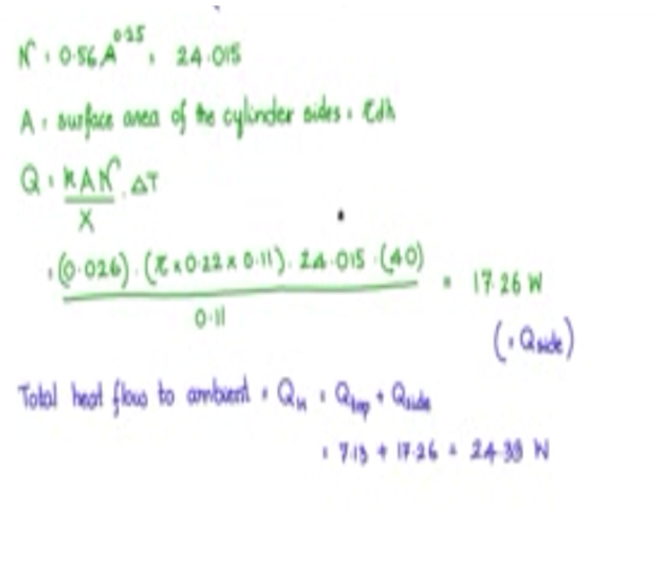

Let me move this up a bit 17.26 watts so this is Q side so from the sides of the cylinder cylindrical aluminum block which is acting as a heat 17.26 watts is flowing out from the top we saw 7.13 watt is slowing out so together you see that the total heat flow to the ambient is Qh totally going out of the aluminum cylindrical aluminum heat sink block which is Q top + Q side.

So this works out this 7.13+17.26 which is equal to 24.39 watts so much amount of watts is going out of the heat sink and that is Qh now how much is Qc which is the amount of heat going from the chamber.

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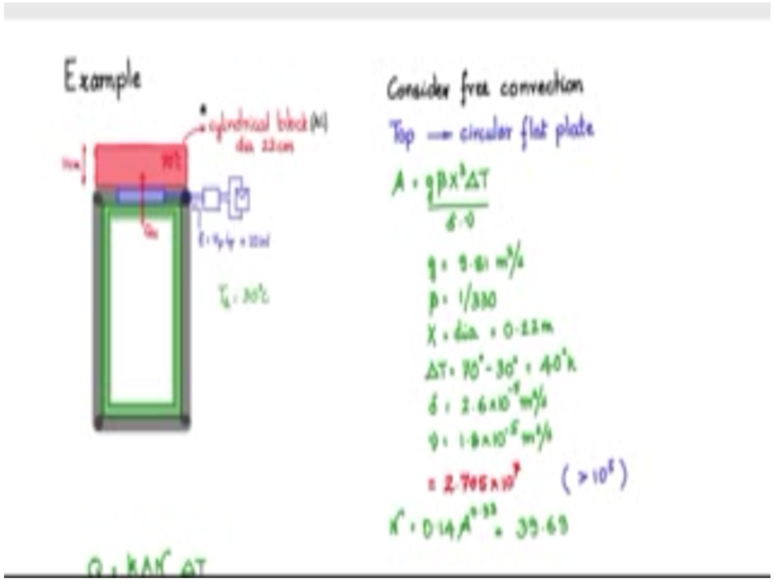

So recall this figure Qc is going to the cylindrical aluminum block is being transferred by the peltier junction there is amount of E electrical power which also goes in Qh here will be Qc+ E so Qc+ E amount is put into the external ambient and that is 24.39 watts.

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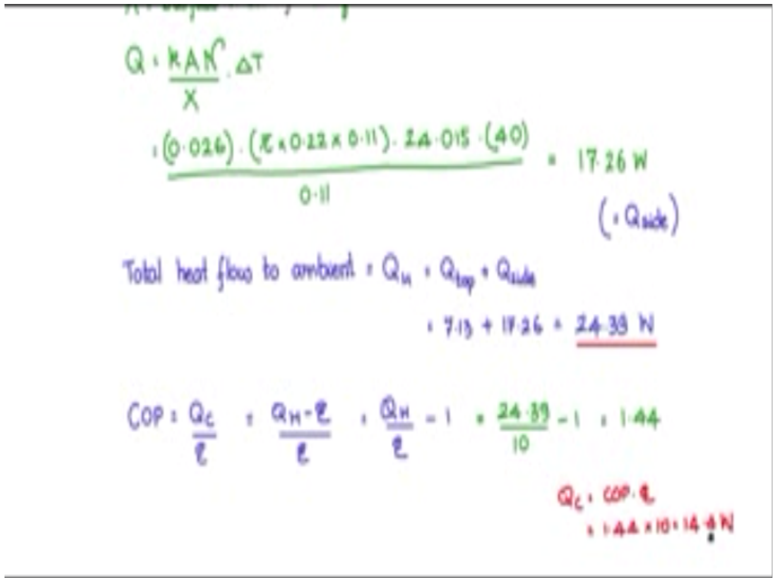

So coefficient of performance we have seen earlier that it is Qc/E Qc is the heat being extracted from the cold junction in this the chamber divided by the electrical energy fed into the peltier element or I can write it Qh-E/E which is Qh/E-1 so Qh is known we know 24.39 so that it is 24.39 we said 10 watts if you take for vp*ip and if we could that value -1 you will get 1.44 this is the Cop value.

So Qc value can be found out now Qc is Cop*E which is 1.44*10 which is 14.4 watts so around 14.4 watts of heat power is removed from the chamber the refrigerator chamber continuously, so the heat flow power Qc is 14.4 W.

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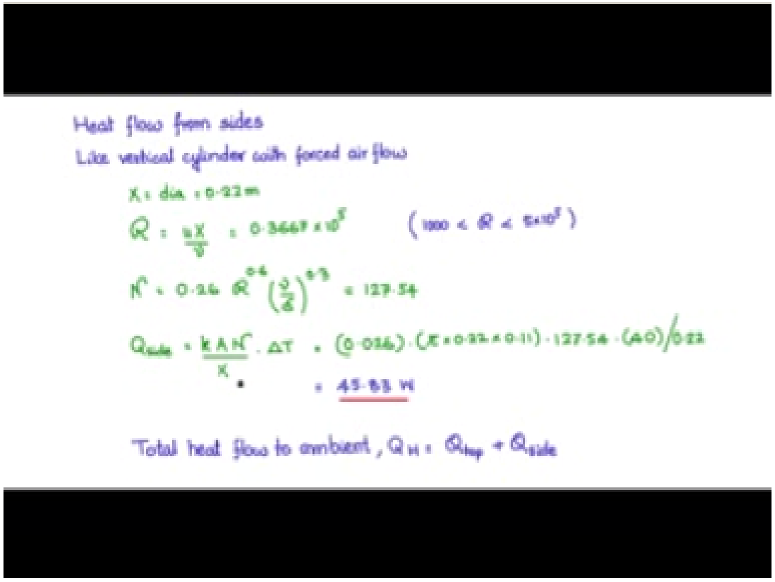

For the same problem for the refrigeration problem where we want to cool inside of this chamber let us keep all things same. Let us say we still want to maintain this aluminum heat sink block as 70^0 centigrade and the external amputate is 30^0 centigrade and we still supply it electric power to the Pelletier element, now let us see what happens if we include the fan and make it as a forced cool system. So let us now include a fan which is going to blow air like this and we now have a forced air flow.

So now it is the problem of forced convection now let us say that this fan you can get it from the fan data sheet at a particular it is giving 3m/sec velocity of the air flow over the aluminum block. Now how much amount of heat can you now drop out f this chamber for all things remaining same, so let us say this is the forced convection problem and let us again consider heat flow from the top and heat flow from the side.

Because the heat can flow only from the top and sides of the cylindrical block all other regions and the spaces are enclosed with the thermo coal. So the top is a like a flat plate, flat circular plate, so we have studied and discussed flat circular plate we call that in the force convection flat circular plate the characteristics dimension is the length of that the plate which is flat circular plate a diameter d. and for the turbulent flow we have the nusselt relationships with the number.

So let us calculate the Reynolds number, so for the flat circular plate the Reynolds number is given by u X/ v u is the velocity of the air flow excess the characteristics dimension, u is given from the fan data sheet 3m/sec, $1.8^{-5m/sec}$ and the characteristics dimension is the diameter which is 0.22m. Now knowing all this substituting we can find that Reynolds number is given by 0.3667×10^5, now this value is $< 5 \times 10^5$.

Recall that for the laminar flow Reynolds number $< 10^5$, we will use this relationship 0.664 x 0.5 raised to 0.33. so nusselt number is given by this, so this is the diffusivity and we will raise it to the 0.33 and calculating you will get nusselt number 112.62. Now we can calculate Q, let me move this up a bit so that you can see Q top is given by the heat flow equation of which is thermal conductivity A nusselt number x ΔT.

We know all these value we can substitute, let me move of the page and then let me write thermal conductivity for A 0.026 we have seen that area of the top plate π4 in the nusselt number 12.62 x .Δt 40 degree Kelvin/x0.22 so this turns out to be 20.24 watts so 20.24 watts amount of heat flow is going from the top surface now let us calculate for the sides what is the heat flow from the sides of the aluminum cylindrical aluminum block.

Calculating the heat flow from the sides now the sides are is like a vertical cylinder with a forced air flow and we have seen the relationship for a vertical cylinder with forced air flow recall this is the vertical cylinder which is having a diameter D the characteristic dimension is D diameter and you have placed a fan here and the lamina of low it is this relationship for turbulent flow where number bring 1005.10^5 we have this relationship.

So we will find out number depending upon where it falls we will use that particular number relationship so x is the diameter 0.22 meter number is ux/μ which is $0.3667.10^5$ and this value is between 1000 and 5.10^5 so this can be considered as turbulent flow and we will use the number corresponding to that .26 number to the power of 0.66μ/Δ and viscosity by diffusivity raised to the power of 0.3 now if you substitute you will get 127.54 now Q side the heat flow from the sides can be found out from KA number by x.Δt substituting you have the thermal conductivity the area of the sides π.d.h number 127.54.Δt 40 degree Kelvin/x which is 0.12 and this comes out to be 45.83 watts.

So what is the total heat flow from the aluminum block to the ampler wave called that as QH which is Q top plus Q sides which is 20.24+45.83,66.07 watts approximately 66 watts or actually going out from the aluminum block into the ambient and this is the amount of heat is coming from a combination of heat QC from the chamber and E from the pettier electrical side so let us look at the coefficient of performance now which is QC/E which is also equal to QH/E-1 which we talked just earlier QH is 66/e10 watts let us say is being complaint to the electrical port of the Pelletier element you have 5.6 now you see that it is vastly improved from the 1.44 of the earlier case reconviction case.

So forced conversion improves the coefficient of performances now you see the amount of QC that is the amount of heat that is removed from the chamber is COP.E which is 56 watts remember that we had just removed around 14.4 watts in the case for the free convection and by putting force convection or else being same you are able to remove 56 watts out of the amount of heat to from the chamber and the refrigeration will definitely be much improved much better so it becomes important that removal of heat from the hot side of Pelletier junction is very important and you have to give some sufficient attention to that if you want to make an effective penal tier cooling system.