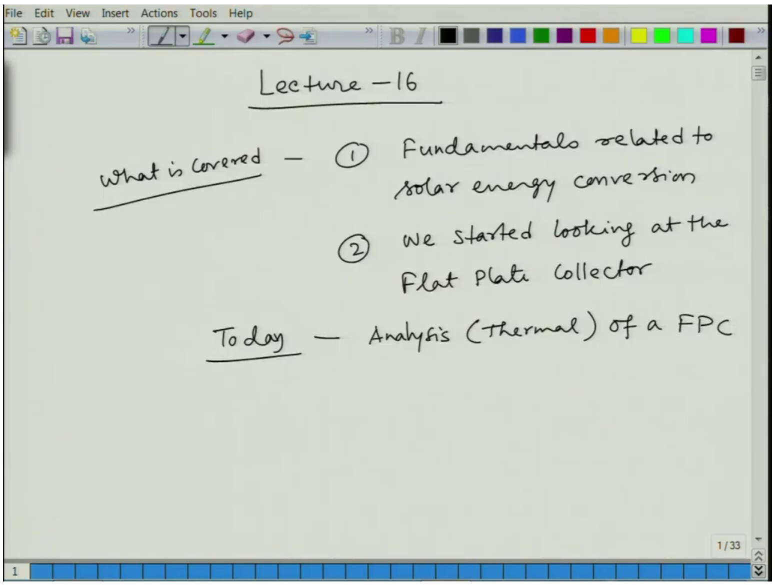
Elements of Solar Energy Conversion
Prof. Jishnu Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture - 16

Hello and welcome back to the series of lecture on Elements of Solar Energy Conversion. We have gone through 15 lectures prior to this one and we have covered all the background that you require and you do not have from the other courses like thermodynamics, heat transfer and other courses of physics, so that we have developed in those lectures.

And in the last class, we have started to look at the most fundamental solar conversion device, which is a flat plate collector. So, we have introduced few basic concepts related to flat plate collectors and we started looking at the analysis part just at the end of the last class.

(Refer Slide Time: 01:11)



Lecture – 16

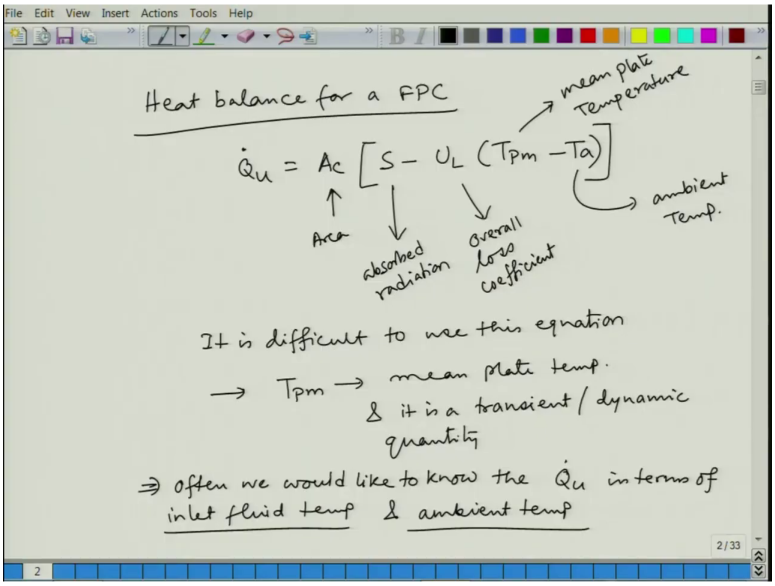
What is covered – ① Fundamentals related to solar energy conversion

② We started looking at the Flat Plate Collector

Today – Analysis (Thermal) of a FPC

So, today here we are at lecture number 16. So, what is covered so far, that is the fundamentals related to solar energy conversion, ok. And we started looking at the flat plate collector, which is the basic solar energy conversion device. So, today what we are going to do is, the analysis, I should say thermal analysis of a flat plate collector, ok.

(Refer Slide Time: 02:37)



Heat balance for a FPC

$$\dot{Q}_u = A_c \left[S - U_L \left(T_{pm} - T_a \right) \right]$$

mean plate Temperature

Area

absorbed radiation

overall loss coefficient

ambient Temp.

It is difficult to use this equation

→ Tpm → mean plate temp.
& it is a transient / dynamic quantity

⇒ often we would like to know the $\dot{Q}_u$ in terms of inlet fluid temp & ambient temp

So, we ended up with this equation which does the heat balance for a flat plate collector. So, we wrote this equation S minus U L T pm minus Ta. So, you are familiar with the terms or the symbols that, we are using in this equation Q u dot is the rate of useful heat gain from the flat plate collector; A c is the area of the concentrator or the collector, area of the collector ok, S is the absorbed radiation, ok.

So, its not what is falling on the flat plate collector; but it is what is getting absorbed and how we calculate that, we have also seen before this, ok. And U L is the overall loss coefficient, ok. This is equivalent to h, which is the heat transfer coefficient; but U is used when we have a overall effect, not just the convection effect, ok. And this T p m is the mean plate temperature ok and T a is the ambient temperature.

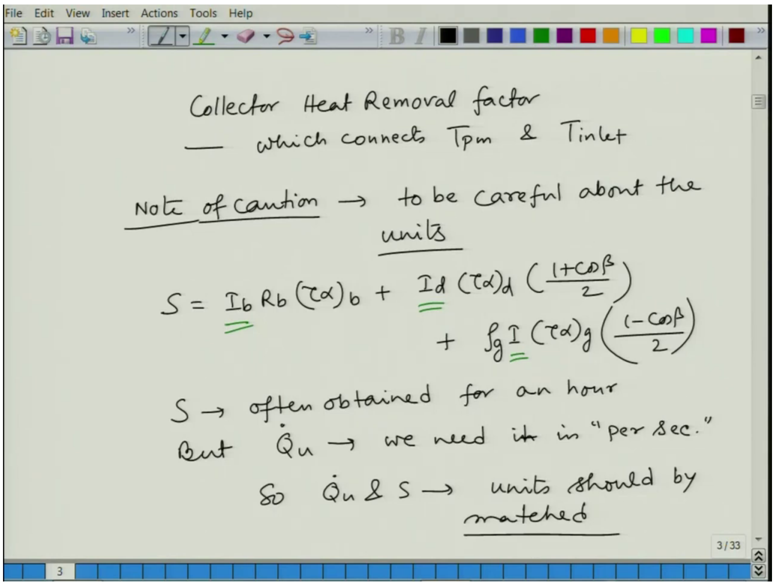
So, this we have seen earlier and we also started to discuss that, even though this equation looks very compact, simple and useful ok; particularly you have U as a subscript which actually is the term useful, ok. So, but the equation itself is not that much useful ok. Why is that?

It is difficult to use this equation. Why? First of all this T pm ok, this is the difficult part, which is a mean plate temperature and it is a transient or dynamic quantity; it depends on all other parameters, so you cannot have directly a T pm without going through a very interrelated problem in terms of different heat transfer phenomena, ok.

So, that is the major problem. And often we would like to know the useful heat gain this Q u dot term in terms of the inlet fluid temperature; because for this, you do not need to analyze anything, you know it a priori like what would be the inlet temperature of the fluid that you are trying to heat up, ok. And what you already know is the ambient temperature.

So, you need something which will relate this inlet fluid temperature to that of the mean plate temperature ok; mean plate temperature is very, like it looks very simple, but it is not very useful, it is more useful to use inlet fluid temperature, ok.

(Refer Slide Time: 07:11)



Collector Heat Removal factor
— which connects Tpm & Tinlet

Note of caution → to be careful about the units

$$S = \underline{\underline{I_b}} R_b (\tau\alpha)_b + \underline{\underline{I_d}} (\tau\alpha)_d \left(\frac{1+\cos\beta}{2}\right) + \rho_g \underline{\underline{I}} (\tau\alpha)_g \left(\frac{1-\cos\beta}{2}\right)$$

$S \rightarrow$ often obtained for an hour

But $\dot{Q}_u \rightarrow$ we need it in "per sec."

So $\dot{Q}_u$ & $S \rightarrow$ units should by matched

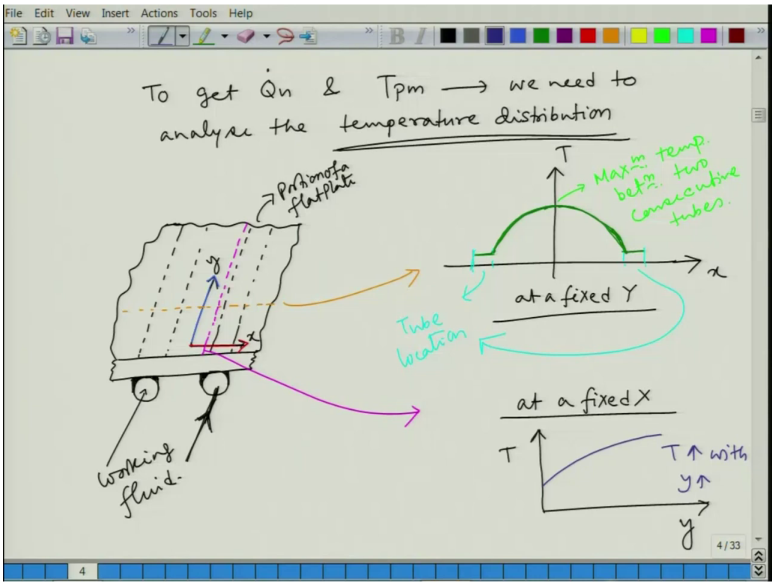
And to get that what we require is called a collector heat removal factor which connects the T pm and T inlet let us say, ok. These two quantities have to be connected to get something meaningful or some or some formulation, which will be useful in terms of the analysis, ok.

Now, one before we proceed with finding this collector heat removal factor; I should put a note here, note of caution rather to be careful about the units, ok. So, what do we mean? So, we know that this I b is written like this, we have seen this earlier, right. But the note of caution here is that, this S is often obtained in terms or obtained for an hour ok; because you can see that these quantities these are often estimated in hourly basis, ok.

So, if you plug those quantities, S will be also obtained in an hour, ok. So, but this quantity Q u we need it in per unit second or per second value, ok. So, the useful heat is not we consider per hour; we consider it per second or maximum we can use per minute. So, this Q u and S, the units should be matched; this is the very common point of mistake that I notice from the students when they approach problem on this particular formula.

So, that is why I put this note of caution that, please make sure that the units are matching, ok. Now, let us try to analyze this equation.

(Refer Slide Time: 10:38)



To get $\dot{Q}_u$ & T_{pm} $\longrightarrow$ we need to analyse the <u>temperature distribution</u>

And to get Q u and T pm; because to get Q u, you need to have some T pm, we need to analyze the temperature distribution, right. So, what do we mean by temperature distribution? Temperature distribution is how at different points on the plate the temperature is varying, right. So, that is called temperature distribution. And to get the mean value for the plate temperature; you have to have some idea about the temperature variation, then only you can know the T pm, ok.

So, now let us take a very crude schematic of a flat, a portion of a flat plate. So, let us say this is the flat plate, ok. And we are not drawing it completely. So, basically we are looking a portion of it ok, portion of a flat plate or absorber plate I would say, ok. And on this plate what you have is, below this you have these working fluid carrying tubes, which are bonded at the bottom of the absorber plate, ok.

And fluid is, so they these will be under the bottom of the plate, right. So, these are fluid carrying tubes. So, fluid is going in this direction, so working fluid. Now, let us say that we fix our coordinate system here at the midpoint of, midpoint between two tubes and one of the axis is parallel to the tubes and the other one.

So, this one is parallel to the tubes y axis, and the other one x axis is perpendicular to the tube, so that whole plane is covered, ok. So, if this is the case, then intuitively before you actually perform any calculation or put some numbers; what you can do, intuitively you can think of what should be the temperature distribution, right.

So, let us say at a fixed Y ok; fixed Y means what? Let us take this is the value of Y and you are going along this line ok and this is the fixed a Y case. So, how the temperature distribution will look like, ok? So, for fixed Y what is varying is, temperature in the dependent axis and x in the independent axis, ok.

So, how the temperature distribution will look like? You can say that at the on the top of the tubes, the temperature will be minimum; because from that side, the temperature or the heat is getting carried away by the working fluid. So, it will be symmetric, because we have chosen the coordinate system in such a way that the origin is at the midpoint between two tubes, ok. So, now, these two will be the; let me draw it, again these two will be symmetric, ok.

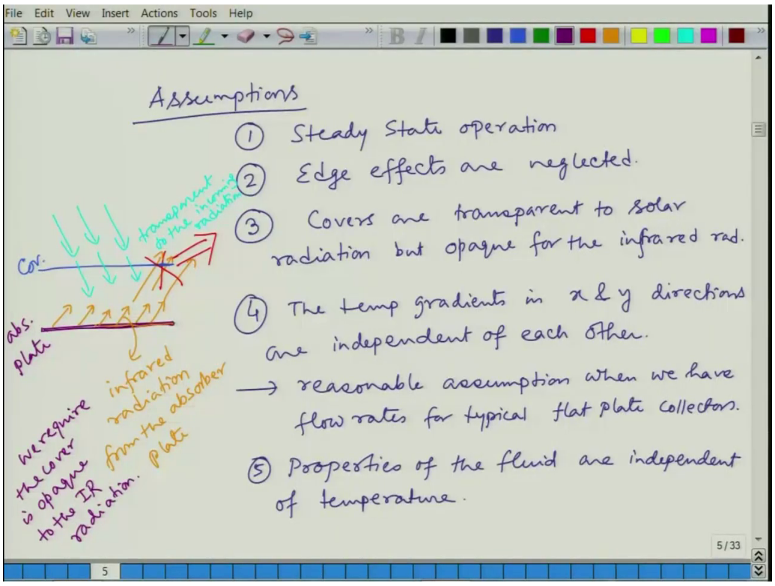
So, what we are getting, these are the tube locations. So, these are the tube locations and this one as well, ok. And here we are getting the maximum temperature, temperature between two consecutive tubes, ok. And you can see that if the temperature profile is like this; then only whatever heat accumulates, accumulates in between, it will go down stream or down the slope and reach the tubes, so that the heat can be carried through the working fluid ok.

So, that is what intuitively; we do not know what would be the value of the maximum temperature and all, but we do know that the shape of the curve will look like this. Now, let us look at another section, where we are looking at a fixed X, ok. So, let us say this is the X and along this line we are looking at, so at a fixed X value.

So, how the temperature will look like here again? So, as the fluid is getting in through this direction; so the fluid temperature will be lower for a lower X value or sorry lower y value, right. So, as y increases, the fluid temperature will increase as well. So, when the fluid temperature increase, the rate of heat transfer will decrease; because the gradient in temperature will be lower as Y goes up.

So, what we will get? If this is the temperature, this is y. So, we will get a gradually increasing temperature profile with rising a y, ok. So, temperature increases with y increases, ok. So, that is how the intuitively we can say that in x and y direction, the temperature profiles will look like this, right.

(Refer Slide Time: 18:33)



Assumptions

① Steady State operation

② Edge effects are neglected.

③ Covers are transparent to solar radiation but opaque for the infrared rad.

④ The temp gradients in x & y directions are independent of each other.

→ reasonable assumption when we have flow rates for typical flat plate collectors.

⑤ Properties of the fluid are independent of temperature.

Now, if we agree to that kind of temperature profile; let us make certain assumptions. First of all let us take it is a steady state operation, we will see the unsteady effects later; but to make the framework work, we will use some assumption, which the most fundamental one we will use the steady state assumption.

The second one is edge effects are neglected; as if the plate is large enough, so that the effect of the edges will be small compared to the rest of the plate. That is also a reasonable assumption for a flat plate collector. And then another assumption we will make here is that, the covers are transparent to solar radiation; but opaque for the infrared radiation, ok. So, what it means? I will come in detail in a minute, ok.

Now, 4th assumption that we make is that, the temperature gradients that we have seen in the earlier page, where we have looked at the x and y direction temperature distribution; here we will make a very crucial assumption that, these temperature gradients in x and y directions are independent of each other.

So, what does it mean? It means that, the x direction temperature variation you can analyze separately and same for the y direction; that is the major assumption, which will make our heat transfer problem a combination of two 1 dimensional problems rather than a 2 dimensional problems.

When you went through the heat transfer course, you must have learnt that 1 dimensional problems are much easier to handle compared to 2 dimensional, and 3 dimensional ones are mostly analytically intractable; you have to use numerical tools to find 3 dimensional. So, we always prefer to have 1 dimensional problems if we can. And this is a reasonable assumption when we have flow rates for typical flat plate collectors.

So, for ultra high speed flow or ultra low speed flow, both those limits are; we cannot take this assumption ok of this independent x and y direction temperature profile. So, for reasonable flow rate, this particular assumption is acceptable, ok. And another assumption that we make, which we make more often than not that, properties of the fluid, here the heat transfer fluid are independent of temperature, ok.

So, for analytical treatment, it is difficult to do the property variation with temperature; because temperature itself is evolving right and that is what you are trying to analyze. So, we assume that, its not varying with temperature. Now, as I promised, I will cover or I will come back to this particular assumption, which says the covers are transparent to solar radiation; but opaque for infrared radiation.

So, let me discuss this a little bit, ok. So, here we have the absorber plate ok and here we have the cover, let us say just one cover we have, ok. So, whatever radiation is falling; so if the cover itself. So, this is the cover and this is the plate, absorber plate, ok. So, now, whatever radiation is coming through or coming on the cover, they have to go through it, right.

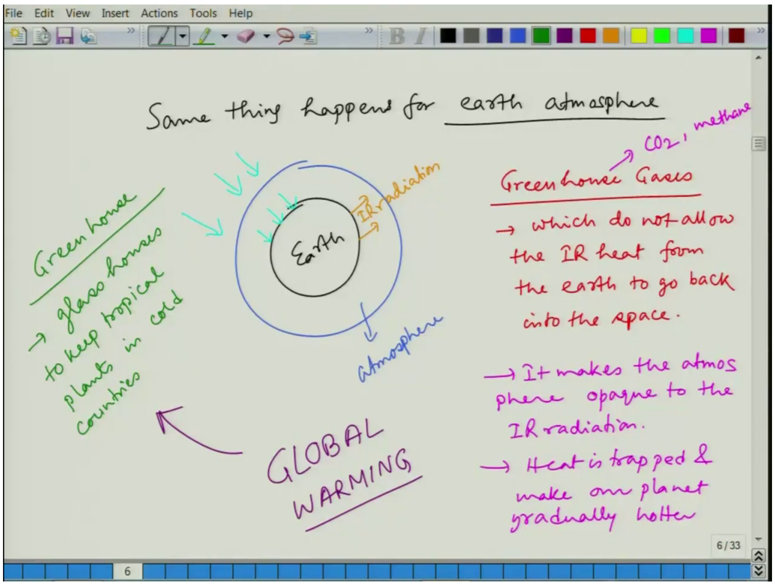
So, here you need transparency; it has to be transparent to the incoming radiation, the solar radiation, otherwise the whole purpose will be defeated, right. But now, once this radiation heats the absorber plate. So, absorber plate will be heated and ultimately it will radiate its own infrared radiation right, so infrared radiation from the absorber plate.

Now, you imagine that the cover, this cover if it is transparent to this infrared region radiation; then what will happen? They will go back to the ambient, right. So, we are losing heat right, which we do not want. What we want? We want that, this particular thing is not allowed; the infrared radiation cannot go back in to the ambient through the cover.

So, that is why we require that the cover is opaque; that means it does not allow the radiation to pass through itself, opaque to the infrared which is designated as IR radiation, ok. And for that what we require?

We require that the cover is made of such material, which will allow most of the solar radiation spectrum that you have seen to go through; but when after getting absorbed on the absorber plate, when it is getting out as infrared, that part should be like blocked or it should not go out of the cover system, ok.

(Refer Slide Time: 27:13)



Same thing happens for earth atmosphere

Greenhouse
→ glass houses to keep tropical plants in cold countries

Greenhouse Gases
→ which do not allow the IR heat from the earth to go back into the space.
→ It makes the atmosphere opaque to the IR radiation.
→ Heat is trapped & make our planet gradually hotter

And the same thing happens; so here this is a side note you can think of, same thing happens for earth, earth atmosphere we can say. What do we mean by that? So, if we have this earth and if we have an atmosphere around it, then the radiation that is coming from the sun; the atmosphere is mostly transparent, not completely transparent is absorbed, it scatters back to the space, but mostly transparent and that is how this radiation reaches the earth surface, ok.

Now, I should write it earth here and this is atmosphere. And when in the earth absorbs that radiation and then emits the infrared radiation, the IR radiation; then we have these different gases which does not allow that infrared radiation to go back into the space. So, and those are called greenhouse gases ok, which are the major culprit which does not or do not allow the IR heat from the earth to go back into the space.

Usually for a clear sky and less polluted atmosphere; you have this infrared radiation, they can go back. But if you have lot of in greenhouse gases, mainly these greenhouse gases are major ones are carbon dioxide and methane, ok. There are plenty more, but these are the major constituents for the atmospheric greenhouse gases.

And what does it do? It does not. So, it makes the atmosphere opaque to the IR radiation and heat is; so that makes heat is trapped and make our planet gradually hotter, ok. That is why we see that we talk about this global warming, which is nothing but due to the greenhouse effect, enough heat is not being able to go back to the space from the earth.

And therefore, overall the temperature of the atmosphere is rising and that has terrible consequences that you can learn somewhere else, I am not going to discuss it here. But it is important to note that, the same effect happens in the atmosphere and that is what cause this global warming, ok.

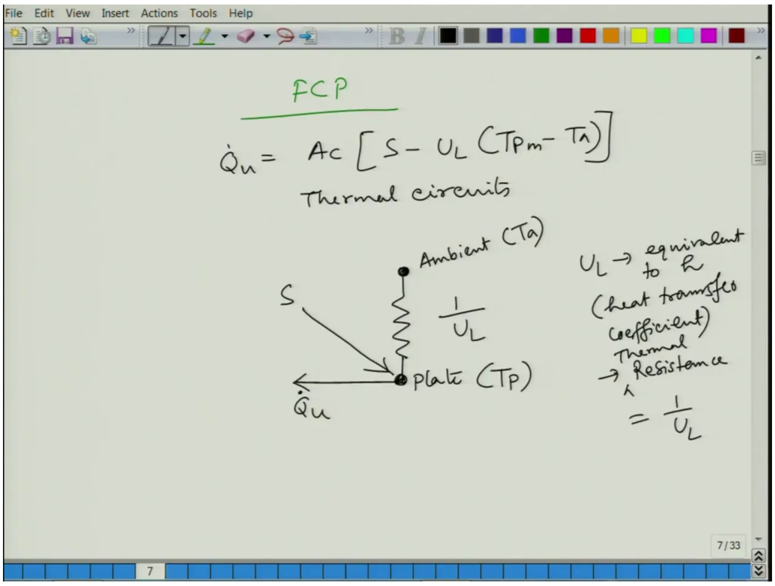
It is not like we are burning too much fuel and lot of heat we are generating and that is how the atmosphere is getting heated; its rather somehow indirectly the fuel that we are burning is actually going to increase the concentration of greenhouse gases in the atmosphere and that is why the overall temperature of the atmosphere is getting hotter, ok.

And this is important in terms to discuss it here, because we are in a solar energy conversion course. And why do we care about solar energy conversion, when we have lot of petrol and diesel and other things, coal available in our mines? Because that if we use all those available resources to run the human civilization, then we are going, we are looking at the doomsday ok; because and that is why the solar energy conversion is relevant to the humankind at this juncture of civilization, ok.

So, its a side talk; but please keep your perspective or overall outlook focused that why we are doing, what we are doing, ok. Now, coming back to the, ok one more point I missed is the why it is called greenhouse gases; because if you are aware of this greenhouse, greenhouse are the like they are made of these glass houses to keep tropical plants in cold countries.

In the winter, these tropical plants cannot survive the severe chilling condition in the cold countries that is why we keep them in a glass house. And what does the glass house does do? It takes the sunlight in; but does not allow the heat to go out of the glass house and that is why we get a greenhouse, which the same effect is obtained for solar atmosphere and we also want it to, which is desirable in case of a flat plate collector.

(Refer Slide Time: 33:44)



FCP

$$\dot{Q}_u = A_c \left[S - U_L (T_{pm} - T_A) \right]$$

Thermal circuits

U_L → equivalent to h (heat transfer coefficient)

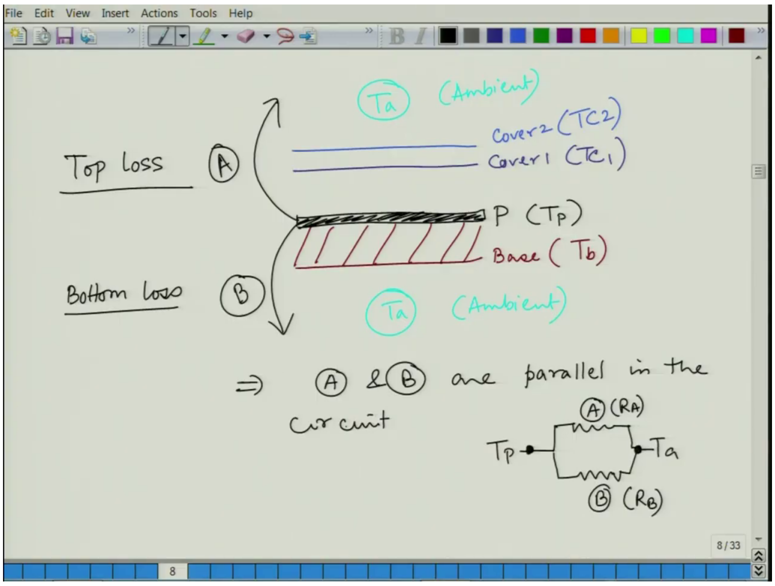
→ Thermal Resistance $= \frac{1}{U_L}$

So, let us come back to the flat plate collector, ok. So, now, the original equation that we started with was this. So, this thing we can pictorially draw this by using some thermal circuit. So, we will draw thermal circuits, which you are familiar with from your heat transfer course, ok. So, if we have plate as one node ok with temperature T p and one thing that is coming in here is S, that is the absorbed radiation.

And what else is happening? You are taking out Q u, which is the useful heat and it is losing some heat to the ambient, which is at constant temperature T a. And what is happening here that, loss of heat you can designate it with a thermal resistance, ok. So, that thermal resistance is nothing, but 1 over U L, ok.

So, U L you can think of this is equivalent to h or the heat transfer coefficient, ok. And so, the resistance or I should say thermal resistance is reciprocal of that 1 over U L, ok. So, this is a very preliminary thermal circuit you can draw, where S is the input, Q u is your output, and the undesirable loss is happening to the ambient through a resistance 1 over U L, ok.

(Refer Slide Time: 36:14)



$\Rightarrow$ Ⓐ & Ⓑ are parallel in the circuit

Now, if we elaborate this, we can think of it like this is the plate, physical plate at temperature T p and we can have two layers of. Again edge effect as we have assumed to be negligible;

what we are drawing, everything is per unit area ok and we are even not even drawing the edges ok, we are just drawing a portion of the flat plate collector and a cross section.

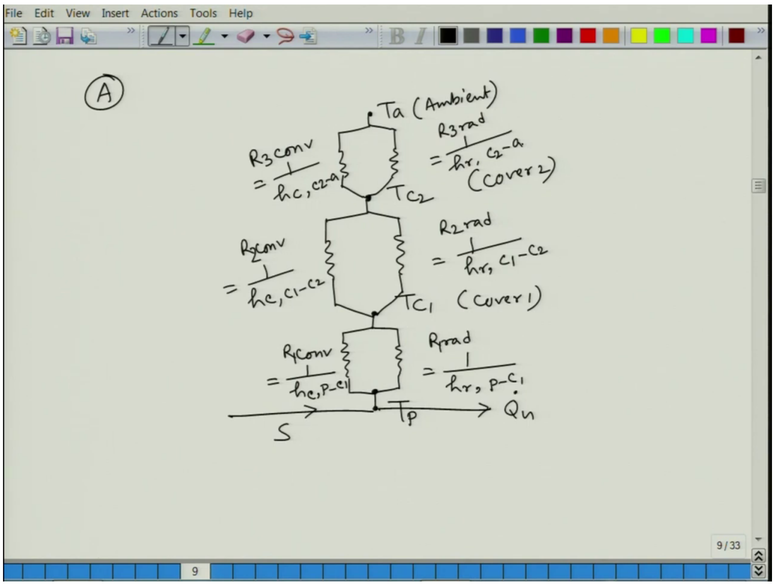
So, this is let us say this is cover 1 at T c 1 ok, the cover 1 temperature is T c 1. And we can have another layer of cover, which is cover 2 and which is maintained at T c 2, ok. At the bottom what we have? We have this insulated layer ok and these temperature. So, this is the base of the flat plate collector and the temperature there we can say this is T b ok or the base temperature.

Now, the heated flat plate ok and at the end of both the sides; so here on the top, we have a temperature node, which is at T a or the ambient temperature, ok. So, this is ambient at T a and at the bottom also the same ambient temperature is there, ok. So, here we have another thermal node, which is maintained at T a the ambient temperature, ok. So, here the plate that we are interested in the temperature has to be high and all, ok. So, this is the plate which we are interested in the temperature.

Now, if you say, what would be the different losses from this plate? You can say that there will be two directions ok; one will be in the top direction which will going, the heat will be lost to the ambient and the another one will be towards the bottom, which is again going to the ambient in one different path. So, if we say that this top path is A and the bottom part is B, ok. So, we can say this is top loss that path we name A, and the bottom loss, both losses are happening at, they are happening to the ambient.

So, here what we can say that, this A and B are parallel right in the thermal circuit. So, basically you have a node here which is at T p and you have a node here which is as T a. There are two alternative pathways; one is top loss which is path A ok with some resistance R A and another one is path B with some resistance R B, ok. They are two alternative paths for the same node; that is why they are parallel, they are connected parallely in the thermal circuit.

(Refer Slide Time: 40:34)

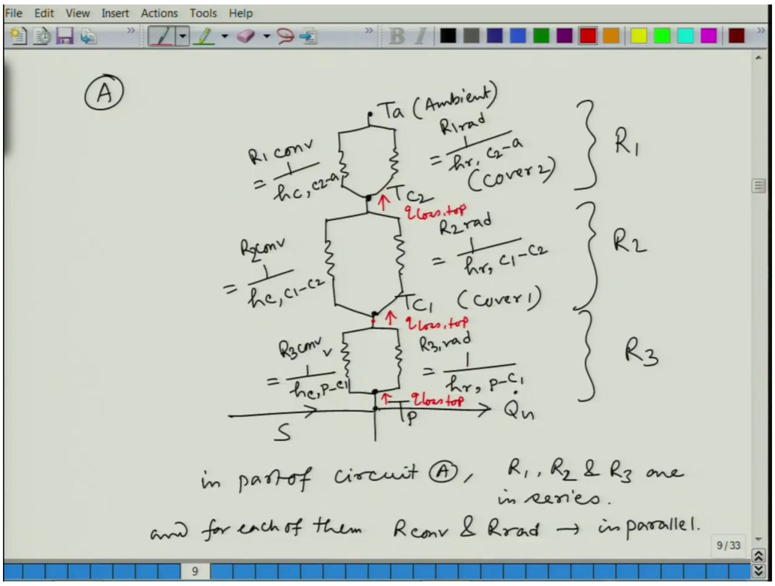


Now, if we look at the constituent resistances in each part; what we can write? Let us first look at A. So, here we have this point T p ok, where S is coming Q u is going this way. And the first resistance it faces is between the first cover T c 1 ok and then the next thermal node will be T c 2 and the third thermal node would be T a, which is ambient, right.

Now, what we can think that, there will be two possible ways; one will be convection resistance and another will be radiation resistance, right. So, we can draw a parallel circuit between these two. So, we can say this is the convection resistance, which is 1 over h c, h c stands for convection and comma p to c 1; that means from plate to cover one. And the other part will be radiation between these two and we can write in terms of h r comma p to c 1, right. And so, this is cover 1 and this is cover 2.

So, similarly here also you will have these two resistances; one will be R convection, that would be h c. So, let me write this R 1, this R 1, R 2 convection h c, c 1 to c 2 right between cover 1 and cover 2; the second one is R 2 radiation that will be h r comma c 1 to c 2, right. And similarly here also we will have two resistances, which will act in parallel and one will be R 3 convection will be h c c 2 to ambient and R 3 radiation will be equal to 1 over h r c 2 to ambient, ok.

(Refer Slide Time: 43:37)

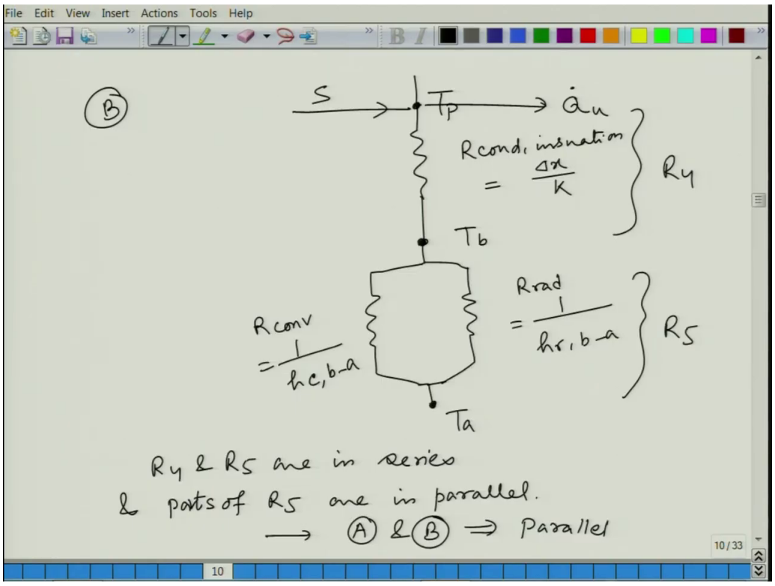


in part of circuit Ⓐ, R_1, R_2 & R_3 are in series.
and for each of them R_{conv} & R_{rad} → in parallel.

And if we can, how do we are naming it? Let us name it in this way, this R 1, this is R 1 ok and this one is R 3, R 3 convection and this is R 3 radiation, ok. So, what we can say that, together this convection and conduction resistances will give you R 1, then R 2 and then R 3. So, what we can say that, in connection or in part of circuit A; this R 1, R 2 and R 3 are in series, right.

And for each of them; this R convection and R radiation, they are in parallel right, this should be pretty straight forward and clear for the heat transfer analysis, ok.

(Refer Slide Time: 45:09)



R_4 & R_5 are in series

& parts of R_5 are in parallel.

$\longrightarrow$ Ⓐ & Ⓑ $\Rightarrow$ Parallel

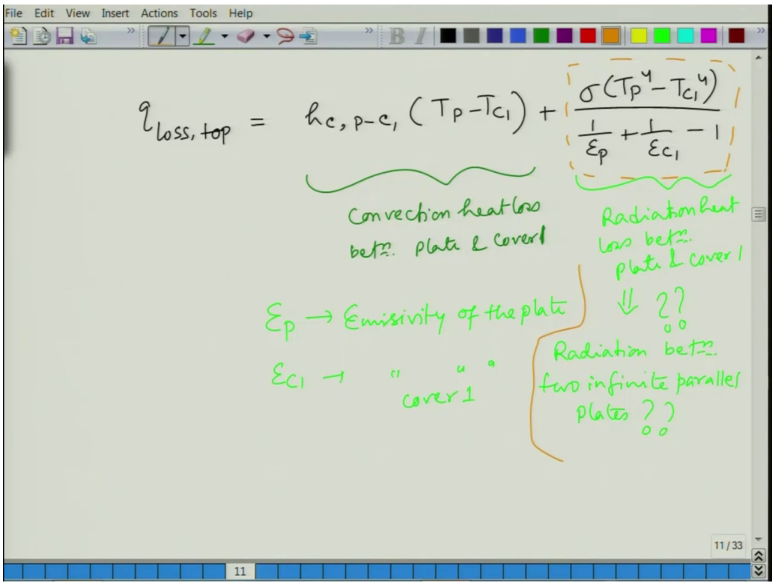
And similarly for part B which is the bottom part, we can write that T p will be same again, S is coming and Q u is going, ok. So, top part we are not showing here and here also the bottom part we are not showing here; but those are there. So, in the bottom part what we will have?

First we have a node next node is T b and in between we have a thick layer of insulation, so it will be only conduction resistance, right. So, we can draw a single resistance here, which will be R conduction due to insulation right, R conduction through insulation layer and the value of that will be delta x divided by K; delta x is the thickness of the layer of insulation and K is the conductivity, right.

And from the bottom layer or the base layer, again we have two resistances; one will be convection, and the other one will be radiation and they will be in parallel, right. So, here we can write R convection will be 1 over h c convection from bottom to ambient and here R radiation that will be 1 over h r, bottom to ambient right and this node is your ambient temperature node, ok.

So, this whole thing again what we can say that, if you say this is R 5 and this is R 4; then R 4 and R 5 are in series right and parts of R 5 are in parallel, right. So, you agree to this point. And finally, this A and B which is the top and bottom, they are in parallel connection, right. So, this is the overall heat loss thermal circuit that we are given here.

(Refer Slide Time: 48:06)



$$q_{loss,top} = \underbrace{h_{c,p-c_1}(T_p - T_{c_1})}_{\text{Convection heat loss betn. plate \& cover1}} + \underbrace{\boxed{\frac{\sigma(T_p^4 - T_{c_1}^4)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_{c_1}} - 1}}}_{\text{Radiation heat loss betn. plate \& cover 1}}$$

$\Downarrow$??

Radiation betn. two infinite paralles plates ??

$\varepsilon_p \rightarrow$ Emisivity of the plate

$\varepsilon_{c_1} \rightarrow$ " " " cover 1

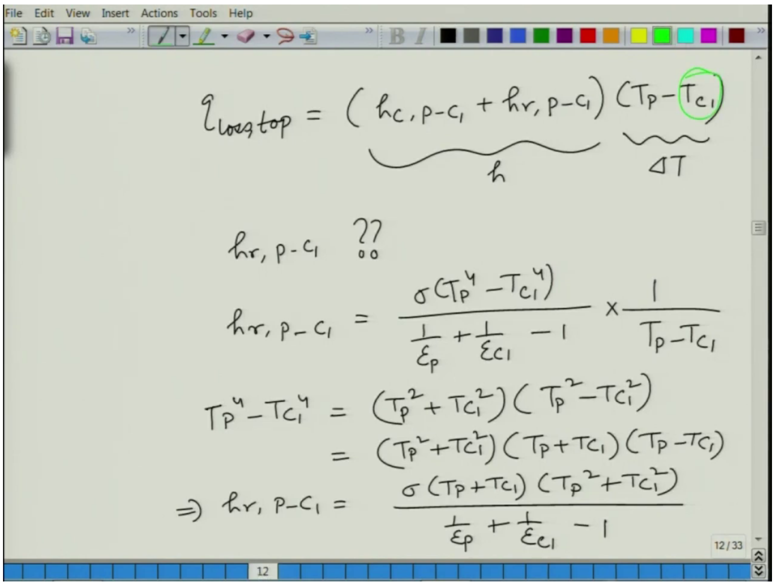
Now, if we wish to look at the individual resistances; then what we can write this q loss, top; that is the rate of heat loss through the top, that we can write to be this h c, p c 1 T p minus T c 1, this is the conduction heat loss to the cover 1 and then the radiation part. Radiation part is what? T p to the power 4 T c 1 to the power 4 multiplied by Stefan Boltzmann's constant and then 1 over epsilon p plus 1 over epsilon c 1 minus 1, ok.

So, what we are showing here? Let me show you here first. So, we can we are showing that the same heat transfer rate; let me draw it here that, the same heat transfer rate or the same heat is carrying through each parts of the node, everywhere this is q loss, top and this is q loss, top right; it is like the current and that does not change in a series circuit, ok. So, going back here.

What we have? This is the convection heat loss between plate and cover 1, ok. And this one is the radiation heat loss again between plate and cover 1. Now, is this formula familiar to you? Do you remember this? If you do not remember, please go back to your radiation heat transfer book and see what is the radiation between two infinite parallel plates.

Please look that up; you will find the exact same formula here, your epsilon p is the emissivity of the plate and epsilon c 1 is the emissivity of the cover 1, ok. So, and that q loss, top gives you the current through the top branch of the thermal circuit, ok.

(Refer Slide Time: 51:31)



$$q_{loss\,top} = \underbrace{(h_{c,p-c_1} + h_{r,p-c_1})}_{h}\underbrace{(T_p - \boxed{T_{c_1}})}_{\Delta T}$$

$$h_{r,p-c_1} \quad ??$$

$$h_{r,p-c_1} = \frac{\sigma(T_p^4 - T_{c_1}^4)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_{c_1}} - 1} \times \frac{1}{T_p - T_{c_1}}$$

$$T_p^4 - T_{c_1}^4 = (T_p^2 + T_{c_1}^2)(T_p^2 - T_{c_1}^2)$$

$$= (T_p^2 + T_{c_1}^2)(T_p + T_{c_1})(T_p - T_{c_1})$$

$$\Rightarrow h_{r,p-c_1} = \frac{\sigma(T_p + T_{c_1})(T_p^2 + T_{c_1}^2)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_{c_1}} - 1}$$

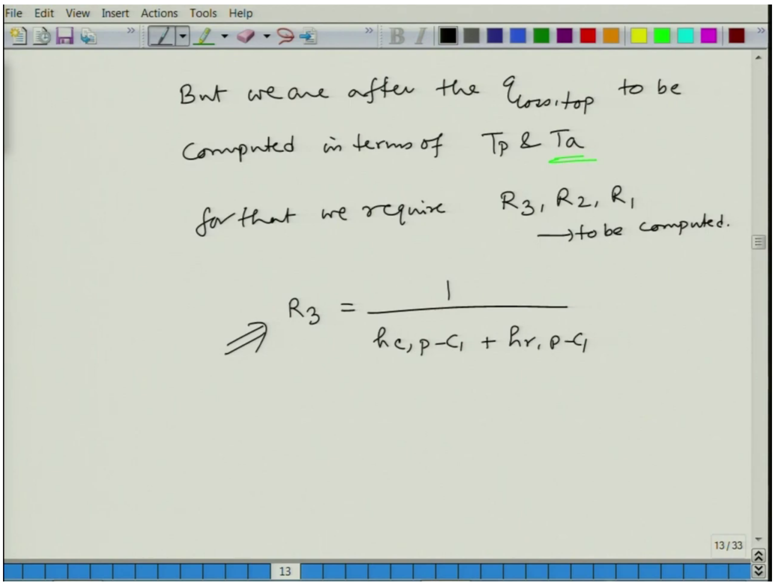
Now, one more thing we can write, this q loss, top ok, you can simplify it with two resistances, one is or two heat transfer coefficient; one is convection heat transfer coefficient, and the other one is the radiation heat transfer coefficient and then the temperature gradient between these two. So, this is basically delta T and this is your h ok. Now, how to get this hr, p c 1?

So, this is basically we are trying to make this term look like the first term, right. So, for that what we need to do? We need to do that, the total heat transfer you divide it by the delta T, ok. So, total heat transfer was T p to the power 4 minus T c 1 to the power 4 divided by 1 over epsilon p 1 over epsilons c 1 minus 1, right. And you divide it by T p minus T c 1, right.

Now, if you do that what you will find that, this T p to the power 4 minus T c 1 to the power 4, that you can write T p squared plus T c 1 squared multiplied by T p squared minus T c 1 squared. So, this part stays same and this part you can write as T p plus T c 1 into T p minus T c 1, ok. So, that is how you can write.

So, now h r, p c 1 you can input this value and you can write that T p plus T c 1 multiplied by T p squared plus T c 1 square divided by 1 over epsilon p plus 1 over epsilon c 1 minus 1, right. So, this is the straight forward conversion of radiative heat transfer coefficient to the same form as the convection heat transfer coefficient, ok.

(Refer Slide Time: 54:26)



But we are after the $q_{loss,top}$ to be

Computed in terms of T_p & T_a

for that we require R_3, R_2, R_1

$\longrightarrow$ to be computed.

$$\Rightarrow R_3 = \frac{1}{h_{c,p-c_1} + h_{r,p-c_1}}$$

But we are after the q loss, top to be computed in terms of T p and T a right; the ambient temperature and the plate temperature these two we are interested in. Now, in the earlier expression what we see here is that, we have dependence of this T c 1 that is difficult, right. So, what we need to make that, we have to make that dependence on ambient temperature only.

So, for that we require this R 3, R 2 and R 1 all of them to be computed, to be computed; otherwise if you knew the cover temperature, then you did not need to know any other thing to get the q loss, top, ok. But here the dependence we have to find will be on the ambient temperature, that is why we need all the temperatures to be covered. First R 3 that we have gotten so far; what we can write, this p c 1 plus h r, p c 1, right. So, these two will give you us the resistance R 3 and the rest of it we will look at in the next class.

So, far we have covered the thermal circuit for top loss and bottom loss coefficients from the flat plate collector and one part of the resistances we have computed so far, which is between the plate and the first cover, ok. Here we stop today and in the next class, we will see you with the other resistances.

Thank you very much for your attention.