Solar Energy Engineering and Technology
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Lecture No. 20
Solar collector losses and loss estimation

Dear students, today we will be discussing about flat plate collector losses and loss estimation.

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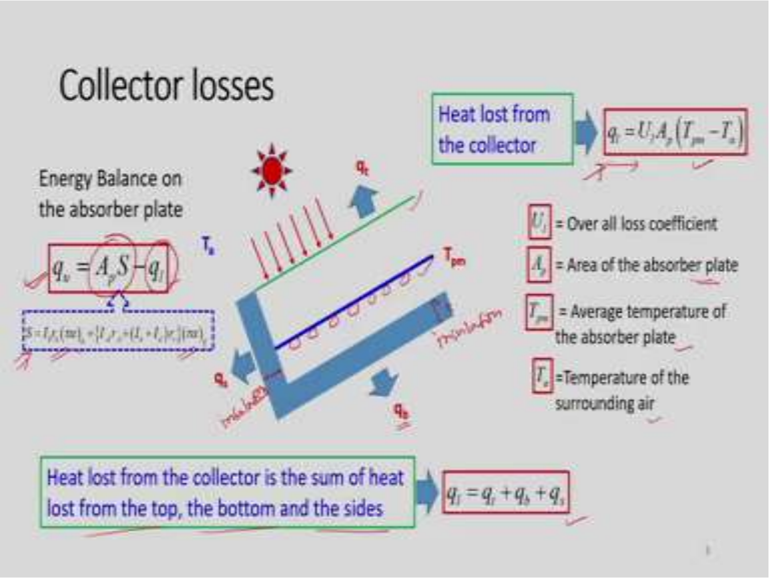

So, what are the different collector losses, like side losses, bottom losses, top losses. So, these losses need to be estimated correctly then only we can investigate the performance of a flat plate collector. As we have understand in the previous classes like energy balance on the absorber plate can be expressed by using this equation. So, $q_u = A_p S - q_l$, what is q_u? This is the useful heat gain, A_p is the collector area or absorber area and S is the flux which is received by the absorber plate, and this S is a function of these many parameters.

So, $S = I_b r_b (\tau\alpha)_b + \{I_d r_d + (I_b + I_d) r_r (\tau\alpha)_d\}$. So, we understood how to calculate these $(\tau\alpha)$ for beam radiation and diffuse radiation, we understand how to calculate this S. So, this part is now known to us, but in order to find out q_u we need to know q_l. So, q_l is nothing but the heat loss from the collector. So, this q_l is a function of all the losses like the kind of losses taking place from the top of the collector, from the side of the collector and from the bottom of the collector.

So, what I have shown here it is a one glass cover and then absorber plate of course tips will be there, through which heat transfer fluid flows, and these are insulation these are insulation, some thickness you have to maintain is an insulation. This is side insulation and this is the bottom insulation in order to reduce the heat losses. So, this q_l that is heat loss from the collector can be estimated by using this expression if we know $q_l = U_l A_p (T_{pm} - T_a)$. What is U_l, is the overall loss coefficient, and A_p is the area of the absorber plate, and T_{pm} is the average temperature of the absorber plate, and T_a is the temperature of the surrounding air or ambient temperature of the air.

So, once you know these values, then straightaway you can calculate what is q_l. So, as we understand this q_l is a function of other 3 losses. So, this $q_l = q_t + q_b + q_s$, this heat loss from the collector is the sum of the heat loss from the top, heat loss from the bottom, then heat loss from the side, so we can add it. And this heat loss or rate of heat loss can be expressed in terms of loss coefficient.

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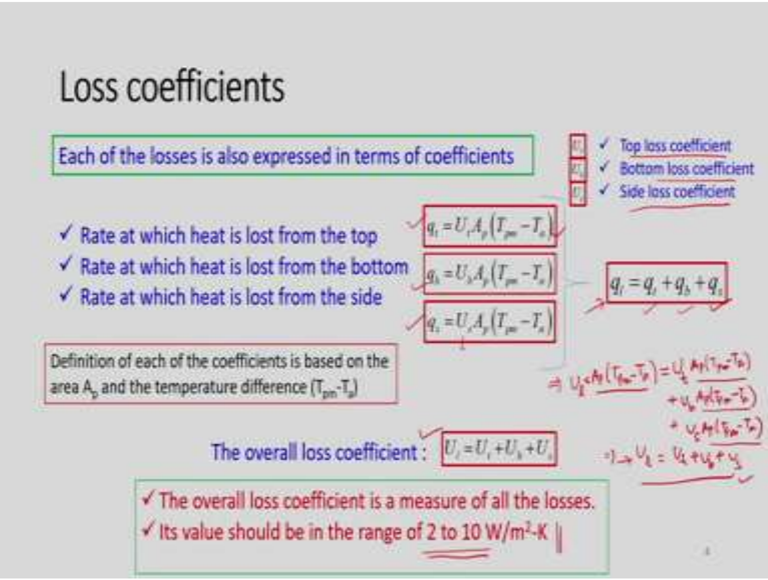

If we express in terms of loss coefficient then our expression will be something like this. So, $q_t = U_t A_p (T_{pm} - T_a)$. So, what is U_t is top loss coefficient. And for calculation of rate at which heat loss from the bottom takes place then we use this expression $q_b = U_b A_p (T_{pm} - T_a)$. So, what is U_b here is the bottom loss coefficient. Similarly, the rate at which heat is lost from the side can be calculated by using this expression where U_s is the side loss coefficient. So, as you understand this q_l is nothing but sum of all the 3 losses this q_t,

q_b and q_s. So, if we substitute this expression for $q_l = U_l A_p (T_{pm} - T_a) = U_t A_p (T_{pm} - T_a) + U_b A_p (T_{pm} - T_a) + U_s A_p (T_{pm} - T_a)$

So, these are common for all the cases, heat losses taking place from the plate to the ambient, so these are common so finally, what we can write $U_l = U_t + U_b + U_s$. Or what we can say if we divide both sides of the expression by $A_p (T_{pm} - T_a)$, so what we will get $U_l = U_t + U_b + U_s$. So, what we have written here this is nothing but the overall loss coefficient. So, this is very, very important parameter to measure all the losses and each value should be in the range of 2 to 10 W/m^2-K.

So, if this value falls in between this range, then our design can be considered. So, otherwise losses will be very, very high so under that conditions we will be losing our efficiencies. So, once you know this value U_l then if we substitute in the energy balance equation, then from there we can calculate what will be that useful heat gain. So, we will demonstrate how this U_l can be calculated by solving a numerical problem. So, let us have a look about U_t or top loss coefficient, how to calculate the stop loss coefficient.

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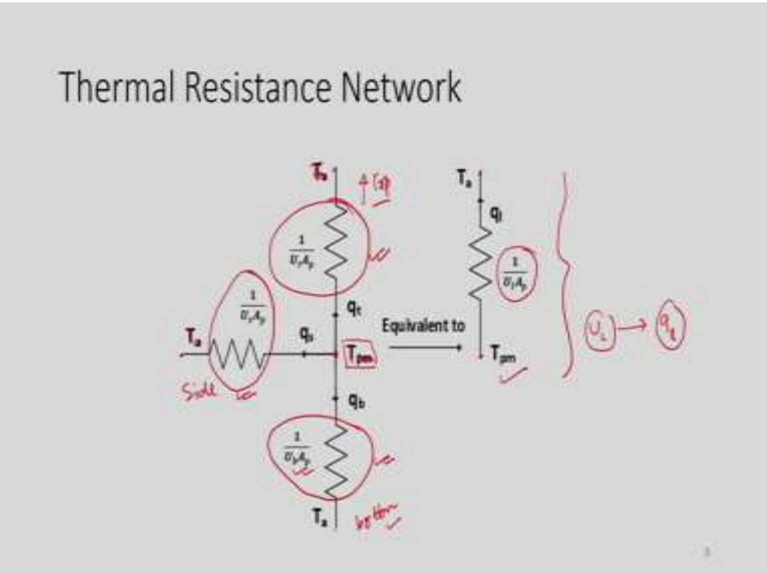

So, before we start the top loss coefficient let us understand this thermal resistance network. So, here what happens if we consider this is the plate, absorber plate at temperature T_{pm} and this is at ambient in all the cases it is ambient, this is towards top, top, this is side and this is bottom. So, heat loss will take place from this plate to the side plate to the top, then this plate to the bottom. So, these are the thermal resistances. So, we can express in terms of thermal resistances. So, this component is the thermal resistance for the when heat is transferring from this plate to the bottom, this kind of resistance is offered and here we can say is the side and this is along the top.

And also what we can do, we can make equivalent resistance diagram. So, if we combine these three components and we can make something like this, and it will be something like this. So, under that condition we can use what will be the U_l, or if we know U_l then we can calculate what is q_l. So, this is the equivalent thermal resistance network. The component what we have discussed in the last slides these are represented in this thermal resistance network diagram.

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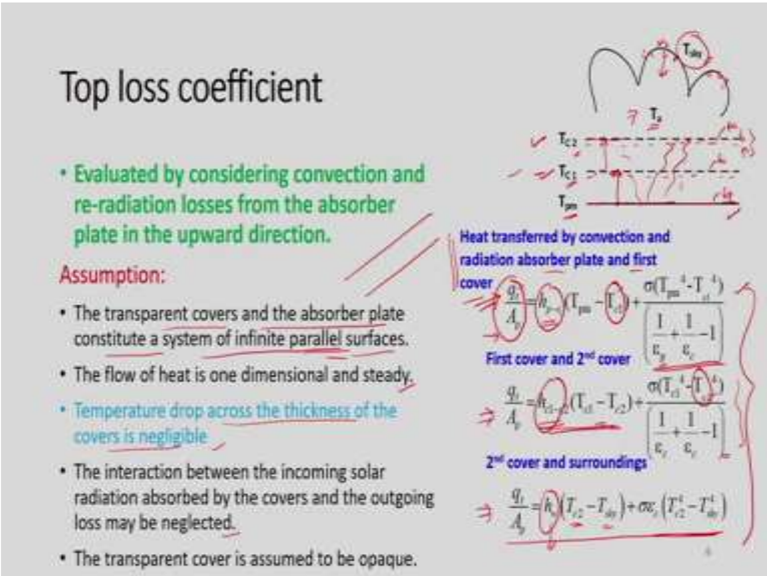

Now, let us say we look how to estimate top loss coefficient. So, this top loss coefficient can be evaluated by considering convection and re-radiation losses from the absorber plate in the upward direction. So, there are some assumptions while evaluating this top loss coefficient, what are the assumptions? First assumption is the transparent covers and the absorber plate constitute a system of infinite parallel surfaces so, it is assumed that it is infinite. And the flow of heat is one dimensional and steady. The temperature drop across the thickness of the covers is negligible.

For example, if we consider this case so here what happens, 2 glass covers are present and 1 absorber plate, and this is the sky temperature. Because of this lot of molecules will be there like carbon dioxide, water vapor, they will also emit some kind of radiation that kind of radiation can also be taken care by using this guy. So if it is thicker, of course there will be it has got some thickness. So, there should not be any heat losses here. So, there will be no drop of temperature in those regions right, here and then here.

So, that is why it is said the temperature drop across the thickness of the cover is negligible, the interaction between the incoming solar radiation absorbed by the covers and the outgoing loss maybe neglected. So, some radiation will fall here, it will go something like this so this kind of things are neglected. So, no losses are taking place it is assumed. The transparent cover is assumed to be opaque. So, no radiation is going out, it is opaque to the long wave radiation so all the waves will be retained inside the collector system.

Now, this heat transfer by convection and radiation absorber plate in the first cover, if we are interested about know from this plate to this plate so, this is heat transfer by convection and radiation from absorber plate to the first glass cover. So, in this case 2 class covers are considered; glass cover 1, glass cover 2, this is the absorber plate. So, in the first case what we will do, the kind of heat transfer taking place from this plate to the glass cover 1, we are interested to develop the equations by which you can calculate the rate of heat transfer.

So, $\frac{q_t}{A_p} = h_{p-c1}(T_{pm} - T_{c1}) + \frac{\sigma(T_{pm}^4 - T_{c1}^4)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_c} - 1}$.

So, since it is infinitely parallel surfaces so we can use this expression for view factor. And if we are interested to calculate the rate of heat transfer from class cover 1 to class cover 2, then we have to use this equation $\frac{q_t}{A_p} = h_{c1-c2}(T_{c1} - T_{c2}) + \frac{\sigma(T_{c1}^4 - T_{c2}^4)}{\frac{1}{\varepsilon_c} + \frac{1}{\varepsilon_c} - 1}$. So, this is h1 to h2 is the heat transfer coefficient and multiplied by $(T_{c1} - T_{c2})$, so, since heat exchange is between these 2 plates and this is the radiative components and this is the convective heat transfer part, this is a radiative heat transfer part.

And if we are interested to develop the equation or heat exchanger between T_{c2} to ambient then we have to use this expression . So, h_w is the heat transfer coefficient when heat is exchanging from this glass cover to the ambient, and this T_{c2} is the temperature of the glass cover, then T_{sky} is the sky temperature. So, please note that this sky temperature is different than this ambient temperature, this sky temperature is from those elements which is absorbed in the atmosphere. And this part is the radiative component part. So, it has got 2 components; one is convective part and then the radiative part. So, we have explained how this can be added and how this rate of heat transfer can be calculated between these parallel plates.

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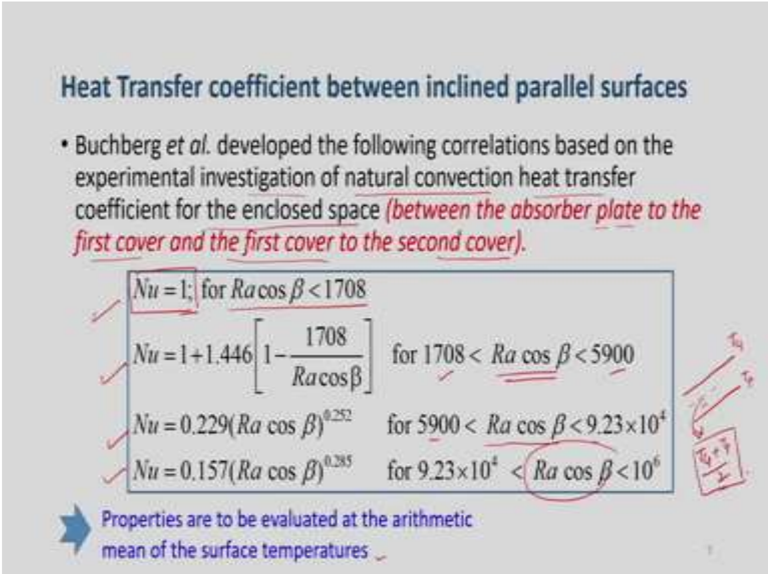

Now, let us learn how this heat transfer coefficient can be calculated, if we go back to the last slide, so these heat transfer coefficients need to be calculated. So in this expression, so our primary intention is to calculate this q_t/A_p, this unknown is q_t and then T_{c1} and here is a T_{c2}. So, q_t T_{c1} T_{c2} are the unknowns. But this h_{P-c1} is heat transfer coefficient when heat is exchanging from the plate to the cover 1 and then from cover 1 to the cover 2 and then from cover 2 to the ambient. So, we can use some correlations to calculate these heat transfer coefficients.

So, let us learn how these correlations can be utilized to calculate heat transfer coefficient between the parallel plates. So, Buchberg Et al developed the following correlation based on that experimental investigations of natural convection heat transfer coefficient for the enclosed spaces, that means between the absorber plate to the first cover and the first cover to the second cover. So, these correlations is something like that so if $Ra\cos\beta$ is less than 1708 then we will use Nusselt number is 1.

So if this value $Ra\cos\beta$ is in between this and this, then we will go for this correlation, if this $Ra\cos\beta$ is in between these 2 arrows, then we will go for this expression and then finally, if this value is very high, then we will go for this expression, but we should be very, very particular about how to calculate the properties of the fluid. So, the properties are to be evaluated at the arithmetic mean of the surface temperatures. So, what does it mean? So, if there are 2 plates they are having at say T_{c1} and then T_p this fluid what is moving inside, so property has to be calculated at $(T_{c1}+T_p)/2$. So, after that only we can do the calculation.

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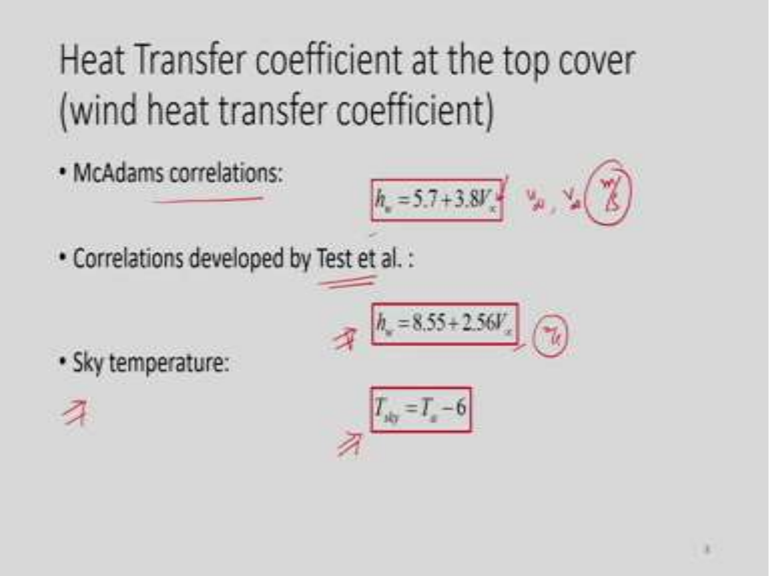

Also we need to use other correlations for calculation of hw that is heat transfer from the top of the glass to the ambient. So, this kind of heat transfer coefficient also known as wind heat transfer coefficient. So, McAdams correlations or something like $h_w = 5.7 + 3.8V_\infty$, this is nothing but your V that is velocity. So, we can write U_∞ or V_∞ is the same meaning, its unit is meter per second. Also, there are other correlations developed by Test Et al. He has demonstrated based on his experimental observations that $h_w = 8.55 + 2.56V_\infty$, so this is in meters per second.

So, either of these 2 correlations can be utilized to find out h_w value. So, if I am interested to calculate the sky temperature then normally we use this correlation. $T_{sky} = T_a - 6$, normally it is assumed that it is less than ambient temperature so $T_a - 6$, if we deduct 6 from the ambient then what we will get is a sky temperature.

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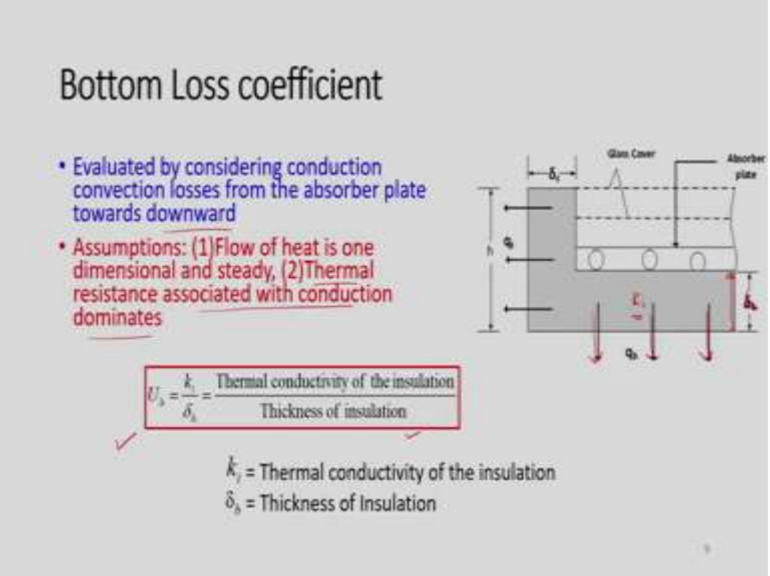

Now, let us learn how bottom those coefficients are evaluated. So, this bottom loss coefficient is evaluated by considering conduction and convection losses from the absorber plate towards downward. So, this way this will come, and assumptions are flow of heat is one dimensional and steady and thermal resistance associated with conduction dominates, that is why convective part is neglected. So, in this case, if we know this thickness of the insulation, that is δ_b and then conductivity of the insulation, then straightway you can calculate what will be the U_b.

So, $U_b = \frac{k_i}{\delta_b}$ which is equal to thermal conductivity of insulation and then thickness of the insulation. So, if these 2 parameters are known, then straight way you can calculate what will be U_b. So, once we are done with bottom loss coefficient then our next attempt is to calculate side loss coefficient.

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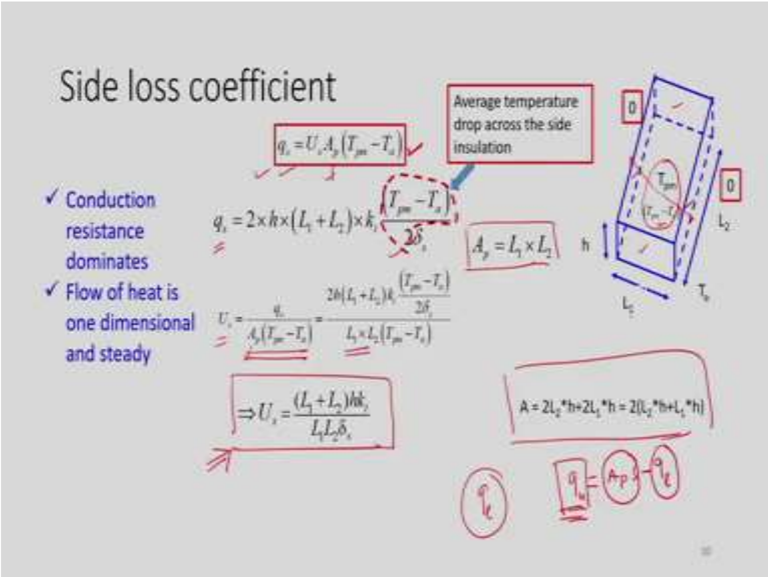

So, let us learn how to calculate side loss coefficient. So, side loss coefficient is estimated based on convection and conduction heat transfer. So, let us learn how to calculate side loss coefficient. So, this side loss coefficients can be estimated by considering both conduction and convective heat transfer. So, here also conduction resistance dominates and the flow of heat is 1 dimensional and steady. As we know q_s can be expressed something like this, $q_s = U_s A_p (T_{pm} - T_a)$.

So here, A_p we can calculate something like this. This area we need to calculate so this way we can calculate the area. So, if we know this l_2 is the length and l_1 is the breadth, and h is the height? So, area will be something like this because there are 2 sides, this sides and this sides and also this sides and this sides so all the things you need to be considered. So, 1 important concern is here $\frac{(T_{pm} - T_a)}{2}$, this component is used. Why this component is used? Because see, if we consider this plate from plate heat loss will take something like $(T_{pm} - T_a)$. And this heat loss will be reducing slowly towards the top and then again towards the bottom.

So, this average can be taken up, the average heat loss can be taken up so that is why this term is divided by 2. So, average temperature drop across the side insulation can be considered something like $\frac{(T_{pm} - T_a)}{2}$. So, if I am interested about this U_s then how we can do it? $\frac{q_s}{A_p (T_{pm} - T_a)}$. So, this is the expression and what is the plate area, if we consider this l_1

and l_2 is the breadth and the length, then if we multiply these then what we will get is A_p, what is written here.

And this expression is known to us if we substitute this value then what we will have is nothing but U_s, this U_s is nothing but the side loss coefficient. So, once we know the side loss coefficient, bottom loss coefficient and top loss cohesion, then we can calculate what will be the overall loss coefficient. So once it is done, then we can calculate what is q_l. So, once we know q_l, then we can go back to our energy equation, $q_u = A_p S - q_l$. So, if this information is known to us and once we know this, then what we can calculate is q_u. So, once we are done with q_u, then we can do all those calculations or performance characteristics calculation.

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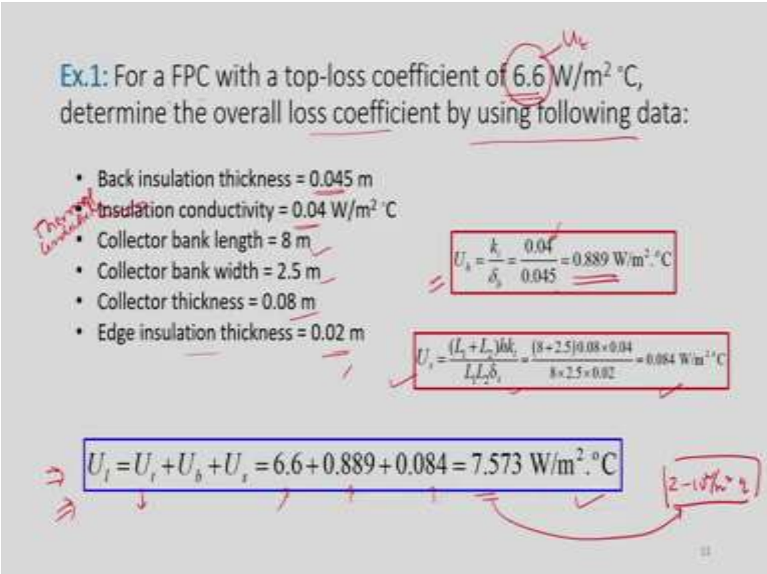

Now, let us take a very small problem, say for a FPC with a top loss coefficient of 6.6 W/m^2°C, if we are interested to determine the overall loss coefficient by using the following data then how to do it? So, back insulation thickness is given as 0.045, then insulation conductivity or this is known thermal conductivity, this is not insulation conductivity this is thermal conductivity, this is thermal conductivity, thermal conductivity is something like 0.041 W/m^2°C then a collector bank length is given collector bank width is given, collector thickness is given then edge or side insulation thickness is given as 0.02 meter.

So, how we can calculate this U_b? Already we have the information $U_b = \frac{k_i}{\delta_b}$. So, straightway we can substitute the values of thermal conductivity of the insulation. So, this is 0.04 and then thickness is 0.045 then what we will get is U_b, U_b is nothing but 0.889 W/m^2°C. And U_s we can apply the knowledge what we have derived now. So, U_s is something like this, then just we substitute the values here what is given in this problem, then we will get a value of 0.084 W/m^2°C.

So, since U_t is given, this value is given to us, this is nothing but U_t, then $U_l = U_t + U_b + U_s$. So, substituting those values what we have calculated now, so then what we will get is about 7.573 W/m^2°C. So, as we understand each value should be in between 2 to 10 W/m^2°C. So, since this value is in between, it is a feasible collector design. So, this kind of design is accepted.

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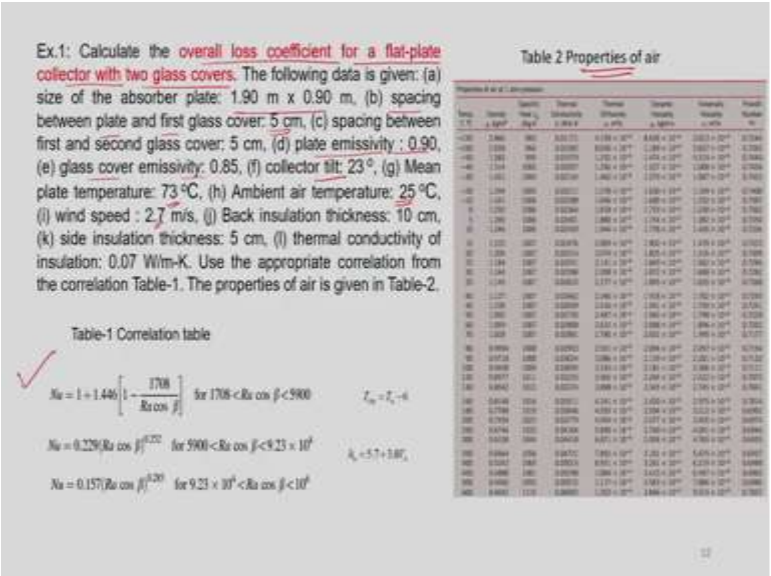

Now, let us take a somewhat bigger problem in order to understand the things very clearly, this problem has been incorporated in this lecture. So, example goes something like, calculate the overall loss coefficient of a flat plate collector with 2 glass covers. We will have 2 glass covers, and following data is given, size of the absorber plate is given, then spacing between the first glass and then plate is given, spacing between the first and second glass is given then the plate emissivity is given, then glass cover emissivity is given, tilt angle is given and mean plate temperature is given as 73 °C, ambient air temperature is 25, wind speed is given as 2.7 m/s, back insulation thickness is 10 centimeter, side insulation thickness is 5 centimeter, thermal conductivity insulation is 0.07 W/m-K.

So, we can use those correlations for estimation of heat transfer coefficient between the plates and plate to the ambient. And also we can use the properties of air.

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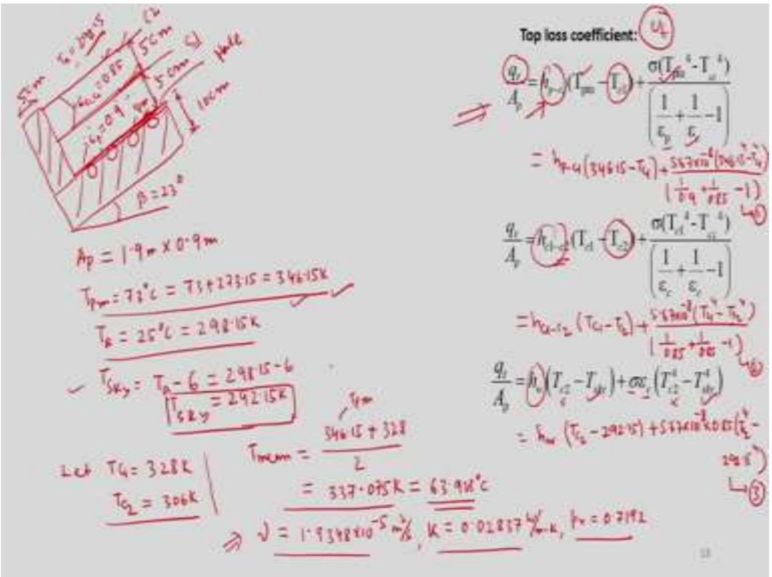

So, to understand clearly let us draw this figure first. So, we will have 2 glass covers. These are 2 glass covers and then we will have 1 absorber plate. And we will have insulation; side insulation as well as we have bottom insulation. So, these are insulation, these are insulation. So, this is given as 5 centimeter, this is also 5 centimeter, and this is 10 centimeter in the problem and this angle beta is given as 23°, and A_p plate area is given as 1.9 meter by 0.9 meter and this thickness is given as 5 centimeter and emissivity of this absorber.

So, this is an absorber plate, this emissivity of this absorber plate will be 0.85, and for these 2 cases so emissivity will be so this is C_1 and C_2 will be 0.85. And also it is given that T_{pm} is 73 °C so we can convert it to K so 73 plus 273.15 to be very precise, so it will be 346.15 K. So, T_{pm} is known to us now. Then what is T_a, which is given in the problem is 25 °C, which is nothing but 25 plus 273 it will be 298.15 K. And also $T_{sky} = T_a - 6$. So, this expression we can use for calculation of T_{sky}.

So, T_{amb} = (298.15 – 6) which will be equal to 292.15 K, this is T_{sky}, this is T_{sky} so, this value is also known to us. Now, what we want, first we need to calculate top loss coefficient then only we can calculate Ul because first if we are interested about U_l then what you need to do first? $U_l = U_t + U_b + U_s$, so all the 3 parameters are required. Let us first calculate this U_t. So, the kind of techniques we are going to use here is a trial and error, it is an iterative technique, we have correlations to get direct result of U_t but first let us understand how this can be calculated by using this iterative technique. So, let us rub this part, this is not required at the moment.

So this top loss coefficient so our interest is U_t we are going to calculate. So in order to calculate this U_t what you need to know, this T_{c1} which is unknown for us, T_{c2} is unknown for us, only known is T_{pm}. Then these values are known, this is known, this can be calculated by using correlations. And these 2 values are known, this is known, this is known, but this is unknown, and this q_t we need to calculate. So, we will get three different nonlinear equations and we need to solve for $\frac{q_t}{A_p}$.

So, let us proceed with the given data. So, what we can write here? So, $h_{p\text{-}c1}$ then we have T_{pm}, what is T_{pm}? $\frac{q_t}{A_p} = h_{p-c1}(346.15 - T_{c1}) + \frac{5.67\times10^{-8}(346.15^4 - T_{c1}{}^4)}{\frac{1}{0.9}+\frac{1}{0.85}-1}$. And for this expression, $\frac{q_t}{A_p} = h_{c1-c2}(T_{c1} - T_{c2}) + \frac{5.67\times10^{-8}(T_{c1}{}^4 - T_{c2}{}^4)}{\frac{1}{0.85}+\frac{1}{0.85}-1}$,$h_{c1\text{-}c2}$ then T_{c1} to T_{c2}, these 2 are unknown. Then we have 5.67×10^{-8}, then we will have $T_{c1}{}^4$, T_{c2} to the power and then these values are known to us. So, 1 by here is for a plate it is 0.85 and then for glass it is let me check for plate it is 0.9, it is 0.9.

So, this for plate it is 0.9, this is 0.9 and this is 0.85, this is minus 1. So here, $\frac{1}{0.85}+\frac{1}{0.85}-1$, and $\frac{q_t}{A_p} = h_w(T_{c2} - 292.15) + 5.67\times10^{-8}\times0.85(T_{c2}{}^4 - 292.15^4)$. So, we can simplify it further. So, this equation maybe you can give is 1 and this may be 2 and this may be 3. So, what are those equations?

These equations take care of the heat transfer or rate of heat transfer takes place between this absorber plate to the glass cover 1, so I will write here cover 1, this is glass cover 2 and this is T_{pm} or say I will write plate having temperature T_{pm}, this T_{pm} is already known to us. Now, our next step is to calculate this heat transfer coefficient. So, we need to use appropriate correlation for calculation of this heat transfer coefficient.

So, before we do that we must know the temperature of T_{c1} but which is not given, we need to assume those values T_{c1} and T_{c2}, we need to apply our common sense. So T_a, if we write T_a here, so T_a will be how much is given? 298.15, so this temperature what we got is

346. So, 346 minus 298.15 is about 48. So, its half is 24, so if we consider this value T_{c1}, say let T_{c1} is equal to 328 K and T_{c2} is 306 K thus we applied our common sense. So, this temperature is 346.15 and ambient is 298.15, and then it is presumed that this should be somewhat in this one so that is how we have considered 328 which is know more than the average of this T_a and T_{pm}, and T_{c2} is know 306 we have considered.

Just we are assuming this value because we have to do trial and error. So, there will be 2 values of T_{c1} and T_{c2} which gives the same result of all the 3 expressions. So, once it is matched then we can say that it is converged. So, this T_{c1} and T_{c2} we have assumed, now what we need to do for calculation of hp 1 means low heat transfer coefficient from plate to the cover 1, then we need to take average of this T_{pm} and T_{c1}. So, this T_{mean} T_{mean} will be 346.15 which is nothing but T_{pm} plus we have this is T_{c1}, T_{c1} is 328 divided by 2 which will give us a value which is equal to 337.075 to be precise in K.

So, once we know this T_{mean}, then we can get the data for air at this temperature because in between we will have air, no liquid is there so our tips will be here. So, in centigrade it will be 63.925 °C. Now what we need to do? We need to use this property table. So, since this is at Celsius so we have 62, this value is in between here so we have to interpolate. So, to get the values of all like we need the Prandtl number, Kinematic viscosity then thermal diffusivity, conductivity, all those values are required.

So, if we calculate it, it is found to be $\nu = 1.9348 \times 10^{-5}$ m^2/s meter square per second, and k is thermal conductivity is 0.02837 W/m-K and Prandtl number is 0.7192. So, these values we can get from the property table, we must know that air is there in between these 2 plates, no fluid is present. So, once we know these values, then what we need to calculate? We need to calculate the Rayleigh number.

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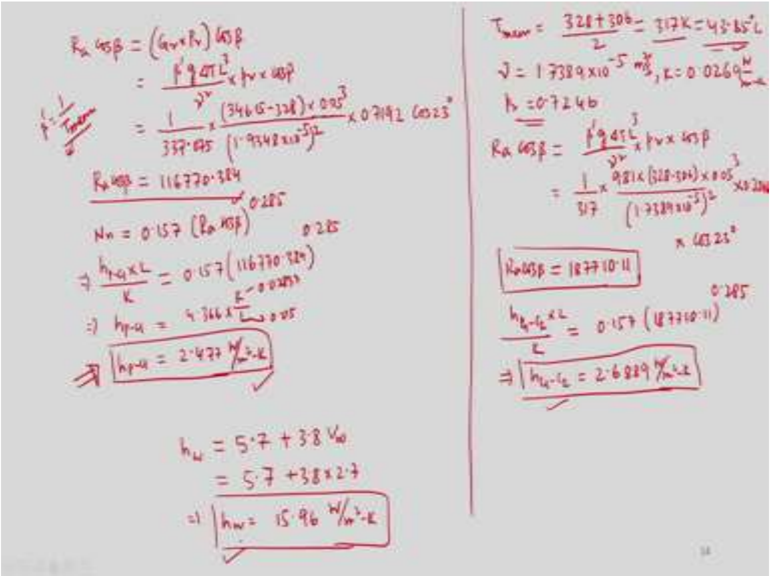

So, let me calculate the Rayleigh number. So, this is $Ra\cos\beta$ so Ra is nothing but Grashof number multiplied by Prandtl number then we have $\cos\beta$. So, this is nothing but that is $\frac{g\Delta TL^3}{\nu^2}$ and then you have Prandtl number because these values are known to us and we have $\cos\beta$. So, this beta this is nothing but 1/ T_{mean} what we have just calculated at which we have taken the property data. So, this is something like 1 /337.075, this is for β and then $\nu = 1.9348 \times 10^{-5}$.

So, this is something like this, then we have ΔT 346.15 minus 328, and length is given as, length means the distance between these 2 plates, so this is 0.05, this is a characteristic length and we have Prandtl number as 0.7192. So this is found to be, and of course we need to multiply by $\cos\beta$, β value is 23? So, if we do the analyses, then what we will get is something like 116770.384. So, this value is for $Ra\cos\beta$. So now, we have to apply the appropriate correlations. So, let us check which correlation can be used for estimation of heat transfer coefficient from absorber plate to the glass cover 1.

So, let us go back and see this value you should remember 116770. So, see you check 116770. So, we must use the correlation here. So, our value falls in between this range, so we need to apply this correlation. So, this correlation Nusselt number is equal to 0.157 then $Ra\cos\beta$ 0.285. So, since you have already understood what is Nusselt number and other parameters then straightaway you can calculate what is the heat transfer coefficient, so this is nothing but $h_{p\text{-}c1}$, then multiplies by characteristics length L, this is k is the conductivity so 0.157 mean $Ra\cos\beta$ is something like $116770.384^{0.285}$.

So, what will be $h_{p\text{-}c1}$, this value multiplied by k by l. So, this is something like $\frac{4.366k}{L}$. So, this is found to be 2.477 W/m^2-K, $h_{p\text{-}c1}$. So, this k value is 0.02837 and this l is 0.05. So, we can know now what the value of $h_{p\text{-}c1}$ is. Now what is next? We need to calculate what is a $h_{c1\text{-}c2}$? So, for this case what we need to do? We need to consider this temperature and this temperature. So, already we have assumed that this T_{c2} temperature is 306, this is 306 and we have 328. So, what will be the mean temperature here, so T_{mean} will be $\frac{328+306}{2}$. So which will give us a value of 317 K, and which is nothing but 43.85 °C.

So this is the temperature, so now properties of air need to be taken at a temperature of 43.85, so just go back to this slide. This is 43, so properties will be in between this 40 and 45, so we need to find out the properties by doing some kind of calculation here. So, this is 43? This is in between in between 40 and 45, so we need to apply this our principle like interpolation. So, I will just show 1 calculation, so if I am interested for say Prandtl number, so this variation is not much. You can take this average here, say for example diffusivity. If I am interested to measure diffusivity at 43, then what we need to do? 2.346×10^{-5}

So you see it is increasing, so then you have to plus, so we need to differentiate it, this maybe 2.416 minus 2.346 divided by 5 into 3 say 43 I am interested. So, that way we can calculate at 43 what will be the value of this thermal diffusivity. So, this kind of calculations we need to do for all the other parameters. So, at temperature 43 the values of thermal diffusivity α will be something like this. So, this is the way we can find out the values, these values are not given in the table.

So, we use the appropriate values and we can do the calculation now. So, at this conditions as per my calculation, so it is found to be ν is equal to kinematic viscosity is 1.7389×10^{-5} m^2/s, and the K is equal to 0.0269 W/m-K, and the Prandtl number is equal to 0.7246. So, these values are known to us then we can calculate what is $Ra\cos\beta$. So, this expression already known to us so beta this $\frac{g\Delta TL^3}{\nu^2}$, then Prandtl number then we have $\cos\beta$. So, β this is here, $1/T_{mean}$, so $1/T_{mean}$ is 317, also it will be in K, and multiplied by 9.81 and delta T is now between 2 glass covers. So, delta T is in between these 2, so this will be 328 minus 306.

So, this will be 328 minus 306 right. And we will have ν^2, now L is again now distance between these 2 plate is 0.05^3, and here a ν^2 is 1.7389×10^{-5}, this is square and multiplied by Prandtl number, what is the value of Prandtl number here? $0.7246\cos 23$. So, this is found to be 187710.11, this is $Ra\cos\beta$, so this is known now. So, once you know this, then we can again see which correlation is appropriate for us, this is 187710, so again the same correlation to need to apply. This value is also in between this range so same correlation we need to apply.

So correlation is here, so $h_{c1\text{-}c\ 2}$, then we have l/k is equal to 0.157 then 187710.11 to the power of 0.285. So, on calculation what value we will get is $h_{c1\text{-}c\ 2}$ is nothing but 2.6889 W/m^2-K so this value we got. What next we want, h_w. So, how to calculate h_w? So, already we know the expression for h_w, which is also given here in the problem. So, these $h_w = 5.7 + 3.8u_\infty$.

So, this is $5.7 + 3.8u_\infty$. So, these values are given $5.7 + 3.8\times0.7$. So, this is found to be 15.96 so this is W/m^2-K. So, we know now $h_{p\text{-}c1}$ $h_{c1\text{-}c2}$ then h_w. So, now go back to this expression.

So, these values are calculated now, this is known, this is known, this is known and these are the assumed values. Now, we need to check what is the value for this expression, what is the value for this expression, what is the value for this expression? If these values are not equal then we have to come back to here again and we have to select 2 values of T_{c1} T_{c2}, which gives approximately similar result of all these 3 equations. So, if we use now this equation 1, 2 and 3.

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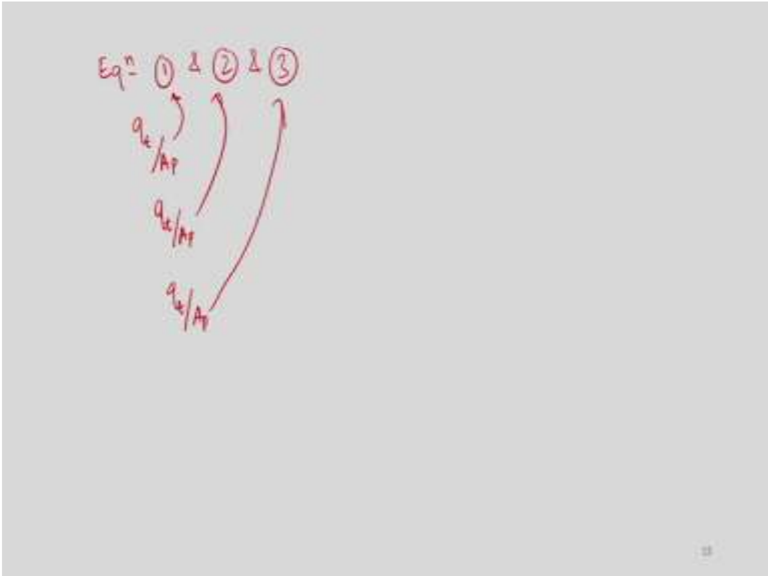

So, if we use equation 1 then 2 and 3. So, already we have done it like $\frac{q_t}{A_p}$ for this equation and then $\frac{q_t}{A_p}$ for this equation, then $\frac{q_t}{A_p}$ for this equation. So, this expression is known to us. So, if you do the calculation, so what we have already I had done the calculation, so if you substitute those values, then we will get something like this.

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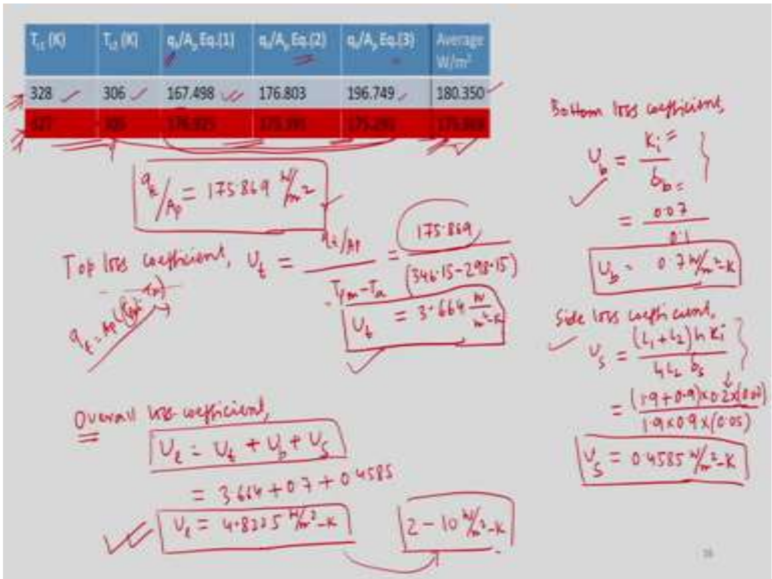

So, if 328 was the first assumption for T_{c1} and 306 for T_{c2}, then by using the equation 1 we will get this value, 167.498. And by using equation 2 we get 176.803, and by using equation

3 we get 196.749. So, since the variation is very, very high, we cannot use this combination to calculate q_t values. So, then we need to assume another sets of data, so as per my calculations what I have done, I have varied the temperature to 327 for T_{c1} and then 305 for T_{c2}, and it is found that this approximation gives very close result. So, it is about 176.925, 175.391 and 175.293, so these are very, very close.

So what we can do, we can take average of these 3 results. If we take the average, then what we will get is 175.869. So, this value we can take for calculation of $\frac{q_t}{A_p}$. So, this $\frac{q_t}{A_p}$ will be 175.869, this should in W/m^2. So, what happens now, this is a W/m^2, we will calculate what is U_t. So, top loss coefficient top loss coefficient that is U_t is nothing but, $\frac{q_t}{A_p}$ then you will have $(T_{pm}-T_a)$. So, this value is 175.869 to T_{pm}. So, T_{pm} was (346.15-298.15). So, once you do this calculation then what we will get is the value for U_t which is nothing but 3.664 W/m^2-K, this is U_t. So, U_t is done. Then, we can calculate what is bottom loss coefficient and side loss coefficient.

So, for bottom loss coefficient, bottom loss coefficient that is, $U_b = \frac{k_i}{\delta_b}$, k_i is the conductivity of the insulation and δ_b is the thickness. So, this value is 0.07 in this problem and δ_b is given as 0.1 meter, so it will be 0.7 W/m^2-K. So, U_b also we have calculated now, then we will calculate side loss or edge loss. Side loss coefficient, side loss coefficient that is U_s is, we can use that equation $U_s = \frac{(L_1+L_2)hk_i}{L_1L_2\delta_s}$. So, if you substitute those values, L_1 and L_2 is 1.9 is the length, and width is 0.9 and h is height is 0.2 and then we will have k_i is 0.07, and then we will have L_1 is 1.9 multiplied by 0.9 into δ_s is given as 0.05, side thickness is 0.05.

So, what is the height here? I will go back here to get this height. So, this is 5 centimeters, this is 5 centimeter and this is 10 centimeter. So, 5 plus 5 plus 10 is becomes 20 centimeter. So, 20 centimeter means 0.2 meter that is how is the height of the collector so, this is nothing but the h. So, what we have to use for calculation of side loss coefficient. So, this is what we got this 0.2, and once you do these calculations then U_s is found to be 0.4585 W/m^2-K. So, this U_s is something like this.

So, as we know overall loss coefficient overall loss coefficient overall loss coefficient can be defined as $U_l = U_t + U_b + U_s$. So, if we substitute those values $U_l = 3.664 + 0.4 + 0.4585 3.664$ plus Ub is 0.7 plus 0.4585, so it is found to be 4.8225 W/m^2-K. So, this is the overall loss coefficient which is in between 2 to 10 W/m^2-K which is recommended, so our design is a good design. So, losses are not much so this design can be adopted. So, I will just briefly tell what we have done in this problem. So, problem was something like calculation of overall loss coefficient.

So, in order to find out the overall loss coefficient we need 3 parameters; one is top loss coefficient, one is bottom loss coefficient and one is side loss coefficient, these 3 loss coefficients are required to calculate U_l. To find out this U_t, we have adopted trial and error methods. So, we know the heat exchange between this plate to the glass cover 1 can be represented by this equation and then heat exchange from this plate 1 to plate 2 can be represented by this equation and then from plate 2 to ambient can be represented by this equation, it involves 2 components, radiative heat transfer components and convective heat transfer component in all the 3 cases.

So what we did first, we have substituted those values and we have identified the unknowns, the $h_{p\text{-}c1}$, is $h_{c1\text{-}c2}$,h_w these are unknown and this was calculated by using standard correlations. And T_{c1} and T_{c2} are unknown for us, we have assumed it sets of values and we try to see the numerical values what we have received based on this assumption, if these values are found to be same for 3 cases then that set can be considered as the final glass temperatures or cover temperatures. And also we need to find out the properties at the mean temperature of these 2 parallel plates for all the cases.

So, if we are interested about this, then we need to consider the plate temperature and then glass over temperature then we have found out the values of T_{mean} and then we can get the air data from the property table, then we can use it for calculation of these 3 values. So, we have done the calculations how this can be applied. So, once we know $Ra\cos\beta$, then we must check which correlation to be used for this appropriate application, then once we are finalized with that, then from that we can calculate what is $h_{p\text{-}c1}$, and accordingly you can calculate, what is $h_{c1\text{-}c2}$ and then hw.

So, once you know this, then we need to check whether all are same or not, if it is not same, then we have to go back again and we have to consider a new set of T_{c1} and T_{c2}. And that will continue till we get a uniform result of $\frac{q_t}{A_p}$ for all the 3 equations. So, first set of reading we got this which are different from each other, then finally what we got is a very close values given by all the 3 equations, then we have taken the average, and once you know these values, then straightaway we can calculate what will be the top loss coefficient because we know the expression $q_t = U_t A_p (T_{pm} - T_a)$.

So, heat loss is taking place from the plate to the ambient. So, these values are known to us and this is calculated, from that we have calculated the U_t, then we have calculated the U_b, these are the standard equations, then side loss coefficients we have calculated, then overall loss coefficients we have calculated which are the sum of all the 3 losses or loss coefficients. So, which is found to be 4.822 and which is fall in the recommended values which is 2 to 10 W/m^2-K. So, that way we can calculate the loss or estimate the losses taking place in a flat plate collector.

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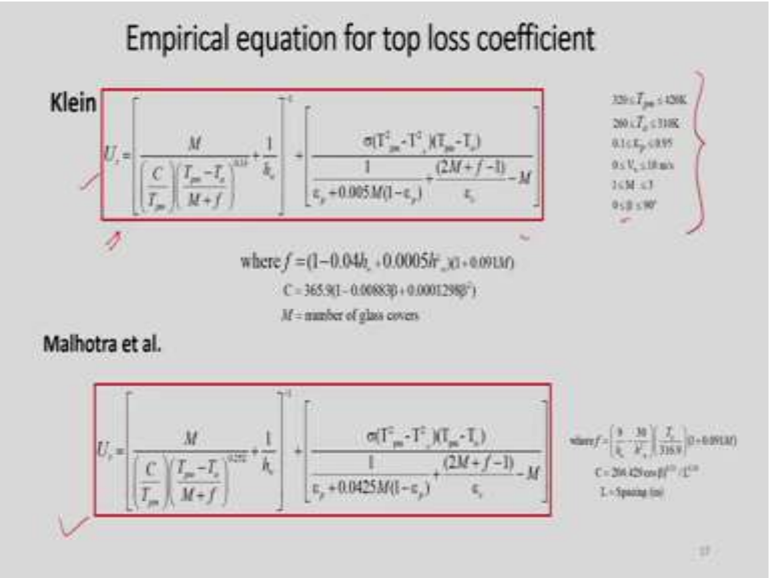

So, there are empirical relations available. So, without going this trial and error we can straightway use some kind of established correlation to find out U_t values of the particular collector. So, this correlation was developed by Klein. So, these are very long correlation and there are are set of datas, we need to check what is the will of T_{pm} that has to be in between 320 to 420 K, then what is the ambient temperature, this ambient temperature must be in between 260 to 310 K.

Then what is the emissivity of the plate, it should be from 0.1 to 0.95, then what is the velocity of the wind and then number of covers and then what is the tilt angle, all those things need to be in the range, then only we can use this correlation. And one more correlations which is developed by Malhotra Et al. So, these correlations can also be used for calculation of top loss coefficients without doing the iteration method.

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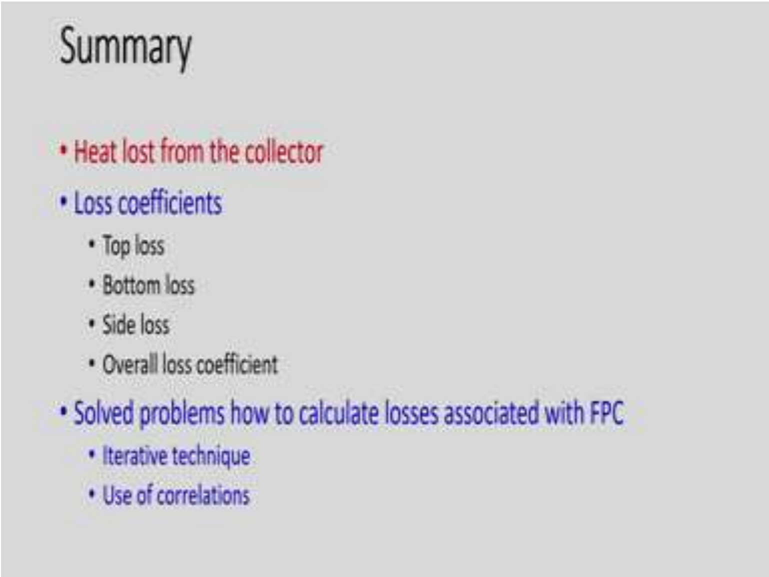

So, we can summarize what we have discussed today. Primarily, we have discussed the heat loss from the collectors, what are different heat losses, and then heat loss coefficients like top loss coefficient, bottom loss coefficient, side loss coefficient. And if we combine all these losses, what we will get is an overall loss coefficient. We have also solved problems, how to calculate losses associated with FPCs.

There are 2 techniques; one iterative techniques for calculation of U_t or top loss coefficient or we can go for standard correlation for estimation of U_t values. So, I hope you understand what we have discussed today. And these are the basis of estimation of losses, and which finally give the information about the performance of a flat plate collector. So, thank you very much for watching this video.