Solar Energy Engineering and Technology
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Lecture 18
Fundamentals of Flat Plate Collectors

Dear students, today we will discuss about the fundamentals of flat plate collectors. So, what is solar collector?

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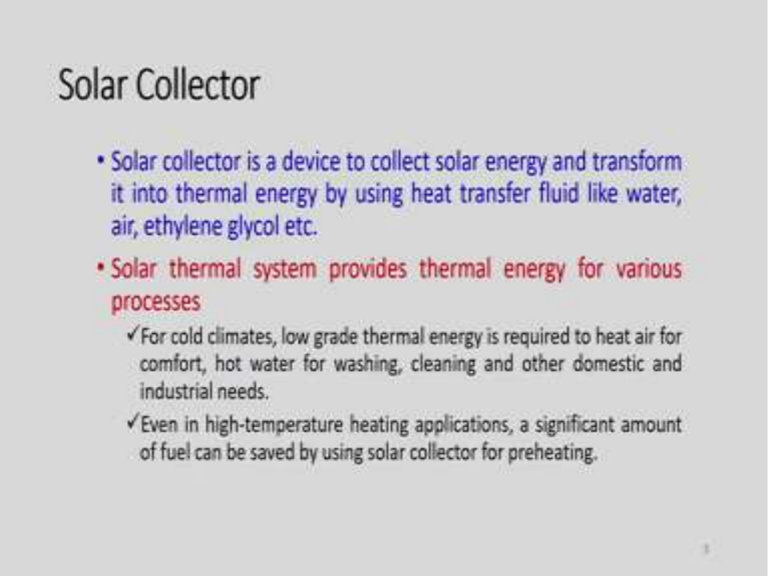

The solar collector is a device to collect solar energy, and transform it into thermal energy, by using heat transfer fluid like water, air or ethylene glycol. So, when the ambient temperature goes below 0 degrees C then we have to think of some other material, like water with ethylene glycol, in order to make it operative. The solar thermal system provides thermal energy for various processes.

For example, if we consider cold climates, the low grade thermal energy is required to heat air for comfort, hot water for washing, cleaning and other domestic and industrial needs. And even in high temperature heating applications, a significant amount of fuel can be saved by using solar collector for pre heating. Of course, it has got plenty of applications like drying and any other agricultural field. So, how these solar collectors can be classified?

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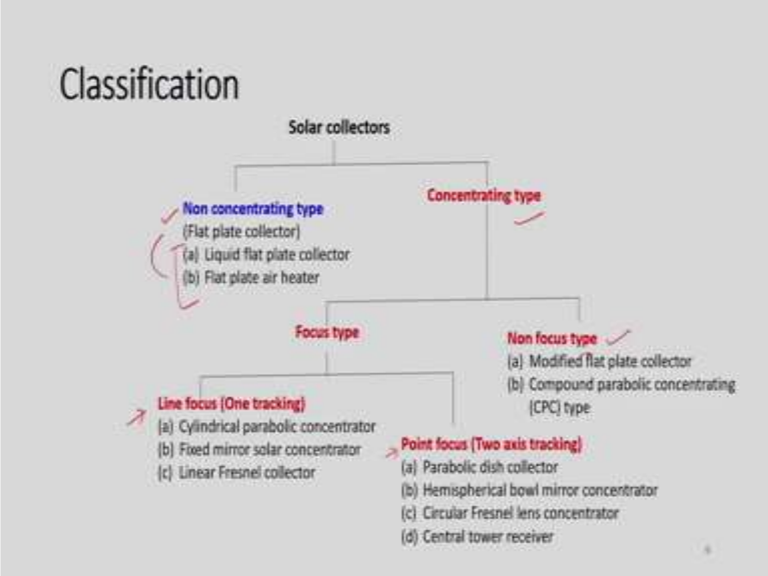

Majorly there are 2 categories, first is non concentrating type and second one is concentrating type. So, flat plate collectors that may be liquid flat plate collectors or maybe air flat plate collector this will be under non concentrating type. So, under concentrating type we will have 2 classes, focused type and non focused type. Then, in under focused type, we will have again 2 more classes, line focused that is single tracking and point focus systems prior 2 axis tracking is mandatory.

So, examples of line focus systems are, cylindrical parabolic concentrator, fixed mirror solar concentrator, then linear Fresnel collector. And under point focus systems we will have parabolic disc collector, then hemispherical bowl mirror concentrator, then circular Fresnel lens concentrator and central power tower or central tower receiver system. And under the class of non focusing systems we have 2 categories then modified flat plate collector and compound parabolic concentrating type collectors.

So, this is how solar collectors are classified. We will learn with time the difference between these two and then which one is important and what condition, what type of collectors can be utilize for harvesting thermal energy.

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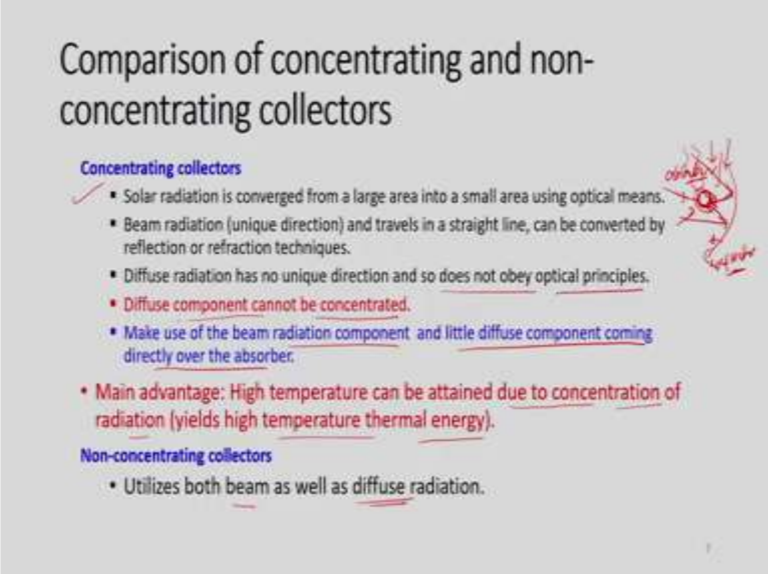

Now, if we briefly compare between concentrating type and non concentrating type collectors, then what are the differences. So, under concentrating type collectors, this solar radiation is converged from a large area into small area using optical means. So, this will be something like, we will have this large area and absorber will be here, solar radiation will fall here and it will reflect here. So, this part is absorber, and this will reflect, a reflector.

So, solar radiation first strike on this reflector and this goes back to this absorber. So, concentrated solar radiations are used here. So, beam radiation which has got unique direction and travels in a straight line, can be converted by reflection or refraction techniques. So, in case of concentrating collectors only beam radiations are applied. So, diffused traditions cannot be applied because it has know defined direction or I should say it will come from different directions and intensity is lower.

So, this diffused radiation has no unique direction and so does not obey optical principles. So, these diffused components cannot be concentrated, that we should keep in mind in case of concentrating collector. Also these concentrating collectors make use of beam radiation component and little diffuse components coming directly over the absorber. So, there are some radiation which comes from Sun and it strikes on the absorber.

So, these components are used, but know amount of contribution for heating effect for this diffused radiation is very very less. The primary advantage of this concentrating collector is high temperature can be attained due to concentration of radiation, which yields high temperature thermal energy. And in case of non concentrating collectors, both beam as well as diffusion radiations are utilized. So, here this is one advantage. So, both the components can be applied for generation of thermal energy.

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So, if we talk about flat plate collectors, a flat plate collector is simple in construction and does not require tracking. So, which is under non concentrating type. So it can properly secured on a rigid platform and thus becomes mechanically stronger than those requiring flexibility for tracking purposes that is obvious now. These collectors are installed outside or outdoor applications and these are exposed to atmospheric disturbances like rain, storms and any other kind of disturbances. So mechanically there has to be stronger.

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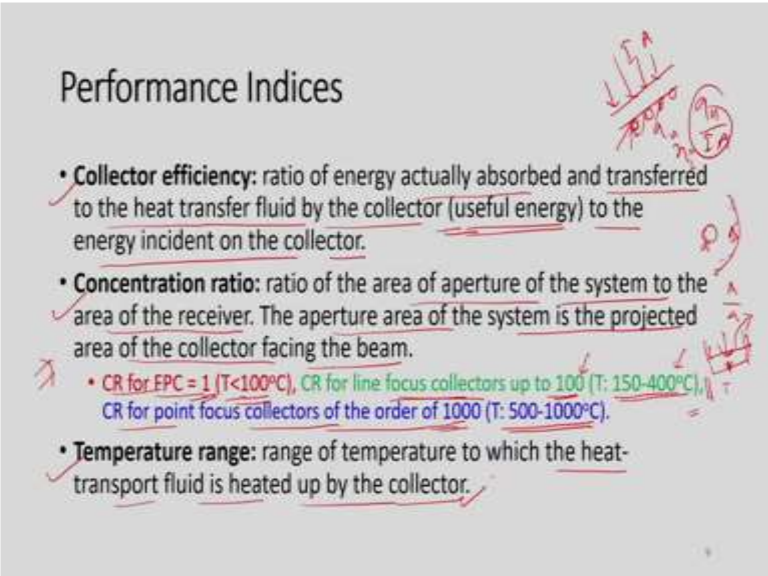

Now, there are 3 primary performance indices in case of flat plate collectors. These are collector efficiency, concentration ratio and temperature range. So, what is collector efficiency? It is defined as the ratio of energy actually absorbed and transferred to the heat transfer fluid, by the collector. So, this is nothing but useful energy to the energy incident on the collector.

So, that means, so we have this absorber, so we learn the different components so we will have glass, then we will have a absorber, then some tubes will be there. So, the heat transfer fluid will flow through these tubes. So, as you can understand by, analyzing this collector efficiency how we can define it is the energy actually absorbed and transferred to the heat transfer fluid by the collector.

So, here how much energy is transferred to the amount of radiation which is falling on the collector, maybe I if we have A and this may be qu is the useful energy. So, this will be something like, $\eta = \frac{q_u}{IA}$. So, this is how this efficiency can be defined. And then, next important parameter is concentration ratio which is defined as the ratio of the area of the aperture of the system to the area of the receiver.

The aperture area of the system is the projected area of the collector facing the beam. So, this is something like, this is the aperture area and this is the absorber. So, this area A and this small so A/a is something called concentration ratio. So, for example, this concentration ratio for a flat plate collector is 1 because, this area for a flat plate collector. So amount of energy received here, so same amount of energy flows through to this part.

So, this area is fixed. So, because of that we will have concentration ratio for FPC is 1. And since, more area is exposed, so losses will be more because of that we cannot get a temperature more than 100 °C. This concentration ratio for line forecast system may go up 100, and its temperature varies from 150 to 400 °C, so that lots of heat can be generated by making this kind of collector.

And then if we are interested for very high temperature application , then concentration ratio should be very, very high, it is in the order of thousand. So, we can go up to temperature of 1000 °C. So, we will study these more extensively when we study concentrating collectors. And the third category of performance indices is, temperature range. So this range of temporary to which the heat transport fluid is heated up by the collector.

So, this temperature range is also important and by knowing this temperature range we can classify what kind of collector is required to get that particular temperature. So, these indices are important to characterize a collector.

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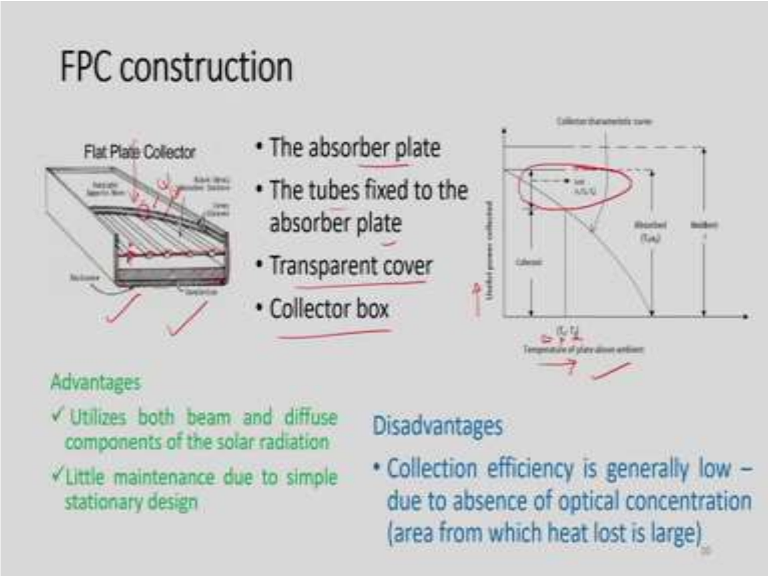

Now come to the construction of a flat plate collector. So, as far as construction of a flat plate collector is concerned, it has got 4 primary components, that is the absorber plate, then tubes fixed to that absorber plate, transparent cover, then collector box. Let us have a look on the sectional view of the flat plate collector. So, this is the outer side and here the top side will have glass cover.

So, here two glass covers are shown here, this is the glass cover 1 and this is the glass cover 2 and this is the absorber plate and you can see the tubes, these are tubes. So, here what happens, same sheet is used and then extruded. So, material of construction is same for both, tube and sheet. So, this is an absorber plate and these are the tube through which heat transfer fluid flows. And we have to provide sufficient insulation to reduce the heat losses. And finally, we need to provide a casing to hold the entire structure. So, this is all about the construction part and here it shows the collector characteristic curve.

In the vertical axis it shows useful power collected or energy collected and here in the horizontal axis shows temperature of plates above ambient. So, this P is for plate temperature, or absorber plate temperature and Ta is the ambient temperature, this temperature difference once you know and we know the other characteristics then we can plot these curve for a flat plate collector.

So, what does it mean? So, amount of energy what is falling on the glass is not received by the absorber plate. So, some losses will be there. So, what are losses? These are the losses, because of the losses, so all the energy what is received by the glass cover cannot be converted to useful energy. And there are some losses with this glass and other factors.

So, we will discuss all those issues step by step and what will be the material, what will be the transmissivity, what will be the reflectivity, all those information are required to characterize completely this kind of flat plate collector. So, finally, what happens this collector's useful energy will be something like this, this part is the useful energy. Since solar radiation is varying, so this component will vary. So, finally we can have this kind of plot.

So, advantages already we have discussed so it utilizes both beam and diffused component of the solar radiation and little maintenance due to simple stationary design. No moving parts, no mechanical components, so it is a very good structure. But primary disadvantages are something like collection efficiency is generally low and this is due to absence of optical concentration and this area from which heat loss is very very large. Because of that we cannot have high temperature application from this FPC collector.

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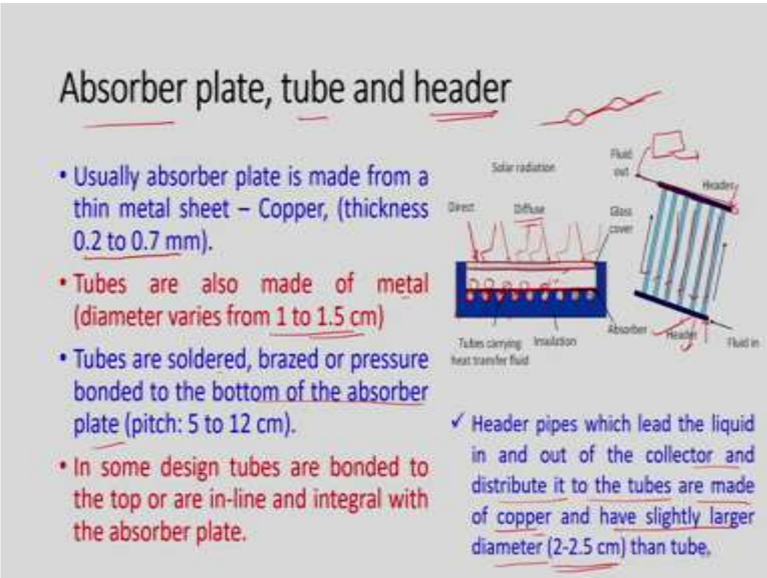

Now, let us have a look about the components. So, primary component is absorber plate then tube, then we need header. So, in this figure this is an absorber plate and these are the tubes through which heat transfer fluid flows and these are soldered here, in this tube. There are different configurations, sometimes we can have this kind of configurations, then we can get this kind configurations and there are different kinds of configurations are available.

There are many manufacturers for this kind of flat plate collectors. So, this is the absorber plate which is a primary component of a flat plate collector and we will have these tubes and these are the glass covers. There may be more than one glass covers and the direct radiation shows in the straight arrows and this is the broken arrows, this is for diffused radiation. And we have to provide sufficient insulation to reduce the heat losses.

This is the sectional view of a flat plate collector to show the glass cover, then absorber sheet, then tubes and this figure shows the tubes and headers. So, usually this absorber plate is made from a thin metal sheet, normally copper is used and thickness varies from 0.2 to 0.7 millimeter and these tubes are also made of metals and its diameter varies from 1 to 1.5 centimeter.

And tubes are soldered or brazed or pressure bonded to the bottom of the absorber plate. Sometimes it is also seen the tubes are attached at the top of the absorber plate this kind of configurations are also available. So, these headers, header pipes which leave the liquid in and out of the collector and distribute it to the tubes are also made of copper and have slightly larger diameter, its diameter varies from 2 to 2.5, so these 2 are the headers.

So, cold fluid enters here and then it distributes through these tubes and then hot fluids are collected here and that can be stored and this can be utilized based on that requirement. So, these are the headers, so these tube diameters are slightly larger than these tube diameters.

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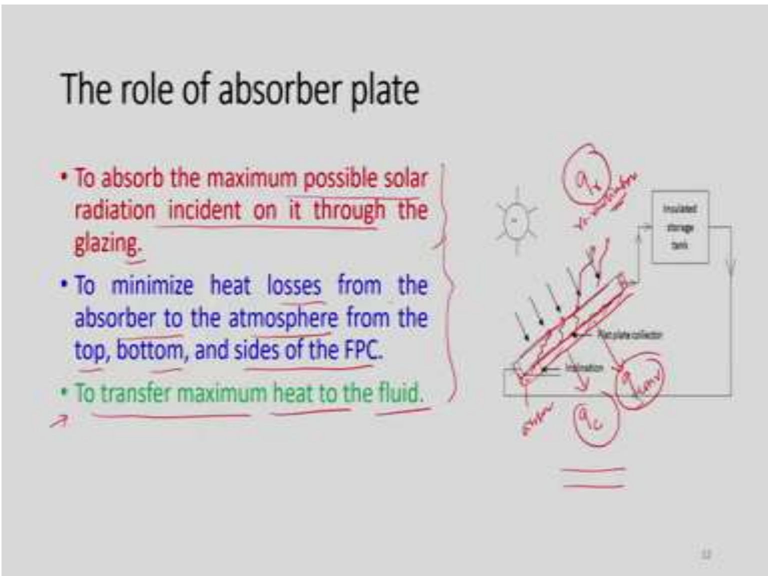

So, what is the role of absorber plate? So, primary role is to absorb the maximum possible solar radiation incident on it through the glazing. So, how this can be maximized? That is the first role of an absorber plate and then to minimize the heat losses from the absorber to the atmosphere from the top, bottom and sides of the FPC.

So, when we are talking about these, then solar radiation falls here and some losses will be there, then some amount of energy will be received in the absorber plate, this may be the absorber. Then what happens some radiation then goes back, so re-radiation will be there. So, these losses is normally high, this is re-radiation part which is taking place from that top of the flat plate collector.

And conduction and convection losses will be there from the sides and the bottom. So, from here conduction q_c and then convection q_{conv}, these losses will be there and this is q_r, re-radiation losses. Since these losses are really very very high. So, we need to do something to reduce those losses so that we can maximize that collector efficiency. And also the third role is to transfer maximum heat to the fluid. So, these are the primary roles of an absorber plate.

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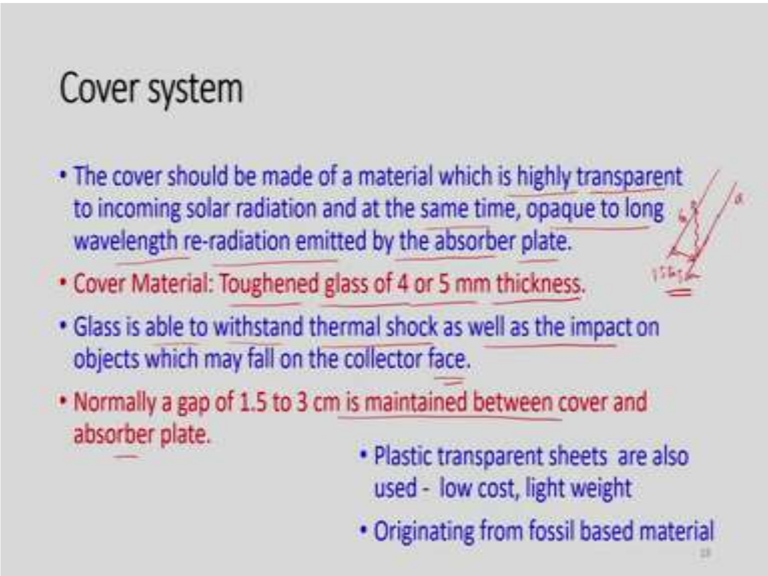

Now, let us see about cover system. The cover should be made of a material which is highly transparent to the incoming solar radiation and at the same time opaque to the long wavelength re-radiation emitted by that absorb plate. So, what I say, so this is the glass cover and then we will have this absorber plate. So, when it strikes, then some of the radiation goes back. So, this cover system has to be designed in such a way that this radiation know should be minimized.

And normally, for this cover system toughened glass of 4 to 5 mm thickness is used. Of course, nowadays plastic transparent sheets are also available, which are used in many of the developed countries because of its low cost and lightweight, but only to see the origin of the plastic, it is originated from fossil fuel. So, it will contribute to greenhouse gas emission. So, that way we need to think the kind of material to be used for a particular application.

This glass is able to withstand thermal shock as well as the impact on objects which may fall on the collector face. Normally a gap of 1.5 to 3 centimeters is maintained between the cover and the absorber plate so this distance is something like 1.5 to 3 centimeter is maintained between this cover and then absorber system.

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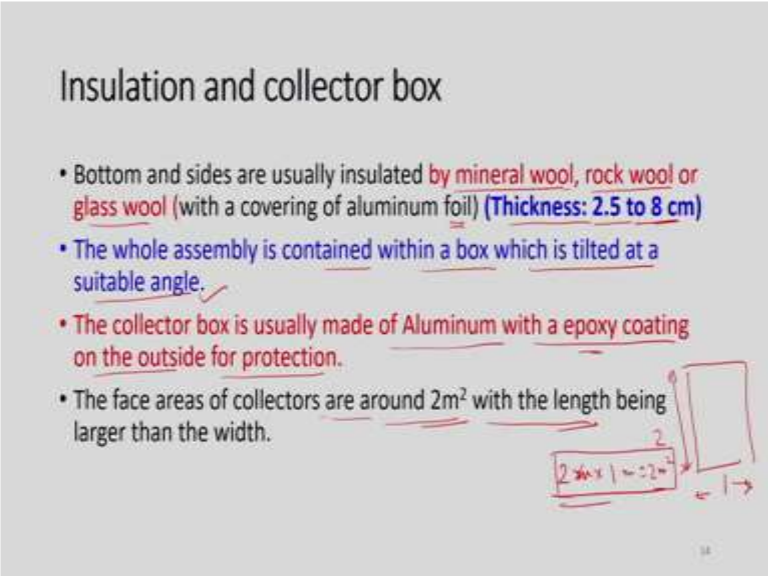

And also we need to think the kind of insulations to be used to reduce the heat losses in the collector system. So, bottom and sides are usually insulated by mineral wool or rock wool or glass wool, with a covering of aluminum foil. So, this thickness is about 2.5 to 8 centimeters, that thick insulation need to be provided to reduce the heat losses. And then the whole assembly is contained within a box which is tilted at a suitable angle.

So, that angle has to be fixed based on the location. The collector box is usually made of aluminum with a epoxy coating on the outside for protection. So, this kind of epoxy coating is also required. The face area of the collector are around 2 meter square with length. So, this is something like, this is maybe 2 and this may be 1 width is smaller than length. So, this configuration 2 meter by 1 meter will be 2 meters meter square. So, this is a standard collector which is available in the market.

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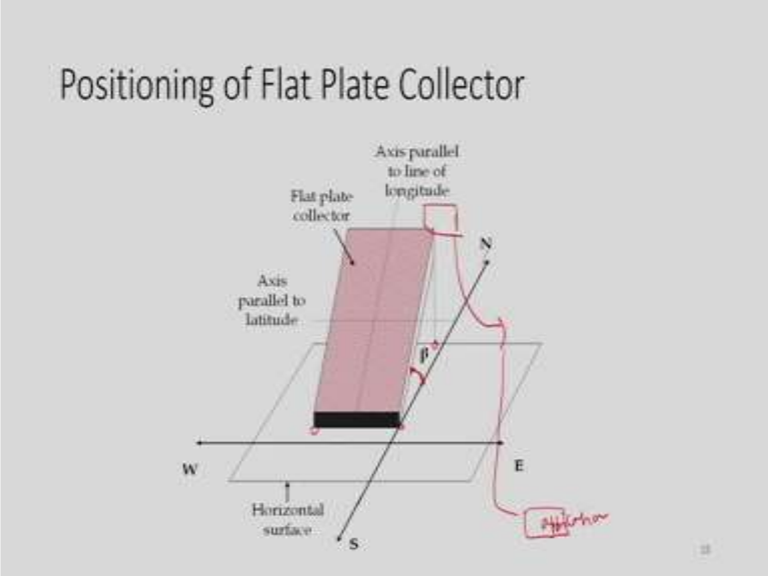

How to position a flat plate collector? So, as we know this is North, South, East and West and we have to install the flat plate collectors towards facing South or due South. So, that we can get maximum exposure to the solar radiation. So, this is the collector and we need some kind of frame to hold the structure, and we need to do some kind of civil work here to install and then we can collect the hot water from the storage bin here.

So, that can be piped and that can be utilized in day to day application. So, installation is made something like this and it has to be maintain some kind of tilt, in order to maximize solar radiation exposure.

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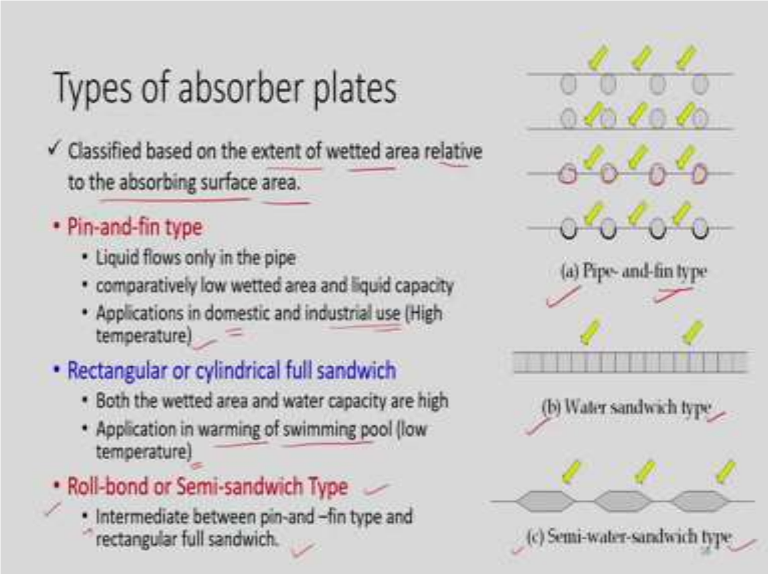

So, what are the different type of absorber plates available in the market? So, how these can be classified? So, these are classified based on extent of wetted area relative to the absorbing surface area. So, first configuration is the pipe and fin type, second one is water sandwich type and third one is semi water sandwich type. So, in case of pin and fin type, liquid flows only in the pipes, as you can see these are the pipes through which, this heat transfer fluid flows, there is no contact with the absorber plate.

And this is comparatively low wetted area and liquid capacity. And applications in domestic and industrial use, because high temperature can be generated by using this configuration and this can be used both in domestic and industrial applications. In case of rectangular or cylindrical full sandwich, both the wetted area and water capacity are high. And it can be applied in warming of swimming pools because it can generate low temperature fluid.

And final configuration is a roll bond or semi-sandwich type and this category is intermediate between pin and fin type and rectangular sandwich type and temperatures are also in between these 2 configurations. So, these are different the configurations are available in the market. So, based on the application we can select which one is appropriate for the particular application.

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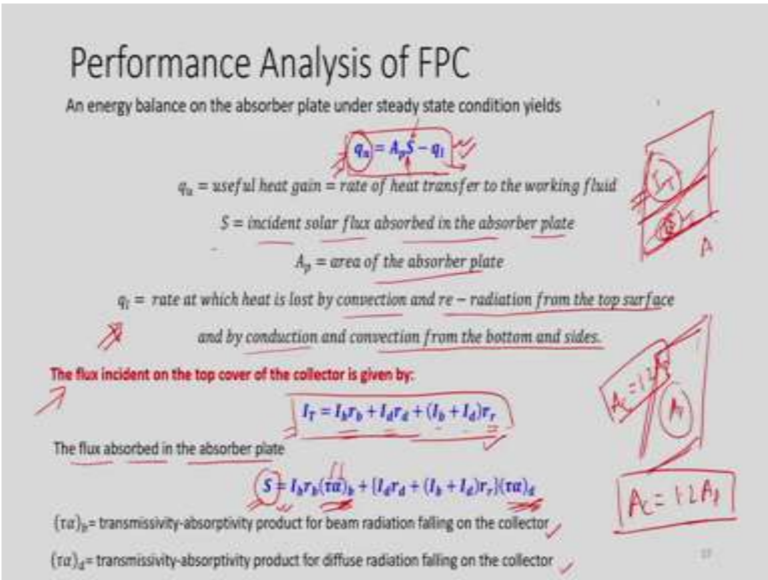

Now, come to the performance analysis of a flat plate collector. So, while analyzing the performance, we must pay attention to the energy balance on the absorber plate under a steady state condition. So, if we are interested to develop this energy balance on the absorber plate under a steady state condition, so we will get something like this. $q_u = A_p S - q_l$. What is q_u, it is the useful heat gain. This is nothing but the rate of heat transfer to the working fluid.

So, we are interested about this q_u only. So, how to maximize this q_u. So, if we minimize these q_l, then we can maximize. And if we can maximize this S, then we can know maximize this q_u. So, we will learn how this q_l can be calculated and how we can minimize these q_l losses and how this S can be maximized to get more useful heat gain. So, what is S? Is the incident solar flux absorbed in the absorber plate.

So, we have a glass cover and absorber plate, so we are talking about S. So, when solar radiation is coming from the sun, so we will say It, the amount of solar radiation received by the glass cover is different than the amount of solar radiation received by the absorber plate. So It is different than S, we need to maximize the S and A_P is the area of the absorber plate, this is the area of the absorber plate. So, this will be something like this.

So, this will be something like this. So, this kind of system it will be, so this is the area the absorber not the collector or just the inside of absorber plate. So, when we talk about collector, so this will be A_C it includes those glass cover. So, normally this A_C is about 1.2 times A_P. So, this A_C is actually 1.2 times of A_P. So, normally it is specified and q_l is the rate at which heat is lost by convection and re-radiation from the top surface and by conduction and convection from the bottom sides.

So, this need to be critically analyzed to reduce the heat losses. So, if we are interested about the flux incident on the top cover of the collector, then how to calculate it. So, this It already we have done the derivation of this expression in the earlier classes. So, this $I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$. So, this is known to us and this gives this It the amount of radiation which is falling on the collector.

So, now we are interested about the flux absorbed in the absorber plate. So, for S, now it is for S. So, if we are interested for S then what we need to do we need to multiply this expression with $(\tau\alpha)$ for beam radiation then $(\tau\alpha)$ for diffused radiation. As we know these flat plate collectors utilizes both direct component as well as diffused component of the radiation.

So, both the things we need to consider here. So, this $(\tau\alpha)_b$ is the transmissivity absorptivity product for beam radiation falling on the collector and $(\tau\alpha)_d$ is a transmissivity absorptivity product for diffused radiation falling on the collector.

So, in order to calculate S we need to understand what is τ and what is α for beam and diffused radiation. So, we must know this then only you can calculate S and then we can calculate q_u of course, we need to know what is q_l. Let us learn how to calculate this $(\tau\alpha)_b$ and $(\tau\alpha)_d$.

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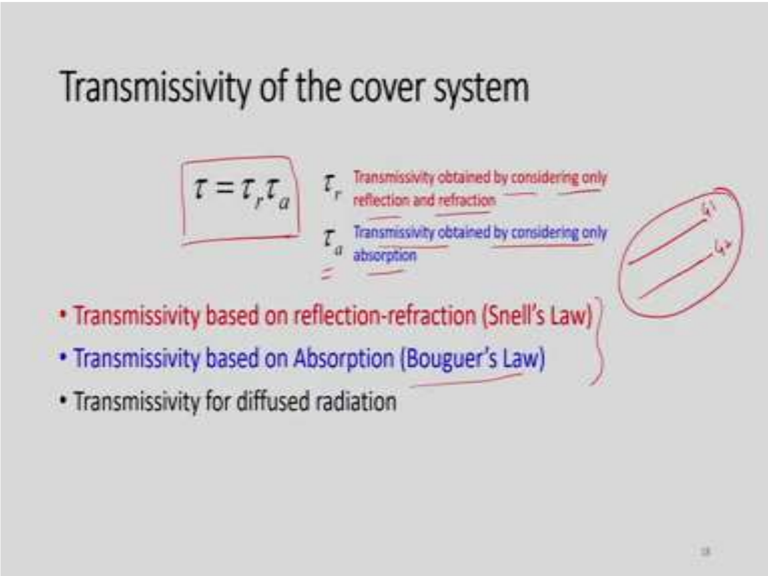

Now, this transmissivity of the cover system. So, we are talking about this cover system only. Suppose to glass covers are here, so glass cover 1 glass cover 2. So, we need to see how these radiations are behaving and what will be the transmissivity of the cover system. So, without knowing this transmissivity we cannot calculate this S or amount of flux received by the absorber plate. So, this τ is a function of τ_r and τ_a. What is τ_r?

So, this is transmissivity obtained by considering only reflection and refraction. So, we need to rely on Snell's law and this τ_a is transmissivity obtained by considering only absorption. So, in order to find out this τ, then we need to use Bouguer's law. So, when we are interested for transmissivity based on reflection and refraction, we will use Snell's law and when we are interested for transmissivity based on absorption, then we will use Bouguer's law.

And these Laws are applied for both diffused and normal radiation. So, at what condition we can consider the τ value for diffused radiation? Once you know the τ value for normal radiation at different incidence angle.

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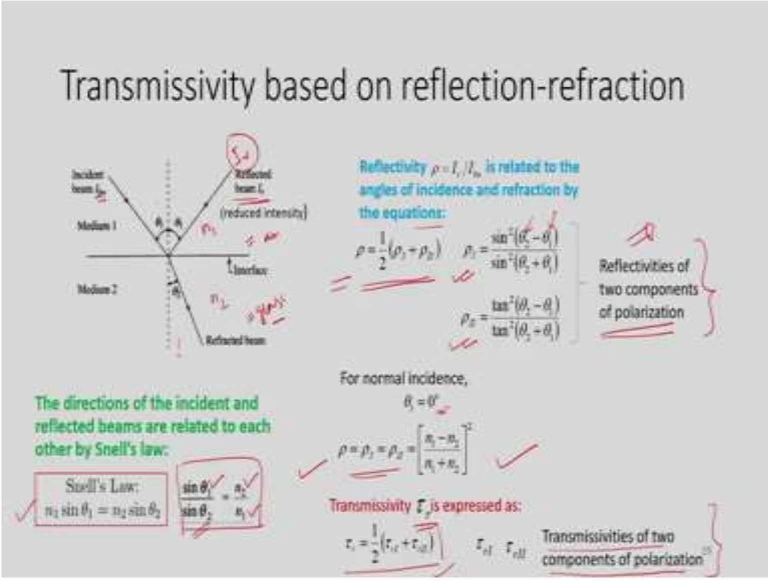

Now, let us learn what is Snell's law. So, if you consider a beam of light that is striking on the interface. So, this may be 1 medium and this may be other medium maybe this is air or this may be glass for our case. So, this beam strikes on this interface at an angle θ_1, this is angle of incidence and this direction of the reflected beam can be demonstrated by this θ_1 which is angle of reflection.

So, θ_2 is the angle of refraction because of these refractive indices. So, this direction of the incident and the refracted beams are related to each other by Snell's law. How can you define the Snell's law? $\sin\theta_1$, this is $\frac{\sin\theta_1}{\sin\theta_2}$ is equal to n_2 if we consider the refractive index of this medium is n_2 and this is for 1, n_1 for this medium then $\frac{n_2}{n_1}$, this relationship gives if we know this n_2 and n_1 and θ_1 of course we can calculate what is angle of refraction.

And this beam has got reduced intensity, this I_r, because this I_{bn} strikes and then some amount of radiation goes into the other medium and then it is reflected. So, this reflectivity that is ρ, this I_r if we consider this is an I_r and this is I_{bn}. So this $\frac{I_r}{I_{bn}}$ that fraction of energy which is reflected is related to that angle of incidence and reflection by the following equations. So, this $\rho = \frac{1}{2}(\rho_I + \rho_{II})$, that is average of ρ_I and ρ_{II}.

What is ρ_I and ρ_{II}? These are the reflectivities of 2 components of polarization. So, mathematically this can be expressed something like this, $\rho_I = \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)}$, θ_2 is the angle of refraction θ_1 is the angle of reflection. And for this second component we will have $\rho_{II} = \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)}$.

So, this are the reflectivities of 2 components of polarization. So, if you are interested to know about the polarization please refer some standard books to know how polarization happens. For a special case, if θ_1 is 0 if this beam of light is incident normally and θ_1 is 0 then under the condition what will be the ρ? $\rho = \rho_I = \rho_{II} = \left[\frac{n_1 - n_2}{n_1 + n_2}\right]^2$ this is the expression.

And similar analysis can be carried out for transmissivity, τ_r which is nothing but average of τ_{rI} plus τ_{rII}. What is τ_{rI} τ_{rII}? They are transmissivity of 2 components of polarization. So, this information is very very important while calculating τ first we must know τ_r then τ_a then finally we will calculate what is τ.

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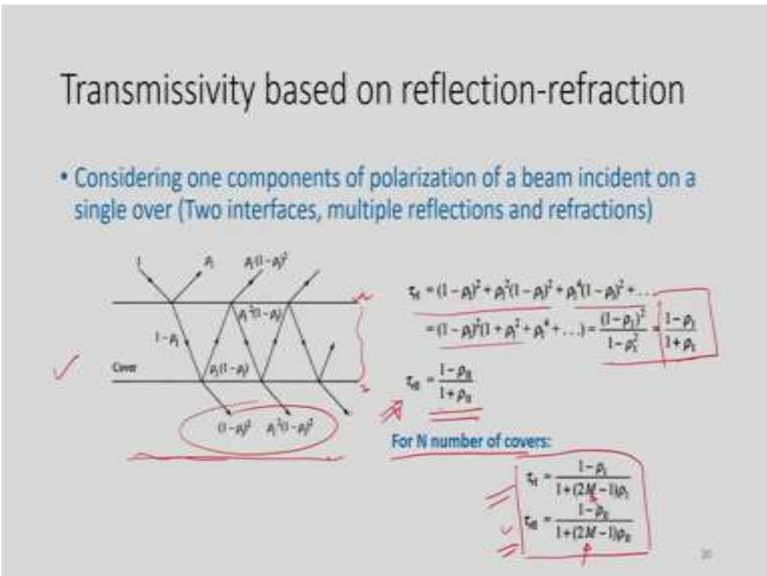

Now in continuation, the considering one component of polarization of a beam incident on a single cover. So, here only single cover is used. So, this as the whole this is a glass. So, there are 2 interfaces, interface 1 and interface 2 and there are multiple reflections will takes place. So, if we consider a beam of light, when it strikes on the interface 1 it is reflected, some amount of radiation goes to the atmosphere and then some amount will travel through this glass cover.

And when it strikes this know interface 2, some component of radiation will again reflected and then some component goes back to that atmosphere and some components will be transferred to the absorber, so the absorber will be here. So, this will continue infinitely. So, if we add these components, amount of transmitted energy, which is going to strike on the absorber, we can add all those components and we can sum it in what will give this expression we will get.

$\frac{1-\rho_I}{1+\rho_I}$. Similarly, we can do it for the other component of polarization, it will be something like this $\frac{1-\rho_{II}}{1+\rho_{II}}$. So, this is a case for single cover this is a glass cover interface 1, interface 2 and these many things are happening inside this glass cover. If there are more number of glasses, then situation will be different. So, under condition we need to use these 2 expressions, for τ_{rI} and τ_{rII}.

So, what difference is? That is M is the number of cover, so number of cover system maybe 2 cover normally 2 covers are optimum if selected coatings are not applied. We will discuss what is selective coating, what is the importance of selective coating. If we apply selective coating on this absorber plate, there is 1 glass cover is enough to harvest sufficient amount of energy.

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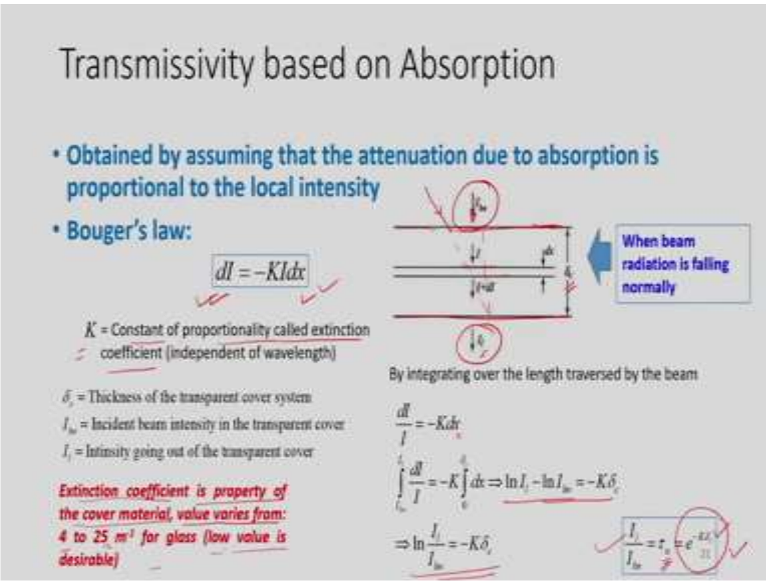

So, now, come to the transmissivity based on absorption. So, this is obtained by assuming that attenuation due to absorption is proportional to local intensity. So, which law tells us about this, it is a Bouguer's law. So, this is something like $dI = -KIdx$. If we consider this configuration where normal radiation is falling perpendicular to this plate, then what happens?

That we will discuss all of course, we will discuss when no solar radiation falls at certain angles, then what happens to this configuration. So, both the case we will study one by one. So, what is K, K is the constant of proportionality and also call extinction coefficient which is independent of wavelength. And if you consider this cover system and thickness of the cover, if we consider δ_C, and if we take a small section here in between this cover system having K now thickness is dx and I, the amount of radiation, what is striking on this side and other side is I plus dI.

So, if we rearrange these values, like $\frac{dI}{I}$ for our own purpose, minus Kdx and if we integrate from I_{bn} to I_l. So, what we will get? we will get this kind of expression. And finally, we will get this and then we will have $\frac{I_l}{I_{bn}} = \tau_a = e^{-K\delta_C}$, .So, this extinction coefficient is property of the cover material, but it is independent of the wavelength. And its value varies from 4 to 25 for glass.

So, lower value is always desirable for this kind of applications because it will give more transmitting range. So, here what happens, this is the incident beam intensity and I_l is the intensity of outgoing radiation. So, we can relate these 2 and we can find out what will be the tau a, that means transmissivity based on absorption, when the beam radiation is falling normally.

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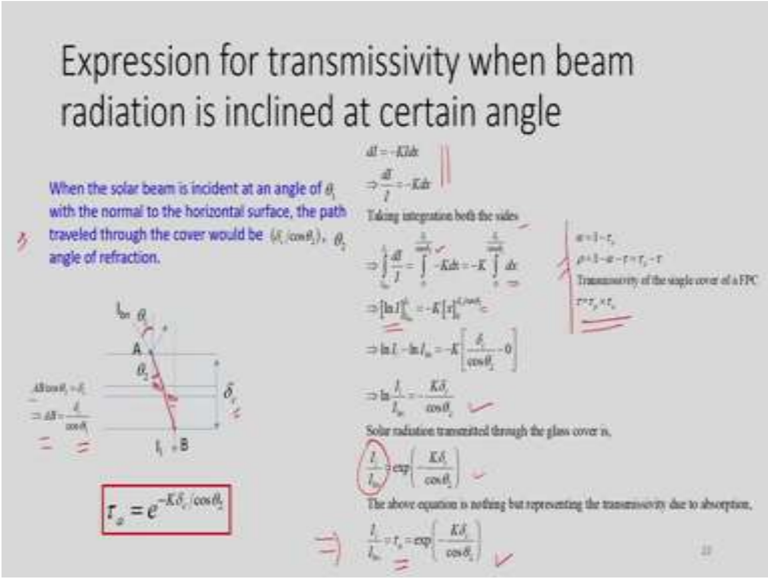

So, if the beam radiation is falling at certain angles, then what will happen to the expression of transmissivity due to absorption. So, our exercise goes something like this, when the solar beam is incident at an angle of θ_1. So, this is the angle of incidence θ_1 with the normal to the horizontal surface and the path, travel through the cover v. So, this is θ_2, is the angle of reflection. So, this thickness is δ_C, already we know and this is the length if we point this as A and this point may be B.

So, what can make A B this is cos of if this is θ_2, this is also θ_2, $AB\cos\theta_2 = \delta_C$. So, $AB = \frac{\delta_C}{\cos\theta_2}$. So, we use that same equation $\frac{dI}{I} = -Kdx$ and we integrate both the sides. Now distance will be 0 to δ_C by $\cos\theta_2$. So, if we do the integration, so we will get something like this and $\frac{dI}{I}$ is ln I from I_{bn}.

So this is from I_{bn} this is I_l. So integrating is from I_{bn} to I_l and then minus Kx, because integration of dx, x it will vary from 0 to $\frac{-\delta_C}{\cos\theta_2}$ and if we substitute their then we will get this kind of equation. And if we are just to know about $\frac{I_l}{I_{bn}} = \exp\left(\frac{-\delta_C}{\cos\theta_2}\right)$,

So, this type of equation is nothing but representing the transmissivity due to absorption when this beam radiation is falling at certain angles, with the normal to the horizontal surface. So, this expression will be something like $\frac{I_l}{I_{bn}} = \tau_a$ which is nothing but $\exp\left(\frac{-\delta_C}{\cos\theta_2}\right)$.

So, once we know this we can also calculate τ, then ρ and then we can calculate the transmissivity of the cover system.

So, this is r and this is τ.

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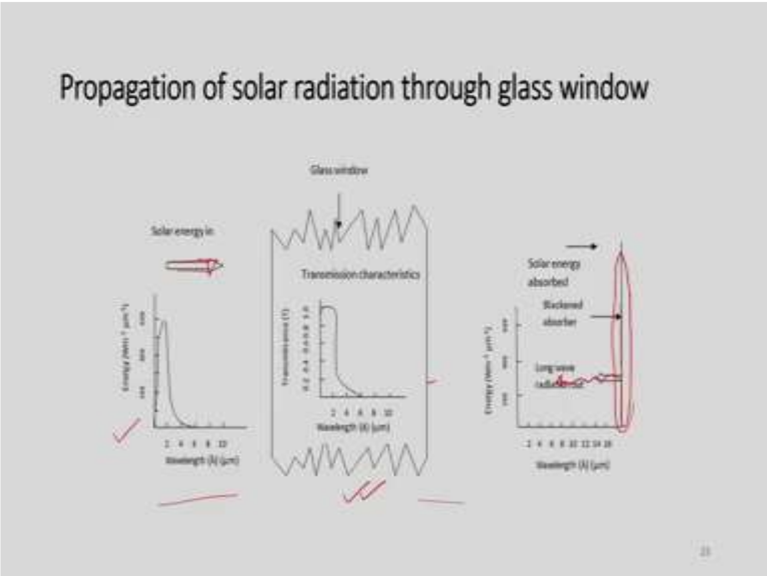

So, how this solar radiation propagates through glass window? So, if we consider this is a glass window and solar radiation is coming from the sun and it passes through this glass cover and then what happens inside this collector. This is an absorber, this is long wave radiation will come out once it strikes and this is a absorber, it is a blackened surface normally, it absorbs the radiation.

So, what happens, this phenomena is presented here this is the energy which is coming from the sun striking on the glass cover and then it goes inside the flat plate collector and then long wave radiation emitted by the absorber and then it goes out, some of the radiation from the glass cover. So, that is how it shows how the solar radiation propagates through glass window.

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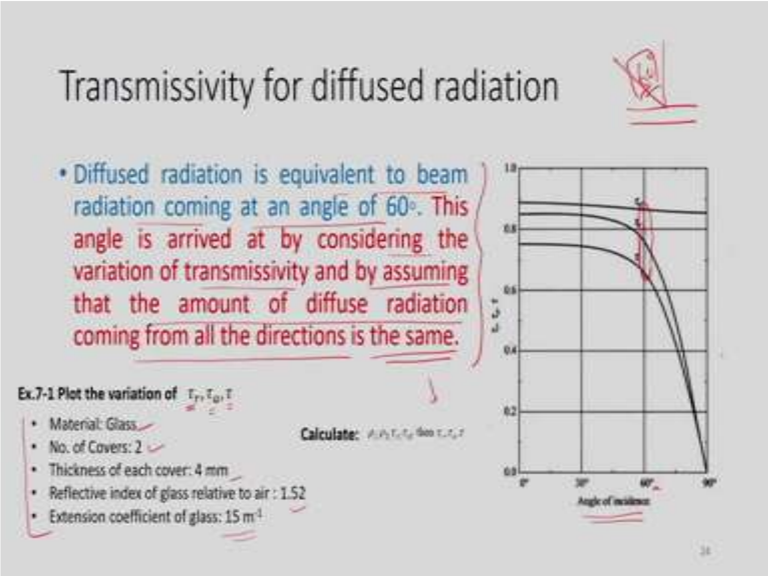

Now, this transmissivity for diffused radiation. So, what we have discussed so far it was transmissivity for normal radiation. So, this diffused radiation is equivalent to beam radiation coming at an angle of 60 degree. If this angle, so this is a system and if this angle is 60 degree, so then what we can consider, so it is a value for diffused radiation. This angle is arrived at by considering the variation of transmissivity and assuming that the amount of diffused radiation coming from all the directions is same.

So, under that condition we can do this, because it is very difficult to predict because it has no direct direction. So it is anisotropic. So, we can also plot this variation of $\tau_r \tau_a$ and τ for this example. Maybe we can take glass, then number of covers then thickness of each cover, then reflective index of glass leading to air to here is 1.5 to extinction coefficient is 15.

So, we can develop this plot by varying the angle of incidence. So, we can use the equations what we have discussed and we can generate this kind of plot for tau, tau r and tau a. So, at this 60, so once we got this value here, so the radiations which is coming at an angle of 60 can be considered now radiation value for diffused radiation. So, let us do one exercise to strengthen our understanding how to calculate this tau.

So, in order to calculate this τ, we need to know what is τ_r and τ_a and those are components.

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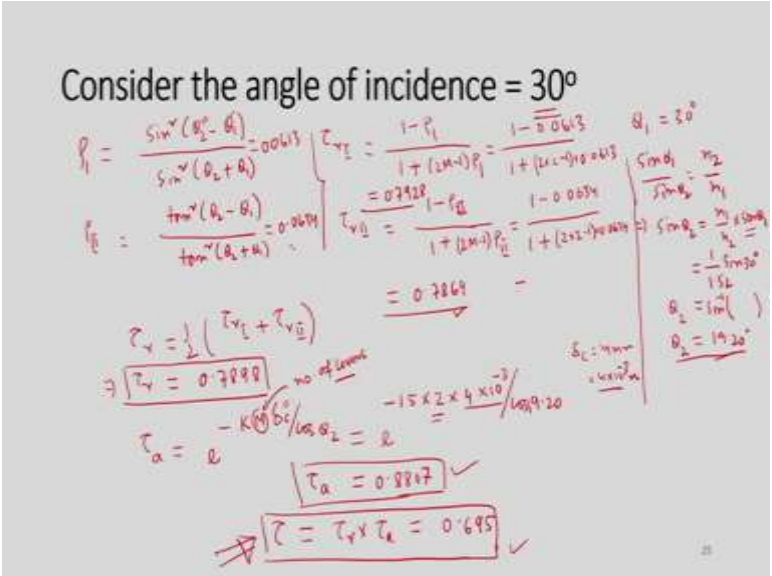

So, taking the same problems and taking the angle of incidence 30 degree. So, let us now calculate what is ρ_I. So, already we know what is $\sin^2(\theta_2 - \theta_1)$, and then $\sin^2(\theta_2 + \theta_1)$and $\rho_{II} = \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)}$. And also we know that τ_{rI} and τ_{rII}.

So, what is τ_{rI} and τ_{rII}? $\tau_{rI} = \frac{1-\rho_I}{1+(2M-1)\rho_I}$ $\tau_{rII} = \frac{1-\rho_{II}}{1+(2M-1)\rho_{II}}$. Before that we must know what is θ_2, so θ_1 is known to us, θ_1 is 30 degree and in order to calculate θ_2 already we know $\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$ by using Snell's law. And from there we can calculate what is $\sin\theta_2$ will be $\frac{n_1}{n_2}$, then this will be $\sin\theta_1$.

So, if we substitute these values, so this is 1, this value is 1.52 and then we will have sin30. So, this will give, θ_2 is something like sine inverse of this value once is calculated. So, this value, this will give a value of 19.20 degree. So, θ_2 will be 19.20. So, now, if we substitute this value here θ_2 and θ_1, θ_1 is known as 30 and then θ_2 we have calculated is 19.20. So, this value, once you calculate this will be 0.613 and this value is 0.0634.

So, once we utilize this here, so in this expression $1-\rho_I$ is 0.613, divided by 1 plus how many covers, 2 covers are there, so 2 into 2 minus 1 into 0.613. Similarly, we will have the value for τ_{rII}. So, this is 1 minus 0.0634, I think this is somewhat wrong, these values I think

0.0613. And now this is $1+2(2-1)0.0634$. So, this value I can write here this value is 0.786, 69 I can write to be precise. And here it is 0.7928, so this is for τ_{rI} this is for τ_{rII}.

So, once we know τ_{rI} and τ_{rII} then we can calculate what is τ_r which is nothing but average of $\tau_{rI} + \tau_{rII}$. So, on substitution what we get, τ_r value will be 0.7898. And now we need to calculate τ_a, we know the expression $\tau_a = e^{-KM\delta_C/\cos\theta_2}$. We have delta m is number of glass cover and then we have $\cos\theta_2$.

So, this extinction coefficient is given as 15 and number of cover is 2 and then this δ_c is $4\,mm \times 10^{-3}$ if we have to convert it to meter. Then we will have $\cos\theta_2$ we already have calculated, it is 19 point, 19.20. So, this will give a value of 0.8807. So, this is tau a and this component was tau r. Now, immediately you can calculate what is tau. This τ is nothing but τ_r multiplied by τ_a.

So, if we multiply both these terms what you will get is the transmissivity of the cover system. So, this is something like 0.695. So, we should not confuse about this M, M is the number of covers. So, in this case it is 2, that is why it is multiplied by 2 and it was given δ_c was 4 mm so that is why it is 4×10^{-3} meter. So, on substitution what we get this τ_a and finally, what we have calculated is τ, its value is 0.695. It is transmissivity of the cover system.

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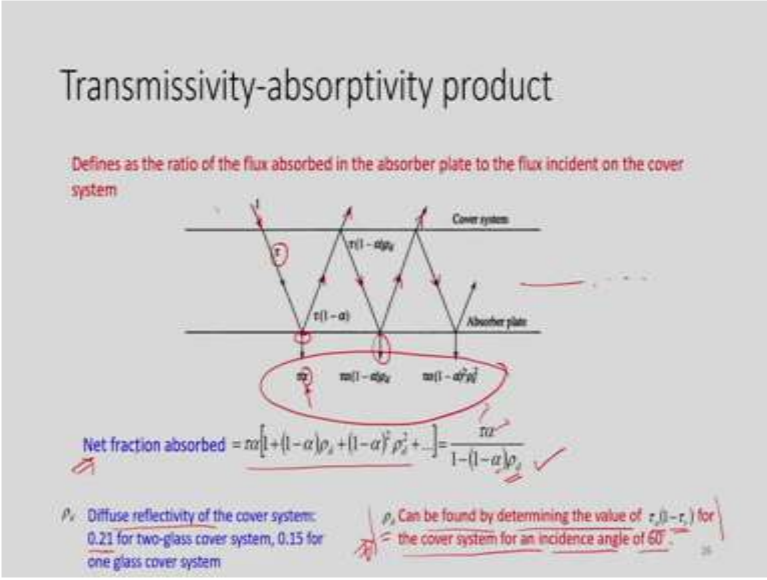

Now, let us also learn about transmissivity absorptivity product. So, which defines the ratio of flux absorbed in the absorber plate to the flux incident on the cover system. So, if we consider a beam of light and it transmitted through this cover system and maybe this τ what we have calculated now, this τ will introduce here and it will strike on the absorber plate. Once it strikes on the absorber plate what happens it is reflected some component will be absorbed here.

So, this α will come here, some absorptivity will be there. So, what happens we need to maximize this α. How to maximize it? That we will discuss like we need to apply some kind of coatings here, so that we can maximize the absorptivity. And when it travel through this line again it will move out from the cover system some losses will be there and from there beginning it will be reflected back to the absorber, then it will absorb some component and again it will reflect some component and it will goes off from the cover system and from that again it will come and it will continues infinitely, it will continues infinitely.

So, if we sum these values then what we will get, that much off energy will be absorbed in that absorber plate. So, that net fraction absorbed will be something like this. So, this component is common. So, we can take common from all the expression and we can now make this kind of summation. So, what is a ρ_d here? So, this is a diffused reflectivity. So, that has to be calculated.

So, normally what happened? This diffused reflectivity of the cover system is considered to be 0.21 if 2 glass cover systems are used. And 0.15 for single cover system if it is used in operation. And this ρ_d can be found by determining the value of $\tau_a(1-\tau_r)$ for the cover system for an incidence angle of 60 degree. So, this is the procedure by which you can calculate what is ρ_d.

So, once we know this ρ_d then we can substitute here and these values are known this has already been calculated this is the property of the material, what is used as the absorber plate and when some kind of coatings are applied, so we must know what is the absorptivity of the coating or selective coating. And this is known, so we can calculate what is the net fraction of radiation absorbed in the absorber plate. So, this is how we can calculate and this we need to understand very carefully, then only we can feel how a flat plate collector can be designed and what is the complexity in designing a flat plate collector.

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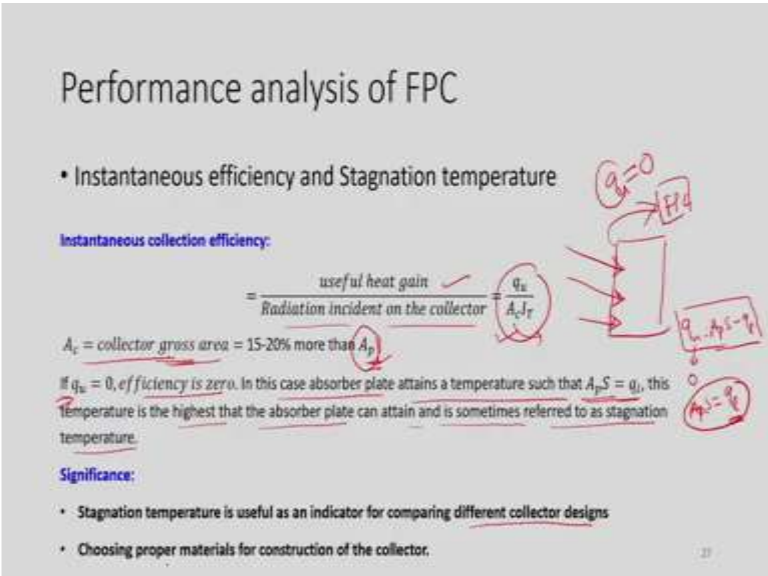

Now, we must know two important parameters, one is instantaneous collection efficiency and other one is stagnation temperature, they are related. So, how do you define instantaneous efficiency? It is useful heat gain as I have discussed this issue in the earlier slides. Useful heat gain to the radiation incident on the collector which is nothing but $\frac{q_u}{A_c I_T}$. So, here we have used A_C as I said this collector area is 15 to 20 percent more than A_P.

That is how it is more and this is the absorber area. So, sometimes we need to define this in terms of A_C and sometimes you can define in terms of A_P. If for example, this collector were not collecting any heat from this FPC. No heat is collected means no useful heat, but solar radiation is falling. So, if no heat is collected, but solar radiation is falling on the flat plate collector then what will happen, this q_u we will be 0.

So, under the condition what will happen instantaneous efficiency will be 0, but already you know this $q_u = A_p S - q_l$. So, if this part is, this is the energy balance equation, already we know on the absorber plate when we write the energy balance equation. So, this part is 0 means $A_P S$ is equal to q_l. So, that is how if q_u is 0 efficiency is 0 in this case absorber plate attains a temperature, such as that $A_P S$ is equal to q_l.

So, the amount of energy what is received in the absorber plate is equal to the loss, no energy is utilized. So, this temperature is the highest that the absorber plate can attain and is sometimes referred to as stagnation temperature that is the maximum temperature attained by a flat plate collector. So, what is the significance of this stagnation temperature. So, this is an useful indicator for comparing different collector designs.

So, once we know the stagnation temperature for a particular flat plate collector, we can know compare the performance with the others. Also, this is helpful in choosing proper material for construction of collector. So, this stagnation temperature plays a key role in comparing the flat plate collector as well as selecting the right material for right collectors. So, this 2 parameters are very very important as far as performance analysis of a flat plate collector is concerned. So, now, let us summarize what we have discussed in this class.

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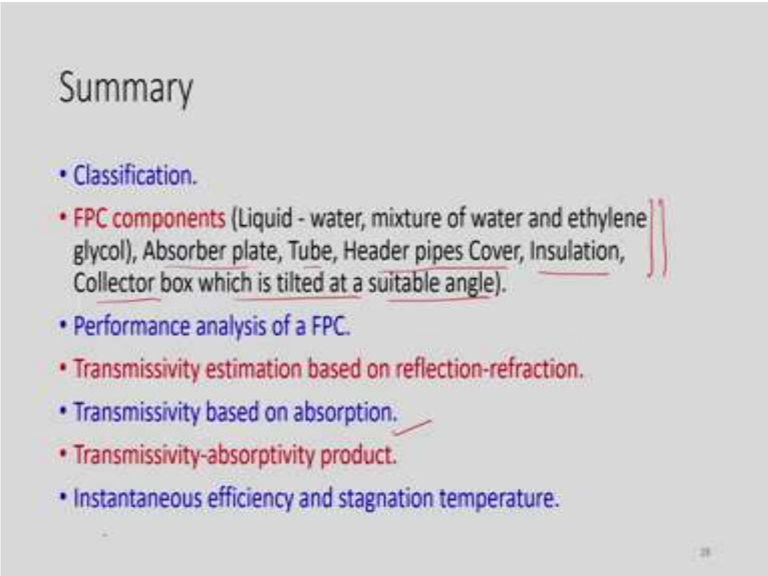

So, initially we have classified the different collectors and we have learned the different components of a flat plate collectors and the kind of heat transfer fluid normally used for this kind of collectors. So, heat transfer fluid like water, mixture of water and ethylene glycols are also used when the temperature of the surrounding goes below 0 °C and the primary component of a flat plate collector are absorber plate, then tube, header pipe, cover, insulation, then collector box which is tilted at a suitable angle.

So, these are the primary components and how these can be installed for harvesting solar energy. And also we have studied the performance analysis of a flat plate collector and we have studied transmissivity estimation based on reflection-refraction and absorption and also we have studied the significance of transmissivity and absorptivity product and finally, we have discussed the importance and significance of instantaneous efficiency and stagnation temperature. Hope you have enjoyed this video. So thank you very much for watching this video.