Renewable Energy Engineering Solar Wind and Biomass Energy Systems

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Lecture – 5
Non-Concentrating Solar Collectors: Part1

Hi everyone today in renewable energy engineering solar wind and biomass energy system we are going to discuss about lecture 4 which is about non concentrating collectors before going into the actual lecture of 4.

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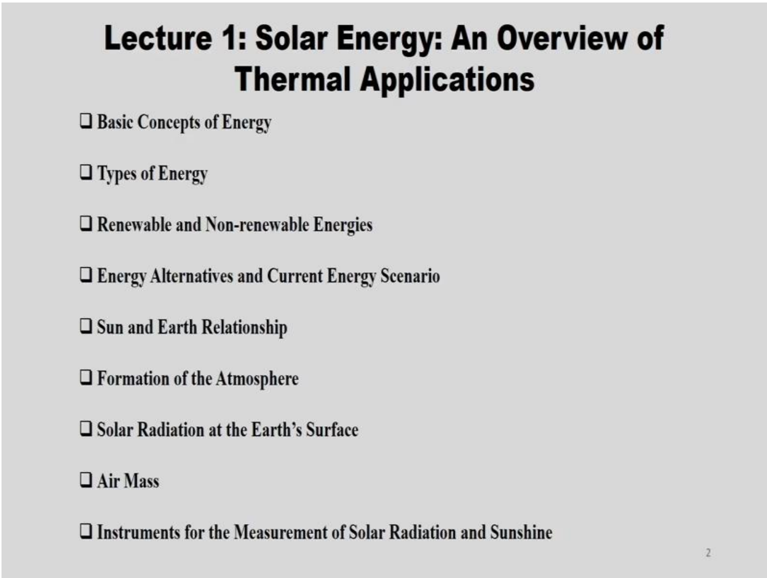

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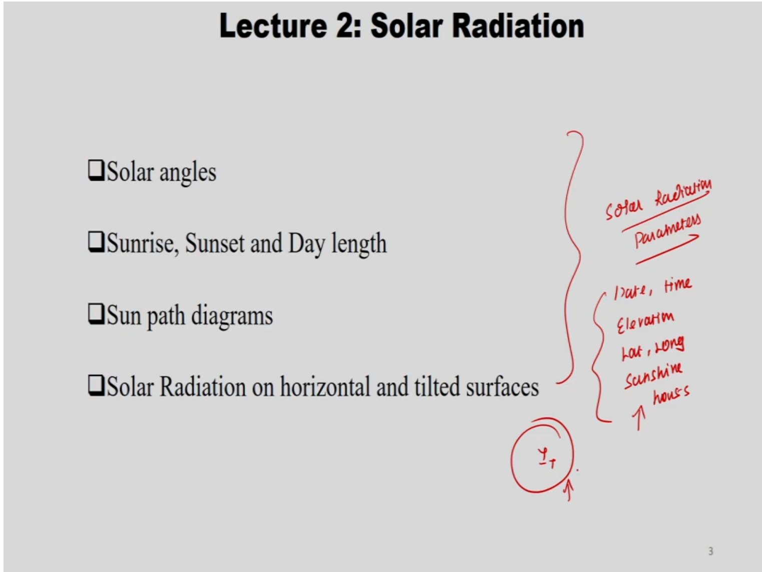

So we will review what we have discussed or learned at last week that is lecture 1 and lecture 2. Lecture 1 was all about the basic concepts of energy types of energy renewable and non renewable energies energy alternatives and current energy scenario. And we also had seen about sun and earth relationship and formation of the atmosphere and solar radiation at Earth's Surface air mass and instruments to measure the solar radiation and sunshine along with that we reviewed some of the major solar thermal applications as well.

And in lecture 2 we mostly learned how to calculate various solar radiation parameters which includes all solar angles sunset, sunrise and day length and sun path diagrams and solar radiation on horizontal and tilted surface. So till then we presume that we know how to calculate solar radiation parameters based on given environmental parameters like for example date of the year, time of the day and then elevation of the location and their latitude longitude and then the sunshine hour’s etcetera.

And we also learned how to get these parameters sometimes for example sunshine hours we know how to calculate from the given other parameters. So it is basically whatever the parameters you are given or you are available with which how to calculate solar radiation parameters and also before calculating that we had seen the Sun and Earth relationship and formation of that atmosphere.

And what is DNI what is DHI what is GHI and beam radiation global radiation and then diffusive radiation how to calculate them in the horizontal surface and tilted surface etcetera and after that we also have done some practice problem on lecture 3. So from that we know how to calculate the I T that is total radiation falling on the surface of the collector.

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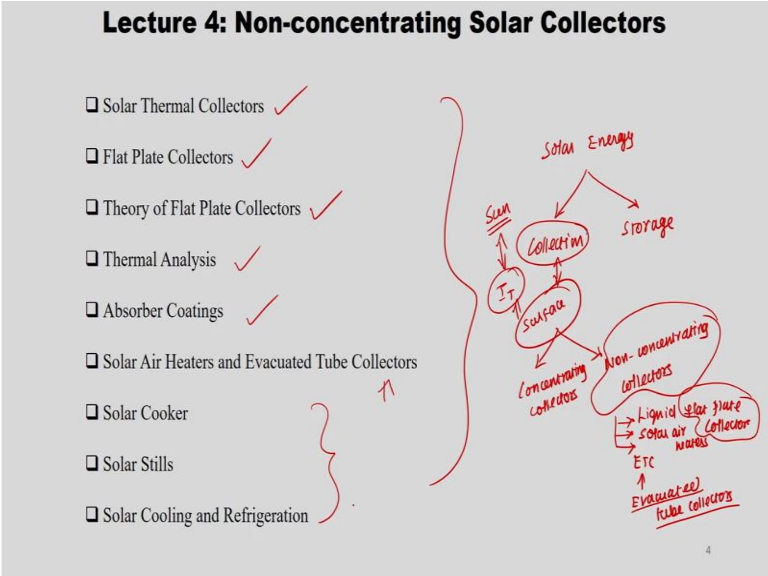

So now in today's lecture we are going to see about non concentrating collectors. So in the solar energy harvesting there were 2 main terms we discussed in first lecture or an introduction lecture itself. So one is collection how do I collect the solar radiation and then how to store them for off sunshine hours. So these 2 are critical. So in the first 2 weeks we are going to concentrate on this. So first collection we need to convert sun's energy into I T which is nothing but total radiation falling on a surface whether it is a horizontal or tilted.

So we are talking about surface so what is that surface and how do we collect that I T on a surface. So there comes 2 categories one is concentrating collectors second one is non concentrating collectors. So we will review in detail about non concentrating collectors. So in that there would be 3 major categories we are going to discuss in this course. So one is about liquid flat plate collector, second one is solar air heaters, third one is ETC that is a evacuated tube collector.

So basically we are going to see FPC in that liquid type as well as air if the fluid is liquid or water then it is called liquid flat plate collector if the fluid is air which harvests the solar energy into useful heat for various applications that is called solar air heaters, evacuated tube collectors there is a vacuum between 2 tubes outer tube and inner tube. So that is the way we reduce the convection **losses.**

So basically this is what we are going to discuss common solar thermal collectors and then that theory of flat plate collector then thermal analysis and absorber coatings so to increase the absorbing radiation and then solar air heaters and evacuated tube collectors and in the application side solar cooker solar stills and solar cooling and refrigeration this already we have reviewed but still using FPC we will see how it can be done.

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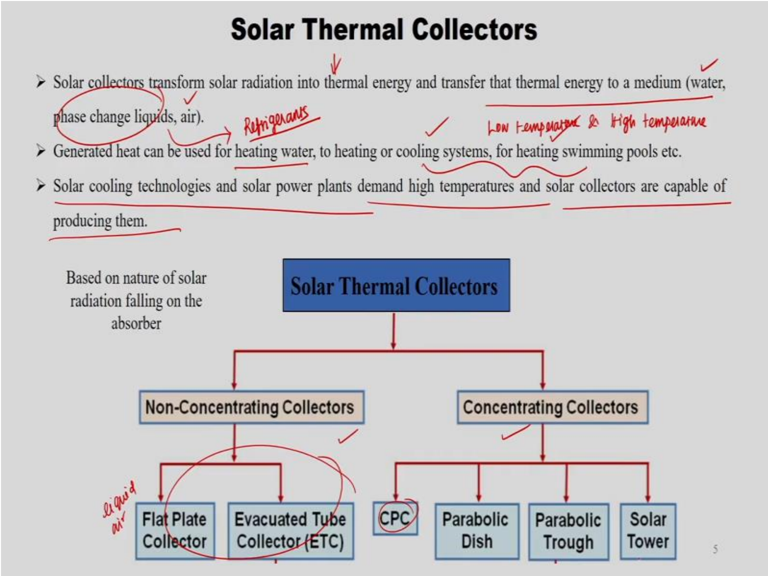

Usually solar collectors transform solar radiation into thermal energy and transferred that thermal energy into a medium. So it may be water or it may be air that we have seen and sometimes it may be a phase change liquids nothing but refrigerants. So this generated heat can be used to for heating water simply water heating or to heating or cooling systems are sometimes for heating swimming pools etcetera.

So basically it is for low temperature applications as well as high temperature applications low temperature as well as high temperature applications. So based on this temperature range only we divided them into non-concentrating and concentrating type the solar thermal collectors also used for solar cooling technologies as well as for solar power plants which demand high temperatures and solar collectors are capable of producing them.

So it may not be non-concentrating collector but concentrating collectors are able to produce the high temperature which is required for solar power plants as well as solar cooling technologies. So based on the nature of solar radiation falling under absorber so it is divided into non - concentrating and concentrating. So this is what we are going to see here. So in this liquid as well as air but in concentrating collector we will review about certain terminologies used and then CPC parabolic dish, parabolic trough and solar tower.

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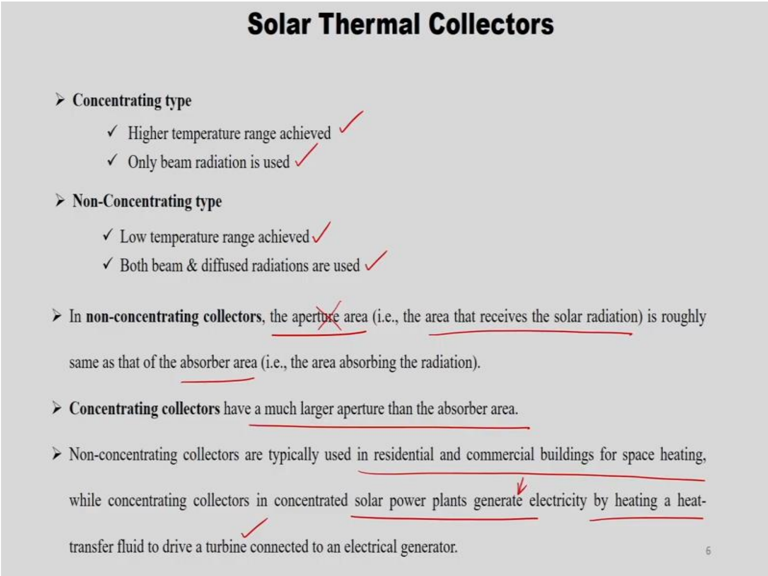

So concentrating type we can get higher temperature range achieved and only beam radiation is used and in a non concentrating type we can serve for low temperature range applications and were in non concentrating type both beam as well as diffused radiation are used and in non concentrating collectors the aperture area which is nothing but an area that receives the solar radiation is roughly same as that of absorber area absorber area aperture area both are same.

So we do not use this word of aperture we normally use the word of absorber for concentrating collectors they have much larger aperture area compared to absorber area. Non concentrating collectors are typically used in residential and commercial buildings for space heating applications while concentrating collectors in concentrated solar power plants generate electricity by heating a heat transfer fluid to drive turbine connected to one electric generator. So this is basically a power plant in solar power plant we use concentrating collectors because high temperature ranges required.

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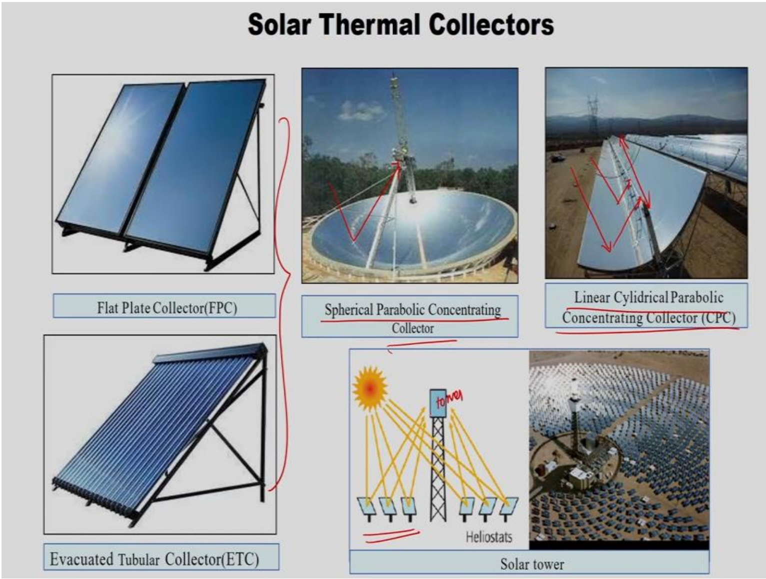

So this is basic installed concentrating and not concentrating collectors diagrams. So these both are non concentrating this is simple flat plate collector and this is evacuated tube collector and these 3 are concentrating collectors. So this is spherical parabolic concentrating collectors so that is point concentration. So this is linear cylindrical parabolic collector which is nothing but CPC. So this is linear. This is the absorber tube radiation comes and reflects to the linear absorber tube solar cover also same principle. So we have heliostats where sun's energy that reflects back to the point. So this is nothing but a tower. So it points to tower.

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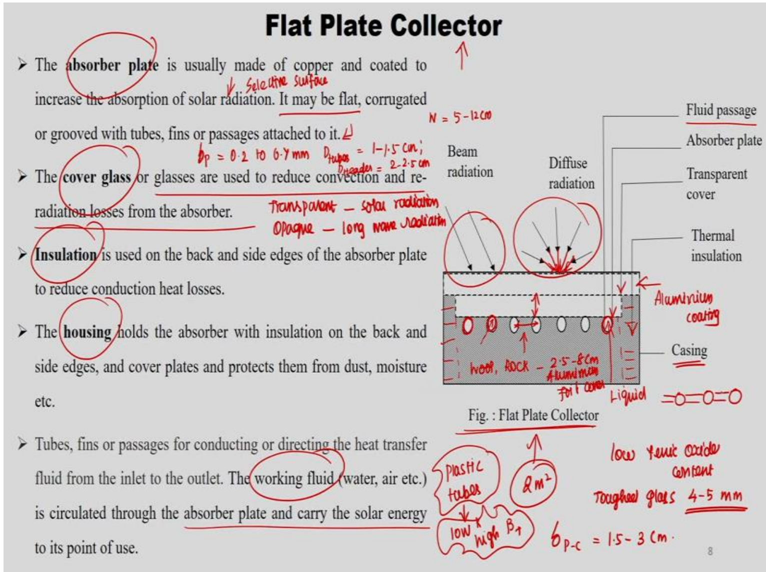

In the flat plate collector. So what are all the major components absorber plate, cover glass, insulation housing and then the working fluid this is a simple flat plate collector schematic. So if you see this is fluid passage or we call it as a tubes width which your liquid is flowing through and this particular one is absorber plate and this is nothing but transparent cover and this is thermal insulation. So bottom part also this is bottom.

So this is side, this is the side insulation and this total is covered in a casing we call it as a housing and we get both diffusive radiation as well as beam radiation so point towards the surface. So absorber plate is usually made of copper and coated to increase the absorption of solar radiation. So in that case we call it as a selective surfaces normally it is a black surface. So if we want to use any selective surface that also can be done.

Selective surface to increase the absorption and to decrease the emission and it may be flat because the name says it as a flat plate collector but it may be flat or corrugated or grooved with tubes, fins or passages attached to it. So it is not always possible to have a flat plate collector It is based on the application or what type of absorb what type of fluid passages you want to use it. And then the plate thickness normally of plate thickness that is delta p which is normally 0.2 to 0.7mm.

And this absorber plate if you see here the absorber tubes with which the liquid or water flows through it so that tubes will be of dia, dia of tubes would be of 1 to 1.5 cm and then this pitch which is nothing but center to center distance between 2 tubes. So that I will put it as a W. So which would be around 5 to 12 cm. So if you see all these tubes are connected to the header , the header pipe diameter would be a little bit higher than this tube diameter so which would be of 2 to 2.5 cm.

So this is nominal size based on your requirement you can size it. So normally this flat plate collector liquid flat plate collector available with around 2 meter square area. So far that these are nominal dimensions. So that covered glass or glasses are used to reduce the convection and re radiation losses from the absorber it is not only this application it also protects the collector or absorber plate from the environmental disturbances and also it allows that is transmits the solar radiation to hit on to the absorber surface.

So usually this class cover should be of transparent to solar radiation and opaque to long wave radiation. So usually low ferric oxide content is preferred in glass material so normally this would be a toughened glass because we said that it also forms a protective layer other than main applications of transmittance and reducing re-radiation losses and thickness of this glass would be around 4 to 5 mm and distance between cover the absorber plate.

So that is delta p to c that would be normally 1.5 to 3 cm. And this insulation material would be wool or rock kind of material which is above 2.5 to 8 cm and with aluminum foil cover and the collector box or casing is covered with aluminum with some coating. So the housing holds the absorber with insulation on the back and side edges and cover plates and protects them from dust moisture etcetera.

And tubes fins are passages for conducting or directing the heat transfer fluid from inlet to outlet. So that is nothing but this particular tubes whatever we have seen and this working fluid either water or air is circulated through the absorber plate and carry the solar energy to its point of use. So this is about overall components of flat plate collector absorber plate tubes are made up of copper but recent days plastic tubes plastic absorber plates are being also used.

But here the problem is they are low thermal conductivity and a high thermal coefficient of expansion but with recent advancements in polymer technology this may also be possible and you are requested to refer the recent plastic materials which are being used as a absorber plates or tubes which is nothing but fluid passage material.

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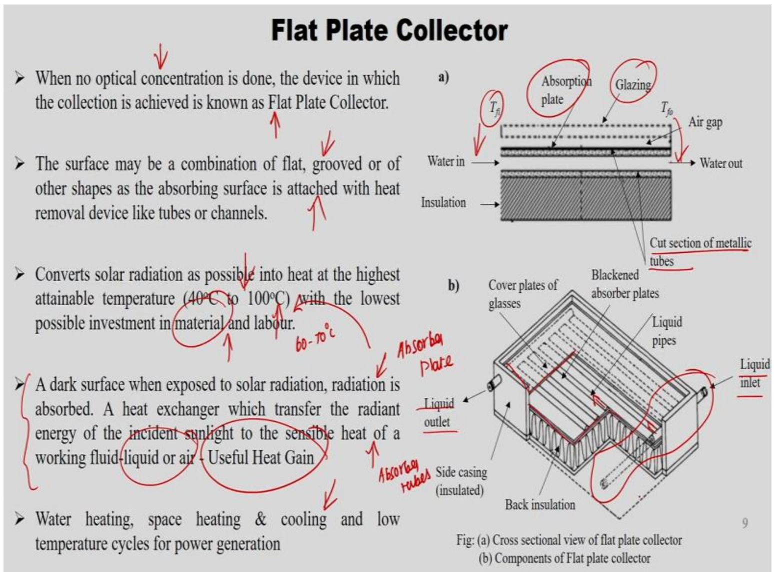

So this flat plate collector there is no optical concentration that is why they are called as non concentrating collectors. So the collectors which has no optical concentration is called flat plate collector the surface may be combination of flat grooved or of other shapes as absorbing surfaces attached with the heat removal device like tubes or channels because the absorber plate here and we have seen in this diagram it is attached below the absorber plate.

So this may be kept within the plate itself something of this kind. So that is what here it has said it may be flat or grooved or of other shapes as the absorbing surfaces attached with the heat removal device like tubes or channels and this converts the solar energy into heat at the highest attainable temperature of 40 to 100 degree. So normal you can expect 60 to 70 if you use any selective surface then you can attain even 100 degree temperature as well.

So with the lowest possible investment in material and labour that is the most important parameter because the design is simple it is, it attracted more applications and we do not require much labour as well. The working principle is a dark surface when exposed to solar radiation; radiation is absorbed that is work done by absorber plate a heat exchanger which transfers the radiant energy of the incident sunlight to the sensible heat of working fluid which is nothing but liquid or air.

So this is done by tubes absorber tubes which are attached with the absorber plate. So this particular amount of heat gained from the absorber plate to the working fluid which is called useful heat gain. So this is already we have seen it as used for water heating, space heating, cooling and low temperature cycle power generation as well. So if you record high temperature you supposed to go to concentrating collector.

So this is absorber plate we have seen this is the glazing or glass cover and this is inlet temperature of the water in outlet temperature of the water out. So between the glass cover and the absorber plate there is an air gap this is a back insulation. So this is nothing but cut section of the metallic tubes so inner diameter outer diameter and one more thing I told over there is the header pipe so with which you are all the absorber tubes are attached. So header pipe with which liquid is in and liquid is out. So this is the casing and above one is this particular one is glass cover and this particular one is absorber plate and these are liquid pipes.

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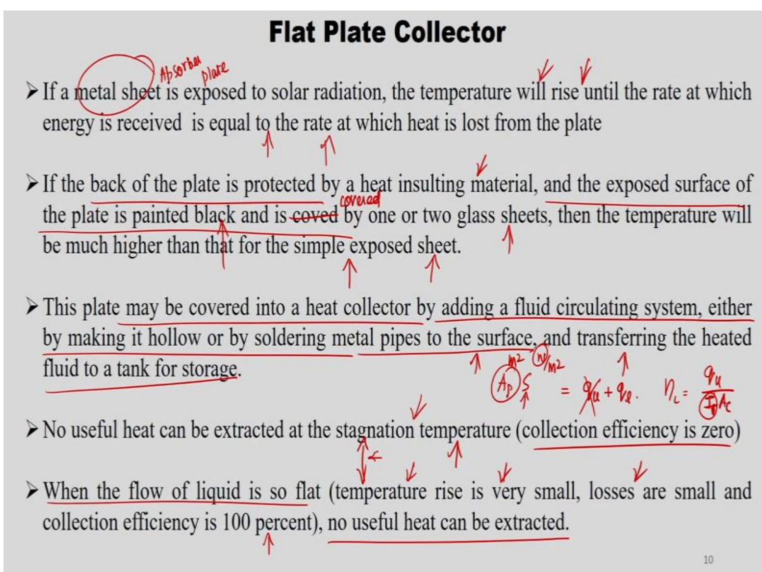

So if a metal sheet is exposed to solar radiation the temperature will rise until the rate at which energy is received is equal to the rate at which heat lost from the plate. So this is nothing but simple the energy balance so the metal sheet which is nothing but a absorber plate. So this is a basic how it works. So if you expose a metal sheet with a good absorbing capacity then the temperature of the sheet starts increasing when it is exposed to solar radiation.

So this is until the point the rate at which the energy is received is equal to the rate at which heat is lost from the plate if the back of the plate is protected by heat insulating material now the basic principle is this one. So now we are moving in a direction how to reduce the loss and how to gain maximum collection of solar energy. So far that we supposed to insulate in the back and the exposed surface of the plate is painted in black.

So to increase the solar radiation absorbing capacity and covered by why not to glass sheets then the temperature will be much higher than that for the simple expose to sheet. So the principle is this then we started reducing the losses and how to protect that particular sheet into from the atmosphere. So for that what we have done to increase the absorption we painted it with the black and to reduce the losses we insulated.

And then to protect from the environment or to transmit the solar radiation and to remove the re radiation losses we have put the glass sheets as well. So because of which whatever the temperature we get here we will get more temperature than this if you do such an arrangement. So this plate may be covered into the heat collector by adding a fluid circulating system either by making it hollow or by solid ring metal pipes to surface this we will see how this being done.

There are different designs varieties are there. And when you attach a fluid circulating system in the absorber plate then the heat will be transferred to the working fluid then once it is heated through absorber plate then that particular heated fluid will be sent to the storage tank based on the application we will be using it there are 2 extreme cases if there are no useful heat can be extracted then what happens?.

For example we are collecting A p which is nothing but a plate area into S that is the flux incident or flux absorbed by absorber plate which is nothing but what per meter square A p is meter square. So this is the amount of heat and which is equal into useful heat gains and losses. So if there is no useful heat then what happens so the losses are equivalent to A p into S. So in that case the absorber temperature is called stagnation temperature.

And our collection efficiency would be 0 because collection efficiency is how much useful he did and I T into A c I T is total flux falling on the collector and A c is nothing but collector area. So in this case the collection efficiency is 0 another extreme cases when the flow of fluid or liquid is so flat then you are del T is very small losses are very small in that case collection efficiency would be 100 percentage but there would be any useful heat gain. So the operation is in between there should not be any stagnation temperature and there should not be any flat temperature profile in the flow of liquid. So the operating temperature of the absorber plate is in between.

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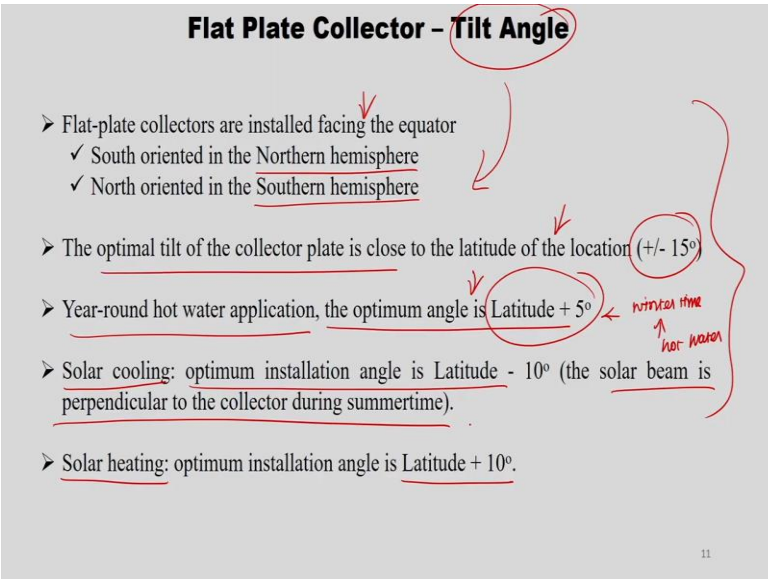

So this is about the tilt angle because this we learnt in lecture 1 and lecture 2 usually flat plate collectors are installed facing the equator. If we are living in northern hemisphere then it should be south oriented. If you are living in southern hemisphere it should be north oriented optimal tilt angle of the collector plate is close to latitude of the location or plus or minus 15 degree year round hot water application if we want to have year round application the optimum angle is latitude +5 degree.

So this is taken into consideration when at the wintertime also you would require the hot water or sufficient hot water. So for that reason the optimum angle is given us latitude +5 degrees and if our application is solar cooling the optimum installation angle is latitude -10 degree because the solar beam is perpendicular to the collector during summertime and if the application is solar heating then optimum installation angle is latitude +10 degree.

So these are all you can get from the references which was mentioned in this lecture because we discussed enough all these angles how to calculate the tilt angle and how to get the angle of incidence using latitude etcetera. So you can just review that and get to know what is the basis for this optimum angle here it has given us the information.

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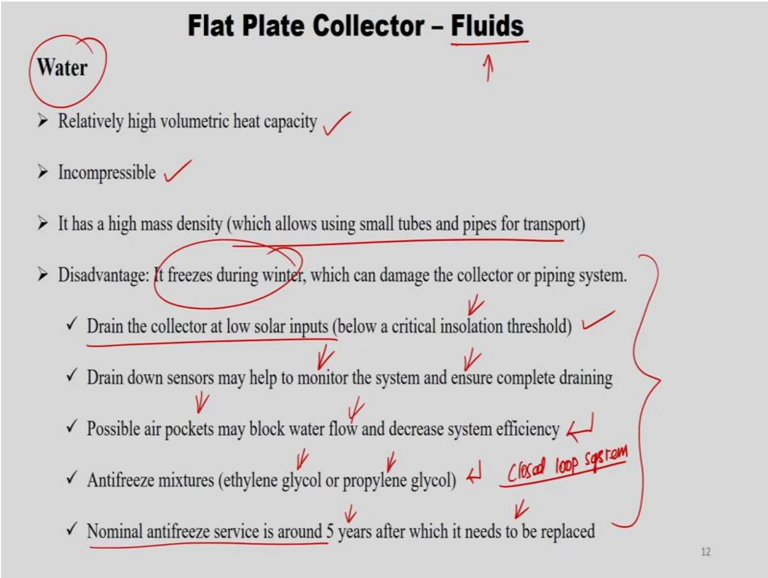

And about the fluids. So the water is the mostly used or most wanted fluid in flat plate collectors the water collectors are the famous one because of the fact that it has relatively high volumetric heat capacity and also it is incompressible the density change with the temperature is moderate and it has a high mass density which allows that using small tubes and pipes for transport we do not require any larger system.

And disadvantage side it freezes during winter which can damage the collector or piping system. So far that normally they drain the collector at low solar inputs if the insulation goes below the critical value then they use the sensors to monitor the system and ensure complete draining. So if the insulation goes below the critical value the sensor will sense and it helps to monitor the system and also ensure that complete draining.

If you are doing complete draining and restart the system we need to also think about the possible air pockets. So which may block the water flow and decrease the system efficiency. So this particular point also to be taken into account when you are completely draining the system. Normal practices use the antifreeze mixtures either ethylene glycol or propylene glycol. So this particular antifreeze mixture is added in the water in the closed loop system.

That means you cannot directly use that water for application purpose you will use some other heat exchanging system to remove the heat. So nominal antifreeze services around 5 years after that you supposed to replace the system. So this is except this anti freezing at winter there are not much disadvantages using water as a working fluid in flat plate collector.

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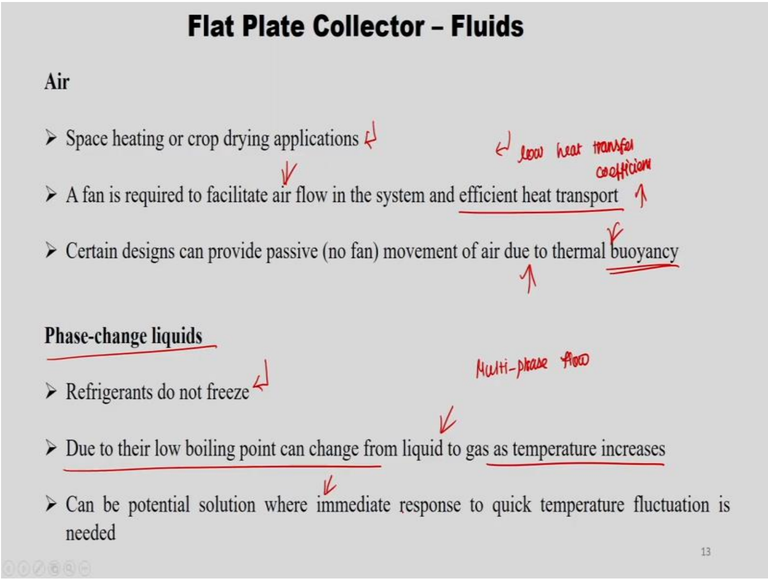

And then the air so air solar heaters are famous in space heating applications and crop drying applications here a fan is required. So in that way it is forced to circulation system your fan or blower is required to facilitate the airflow into the system and for efficient heat transfer certain designs can provide passive movement of air also due to thermal buoyancy. So as we know already so the natural convection we may get less efficiency compared to forced circulation system. So this also I mentioned the phase change liquids.

Normally nowadays the refrigerants are preferred one solar air heaters are not being used much due to low heat transfer coefficient. So to avoid this normally liquid flat plate collectors are required but due to this freezing then the alternative is refrigerants. So because refrigerants do not freeze at this temperature during wintertime. So due to their low boiling point they can change from liquid to gas in that case we need to analyze in the region of multi phase flow.

And as the temperature increases when temperature increases their phase changes from liquid to gas it can be a potential solution where immediate response to quick temperature fluctuation is needed. So either water or air or fluid change liquids can be used as a working fluid in flat plate collector.

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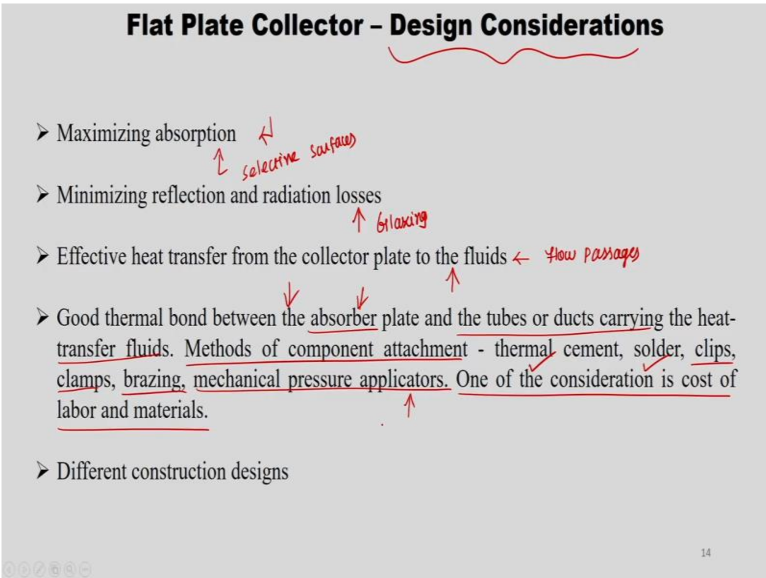

So while designing this flat plate collector so what are all the key points we suppose to consider one is maximum absorption this is where we told the selective surfaces the second one is minimizing reflection and radiation losses. So that is taken care by the glazing part and effective heat transfer from the collector plate to the fluids. So that is nothing but the flow passages and another important point is good thermal bond between the absorber plate and the tubes are ducts carrying the heat transfer fluids.

So they should not be adding up any extra resistance for the thermal conduction methods of component attachment maybe of thermal cement or solid ring tubes with the absorber plate or using clips clamps bracing mechanical pressure applicators etcetera, any of the method can be used to attach the tubes or ducts with the absorber plate when after consideration which determines them is labour and materials. It is not easy to do this job. And top of that there may be some resistance which also adds to the heat transfer then different construction designs are there.

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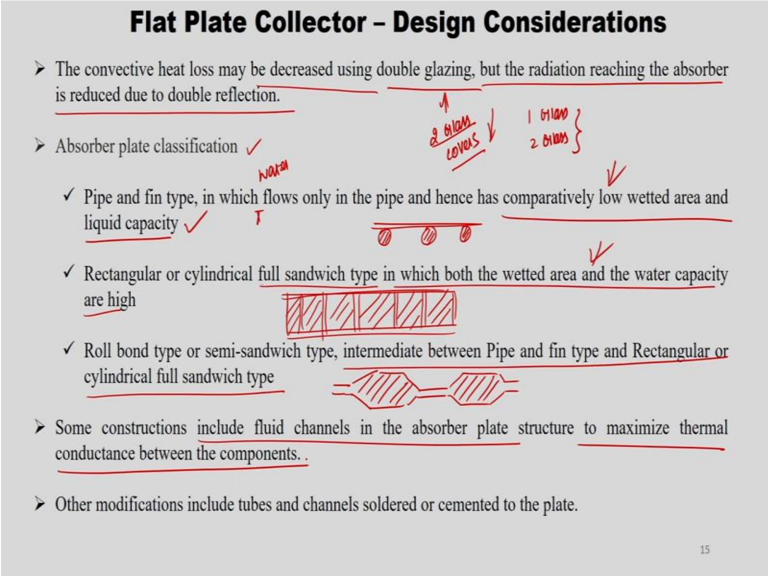

So that we are going to see one is the pipe and fin type in which flows only in the pipe in which the water flows only in the pipe and hence has comparatively low wetted area and liquid capacity. So this will be of something like this is the absorber plate and you will have tubes here with the w that is center to center distance between 2 tubes. So this is nothing but simple absorber plate classification so pipe and fin type.

So this is absorber plate this is tubes and the second one is rectangular or cylindrical full sandwich type in which both the wetted area and the water capacity are high. So if you see this is something like this is absorber plate. So this is a rectangular or cylindrical arrangement. So this is full sandwich type. So this is fluid passage the third one is role bond type or semi sandwich type where intermediate between pipe and fin type and rectangular and cylindrical full sandwich type. So here low wetted surface area and liquid capacity.

So here high wetted surface area and water capacity is also high. So this third type which is of semi sandwich type so we have in between the first 2 types so this will be something like this. And if you see in terms of the glazing whatever we choose here we said one is maximizing absorption that is what selective surface second one is minimizing reflection and radiation losses. So here if you see that convective heat losses may be decreased using double glazing double glazing in the sense 2 glass covers.

However when you use 2 glass covers the convective heat losses may be decreased but if you see the solar radiation should get transmitted through 2 glass covers. So in that way it may be less advantageous but the radiation reaching the absorber plate is also reduced due to double reflection. But one has to choose wisely 1 glass cover and 2 glass covered using this optimal decision whether you are contributing to decreasing the conviction losses or you are contributing to increase in reflection double reflection if you are using 2 glass covers and then we are back to absorber plate and flow passages.

So some constructions include fluid channels and the absorber plate structure to maximize the thermal conductance between the components.

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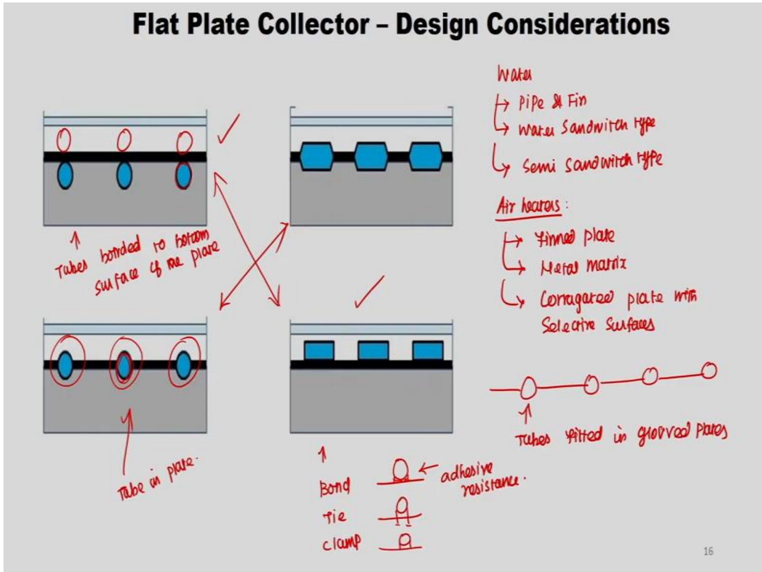

So those are of these types. So here if you see the tubes are within the absorber plate. So this is probably the rectangular type. Then other modifications include tubes or channels solid or cemented. So here we have seen so that will cement solders clips or clamps etcetera. So the other modifications include tubes and channels salted or cemented the plate that is of this type. So this is rectangular so which is salted about the absorber plate.

So here the tubes are soldered below the absorber plate other than that there are many designs for example if you see the water collector in the design wise there are 3 categories we have learned pipe and fin type another one is water sandwich type the third one is semi sandwich type if you see in terms of air collectors or air heaters that we will see when we discuss about air heaters. So there are different varieties one is finned plate these are all the absorber plate design considerations.

And another is metal matrix type another is corrugated plate with selective surfaces. So apart from these designs there are tube in plate we have already seen here. So you have absorber plate in there itself you have a fluid passages so this is nothing but tube in plate. So this is tubes bonded to bottom surface of the plate. So here it is not only in the bottom then some designs it is kept on above also that is to the upper surfaces and the same way that flow passages can be grooved in the absorber plate as well.

So this is tubes fitted in grooved plates and normally how it is being attached for example this and this if you see so here we have attached to the flow passages in the absorber tube. So that can be of bond type and tie type and clamp type. So in the bond if you have a absorber plate you were tube is bonded here. So here we use some adhesive material. So this also added to adhesive resistance tie diapers something of this kind and clamp diapers this you know you might have seen. So this is clamped there are many designs with which the absorber plate is attached with the flow passages. So you are requested to refer the references given in this lecture to get in detail about various design considerations.

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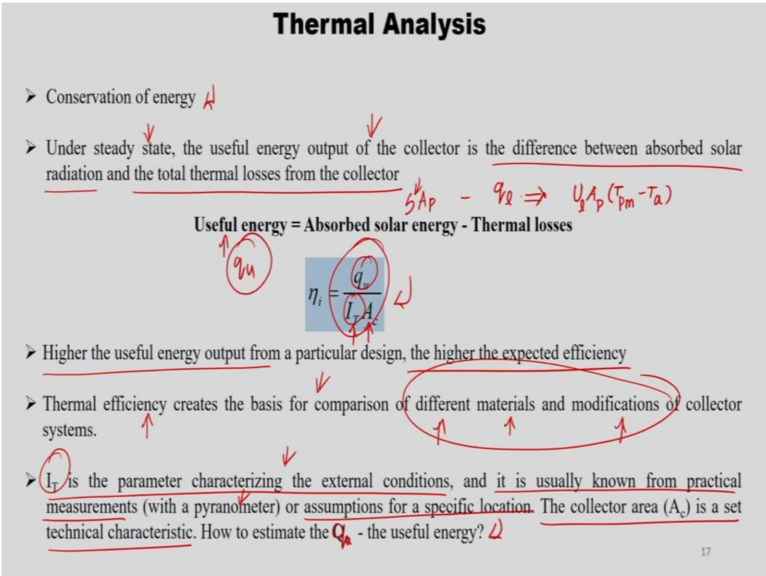

The next one is thermal analysis for any thermal analysis the basic thing what we do is conservation of energy. So under steady state steady state even though we say it should be quasi steady state the useful energy output of the collector is the difference between the absorbed solar radiation and the total thermal losses from the collector. So useful energy that is nothing but q u which is equal to absorb the solar energy.

So that is S which is absorbed by the absorber plate into plate area which is nothing but A p and thermal losses which is nothing but q l. So once you calculate useful energy then from that you can calculate instantaneous efficiency which is nothing but useful energy upon I T into A c. I T is nothing but total flux falling on the collector into collector area. So higher the useful energy output from a particular design.

Particular design in the sense particular flat plate collector design the higher the expected efficiency the thermal efficiency creates the basis for the comparison of different materials and modifications of the collector system. So this way we only normally the comparison is done by thermal efficiency which creates the basis for different materials as I said absorber plate there is a black surface or selective surface or many different considerations are being used.

And also the modifications there are certain modifications we have seen but other than that the research says day by day improvement. So in that way also we get many modified designs of the collector. So all these things are being compared using thermal efficiency only because our ultimate aim is to gain maximum amount of energy to the working fluid from the absorber plate. So I T is the parameter which characterize the external radiation.

So because we learned that any new modifications or new materials can be compared with the efficiency of the collector. So we need to analyze like what are all the parameters we required to calculate efficiency. So in such case if you see I T so this I T is totally based on external conditions by now we are very much comfortable how to calculate I T otherwise also there are instruments which measures the beam radiation diffuse radiation and sunshine hours.

And other than that if that is not available experimental measurements are not available we know how to calculate them using correlations and formulae available and it is usually known from practical measurements that is what we use pyranometer or assumptions for a specific location the collector area is a set technical characteristics. So that also we will be able to get and how to estimate the q u which is nothing but useful energy. We will use same symbol q because it is a rate how to estimate that q u which is nothing better useful energy that is where the effort lies.

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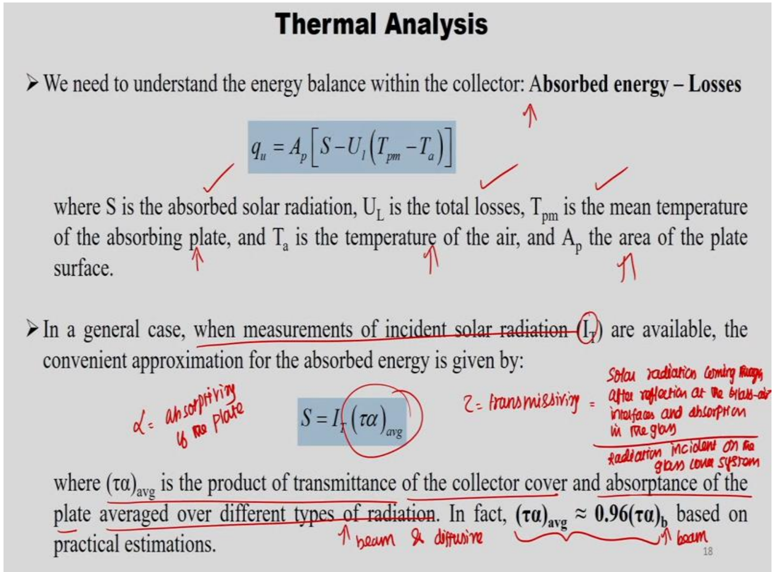

So we need to understand the energy balance within the collector which is nothing but absorbed energy minus losses is nothing but q u. So here we said q l. So this normally cues you a delta T so since we are working with absorbed energy so this should be T pm the mean plate temperature minus T a which is nothing but an atmospheric temperature. So this A is nothing but A p U is nothing but U l that is total loss coefficient.

So that is what we substituted here A p into S U l A p T pm - T a. So S is absorbed solar radiation on the absorber plate U l is the total losses T pm is the mean temperature of absorbing plate and T a is the temperature of the air, A p is that area of the plate surface. So in general when measurements of solar radiation are available we know how to calculate I T the convenient approximation of the absorbed energy is nothing but I T into tau alpha average.

What is tau alpha? tau is nothing but transmissivity which is nothing but solar radiation coming through after reflection at the glass air interfaces absorption in the glass there are 2 components one is between glass and absorber plate there is a air so that glass air interfaces and absorption in the glass. So it is the ratio between solar radiation coming through after reflection at the glass air interfaces and absorption in the glass to the radiation incident on the glass cover system. So this is nothing but transmissivity of the glass cover.

Then alpha is nothing but absorptivity of the plate. So out of I T how much is being observed on the absorber plate. So S is nothing but I T into tau alpha average. So usually tau alphaaverage is the product of transmittance of the collector cover and absorptance of the plate average to over different types of radiation beam as well as diffusive. In fact tau alpha average is approximately equivalent to 0.96 tau alpha b. Which is nothing but beam radiation based on practical estimations but still we must be knowing what should be tau alpha b which is nothing but transmissivity absorptivity product based beam radiation.

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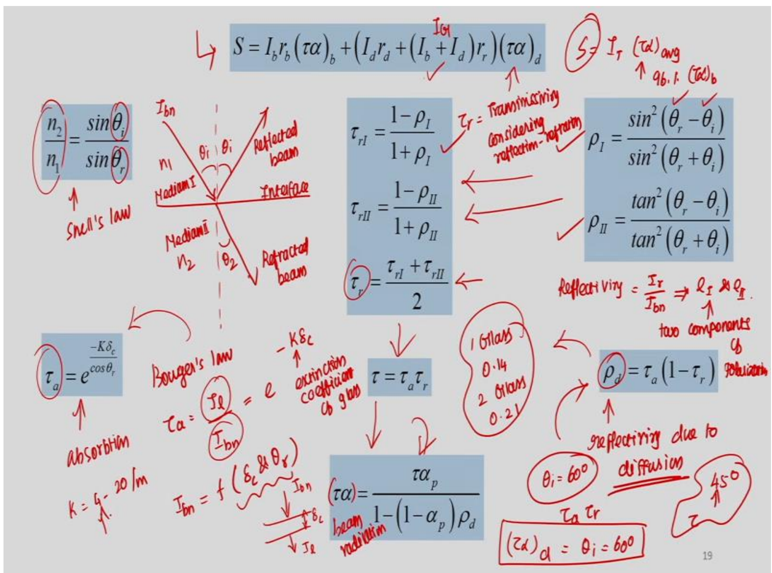

So there are 2 things one is if you know the tau alpha average you can directly calculate the S using I t. So even for tau alpha average the estimation says that it is 96 percentage of tau alpha b that is beam radiation. So how to calculate that tau alpha. So normally this is nothing but Snell's law where you have a incident beam incident radiation I bn which this transmitting through a medium one to medium 2.

When it is so it gets reflected and it gets refracted. So this reflected angle and incident angle both are same. So this is nothing but reflected beam. So this is nothing but refracted beam medium one and medium 2. So when it transmits through the interface so this is nothing but interface when it touches the interface so it refracted and reflected. So this angle of reflection is nothing but angle of incidence but that is not the case for angle of refraction.

So this relation is given by Snell’s law so theta r is nothing but angle of refraction theta i is nothing but angle of incidence and their refractive indexes are n1 for medium 1 n2 for medium 2 then from this we are calculating first rho 1 and rho 2 what is rho. Rho is nothing but reflectivity which is nothing but a I r upon I bn yen. So there are 2 components of reflectivity rho 1 and rho 2. So what are called rho 1 rho 2 they are 2 components of polarization the same way after calculating angle of incidence and angle of refraction and the angle of incidence.

So we would calculate the reflectivity of 2 components of polarization. So for each you will have transmissivity due to reflection refraction what is tau r tau r is nothing but transmissivity considering reflection and refraction we calculate tau r 1 r 2 in relation with rho 1 rho 2 and then we calculate average tau r which is nothing but due to reflection and refraction and then we calculate the transmissivity due to absorption as well.

To do that we use Bouger’s law. So which says tau a is nothing but a I l upon I bn which this again here I bn is a function of delta c which is nothing but thickness of the cover system and theta r which is nothing but angle of refraction. So he said that this is equal into e power - k delta c what is k k is nothing but exension coefficient of the glasses extension coefficient of glass. So tau a is nothing but I l upon I bn which is equal to e power - k delta c.

So this I bn can be again returned in terms of delta c and theta r. So that is the way this formula is derived. So I am not going into deep I am just giving you overview how to get this S done because to calculate useful energy first we need to calculate how much energy is absorbed on the absorber plate. So to do that we have simply said I T tau alpha average. So to even with the practical estimation we would require tau alpha of beam radiation.

So we use this particular formula to calculate the transmissivity by considering only absorption. So here the K alies between 4 to 20 for most of the classes but however the lower is the K you would get better transmissivity once you are done with tau a and tau r then total tau is tau a tau r and the tau alpha product is nothing but tau whatever you calculated for the cover system into alpha p which is nothing but absorptivity of the plate divided by 1-1 - alpha p into rho d.

So this is nothing but reflectivity due to diffusion. So as we discussed in the lecture 1 lecture 2 normally diffusive radiation comes from various directions however we considered them as a beam radiation which comes with the incident angle of 60 degree. So here also we use the same angle of incidence of 60 degree and calculate tau a and tau r and substitute in rho d irrespective of whether you calculate tau alpha for beam radiation or a diffusive radiation this rho d is nothing but reflectivity due to diffusion that has to be calculated with the angle of incidence of 60 degree.

And tau a tau r substitute back you will get are the simple again the assumption is if it is a one glass cover system we use point 0.14 directly or if it is a 2 glass cover system we use 0.21. So using rho d and tau whatever we calculated we get tau alpha beam radiation if it is a. So once we calculate the tau alpha for beam radiation we can substitute here 96 percentage of a beam radiation if we take.

So that serves the purpose of tau alpha average when it is multiplied with I T you will get S or otherwise the correct way to do is this formula I b r b tau alpha b and then I d r d + I b I d this is nothing but I G into r r this total is to be multiplied with tau alpha of diffusive radiation. So how to calculate tau alpha of diffusive radiation the same way you calculate using theta i equal to 60 which is nothing but angle of incidence.

So any way this calculation we will do it in practice problem here also it says. So practical estimation gives this assumption because it may not be changing that abruptly and also if you see for around till the incidence angle of 45 degree you would not see much change in calculation of tau which is nothing but transmissivity. So in that case doing all these calculations may be of unwarranted one but however.

If you know how to calculate this particular parameter it might be useful when you are working in some new materials and new designs then you may get the properties calculated correctly to compare the efficiency in the same way if you calculate tau alpha d either you can use this particular formula to calculate S are you can use the assumption of tau alpha average and calculate S.

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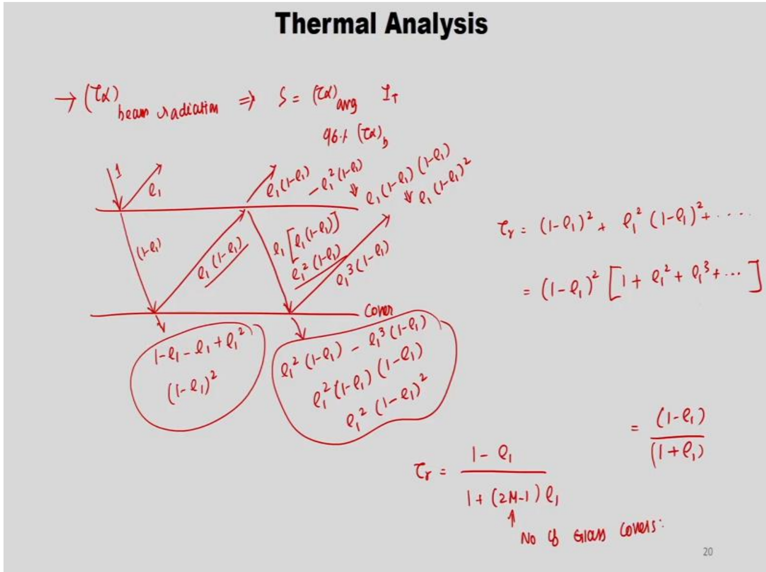

After learning how to calculate tau alpha of beam radiation. We told that the S can be directly calculated by taking into account tau of average which is nothing but 96 percentage of tau alpha beam radiation into I T so before going in to that way we need to calculate tau alpha. So what is the theory behind it. So here what we told us about Snell's law so to calculate the theta of refraction and from there we calculated tau r which is nothing but transmissivity due to refraction reflection and we also learned how to calculate tau a.

So if you see a certain theory behind it so this is your cover system. So wave your total energy comes which we take it as 1 so that reflection is rho 1. So remaining which reaches the cover system is 1 - rho 1. So in that how much is reflected back is rho 1 of 1 - rho 1. So how much transmits 1 - rho 1 minus of rho 1 + rho 1 square so this is basically 1 - rho 1 whole square. So this out of which how much is reflected back is rho 1 into rho 1 of 1 - rho 1. So this is rho 1 square 1 - rho 1. So this is going back and for this is reflecting back.

So how much goes above which is rho 1. 1 - rho 1 minus of rho 1 square 1 - rho 1. So this particular value would be rho 1 1 - rho 1 this is common and 1 - rho 1. So totally this will be rho 1. 1 - rho 1 square. So then this balance is done so how much ever comes here. So that is again back reflected so that is rho 1 q 1 - rho 1 because rho 1 of rho 1 square 1 - rho 1. So how much is reflected here so which is nothing but rho 1 square 1 -rho 1 - rho 1 q 1 - rho 1. So if we take rho 1 square 1 - rho 1 common then 1 - rho 1. So this is rho 1 square 1 - rho 1 square.

So this is the way all the transmitted energy through the cover is being added for example tau r which is nothing but 1 - rho 1 square + rho 1 square 1 - rho 1 whole square. So this goes on so if you take 1 - rho 1 square out this will be 1 + rho 1 square + rho 1 cube this goes higher order terms. So what do you get this 1 - rho 1 upon 1 + rho so this is the way this tau r component here is being calculated? So you can do it for other component also in same way and from here we calculated tau r and tau a as we said already the I l upon I bn what is I l.

So this is your I bn when it passes through the glass cover of delta c which is nothing but thickness then what intensity of radiation comes out of the glass cover is nothing but I l. So this relation is given us e power -k delta c upon cos of theta r this theta r is nothing but angle of reflection. So from this you will calculate tau a which due do absorption where k is nothing but extinction coefficient we already told that so how much ever less extension coefficient you get. So that effective you are glass cover system is so this also can be extended to any number of glass cover system 1 - rho 1 upon 1 + 2M - 1 rho 1. So M refers to number of glass covers.

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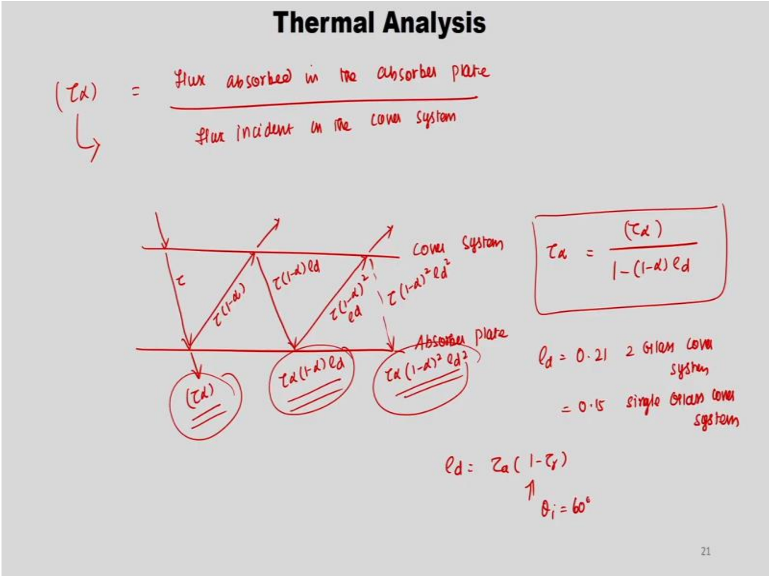

And from this you can also find out tau alpha what we just found out so the theory behind it also we will see so tau alpha is nothing but flux observed in the absorber plate upon flux on the cover system. So we need cover system this absorber plate so energy incident and cover system it transmits. So this is tau so what comes out of absorber plate is tau alpha. So this towel alpha if it is this if this is tau alpha this is tau into 1 - alpha.

So this comes back is reflected so tau of 1 - alpha into rho d that is what diffusive reflectivity. So then what comes out of it so which is nothing but tau alpha 1 - alpha? So this is tau 1 - alpha into rho d. So when it comes out of the absorber plate there is absorptivity multiplied into rho d. So when it goes reflected back then how much it would be so tau of 1 - alpha whole square. This part of it whatever is left out so that would be into rho d because it is reflected.

So when it comes back as the reflected radiation so how much it would be tau 1 - alpha whole square into rho d square. So how much it would have been reflected so tau alpha of 1 - alpha whole square rho d square. So this is the energy we are not going to count it. So this should be added to get total tau alpha which is nothing but tau alpha upon 1 - 1 - alpha into rho d the same way whatever we have done here you can do it.

So I have given you all the transmissivity absorptivity product of absorber plate so you can do the same mathematical manipulation and get finally tau alpha as tau alpha upon 1 - 1 - alpha into rho d. So as we said rho d is normally 0.21 for 2 glass cover system it is 0.15 for single glass cover or 0.14 also some may use glass cover system. So how to calculate this rho d rho d we have given tau a into 1 - tau r so when angle of incidence is 60 degrees. Thank you.