Renewable Energy Engineering Solar Wind and Biomass Energy Systems

Prof. Dr. R.Anandalakshmi
Department of Chemical Engineering
Indian Institute of Technology – Guwahati

Lecture - 09
Practice Problems

Good morning everyone today in renewable energy engineering solar wind and biomass energy system we are going to discuss about lecture 6 again on practice problems whatever we learned in lecture 4 and lecture 5. We are going to do this problem for liquid flat plate collector. So before going into the problem we will review whatever we have done on week 1 there also lecture 3 we had a practice problem. So that was on calculating solar radiation parameters some of the parameters we are going to use here as well. So first we will review and then go to lecture 6.

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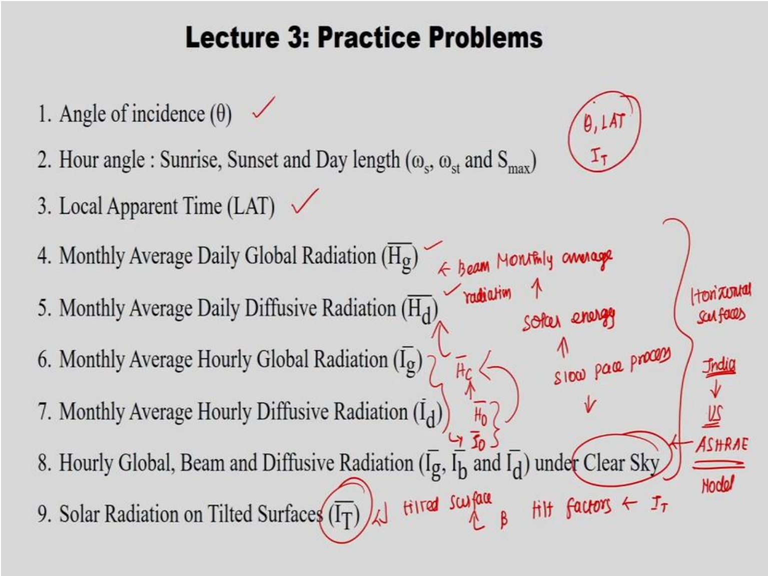

In lecture 3 we learned how to calculate angle of incidence, hour angle sunrise sunset day length local apparent time, monthly average of daily, hourly global and diffusive radiations and hourly global beam diffusive radiation under clear sky and solar radiation or tilted surfaces. So this is the important parameter today also we would require to calculate incidence efficiency for liquid flat plate collector and local apparent time is another parameter.

And solar radiation of tilted surfaces. So here if you see all the (())(01:43) for monthly average as we learned solar energy is slow pace process. So the instantaneous efficiency or instantaneous value will be less useful it is not that it would not be useful but it would be meaningful if we do it for daily or hourly calculations. So because of that we learnt how to calculate monthly average of daily and hourly radiations.

And global and diffusive radiation if we get to know then from there we will always calculate beam radiation. But these are all we learnt for horizontal surfaces. But today whatever we are going to discuss is for tilted surface this also we already mentioned normally collectors are tilted at an angle of beta to gain maximum solar radiation. So in that way the calculation of I T is going to be useful in today is problem as well.

So in short in this particular lecture we got to know how to get the angle of incidence local apparent time and daily or hourly global diffusive radiation from there we will calculate beam radiation and then using tilted factors we learnt how to calculate I T as well. Under clear sky we used a certain model of ASHRAE because here in calculating H g and H d the actual formula was H c bar. So that was under clear sky.

Since we did not have defined a parameter we converted that into H naught bar that is monthly average of daily extra terrestrial radiation and the same way for I g I d we used I naught that was monthly average hourly extra terrestrial radiation. So using this we calculated H d H g and I d I g but there was ASHRAE model which predicted global beam and diffusive radiation under clear sky but that was based on US. For India it might be matching. So we can check it with actual experimental data. So this is the short recap of what we have done and we know how to calculate theta and how to calculate LAT. We also learned how to calculate I T.

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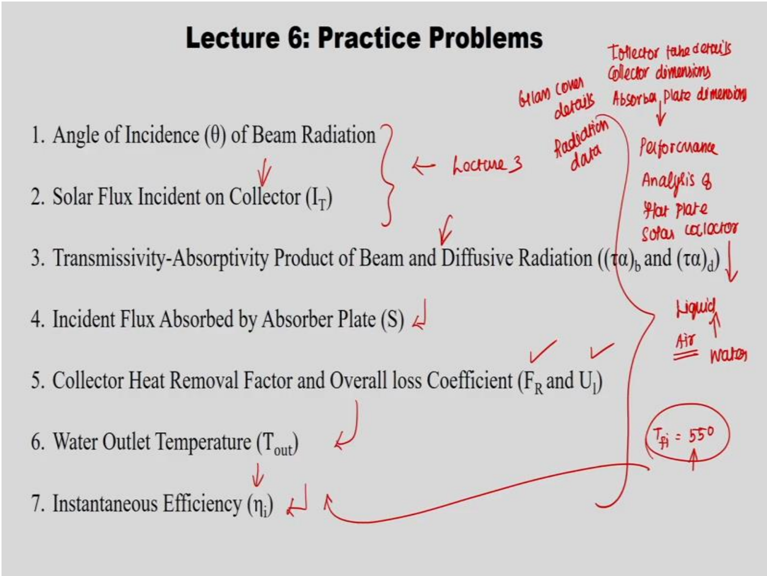

So using these 2 already we learned in lecture 3 now the new one is transmissivity absorptivity product of beam and diffusive radiation incident flux absorbed by absorber plate what we learned is I T that is solar flux incident on collector but what we need is incident flux absorbed by absorber plate. So that we are going to calculate and then collector the heat removal factor and overall loss coefficient which is a F R and U L.

From here we will also calculate water outlet temperature and the final goal is to calculate instantaneous efficiency. So this see if you see this I can put it as a performance analysis of flat plate solar collector as said an lecture 4 this may be of liquid type or air that is solar air heater. So here we are going to use water as a liquid. The performance analysis nothing but you were given the collector dimensions and absorber plate details or dimensions.

And then tube collector tube details, glass cover details to calculate radiation parameters, radiation data as well we are given. So given all this we are going to calculate the instantaneous efficiency of the liquid flat plate solar collector. So in a way once we are done with the problem then you would be comfortable to change the various properties. For example if you are given fluid inlet temperature is 55 degree.

So for that if you are calculating instantaneous efficiency and you can change this fluid inlet temperature to lower value or higher value and check how the efficiency increases or decreases in that way you will learn what is the dependency of fluid inlet temperature on liquid flat plate collector. So instead of me drawing the graph and explaining you so you might be able to do all this performance analysis however we are going to do this problem for 1 set of values.

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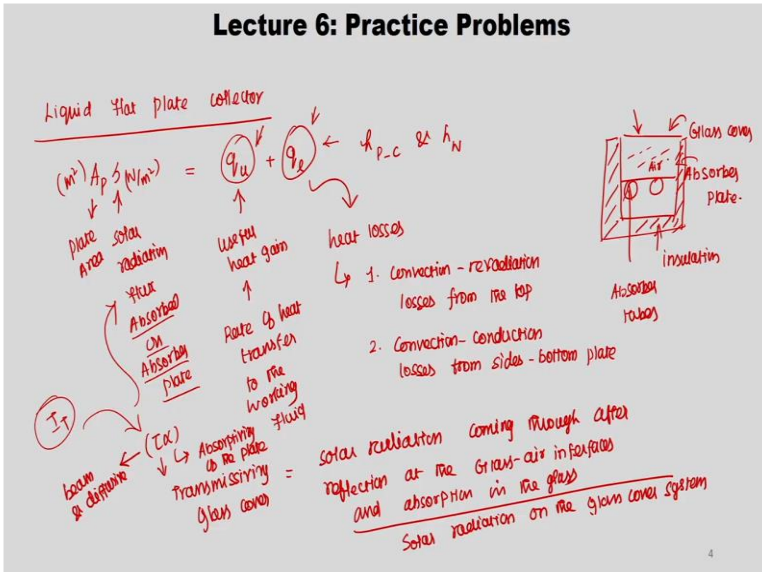

So before going into that details of given data we are going to see certain parameters whatever we learnt in lecture 4 flat plate collector. Whatever the plate area into this is solar radiation Flux observed on absorber plate. So this is plate area which is equivalent to q u + q l what is q u this is nothing but useful heat gained what is that? That is nothing but rate of heat transfer to the working fluid then this is q l which is nothing but heat losses.

This may be of 2 types one is convection and re radiation losses from the top if you remember the design so this is glass cover this is absorber plate here you have tubes in which working fluid is flowing and all the casing is insulated this is a simple drawing I am saying. So this is glass cover absorber plate this is insulation this is absorber tubes the second one is convection conduction losses from bottom and side. And bottom plate.

Though it is insulated there may be some losses. So if you see this is in watt per meter squared so this is meter squared. So q l and q u would be in Watts because whatever the I T is flux falling and out of which this is absorbed by absorber plate which is multiplied with the plate area would give you the total rate of energy and that is divided into 2 parts one is useful heat gain that is given actually given to the working fluid and other one is heat losses.

And to calculate this S we might be using tau alpha what is tau? tau is nothing but transmissivity which is nothing but solar radiation coming through after reflection at the glass air interfaces. So this is filled with air and absorption in that glass upon solar radiation on the glass cover system this is the transmissivity of the glass cover system glass cover alpha is nothing but absorptivity of the plate of the plate.

So this tau alpha product should be calculated for beam as well as diffusive radiation. So we know now how to calculate I T using tau alpha how to calculate S and collector plate area is given how to calculate q u and q l and check whether both matches. And to calculate q l there are certain correlations again we are going to use for calculating heat transfer coefficient between plate and collector system and heat transfer coefficient on the cover system that is h w. Because the space between glass cover and absorber plate is filled with air there may be convection losses.

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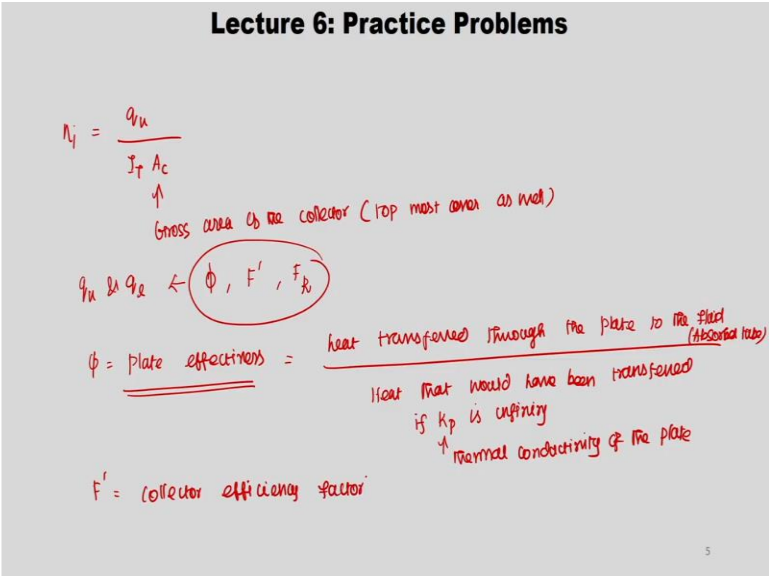

After doing that we are going to calculate instantaneous efficiency which is nothing but q u upon I T into A c this A c is nothing but grass area of the collector which includes the topmost cover as well. In calculating this q u and q l we might require certain other parameters which are phi F dash and F R. So what are all these phi nothing but plate effectiveness which is he transferred through the plate to the fluid upon heat that would have been transferred if K p that is thermal conductivity of the plate material is infinity that is plate effectiveness.

So how much heat it is able to transfer through the plate to the fluid. So fluid is there in the absorber tube. So the same to the it is the ratio of heat transferred through the plate to the fluid which is flowing through the absorber tube to heat that would have been transferred if K p which is nothing but thermal conductivity of the plate is infinitely the second parameter is F dash which is nothing but collector efficiency factor.

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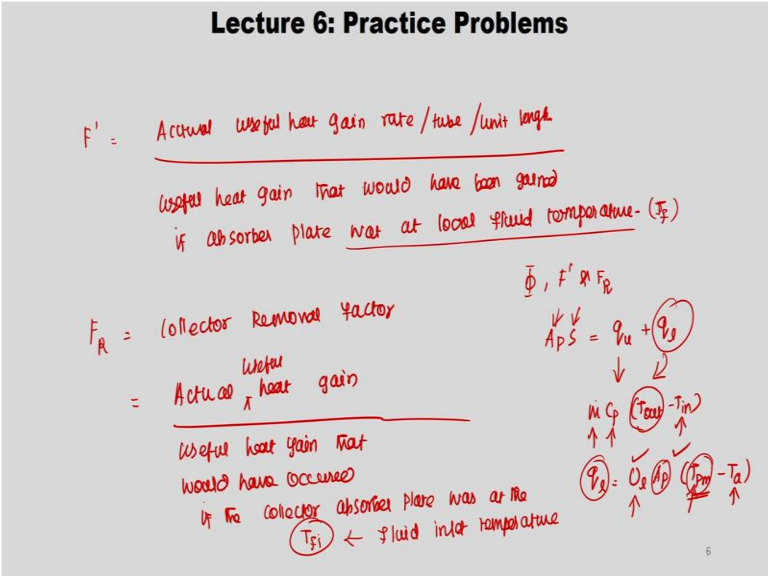

Which is defined as actual useful heat gain rate per tube per unit length upon gain, gain in the sense useful heat gain that would have been gained by gained if absorber plate was at local fluid temperature local fluid temperature F dash is actually useful head gained rate per tube per unit length to useful head gained that would have been gained if absorber plate was at local fluid temperature which is nothing but T f.

And then another parameter all these parameter we learnt in lecture 4 I am just reminding you F R with this collector removal factor which is nothing but actual useful heat gain upon useful heat gain that that would have occurred if the collector absorber plate was at the T fi. So this is nothing but fluid inlet temperature. So F R is the ratio of actual useful heat gain upon useful heat gain that would have occurred if the collector absorber plate was that T fi which is nothing but fluid inlet temperature.

Now we might be wondering then why I would require phi F dash and F R so what is the use. So if you see here just before we define A p into S which is nothing but useful heat gain plus heat losses. So how to calculate heat losses because this you might be knowing as m dot that C p T out – T in that is useful heat gains given to the working fluid. So here this might be knowing what is mass flow rate what is fluid inlet temperature and what is C p.

To know T out because that is unknown to me for the given absorber plate flux and absorber plate area at least I require q l to know q l this is nothing but U l will A p T pm T pm is nothing but mean plate temperature minus T a T a is nothing but surrounding temperature or atmospheric temperature. So to calculate q l would require U l which is nothing but overall loss coefficient and A p which is nothing but plate area and T pm which is nothing but mean plate temperature and T a surrounding temperature.

So here this I might be knowing this I can even calculate because the overall heat loss coefficient again if you see. So there is a losses from top U t there is a losses from site U s there is a losses from bottom as well U b. So U l is U l comprises of top loss bottomless as well as side loss overall coefficient can be an addition of all these that I should know and plate area I am available with and this plate mean temperature is very much difficult to calculate at the first instance. So, to replace them in terms of known quantities for example if you see here T fi that is very much known to the user so T fi.

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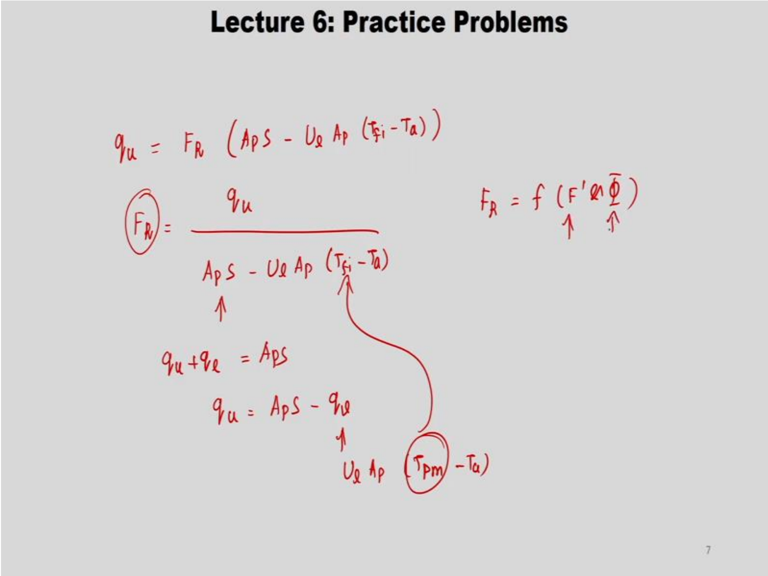

So if you remember useful heat gain formula in terms of F R q u is nothing but a F R A p S - U l A p T fi - Ta this is one of the formula from this a few define a F R which is nothing but q u upon A p S - U l A p T fi - T a. So this is nothing but if you compare them with q u + q l which is equivalent to A p into S. So, for q u you can write them as A p s - q1 but q l is always defined with U l A p T pm - T a.

So instead of unknown plate mean temperature if I want to substitute with known fluid inlet temperature then the factor the ratio is nothing but collector heat removal factor. So that is the reason we wanted to calculate F R it is again the function of F dash and phi which is nothing but collector efficiency factor and plate effectiveness.

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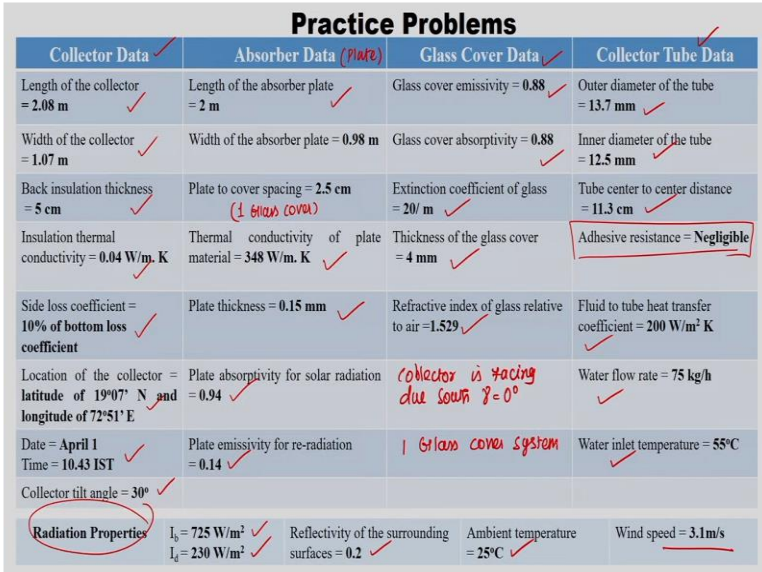

Practice Problems

Collector Data	Absorber Data (Plate)	Glass Cover Data	Collector Tube Data
Length of the collector = **2.08 m**	Length of the absorber plate = **2 m**	Glass cover emissivity = **0.88**	Outer diameter of the tube = **13.7 mm**
Width of the collector = **1.07 m**	Width of the absorber plate = **0.98 m**	Glass cover absorptivity = **0.88**	Inner diameter of the tube = **12.5 mm**
Back insulation thickness = **5 cm**	Plate to cover spacing = **2.5 cm** (1 Glass cover)	Extinction coefficient of glass = **20/ m**	Tube center to center distance = **11.3 cm**
Insulation thermal conductivity = **0.04 W/m. K**	Thermal conductivity of plate material = **348 W/m. K**	Thickness of the glass cover = **4 mm**	Adhesive resistance = **Negligible**
Side loss coefficient = **10% of bottom loss coefficient**	Plate thickness = **0.15 mm**	Refractive index of glass relative to air =**1.529**	Fluid to tube heat transfer coefficient = **200 W/m² K**
Location of the collector = **latitude of 19°07' N and longitude of 72°51' E**	Plate absorptivity for solar radiation = 0.94	Collector is facing due South γ = 0°	Water flow rate = **75 kg/h**
Date = **April 1** Time = **10.43 IST**	Plate emissivity for re-radiation = 0.14	1 Glass cover system	Water inlet temperature = **55°C**
Collector tilt angle = **30°**			

Radiation Properties	I_b = 725 W/m², I_d = 230 W/m²	Reflectivity of the surrounding surfaces = **0.2**	Ambient temperature = **25°C**	Wind speed = **3.1m/s**

So by using all these things and the given data we are going to do the problem to calculate instantaneous efficiency. So here collector data is given length of the collector width of the collector back insulation thickness that is bottom insulation thickness and bottom insulation thermal conductivity is given 0.04 watt per meter Kelvin and for sight loss coefficient instead of calculating it is given here to assume 10 percentage of bottom loss coefficient.

This is assumption again and location of the collector is given latitude longitude and date and time for which we are going to calculate instantaneous efficiency that is also given and collector tilt angle is given as 30 on absorber plate side length of the absorber plate width of the absorber plate, plate to cover spacing thermal conductivity of the plate material plate thickness plate absorptivity of solar radiation and plate emissivity for radiation are given.

On glass cover side glass cover emissivity absorptivity extension coefficient of the glass thickness of the glass cover refractive index of the class relative to air is given collector tube side out diameter of the tube inner diameter of the tube, tube center to center distance adhesive resistance is negligible again. So we need not take into account while calculating resistance we need not take into account adhesive resistance.

Basically this resistances are going to be calculated in calculating F R which is nothing but the collector heat removal factor and then fluid to heat transfer coefficient is given as 200 watt per meter squared Kelvin water flow rate and water inlet temperature is also given and we can take the gamma as 0 degree because the collector is pointing dues of so if any other data is required then we may assume while doing problems.

And radiation properties are given I b is 725 I d is 230 reflectivity of the surrounding surfaces given us 0.2 ambient temperature is given us 25 degree wind speed is given us 3.1 meter per second if any other data is required we will assume and proceed the problem to calculate instantaneous efficiency.

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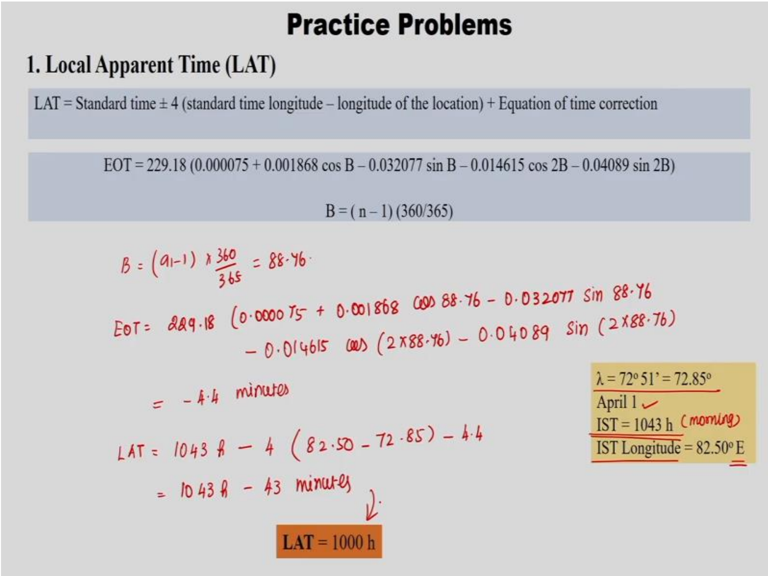

The first step is calculating local apparent time because we supposed to calculate angle of incidence So far that we would be requiring this particular information. So local apparent time you have already done the same problem in your lecture 3 the same thing we are going to do here Indian Standard Time has given us 1043 hours in the morning and IST longitude is given and longitude of the location is given and the data is given. So first we supposed to calculate B.

So n is April 1st so 91st minus 1 and into 360 upon 365 So you would be getting 88.76 then he was supposed to substitute in EOT the same thing you have done with for same given data in your lecture 3 I am just repeating it here what you would be getting us -4.4 minutes then after that we supposed to find out LAT. LAT is Indian standard time that has given us 1043 hours. So this is in eastern hemisphere the IST of longitude is an eastern hemisphere. So -4 into standard time longitude 82.50 minus longitude of the location 72.85 - 4.4 minutes. So if you calculate this 1043 hour - 43 minutes so LAT is 10 hours.

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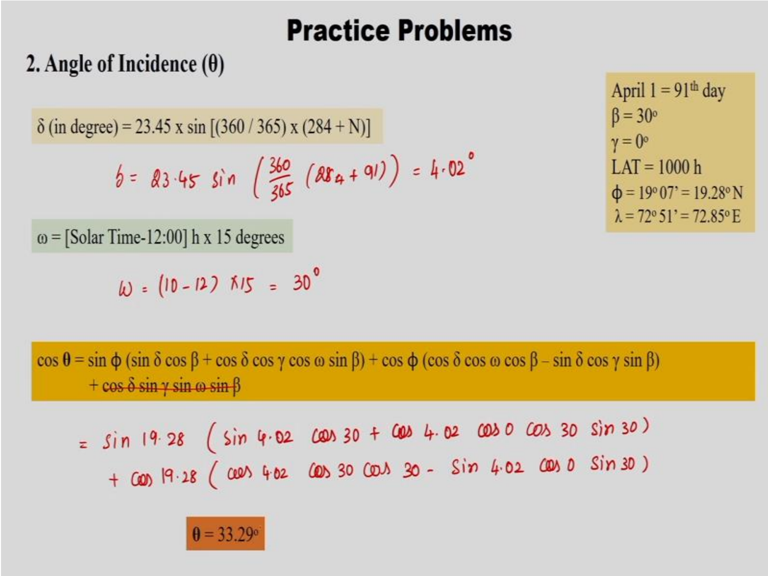

And then using this we would be calculating delta which is declination angle 23.45 sin 360 upon 365 284 + 91. So if you call it this would come around 4.02 degree. So omega is solar time that is 10 -12 into 15 since it is in the morning it should be in plus so 30 degree then substitute the same and 19.2 sin 4.02 cos 30 + cos 4.02 and the collector is facing due south.

So here itself he will say that collector is facing due south for which gamma is 0 degree and also we have seen a we have said that 1 glass color system is cos of 0 and cos 30 sin 30 + cos of 19.28 cos 4.02 cos omega cos beta which is again 30 sin 4.02cos 0 sin 30 5 delta beta delta gamma omega beta 5 delta omega beta delta gamma and sin beta. So here sin gamma becoming so this term goes so you would get theta is 33.29 degree.

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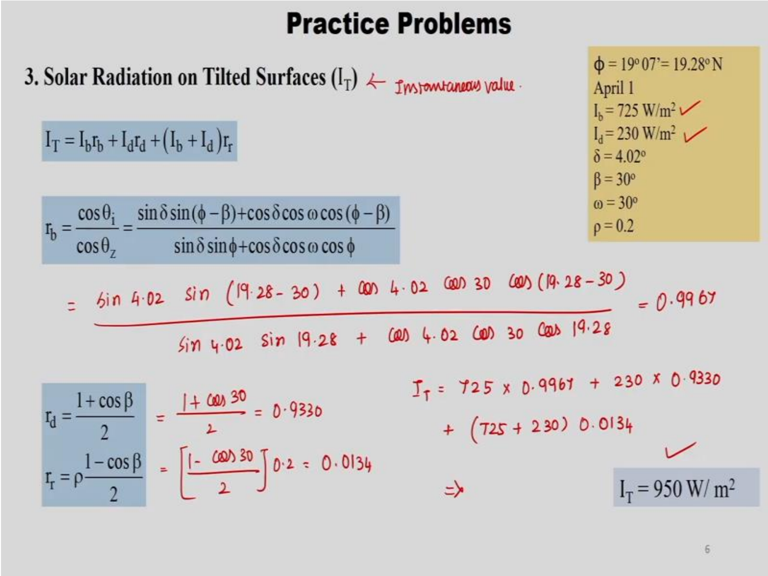

And then we are going to calculate solar radiation on tilted surfaces it is instantaneous value rate for which we are going to first to calculate r b which is nothing but a factor sin 4.02 sin 19.28-30 + cos 4.02 cos 30 cos of 19.28 - 30 upon sin 4.02 sin 19.28 is cos 4.02 cos 30 cos 19.28. So if you calculate this particular parameter it is coming around 0.9967 and then this also we we have calculated for previous problem.

So this is 0. 9330 and this is cos 30 upon 2 into rho is given here in the problem as 0.2 which is 0. 0134. So we have calculated here the r b r d and r r parameters then we will calculate I T for calculating I T the I b and I d is given which is nothing but beam and diffusive radiation. So we can substitute the same 725 into r b 0.9967 + 230 into r d 0. 9330 + 725 + 230 I b + I d into r r 0. 0134. So if you calculate this particular value I T is coming around 950 watt per meter squared. So we have calculated solar radiation on tilted surface I T which is coming as 950 watt per meter square. Rest of the part we will continue in next lecture. Thank you.

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Suggested Reading Materials References

1. S. P. Sukhatme and J. K. Nayak, Solar Energy: Principles of Thermal Collection and Storage, Tata McGraw Hill, 2015

2. H. Buchberg, I. Cotton and D. K. Edwards. 1976. Natural convection in enclosed surfaces- a review of application to solar energy collection. *Journal of Heat Transfer, Trans. ASME*, 98: 182.

3. F. L. Test, R. C. L. Lessman and A. Johary. 1981. Heat transfer during wind flow over rectangular bodies in the natural environment. *Journal of Heat Transfer, Trans. ASME*, 103: 263.

4. J. P. Holman, Heat Transfer Tenth ed. McGraw-Hill Series in Mechanical Engineering, 2010