Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture - 06
Non-Concentrating Solar Collectors Part - II

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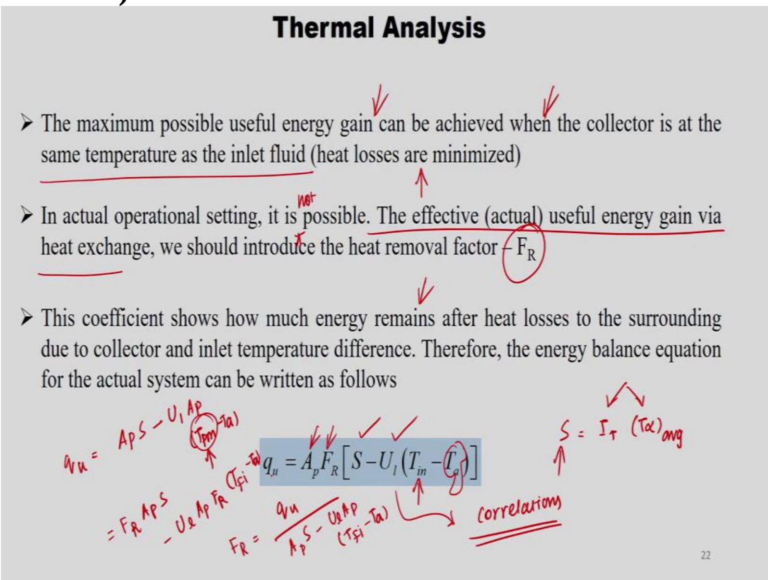

Yesterday we have seen how to calculate the S parameter S based on incident radiation I T and tau alpha average by calculating. So, these 2 values how to calculate the energy which is absorbed by or radiation which is absorbed by absorber plate. So, the maximum possible useful heat gains can be achieved when a collector is at the same temperature as that of the inlet fluid where heat losses minimized. So, in actual practice it is not possible.

It is possible only when if we introduce a parameter called heat removal factor. So, this is ideal case ideal case in the sense so, getting this one done the maximum possible useful energy gain. So, this we reviewed in our lecture 1 itself based on thermodynamics law you cannot convert the energy into 100 % useful work. So, in actual operational setting converting the useful heat gain from the radiation result may not be possible 100 % possible.

So, that effective useful energy heat gain is via heat exchange can be defined by the factor F R which is nothing but heat removal factor. So, this coefficient shows how much energy remains after heat losses to the surrounding due to collector and inlet temperature difference. So, this same formula you might have seen as a q u as A p S – U l A p T pm – T a this is plate mean temperature. So, we do not have plate mean temperature, but we need to analyse the system in terms of inlet temperature.

So, that is what here it is said it is a coefficient which shows how much energy remains after heat losses to the surroundings due to collector and inlet temperature difference. Therefore, the energy balance equation for the actual system can be written as follows. So, here we are introducing factor F R A p S – U l A p T pm – T a. So, if you define F R which is nothing but q u upon A p S – U l A p T fi – T a. This is not pm, this is fm. So, if the plate temperature is at fluid inlet temperature, so, how much actual heat gain we get? So, that is defined by the factor heat removal factor.

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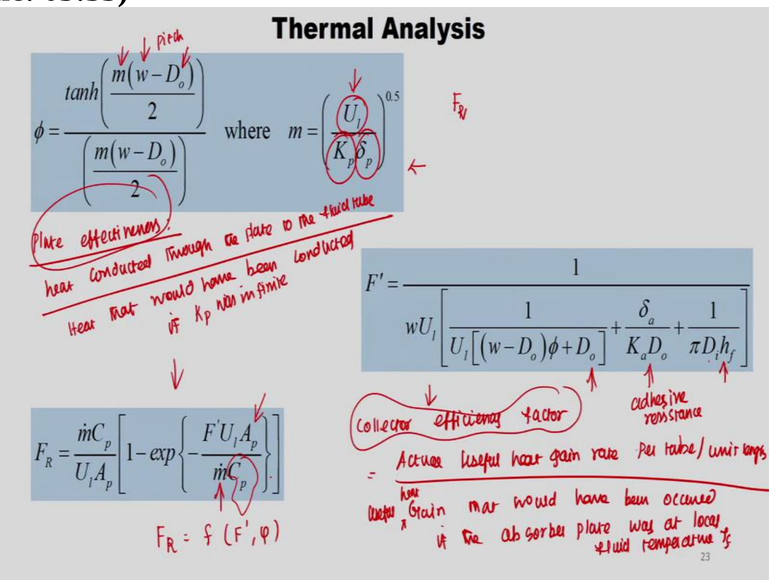

To define heat removal factor again we need these parameters one is plate effectiveness which is nothing but phi. So, this is defined as tanh of m w – D not. So, this m is defined here again. So, this is overall heat loss coefficient. So, this is thermal conductivity of the plate material, this is the thickness of the plate material and this w is center to center distance that is pitch of the fluid passage and D not outer diameter of the tube.

So, which is called plate effectiveness heat conducted through the plate to the fluid tube upon heat that would have been conducted if thermal conductivity of the plate was infinite. So that means the conductivity is so high. So, without any resistance it directly reaches the working fluid. So, that is this parameter plate effectiveness another parameter is F dash which is collector efficiency factor.

So, which is equivalent to the ratio of actual useful heat gain rate per tube per unit length upon gain. Gain in the sense useful heat gain useful heat gained that would have been occurred if the absorber plate was at local fluid temperature that has nothing but T f. Local fluid temperature at that particular point of contact. So, that is nothing but F dash. So, here the problem is if you do not know q priory then F R which is nothing but heat removal factor can be defined using plate effectiveness and collector efficiency factor.

Other than that, what we would require is area of the plate absorber plate that must be known the mass flow rate of the fluid flow that must be known then this is specific heat of the fluid U l is heat loss coefficient it is basically all our resistance. So, this is due to fluid flow. This is due to adhesive resistance. This is heat transfer coefficient h f 1 upon h f is inside the pipe. So, D i is multiplied by pi D i is multiplied. So, these are basically their resistance.

So, all this resistance 1 upon resistance is nothing but collector efficiency factor. So, F R here is a function of F dash this F dash is an again function of phi that is nothing but plate effectiveness. So, in that way one can calculate the q u. So, because what we said here is S we know by calculating I T and U l heat loss coefficient we suppose to get it from correlations. So, we will see in detail how to do that and the inlet temperature we are known the ambient temperature as we get it from environment. So, A p is known then for constant F R and U l this heat gain can be calculated.

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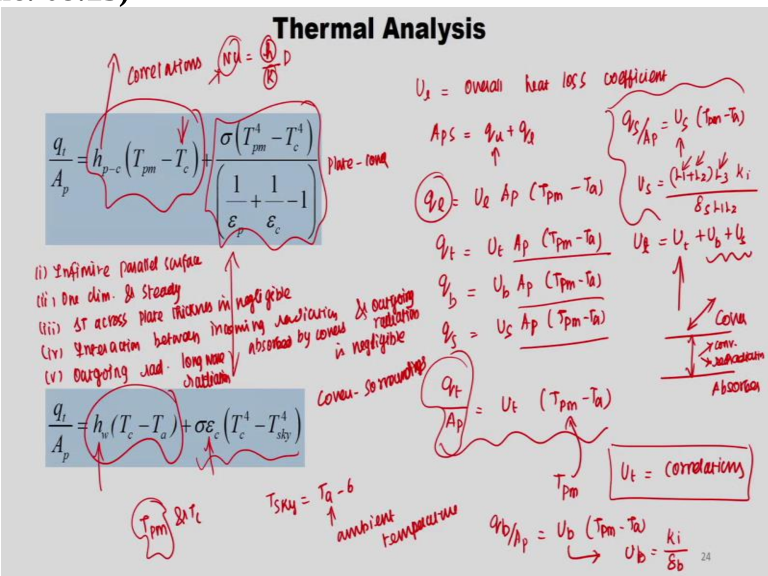

So, after doing so, for example, this U l. What is U l? U l this overall heat loss coefficient. So, whether it is a constant value to be given or if not how to calculate. So, this comes from the basic things A p into S which is nothing but q u + q l. So, q u is useful heat gain. q l heat loss. So, this q l can be further written U l A p T pm – T a. So, this overall heat loss can be divided into 3 q t q b q s this is top loss coefficient.

U t A p T pm – T a. q b is nothing but U b A p T pm – T a and this is U s A p T pm – T a. So, in that way A p T pm – T a is common for all the losses. So, in a way it can be written as the overall heat loss coefficient can be written as summation of top loss, bottom loss and side loss coefficients. So, here if you see these 2 equations, it is a basically q t upon A p. This is to calculate topless coefficient. So, bottom loss side loss we will see in successive slides.

So, U t how to calculate U t. So, if you combine here q t upon A p which is nothing but U t into T pm – T a and same way you can calculate U b U s as well. So, first we are going to see this one. So, I need to calculate what are all the losses from plate to cover and cover to surroundings. So, that is what it basically says. So, this is between plate to cover and the second one is from cover to surroundings.

So, to write this equation there are certain assumptions we take for this thermal analysis whole thermal analysis done it under steady state and one dimensional. So, we consider them the plates. this is your cover and this is your absorber plate. So, we considered them as finite parallel surfaces flow of heat is 1-dimensional and steady the third is del T across plate thickness is negligible interaction between incoming radiation absorbed by covers and outgoing radiation is also negligible and outgoing radiation is only long wave radiation.

Radiation is long wave radiation. So, by considering these assumptions, so, we are going to balance these 2 equations, so, that is nothing but this is absorber plate. So, this is cover. So, from absorber to cover there are 2 components one is convection losses and other one is reradiation losses the same way from cover to atmosphere as well. So, the first component of these 2 equations talks about convection losses.

So, this is heat transfer coefficient between plate and cover system. So, this can be obtained using Nusselt number correlations using Nusselt number which is nothing but h upon K which is heat transfer coefficient upon thermal conductivity multiplied with characteristic dimension of the system. So, if you know correlations if you can calculate N u and then you can get h from there the same way you can use correlations to calculate the air heat transfer coefficient.

So, this is plate mean temperature - cover temperature cover temperature - atmosphere temperature. This is a convection loss and here it is radiation loss. So, which involves plate mean temperature sigma is nothing but Stephen Boltzmann constant and cover temperature This is plate emissivity cover emissivity the same here T sky. sky temperature which is normally taken as T a - 6. This is ambient temperature.

This is plate emissivity and sigma are again Steven Boltzmann constant. So, by comparing these 2 you are plate mean temperature T pm would be fixed. So, for that before if you know this then you can calculate U t are directly you can also fix up U t using again correlations there are correlations, which gives you directly how to calculate top loss coefficient. So, this iteration procedure we will see in detail while doing problems there you will understand better.

So, how to use these 3 equations without U l I do not have U l right now. So, without U l So, there we are going to assume U l and calculate these parameters after calculating these parameters you will find out T pm which is nothing but plate mean temperature. So, that plate mean temperature you would get by assuming U l then how to correct that further and here again one more unknown parameter there which is nothing but T c.

So, out of these 2 equations we would get T pm and T c. So, this is again the value we got by assuming some U l and we do further iterations to correct T pm value and T c value accordingly because we used the T pm and getting T c. So, that we can see in problem section how to do that otherwise one can directly use U t and the U l is for example, if you write it in terms of b q b upon A p which is nothing but U b T pm – T a.

U b can be directly calculated as k i insulation upon delta B and another parameter is q s upon A p which is nothing but U s T pm – T a. So, U s can be returned as L 1 + L 2 into L 3 into K i upon delta S L 1 L 2. So, this L 1 L 2 the collector dimensions length and width and L 3 is nothing but the height of the casing. So, these formulas everything is given in professor Sukhatme and Nayak book that is the main difference book of this particular course, you can refer over there.

So, this one can directly calculate using correlations and the formula directly U l and then from U l, you can get plate mean temperature and plate mean temperature using that you can also calculate the collector temperature, but if not, then one has to do iterations.

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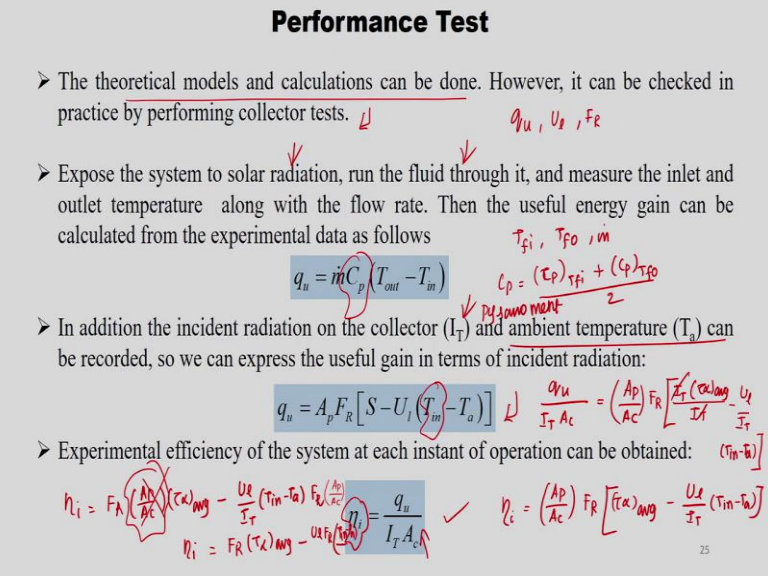

So, the next one is a performance test when you are getting a new collector, so, how to test their performance. So, that is what basically we are going to see here. So, the theoretical models and calculations can be done that is what we have discussed till now, how to get useful heat gain q u, U l, F R. So, that I can directly calculate the instantaneous efficiency. So, the theoretical models and calculations can be done however, it can be checked by practice by performing collector test.

So, whatever numerical modelling and simulation you do, so, that has to be finally validated with the experimental results are if you are designing a new collector that tester has to be performed to compare with the existing collectors and how much performance improvement you are able to bring in the new system. So, for that you supposed to do expose the system to solar radiation and run the fluid through it and measure the inlet outlet temperature along with the flow rate.

So, T fi, T f0 and mass flow rate then calculate the useful heat energy gain from the experimental data. So, mass flow rate we measured T out, T in we measured this is the fluid C p which is the average value of what is the C p at T fi normally we take so, this is the normal calculation we follow. So, average C p and calculate q u. In addition, the incident radiation of the collector I T this also can be calculated we have read the pyranometer using instrument.

We can directly read the particular time or particular day what is the incident radiation and ambient temperature also can be recorded. So that we express q u in terms of A p F R S – U l T in – T a. So, here we used only the inlet fluid temperature that is why we have taken F R. So, if you think a little bit so, q u I will divided by I T A c which is nothing but instantaneous efficiency.

So, this side also, if you divide A p upon A c F R I will keep it so here S I can write it as I t tau alpha average upon one more I T is here – U l I T upon I T. So, this is this one should not get confused T in – T a. This I T, I T get cancel, so, instantaneous efficiency which is nothing but q u upon it A c which is nothing but A p upon A c. This is plate area collector area into F R tau alpha average - U l upon I T into T in – T a.

If you want to write it F R A p A c tau alpha average - U l I T T in – T a F R A p A c which is equivalent to y equal to mx + c form. If you have a plate area as well as the collector area same are one can calculate instantaneous efficiency based on A p as well. So, if both areas are same then this must be going then what you would get is eta i is nothing but F R, tau alpha average – U l F R into the T i – T a upon I T.

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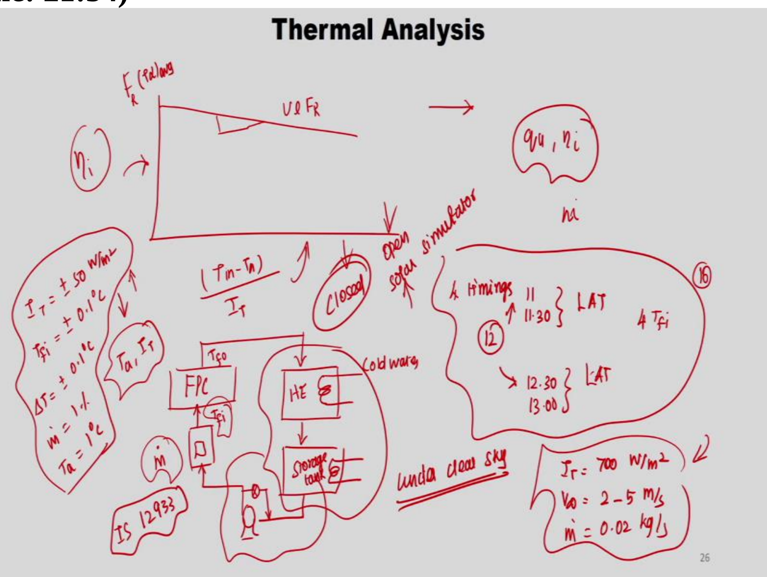

If you plot T in - T a upon I T versus eta i. So, what you will get U l F R as the slope for example, this is the line with the negative slope of U l F R and your intercept would be a F R tau alpha average. So, one can compare the performance of new collector with the existing collector and always come up with the performance curve this has to be done for close to system. For example, so you have a flat plate collector or a new design whatever you come up with.

So, here you may use heat exchanger with the cooling cold water. This is heat exchanger and you can use one more storage tank with heater facility. So, this has to be pumped go to flow meter and go to FPC flow meter you measure m dot here you measure with temperature sensor T f T f not and T a, I T use pyranometer and temperature measurement of the ambient. So, this is this particular arrangement, even pump you can also use one bypass wall to adjust the flow rate.

So, these are all done the axillary arrangements to make sure the mass flow rate and T FS whatever you wanted. So, normally this test has to be performed for 4 timings. So, normally we say to solar noon is the maximum radiation. So, before that to probably 11 and 11:30 LAT local apparent time the same thing here 12:30 and 13 hour of LAT. So, at least for 4 various inlet temperature and by fixing one particular mass flow rate.

At least 16 measurements to be done for one particular mass flow rate value. So, when doing so, be supposed to maintain under clear sky this test has to be performed under clear sky. The I T should be around 700 watt per meter square and the wind velocity should be around 2 to 5 meter per second and mass flow rate should be at least 0.02 kg per second. So, this we need to ensure and also there are some experimental errors.

So, how much it is possible for I T plus or minus 50 watt per meter squared error is allowed for getting T fi we are measuring T fi T fr. So, there plus or - 0.1 degrees allowed and that del t should be about plus or minus 0.1 degree and mass flow rate 1% is allowed and ambient temperature around 1-degree centigrade error is allowed. So, by keeping this error values in mind and by keeping at least this around I T V infinity m dot. So this performance test has to be performed. So, this is based on the Indian standard value 12933.

So, this kind of performance test and this is closed loop. So, one has to perform parallelly the open loop as well as solar simulators to do solar simulator. That is what we learned. So, how to calculate q u and eta i using formulae and calculations and then compare closed loop performance test, open loop performance test and performance test performed by solar simulator. So, that is all about thermal analysis.

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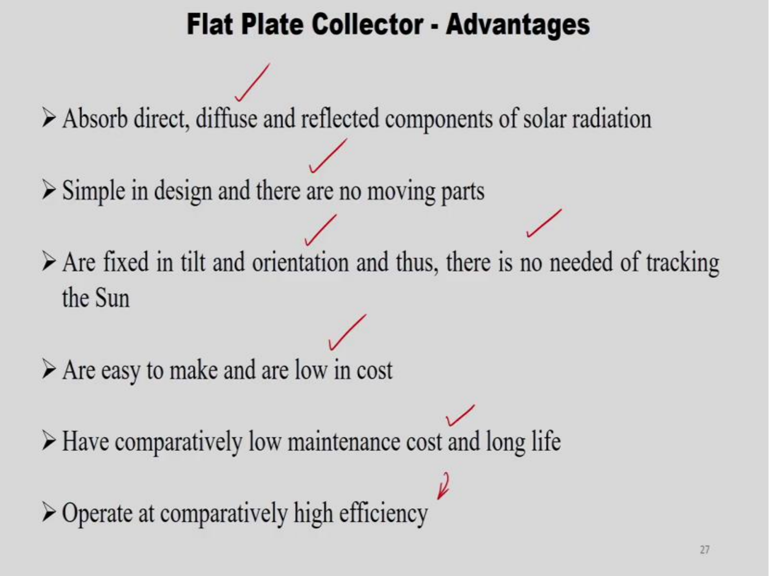

Then next is what are all the advantage of flat plate collector. So, it absorbs direct diffuse reflected components of radiation, simple in design, there are no moving parts and tilt and orientation is fixed. So, no need for tracking the Sun, easy to make and low in cost have comparatively low maintenance cost and long life operate comparatively at high efficiency with less labour and complexity. So that is where advantage of getting comparatively high efficiency for less investment.

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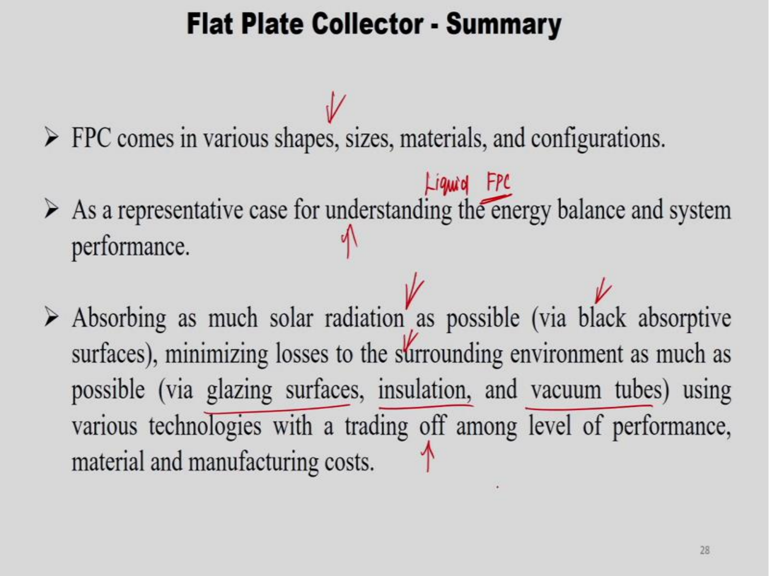

So, summary FPC comes in various shapes, sizes, materials and configurations. As a representative case for understanding the energy balance and system performance. We thoroughly done liquid FPC how to do theoretical calculations as well as how to get experimental parameters and absorbing as much solar radiation as possible using black absorptive surfaces, minimizing losses to the surrounding environment as much as possible using glazing surfaces, insulation, vacuum tubes using various technologies with the trade-off among level of performance and material and manufacturing costs.

We would say flat plate collector would be the best to collect solar radiation for low temperature applications. Then we will see certain modifications and solar heater and their applications in the next lecture. Thank you.

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