Solar Energy Technology

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Lecture - 21

Concentrating Collectors (Contd.)

We shall continue with the theory of concentrating collectors.

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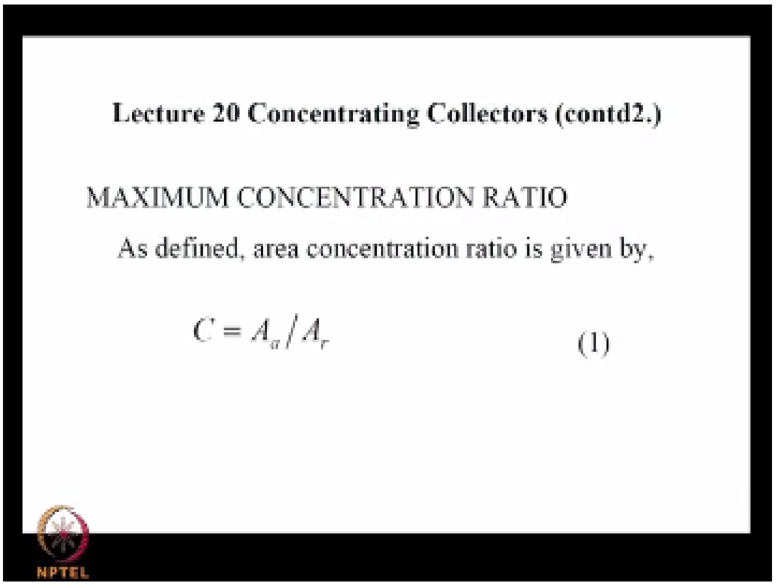

Now we have expressed the solar radiation received by the aperture of a focusing or tracking collector tracked in different modes, and we are also able to evaluate the tilt factor at any instant R b or for the day.

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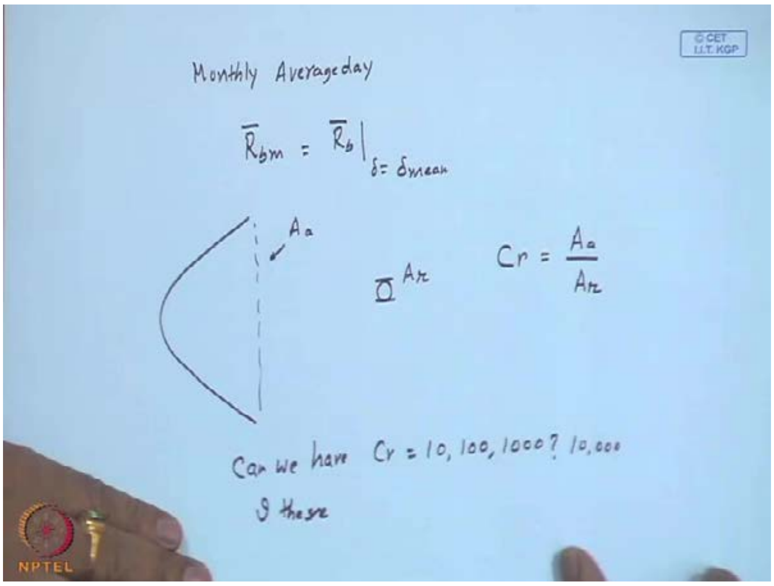

Of course, for the monthly average day as we have done for flat plate collectors or fixed slopes surfaces, R b bar m for simplicity is nothing but R b bar evaluate with delta equal to delta mean, where delta mean is the recommended mean declination for each month. So, the formula are known and there are analytical expressions for mod one and four and five, and mod's two and three are not analytically integrable. So, one may have to go for a numerical integration, whether R b under terrestrial conditions is used or even under extra terrestrial conditions. Now the question comes; we have a parabola and with an aperture area A a focused on to a receiver of area projected A r and the geometric concentration ratio is defined as A a upon A r. Now can I have or can we have Cr 10 may be, yes, 100 yes, 1000 question mark, 10000 or is there a limit.

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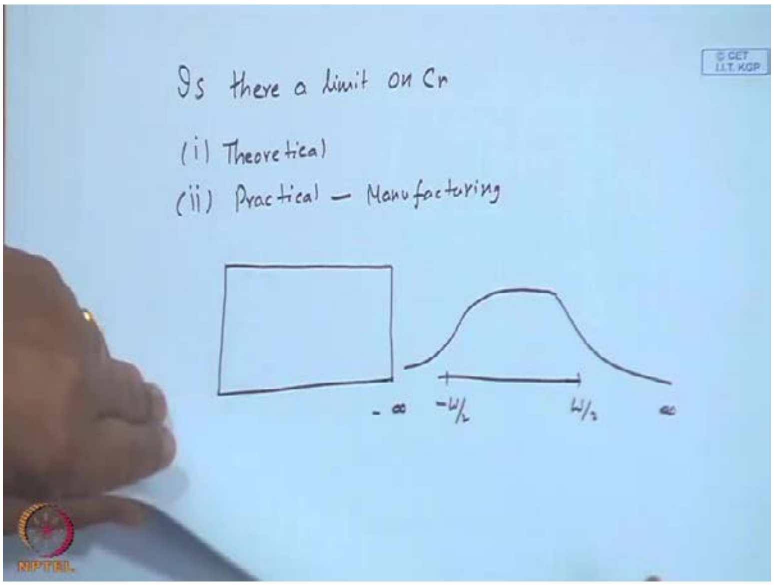

Let me go to the next page; is there a limit on C r? One, theoretical limit, second thing may be practical arising due to manufacturing, like for example, how perfect is the reflector, how perfect is the refractor, how perfect is the optics? And though we do not aim at the 100 percent efficiency from the thermal point of view, will all the radiation that is passing through the aperture gets reflected and goes exactly on to the receiver and depending upon the tracking board. So, practically we may have if you take the plane of the receiver, my distribution will not be a perfect rectangle like this. But it may be something like this, going much bit beyond the receiver, and technically I may have to integrate from infinity minus to plus infinity whereas this may be of minus W by 2 to plus W by 2, and intensity also may not be uniform; this is one aspect.

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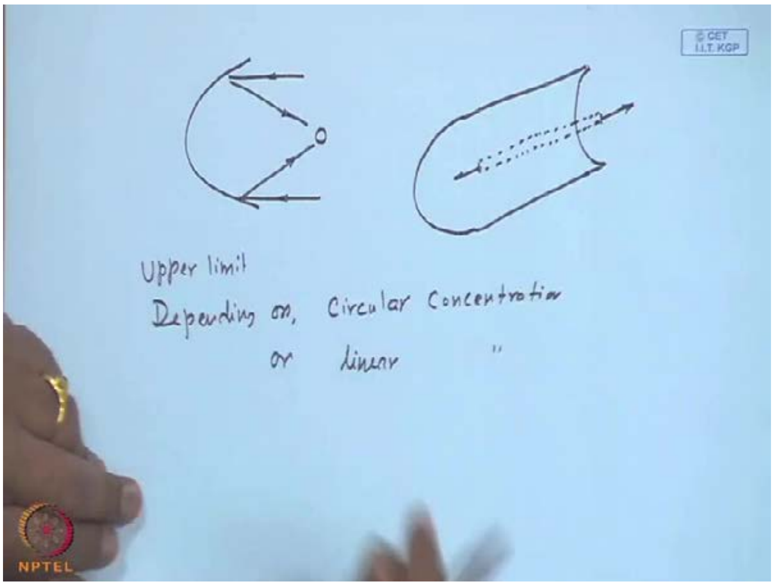

And regarding the reflected rays, whenever we are showing it as a sort of a cross-section, so this is the small receiver classroom diet, and this is the reflector coming over here. Now, if I make it somewhat two-dimensional view, this may be the reflector, and the tube may be here. So, depending upon the tracking mode my reflected rays may go to east or west or north and south, may not exactly fall on the receiver tube. So, all that reflected ration may not be captured by the receiver. So, effectively the concentration ratio could be different.

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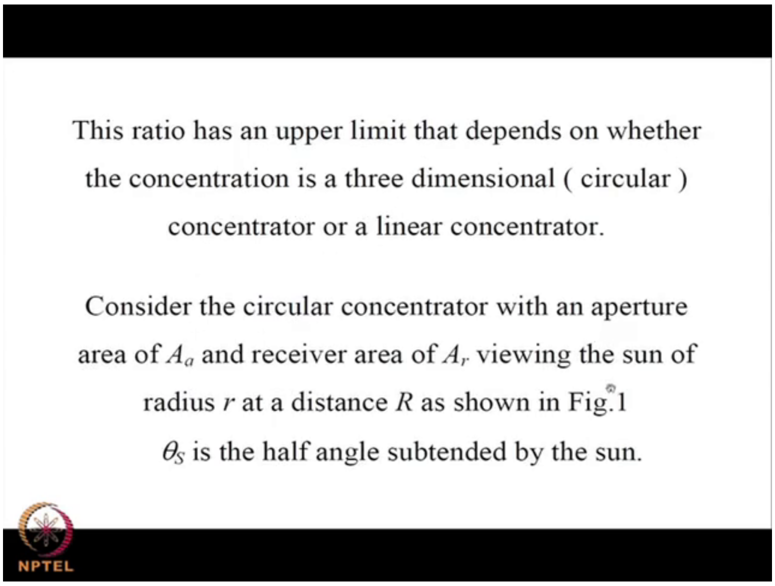

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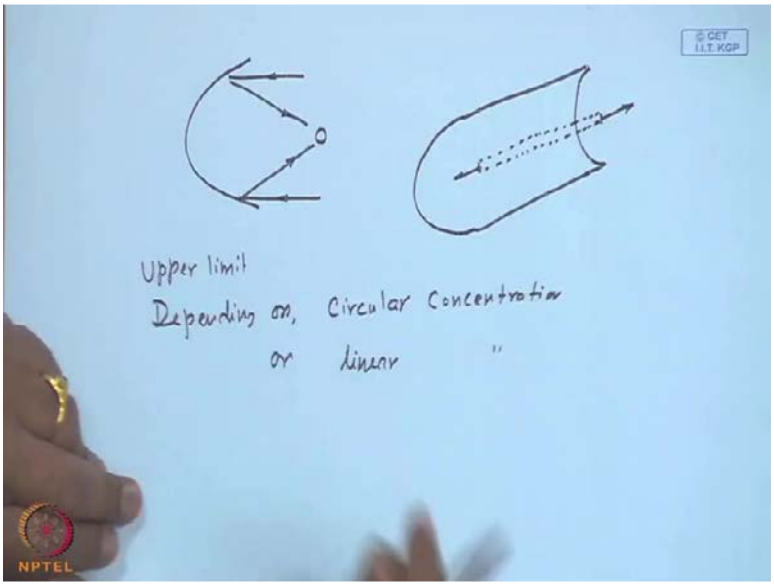

But even if you talk about only the theoretical possible maximum concentration ratio this has an upper limit depending up on whether it is circular concentration or linear.

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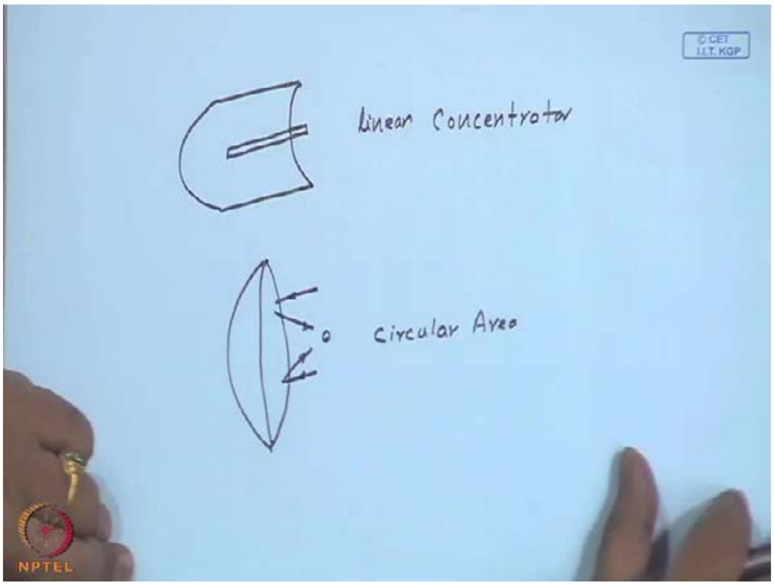

So, if you have a parabolic system, like we have drawn now, the attempt is to focus on to a line. So, this is a sort of linear concentrator. The other way around is if you have a parabolaidal, this will try to focus on to a circular area. So, technically this can be a point, this can be a line, or is it possible? So, which we shall show the possible maximum.

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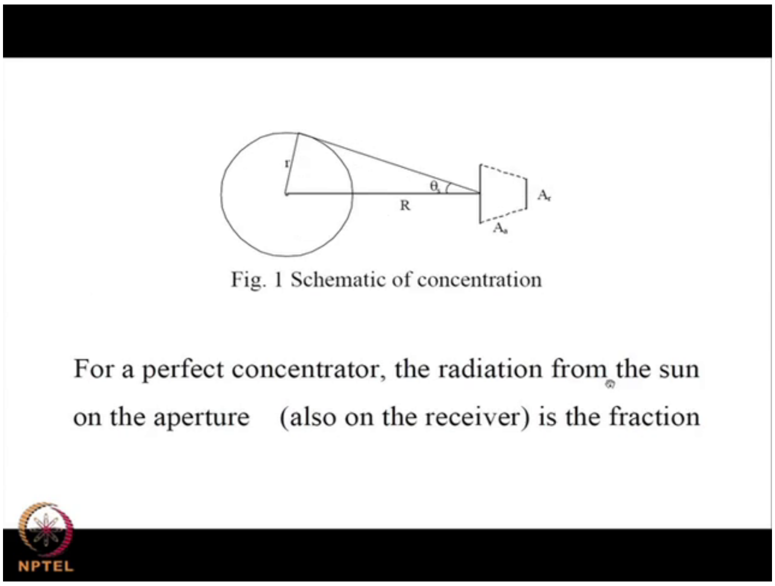

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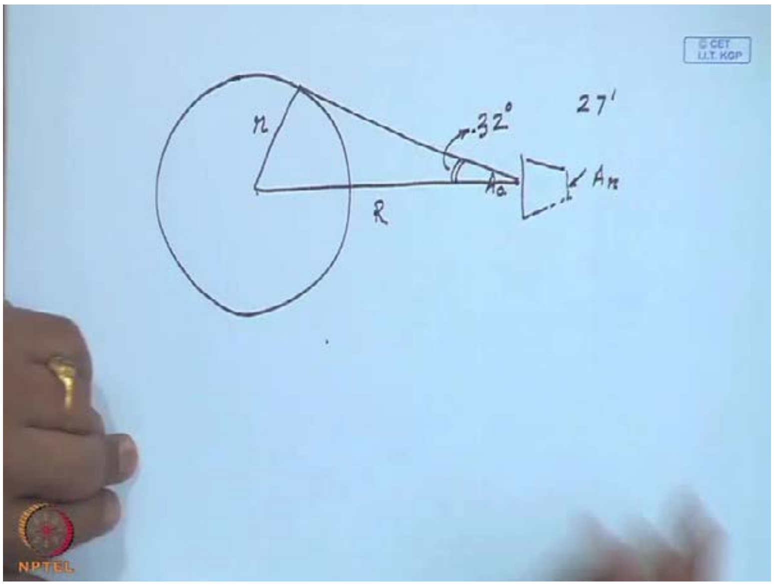

Let this big circle be the sun of radius r at a distance of capital R from the aperture area, and at the same distance receiver also making their half angle theta s or 27 minutes for a perfect concentrator. So this is a sun of radius r at a distance from the earth of capital R, and the angle suspended is 0.32 degrees on to the aperture area of A r and A r is the receiver area; you do not have to worry that this should be before or after, it is only symbolic representation that shows A a is not equal to A r; A r is the smaller thing. The issue is if we consider a circular concentrator, can I make A r zero almost making the concentration ratio infinity.

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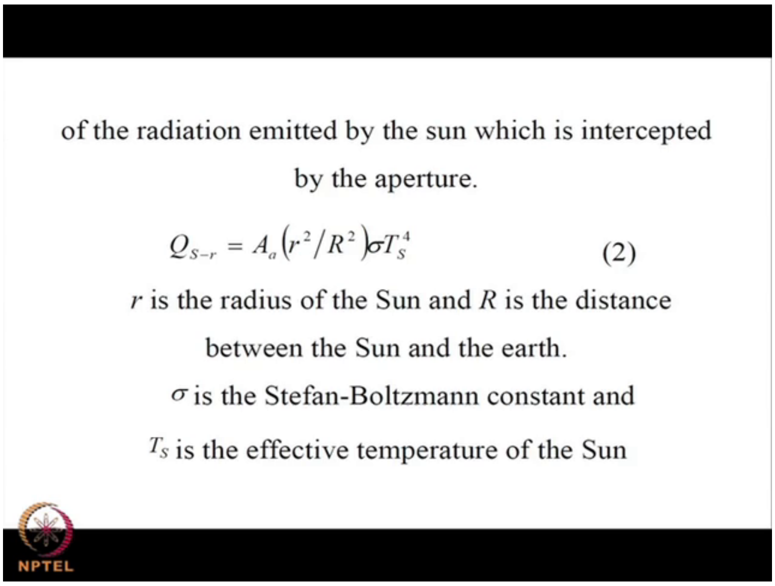

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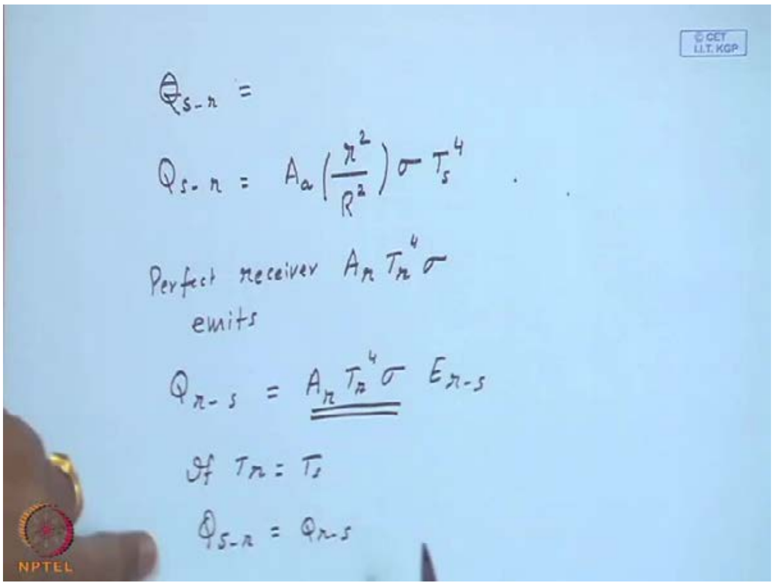

So, the radiation emitted by the sun reaching the receiver will be A a r square upon R square times sigma T s to the power 4; r is the radius of the sun, and capital R is the distance, sigma is the Stefan-Boltzmann constant, and T s is the effective temperature of the sun. A perfect receiver radiates, perfect receiver emits, area A r into T r to the power 4 times the Stefan-Boltzmann constant sigma. Here you may be wondering, we are not really worried about the reflectivity, etcetera; this is the radiation intercepted by the aperture, the same thing will reach the maximum to the receiver.

Now a fraction of this will go from the receiver to the sun, because the receiver is small and the sun is big. A r T r to the power 4 into sigma of course multiplied by the fraction E r s. So, this is half the emitted energy at a temperature of T r by the receiver; a fraction E r s will go back to the sun. Now T r and T s, if T r equal to T s; that means, in principle if the receiver reaches the sun's temperature, my Q s r should be equal to Q r s. Since there is no more temperature change between T r and T s, the emitted radiation should be equal to the radiation received from the sun.

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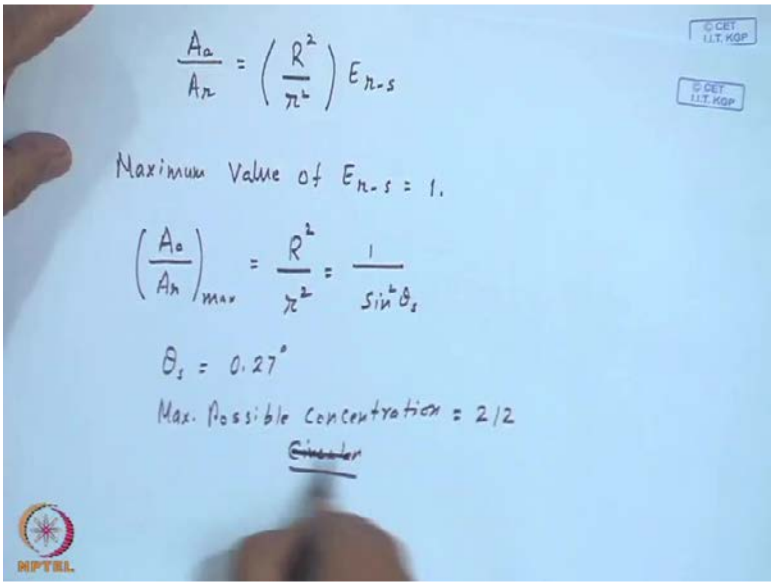

So, that gives us A a by A r equal to R square by r square times E r s. Now maximum value we were estimating the theoretical maximum, so I can assume this of E r s equal to 1. So A a by A r max equal to R square by R square equal to 1 by sin squared theta s. So, if theta s equal to 0.27 degrees maximum possible concentration will be 2 1 2, that you put in the value of theta s you will get 212. This is for a circular concentrator.

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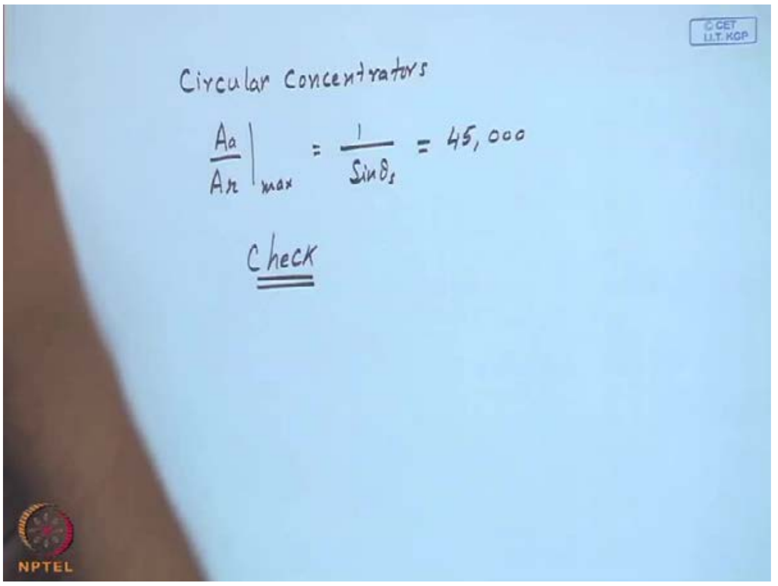

So, a similar procedure for circular concentrators, max which is close to 45,000, okay. I will just check these values in the next class, check, because I think somewhere this linear and circular concentrators, they are confusing; I will just check up these numbers.

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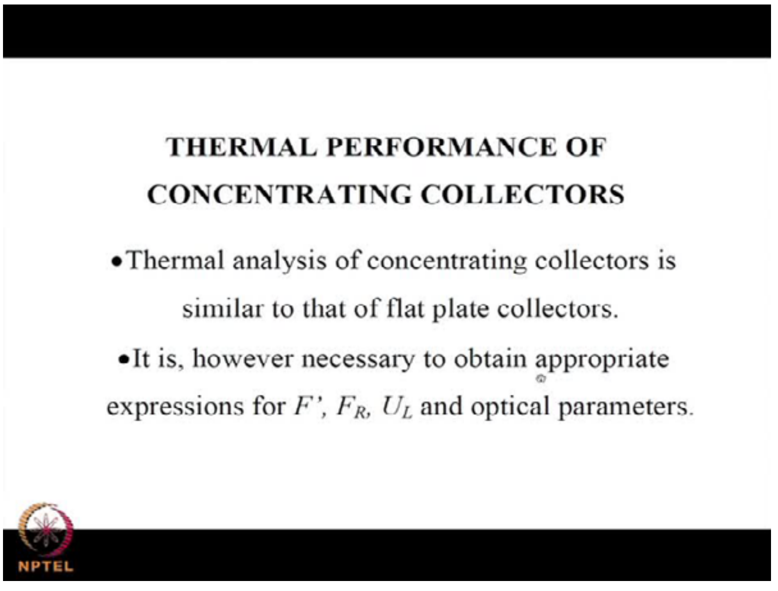

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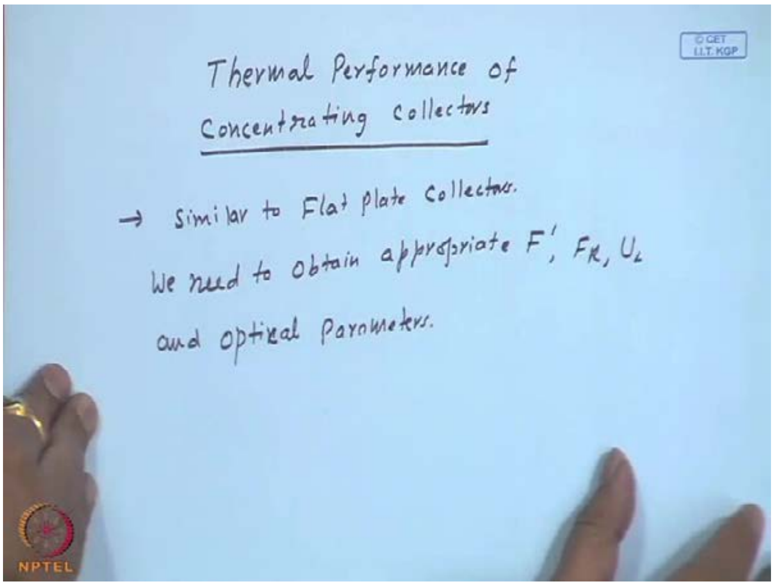

Now, we will go to thermal performance. This is of course similar to flat plate collectors that we have done, and we need to obtain; however, appropriate F dash the collector efficiency factor, F R the heater mode factor, and U L the overall loss coefficient and optical parameters. Compared to a flat plate collector or if you have a concentrating reflector, there will be reflectivity of the concentrating after the aperture.

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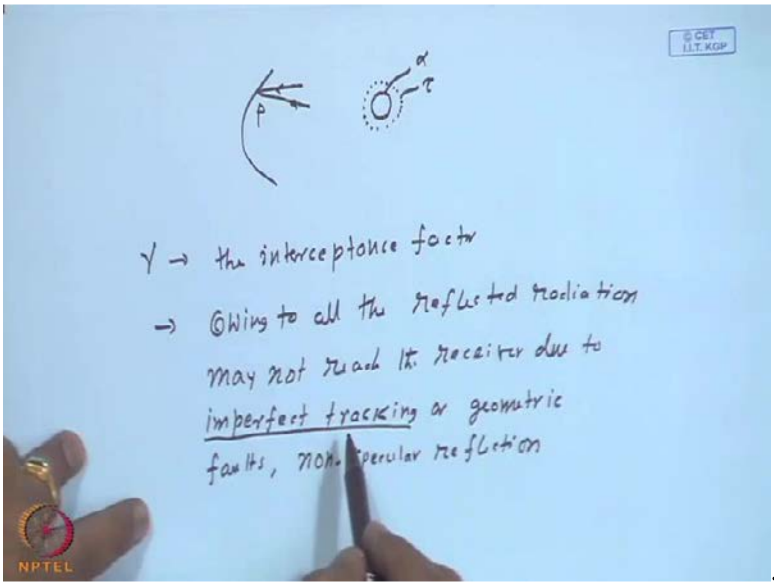

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Then the receiver tube may be having a glass cover to reduce emitted and convective losses. So, this will have a tau; there will be an alpha, and there will be a rho reflectivity of the surface. Instead of just coming to alpha, we have got a reflectivity of the reflector or refractive index in the case of a refractor, and the transmittance of the outer glass cover surrounding the tube and the absurdity alpha.

There is another additional parameter gamma, the interceptance factor. This erases going to all the reflected radiation, may not reach the receiver due to imperfect tracking or geometric faults and non-specular reflection. What we mean is this imperfecting tracking includes my tracking not being towards axes all the time. If you are having a single axis tracking, like the first mode, all the time the reflected radiation may not be within the length of the receiver tube. But many times it is argued that if you have you would not talk about a single collector, but a large number of concentrators one after the other. So, the tube is long enough, so that the reflected radiation will reach the tube somewhere or the other may be that of the adjacent collector, or nevertheless a part of it may be lit, and part of it may not be lit.

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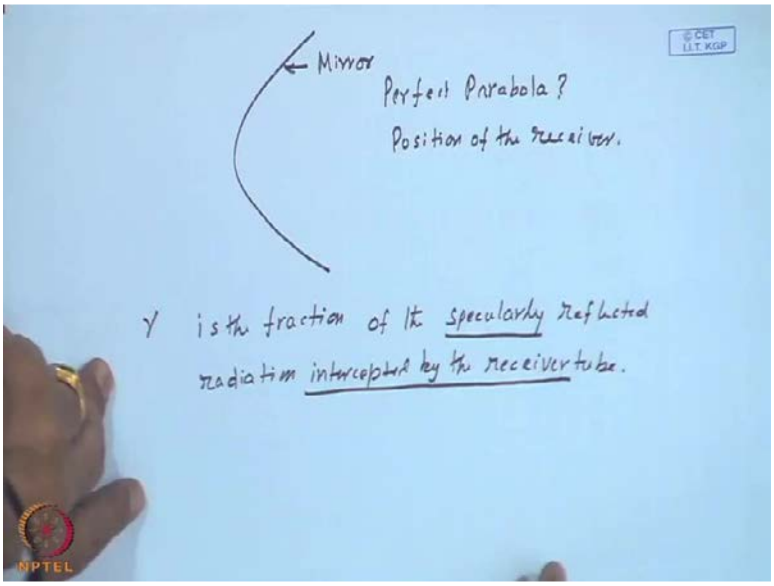

And depending upon your manufacturing technique, the mirror over here may not be perfect parabola. So, consequently, there will be some angulations, because it is a large surface. So, all the reflected radiations may not be striking the receiver. Then position of the receiver itself, there may be imperfection but most of it is due to the tracking not being perfect, and this manufacturing large or reflecting surface may not be following exactly the parabola that optics requires.

So, you may define that gamma the interceptors fraction factor is the fraction of the specularly reflected radiation intercepted by the receiver tube. So, please note; it should be specular and it should be intercepted by the receiver, right, non-specular will not reach the receiver at least. We cannot assure, and either because of imperfect specular reflection or imperfect position of the receiver all the radiation reflected from the mirror may not reach the receiver.

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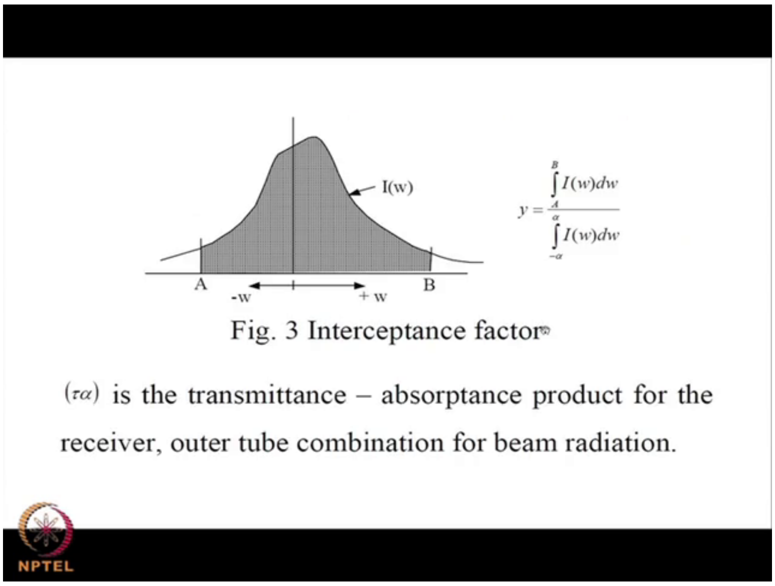

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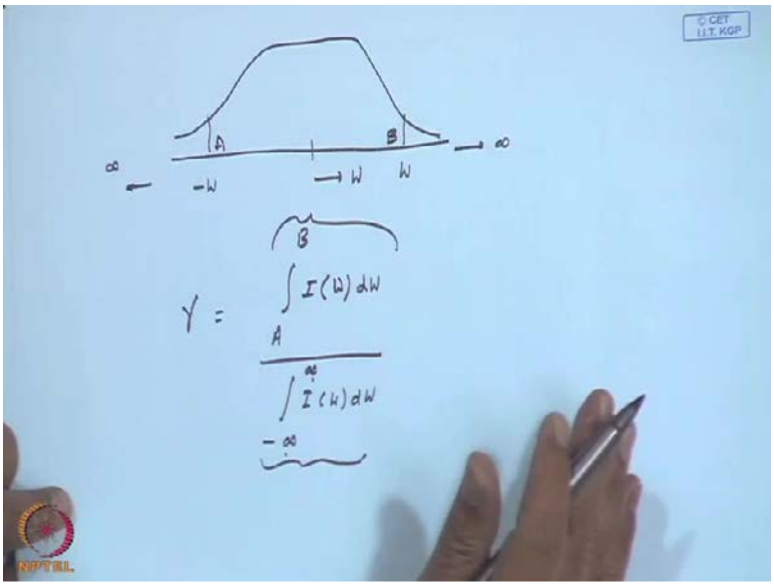

So, schematically you can show something like this; if this is the distribution of the intensity and the receiver plane with a finite width of minus w to plus w, and this may be going as a set to infinity on both sides, no matter how small it is; my interceptance factor gamma will be this may be the point A, and this may be the point B, A to B I w may be the coordinate d w. So, let me put it this way; this is w upon I w d w minus infinity to plus infinity. The figure looks like A B and alpha alpha, but there should be infinity infinity, okay. So, this is the radiation intercepted by the receiver, and this is the radiation that technically got reflected up to including infinity, and if I find out the ratio I will have the interceptance factor.

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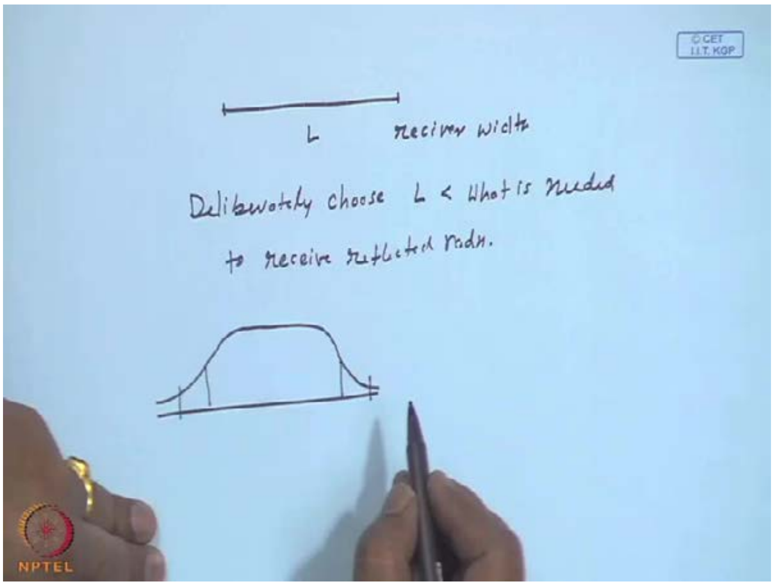

Now some clarification is required; instead of that if I have got some L as the receiver width, we may deliberately choose L less than what is needed to receive reflected radiation, because if you see the type of distribution that we are having over here, 90 percent of it may be in this. So, if I add this much and this much, I will be having a larger area for the heat losses to take place, though the absorbed reflected radiation is relatively a small portion. So, we may deliberately truncate the receiver width to a certain value.

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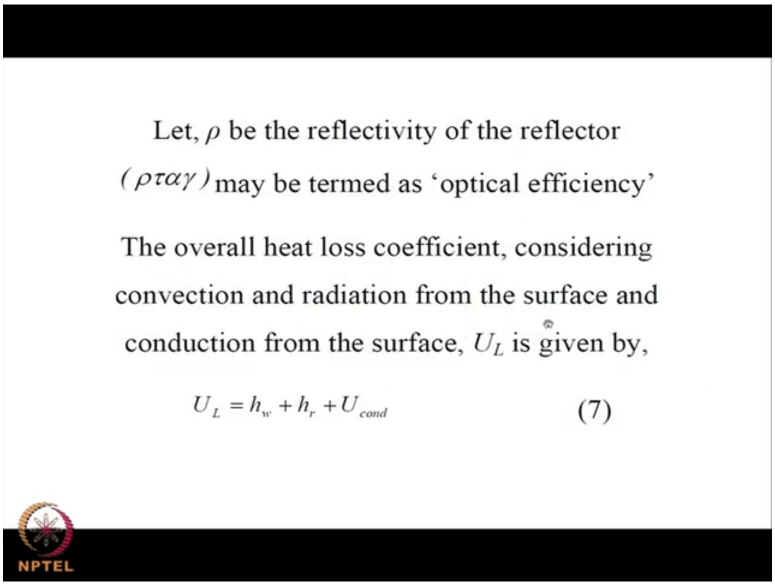

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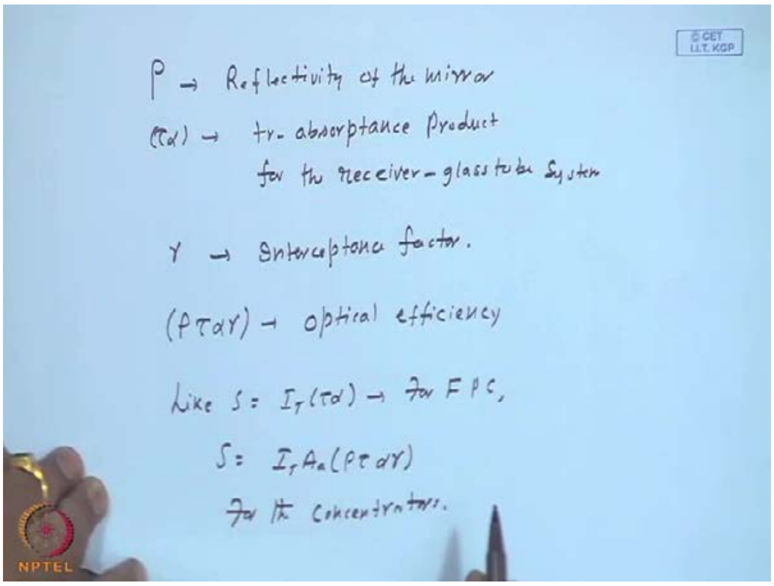

If rho is the reflectivity of the mirror, and tau alpha the transmittance absorptance product for the receiver-glass tube system and gamma is the interceptance factor. So, you have a total rho tau alpha gamma effective is the sort of optical efficiency like S equal to I T tau alpha for flat plate collectors. We may have S is equal to I T A a times rho tau alpha gamma for the concentrators; of course, if you do not have a glass cover, then this tau will be equal to 1.

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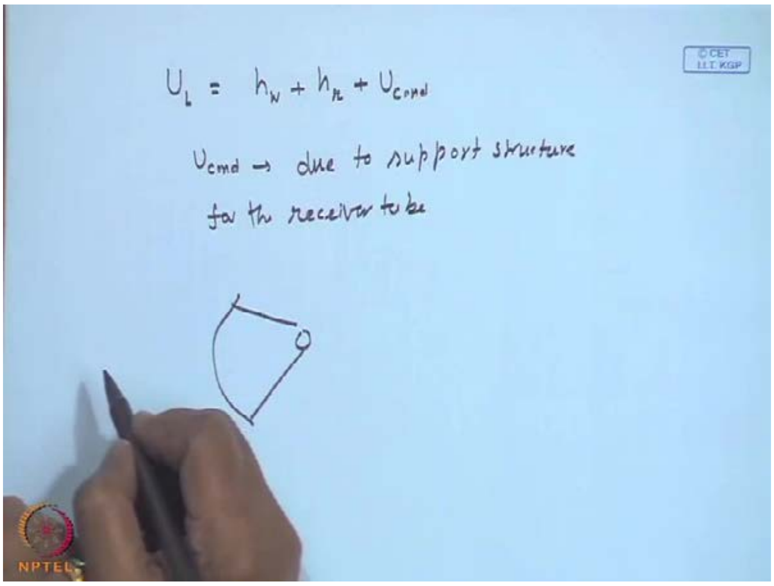

Then the overall loss coefficient should not be comprising of a wind loss coefficient from the receiver plus a radiator loss coefficient from the receiver plus a U conductance; this is due to support structure for the receiver tube. Like we have been showing schematically, the receiver tube will not be just hanging in the air, and it has to be something like, here it may have to get supports with respect to the receiver or this reflector or a frame with that they may act like some sort of fins added to the receiver tube, and hence there may be loss. So, my overall loss coefficient will comprise of the wind loss coefficient, a radiative loss coefficient and conductional loss due to the support structure.

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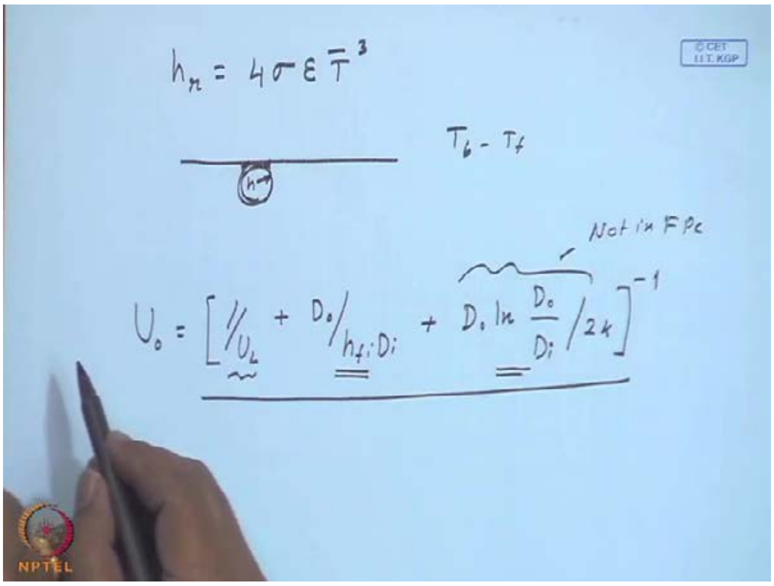

And this is of course we can express the radiate to be trans coefficient in terms of 4 sigma epsilon some T bar to the power 4, whereas we have already defined it is a average temperature of the receiver T R and the surrounding ambient temperatures T a in terms of the fourth powers.

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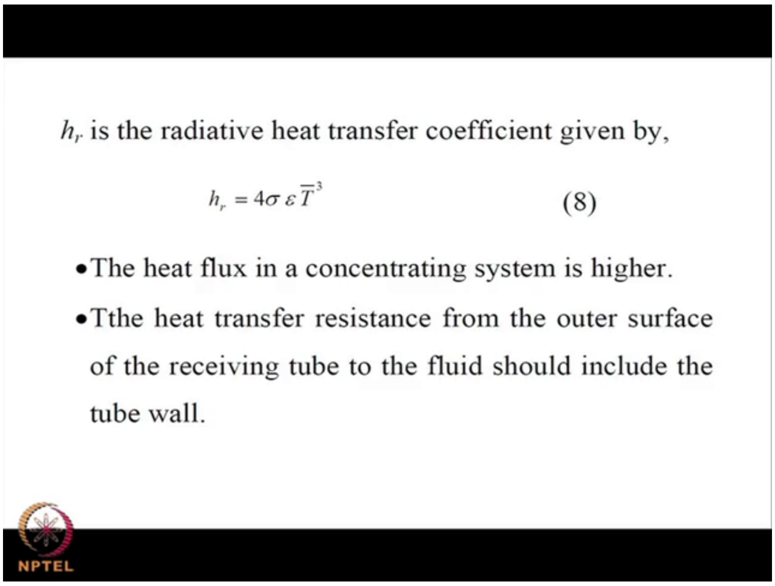

The heat flux in a concentrating system is higher, or the heat transfer resistance from the outer surface of the receiving tube to the fluid should include the tube wall. If you recall in our flat plate analysis that T b minus T f has been expressed only in terms of heat transfer resistance inside and the bond conductance or the resistance due to the bond here. But the thermal conductivity of the material of the pipe has not been included resistance due to the material has not been included, but now my fluxes are larger which calls for including the tube resistance also.

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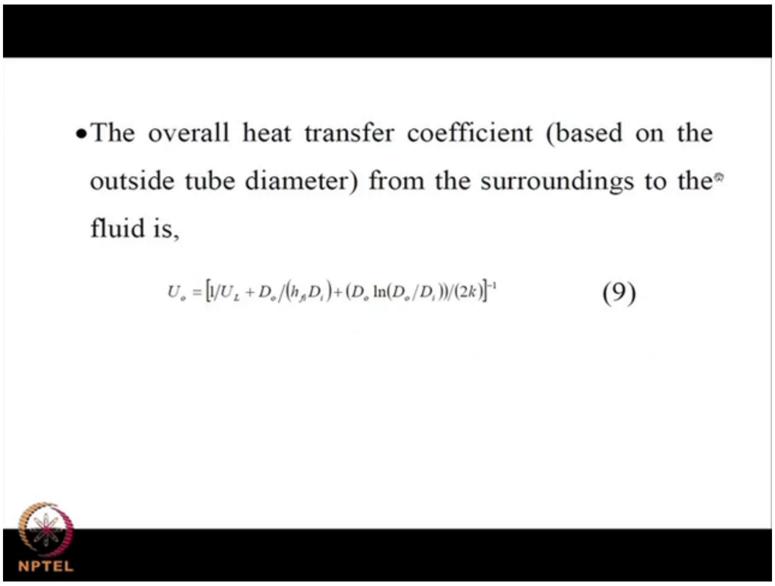

So, now we can write down a U naught, which you know already, I will tell after writing down this expression. This is the resistance between the receiver and the ambient. So, this overall thing is a resistance between the fluid in the tube and the ambient that comprises of the convective resistance inside the tube and the conduction resistance in the material of the tube of thermal conductivity k. This is what we have not included in F P C, not in F P C, okay. So, this is what we have got the resistance and 1 upon U L. So, basically it is the resistance from the fluid to the ambient, and this is the resistance from the receiver tube to the ambient. In fact, F dashed we have defined as 1 upon U L upon 1 upon U naught, right. So, that will be useful in calculating your collector efficiency factor also.

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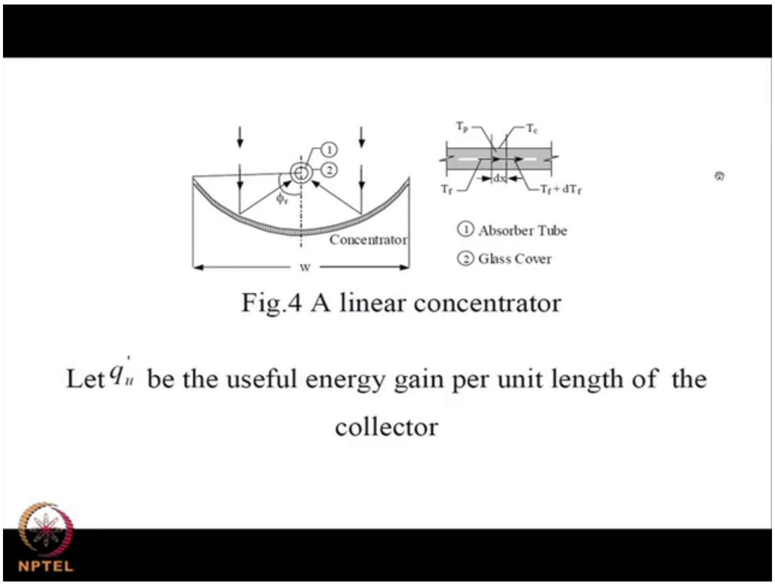

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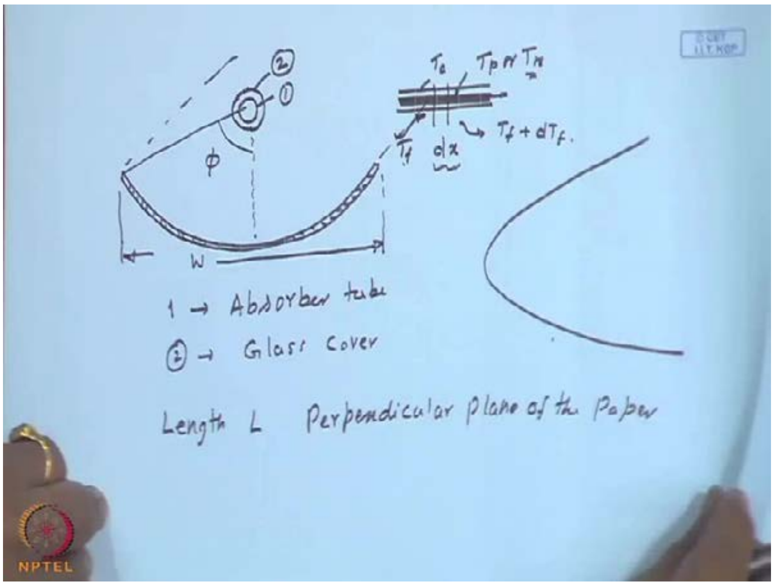

So, if you try to make a thermal analysis for the linear concentrator. So, for use of representation I will show it horizontally. The reflector here is the tube and may be a glass cover or outer end in the tube simply. And if I see it here, the fluid is flowing through if that is the thickness of the pipe, and the temperature T p or T r in this case and then there is a cover temperature T c. And if I consider a length dx the fluid enters at a temperature of T f and leaves at T f plus d T f. This is exactly similar to what we have done for flat plate collectors.

This is 1; this is 2. So, there is a glass cover; 1 is the absorber tube, and 2 is the glass cover. Let the width of this be W; we may have length L perpendicular to the plane of the paper, okay. So, now we have a reflector of width W length perpendicular to the plane of the paper L through which a fluid is flowing across an elemental length of dx, the temperature of the fluid increases from T f to T f plus d T f, and the receiver tube is a T r or T p in your flat plate terminology. And the outer cover is at a T cover of T c and with respect to the axis, and this is some sort of an angle phi. So, this indicates how big is the parabola; I mean parabola technically you can go on up to any extent.

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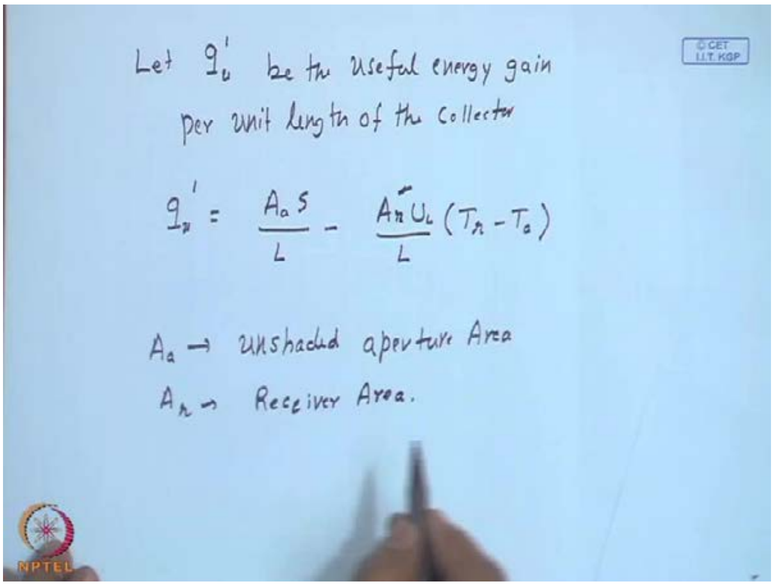

So, now if you have let Q u dashed be the useful energy gain per unit length of the collector, okay, so that perpendicular to the plane of the paper L if 1 unit length we are considering.

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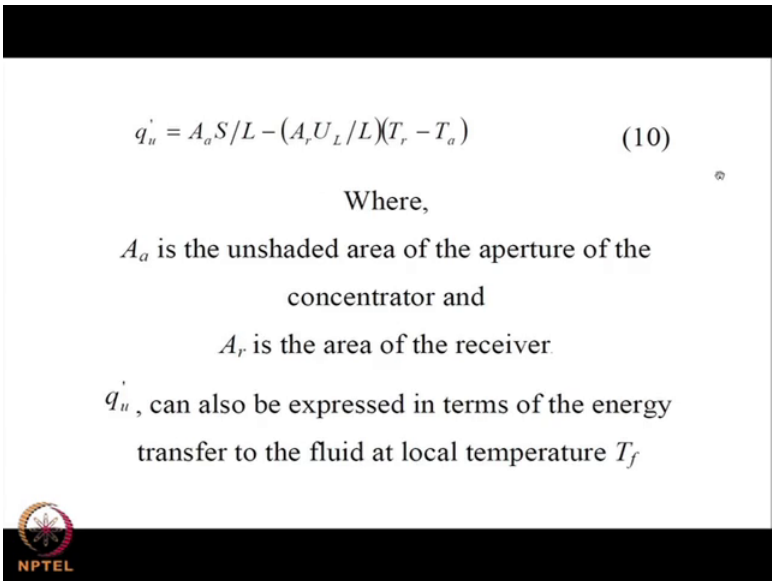

This Q u dashed will be A a trans S by L minus A r u L by L into T r minus T a. So, this A a will be A w will be there into L will be there, w will be there, L will be there or accordingly approximately, appropriately, that is included in this. This is in fact if L is not there, it would have been the total energy gain based upon the area, absorbed energy and the loss based upon the receiver area. So, A a can be considered as unshaded aperture area. At times for more accuracy what we do is we consider that the receiver tube may cast a shadow on the aperture plane or obstruct the solar radiation entering into the aperture; there is no shadow, because aperture plane is only the imaginary line; there is no physical plane present over there.

A r is the receiver area, okay. It is just like the energy balance we have done, and Q u dashed can be written in terms of the local fluid temperature T f and T r. So, Q u dashed will be A r by L into T r minus T f by D naught by h f I D i plus D naught by 2 k log D naught by D i. You will find that this is the temperature difference available between the receiver and the fluid of area A r per unit length, and this is the resistance for the convection inside the tube, and this is the resistance due to the wall of the tube. So, Q u dashed as we commonly expressed as F dashed times A a area of the aperture per unit area times absorbed energy minus A a by A r times U L times T f minus T a. This should be sorry A r by A a; otherwise, it will lose more heat. So, now if you compare this equations F dashed will be given by 1 upon U L by 1 upon U L plus D naught.