Solar Energy Technology
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Lecture - 18
Other Collector Geometries

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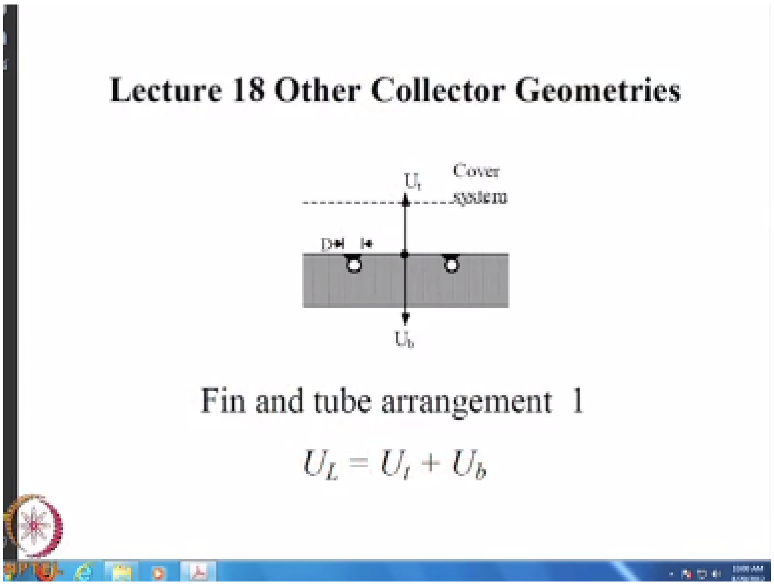

Last time we started considering other collector geometries, particularly for the liquid heaters. We have most commonly employed fin and tube arrangement.

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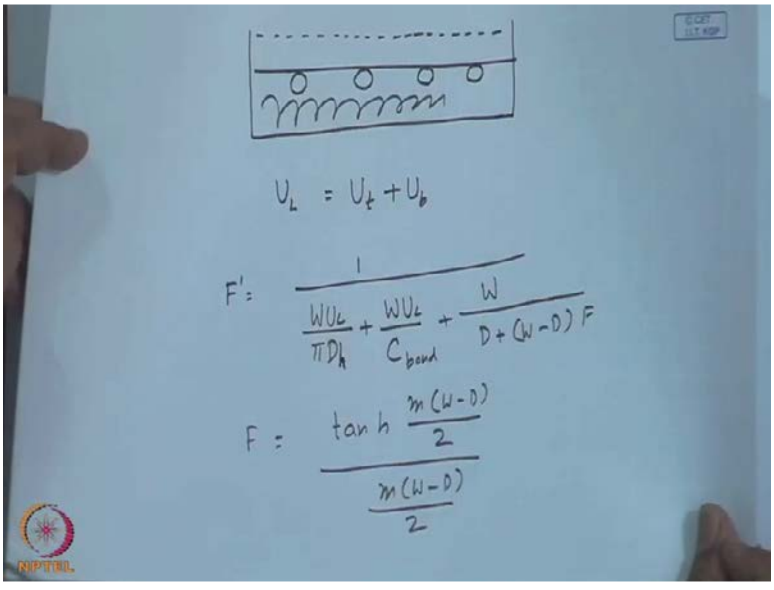

The arrangement number 1 which we have dealt with in detail consists of an absorber tube and fin, and the choose being soldered at the bottom. Of course, along with one or two glass covers and embedded in a box with insulation. For this the top loss coefficient will be a sum of the overall loss coefficient will be sum of top loss coefficient and the back loss coefficient. And we have also obtained the expression for the collector efficiency factor; for the collector efficiency factor F dashed as 1 upon W U L by pi D h where this h is the heat transfer coefficient plus W U L upon bond conductance plus W upon D Plus W minus D times F where F is the fin efficiency given by tan hyperbolic m into W minus D by 2 by m times W minus D upon 2. This should be very familiar; it is nothing but the fin efficiency expression that we do in undergraduate classes as tan hyperbolic m l upon m l, and we dealt with this arrangement in detail.

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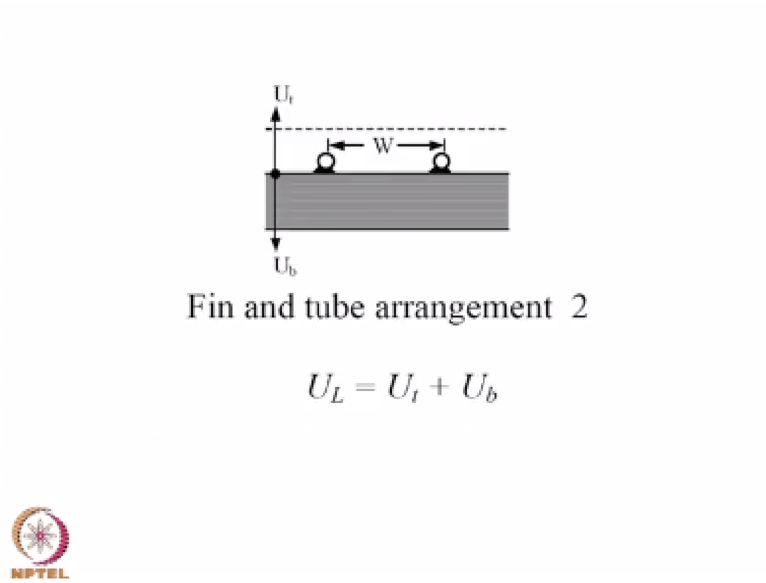

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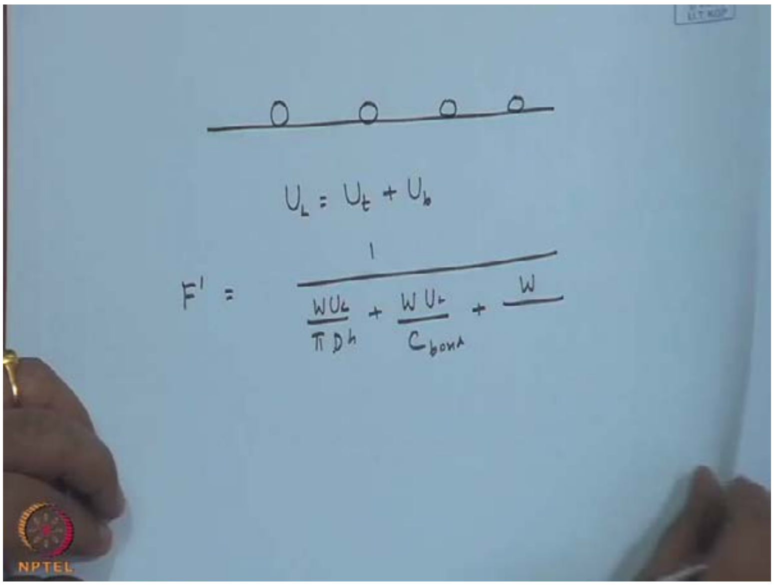

And the second arrangement comprises of the same absorber tube but mounted on top of the absorber plate where again overall loss coefficient is summation of the top loss coefficient plus the back loss coefficient. And of course, the expressions for the collector efficiency factor slightly differs from that for the previous arrangement. This is the previous expression.

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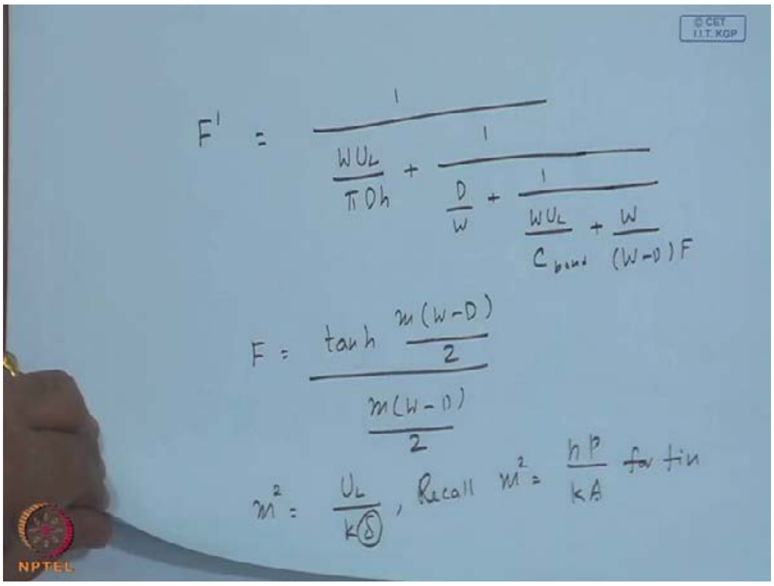

And we have for the second arrangement, I am sorry this F dashed will be 1 upon W U L by pi D h plus 1 upon D by W plus 1 by W U L by C bond plus W by W minus D times

F. Again the fin efficiency has the same expression and that is F is tan hyperbolic m into W minus D by 2 upon m times W minus D by 2 where the fin parameter m square is defined by U L by K delta. Recall m square is h p upon K A for fins in your heat transfer course in undergraduate studies where p is the perimeter and h is the heat transfer coefficient, and area is area a and p upon a will have the length dimensions of delta in this instance and replace U L and h have the same dimensions.

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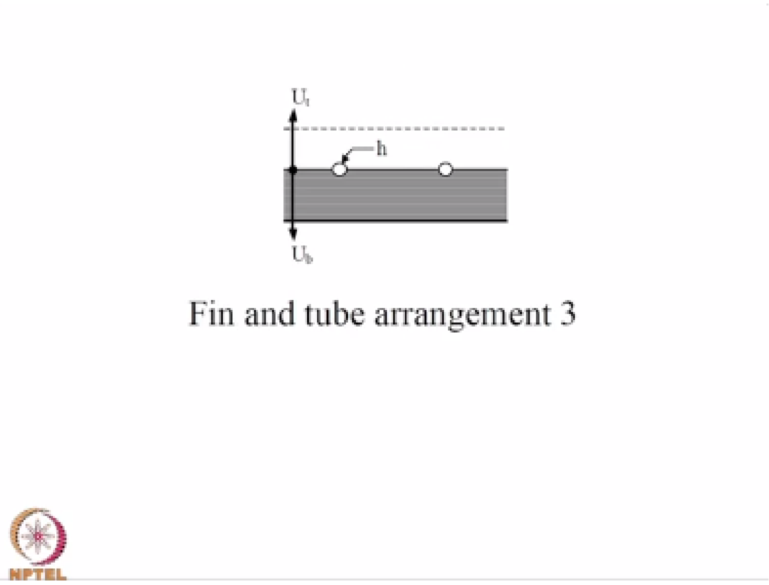

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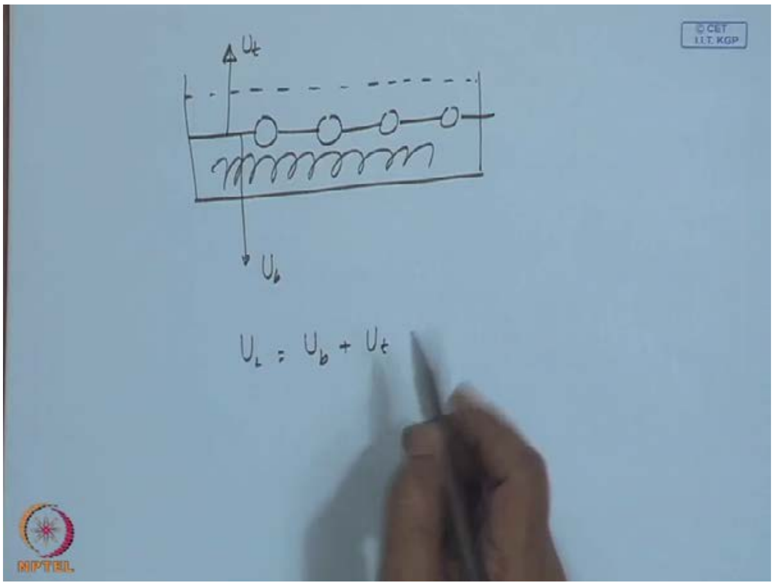

This is a third arrangement where you have a conventional fin attached to the tubes at the middle and with one or two glass covers with again the bottom insulation, you have a overall top loss coefficient of U T and a back loss coefficient of U b and for this arrangement also U L is equal to U b plus U t.

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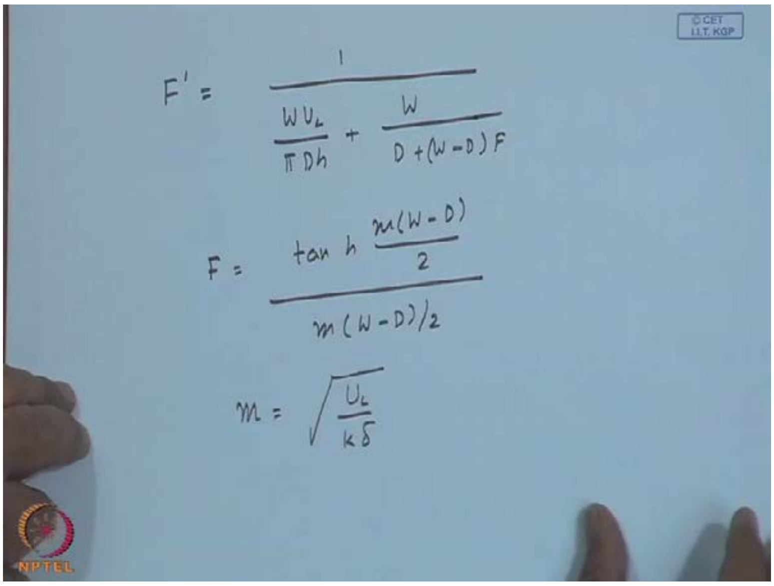

You have the collector efficiency factor again slightly differing because of the differing arrangement of the tube and the fins W U L by pi D h plus W upon D plus W minus D times F. You will notice that the band conductor does not come into the picture here. We assume that the fin is attached with a zero resistance to the tube and the fin efficiency is given by again same expression. Only thing is your W and d have to be appropriately taken depending upon the geometry; of course, m is under root U L by K delta or the same as m squared is equal to U L upon K delta.

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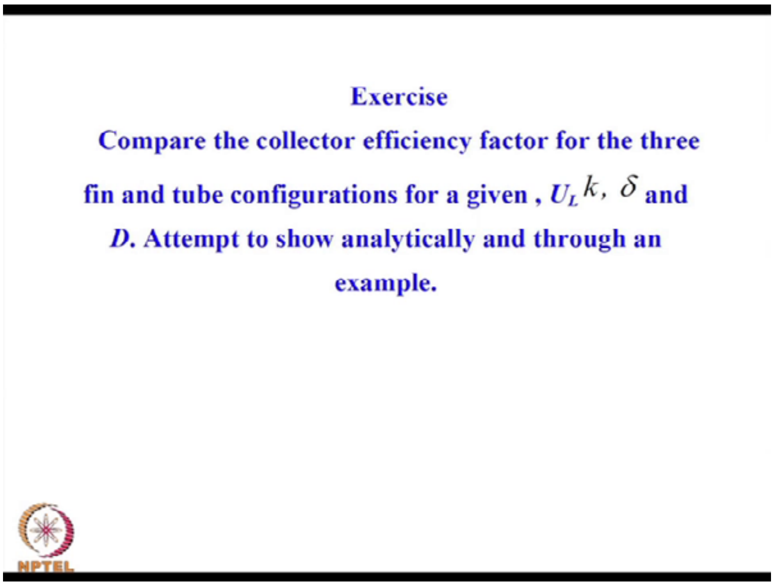

So, this is what we have considered in the last class, and I also said that you can prove analytically or through an example for a given W and D and U L whether first arrangement or secondary arrangement or the third arrangement is better.

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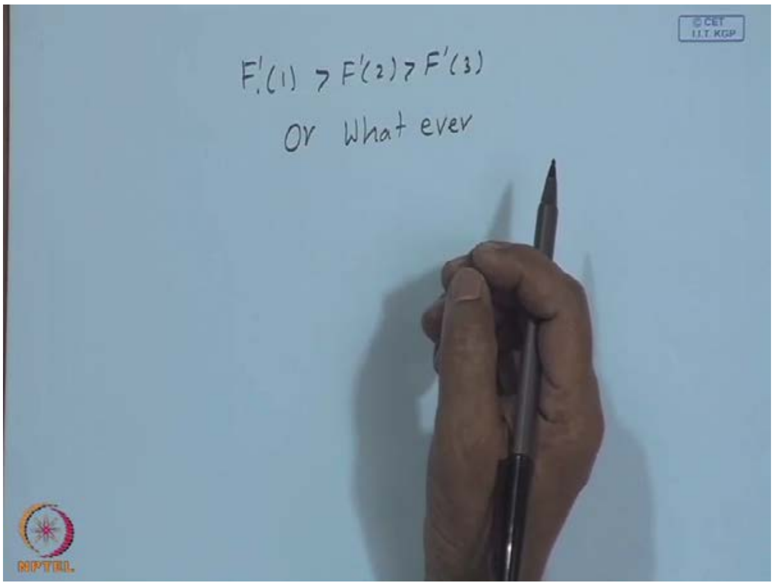

One can do it for example, find out F dashed is higher for one or the other for a change in U L and K delta and analytically prove that F dash 1 is greater than F dash 2 dashed arrangement 1 is greater than F dashed 2 greater than F dash 3 or whatever. Or else one can take a particular material thickness delta and W and U L and compute this numbers for the fin efficiency and the efficiency factor collector efficiency factor and find out which one is better.

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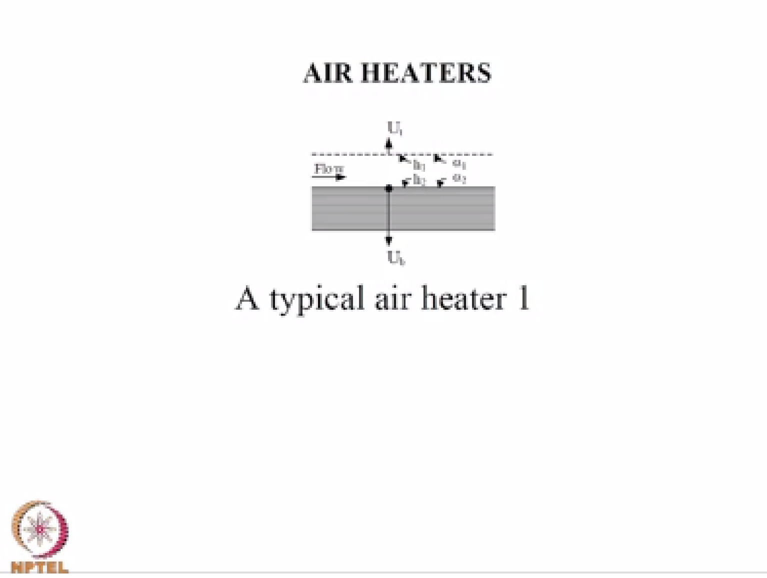

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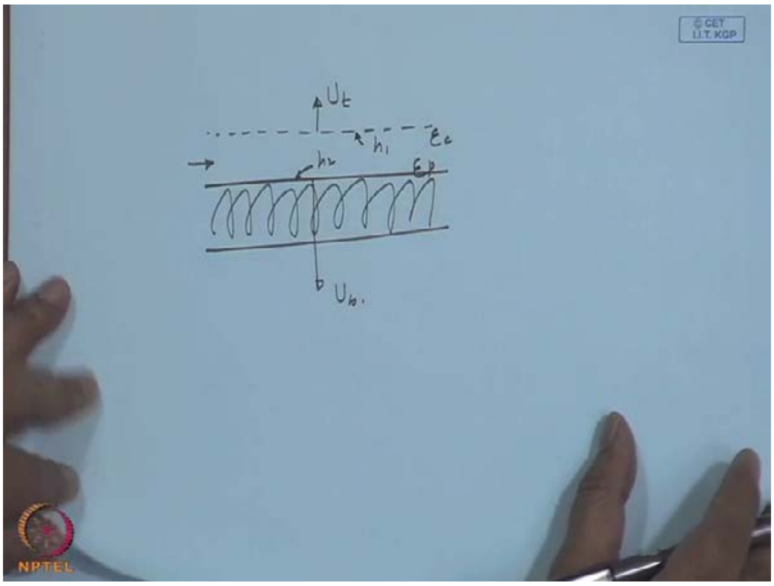

Now air heaters; we have consider in detail two of the typical air heaters where there is one absorber plate, and there is a glass cover at the top of it, and the flow may be like this between the top glass cover which has a loss coefficient of U t and a bottom loss coefficient of U b and the heat transfer coefficients being h 1 and h 2 with a epsilon p and epsilon c or corresponding the absurdities.

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Air heater 1

$$U_L = \frac{(U_b + U_t)(h_1 h_2 + h_1 h_r + h_2 h_r) + U_b U_t (h_1 + h_2)}{h_1 h_r + h_2 U_t + h_2 h_r + h_1 h_2}$$

$$F' = \frac{h_r h_1 + h_2 U_t + h_2 h_r + h_1 h_2}{(U_t + h_r + h_1)(U_b + h_2 + h_r) - h_r^2}$$

$$h_r = \frac{\sigma(T_1^2 + T_2^2)(T_1 + T_2)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

For this we have the overall loss coefficient along expression which we have given last time and it comprises of the back loss coefficient and the top loss coefficient and the convective heat transfer coefficients h 1 and h 2 and the radiation heat transfer coefficient h r. Similarly the collector efficiency factor also has been expressed in terms of the heat transfer coefficients, and the loss factors were of course, we define the radiative heat transfer coefficient in terms of the two temperatures essentially that is to express the radiative heat loss as a product of h r and a delta T.

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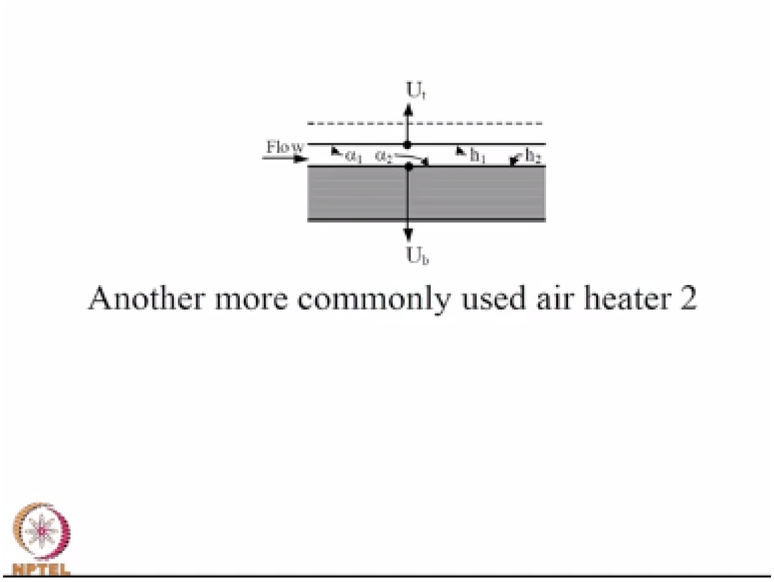

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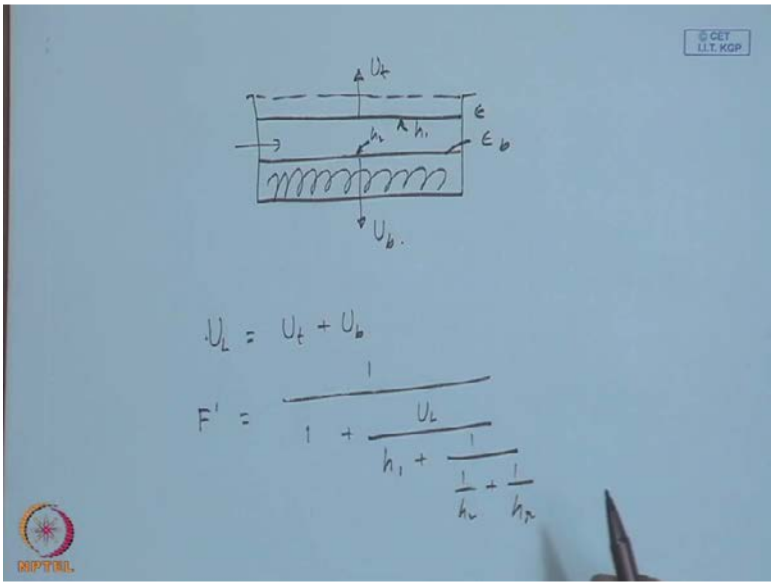

And this is also we have considered a duct formed by an absorber plate of epsilon emissivity and a bottom absorber plate kept in a box with a top cover, and this being insulated, and the flow being in this direction or perpendicular, depends upon the view, and this is your U t, and this is your U b; that is the bottom loss coefficient. So, for this configuration you have U L equal to U t plus U b. As pointed out earlier the heat transfer coefficient loss coefficient will be the summation of the top and the bottom loss coefficient when the fluid does not directly come in contact with a heat loosing surface. Here the collector efficiency factor we have expressed as 1 upon 1 plus U L by h 1 plus 1 upon 1 by h 2 plus 1 by h r. This you can see that this is h 1 at the top, and this is h 2 at the bottom plate.

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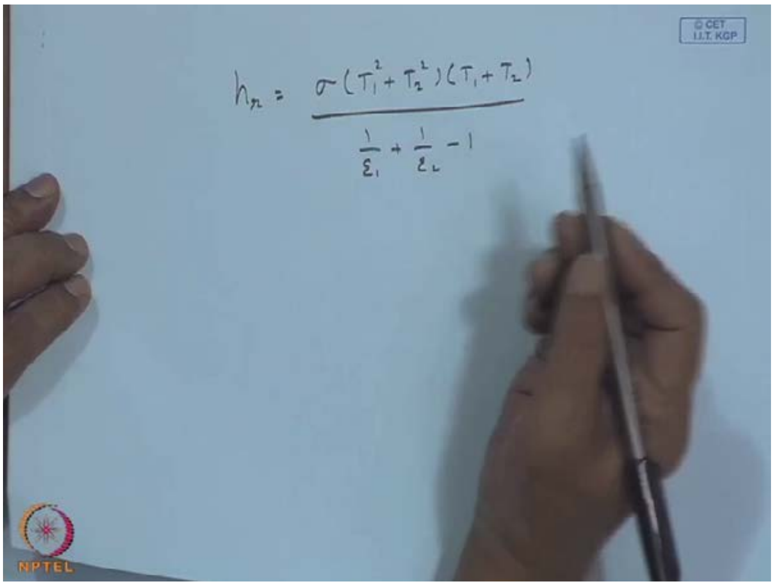

And the effective radiative heat transfer coefficient h r is defined as sigma T 1 squared plus T 2 squared times T 1 plus T 2 upon 1 upon epsilon 1 plus 1 upon epsilon 2 minus 1. Most of these relations are similar and in fact, they are repetitive which we are deliberately doing in order to bring out the certain differences from configurations one, two, three or for the matter even for air heaters. So, one should be careful. The concept of the heat transfer coefficient for radiation is essentially to express the heat loss as a product of the radiative heat transfer coefficient multiplied by delta T. Not that the relation for the radiative loss in terms of the fourth power temperature difference has changed, but we have artificially put it in the form of a radiative heat transfer coefficient multiplied by the temperature difference. Since everything else convective heat transfer loss or gain depends upon just the delta T.

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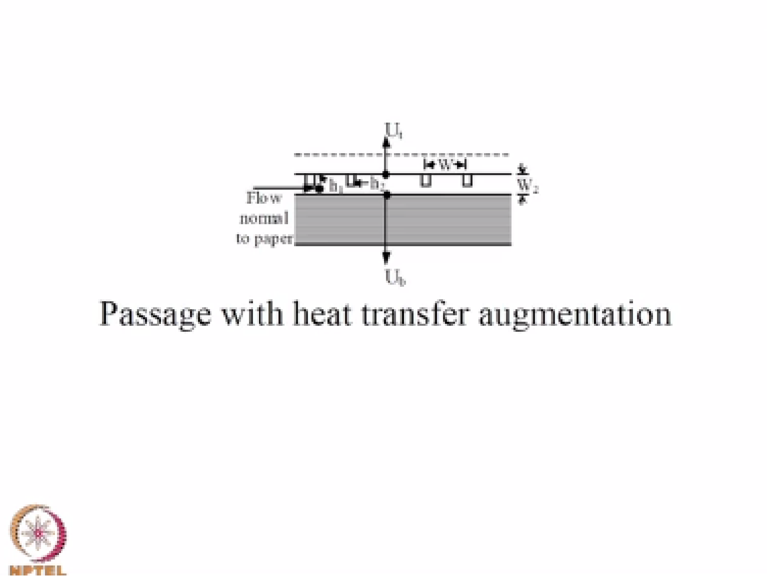

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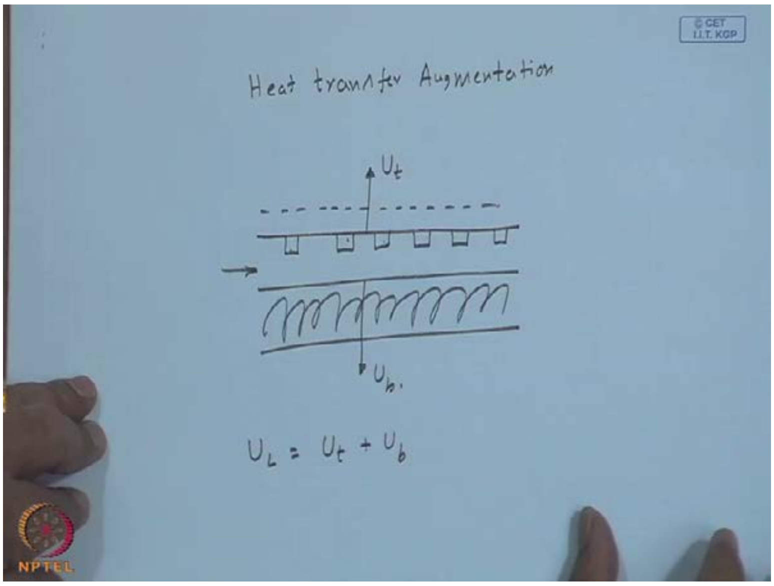

This is a passage with heat transfer augmentation. This is the first time we have seen this configuration. So, we need a little explanation. I was mentioning in one of the previous classes that in general the heat transfer coefficient for air is poorer compared to that for liquids, and here you have an absorber plate with some protrusions and a bottom plate and insulation and flow in this direction let us say and of course, to suppress the convective and radiative losses. You have a glass cover; this will be your U T, and this will be your U p. Now these protrusions provide the breaking of the boundary layer or flow mixing thereby enhancing the heat transfer coefficient. So, for this arrangement again because the fluid does not come directly in contact with heat loosing surface U L will be equal to U t plus U b.

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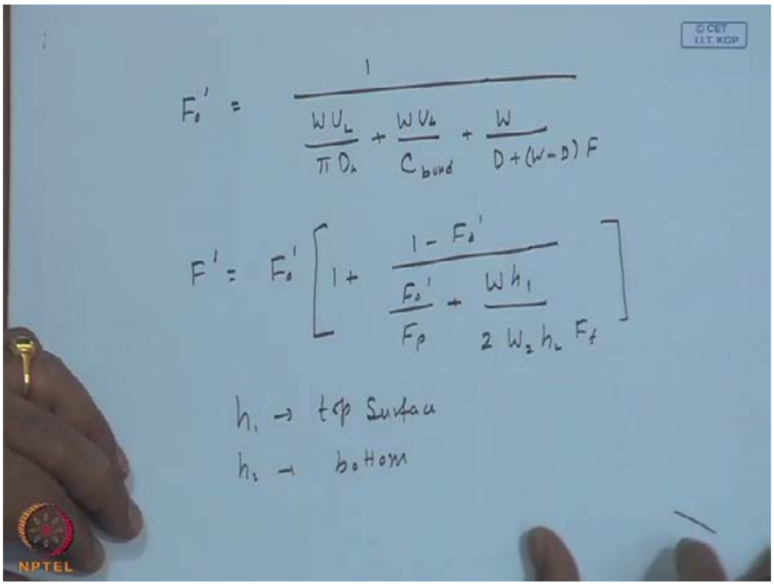

And you have got F naught dashed 1 upon W U L by pi D h plus W U L by C bond conductance plus W upon D plus W minus D times F. Now this you notice is exactly similar to the fin and tube absorber of arrangement number one where the tubes were at the bottom. These tubes you call it or protrusions you call it they are at the bottom though the fluid is not flowing through them. Then the collector efficiency factor F dashed is in terms of the fictitious F naught dashed times 1 plus 1 minus F o dashed by F naught dashed by F p plus W h 1 by 2 W 2 h 2 F f, where in again the heat transfer coefficients h 1 and h 2, h 1 for the top surface and h 2 for the bottom.

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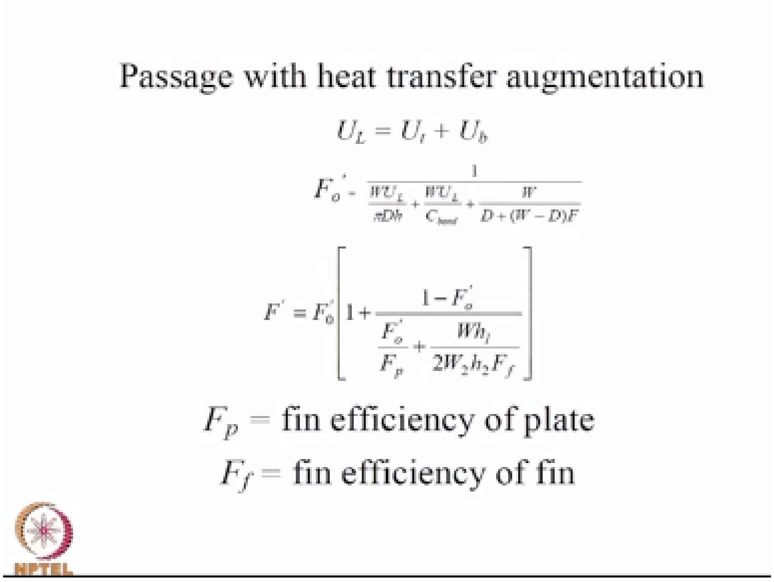

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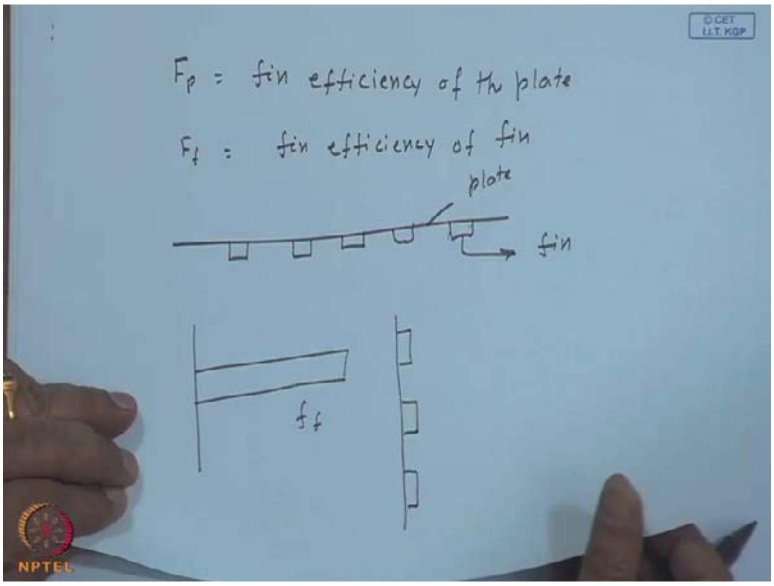

And you have two fin efficiencies here. F p fin efficiency of the plate and F f fin efficiency of the fin. It is a super flow star but we have no alternative. So, this is the fin efficiency of the fin. You can understand that we have got the protrusions like this. So, these are the fin, and this is the plate and a sort of tube with though the flow is not through this. So, this fin efficiency of the plate is similar to the fin efficiency which we have considered in the case of water heaters, and this acts like a fin with its own fin efficiency for the fin.

In other words in classical literature if this is a surface and here is a fin you calculate F f. In this case what we have got is if I put it vertically this is a small fin, this is small fin, small fin, whether it enhances the heat transfer or not it depends upon how thick it is compared to the length dimensions. Then once again the whole game has been to improve the heat transfer coefficient improve of course, the absorptivity.

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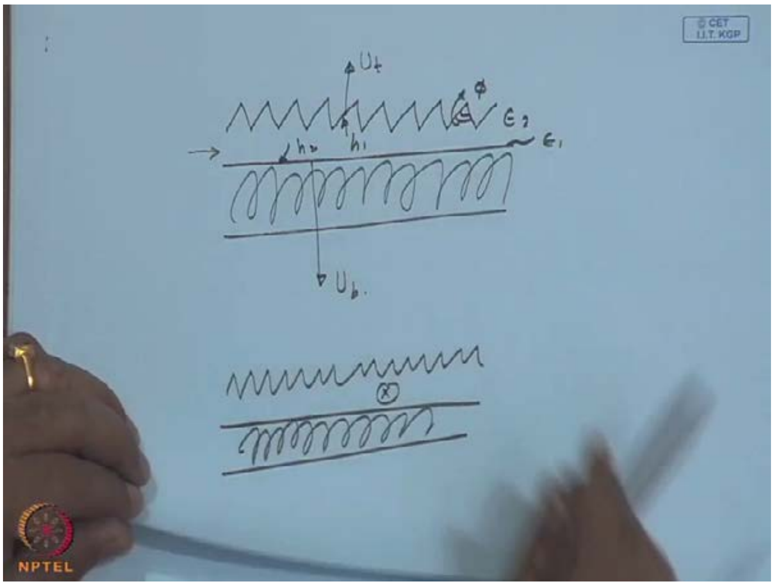

So, people came out with instead of these fins one can have a corrugated sheet absorber and the flow is in this direction. In other words these corrugations help break the boundary layer development and provide flow mixing and enhance the heat transfer coefficient. So, your t and U b or your top loss and bottom loss heat loss coefficients, this is your h 2 to the corrugated plate it is h 1; width of course, you can have a epsilon 2 and an epsilon 1 or correspondingly alpha 2 and alpha 1.

And this angle is phi flow normal to the corrugations, because one can also have a configuration like this with insulation and a corrugated sheet with flow perpendicular to the plane of the paper. Still it will have a larger extended area compared to a plane plate; consequently it may be having better heat transfer characteristics than a simple flat absorber. However, here the phenomenon is different; it aids augmenting heat transfer by breaking the development of boundary layer as well as providing mixing of the fluid.

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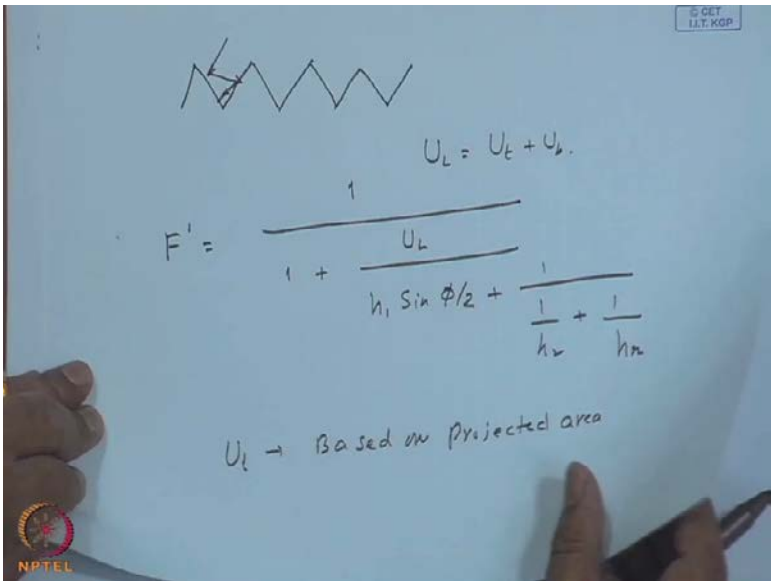

The corrugated sheet also has its own advantage; the effective emissivity or the absorptivity will be larger than a simple plate with same coating, because there could be some sort of multiple deflections and absorption, consequently improving your emissivity or absorptivity. So, F dashed for this particular situation is 1 upon 1 plus overall loss coefficient U L upon h 1 sin phi by 2 plus 1 upon 1 by h 2 plus 1 by h r where h r is the radiative heat transfer coefficient for the situation.

So, of course, U L equal to U t plus U b and U t is based on projected area. In other words as if it is a plane sheet, because if you take the area of the corrugated sheet that will be larger than the plane sheet, and consequently whereas the other losses will be taking place h 2 particularly and U b will be from the area which is just that of a plane sheet. So, everything is based upon the projected area.

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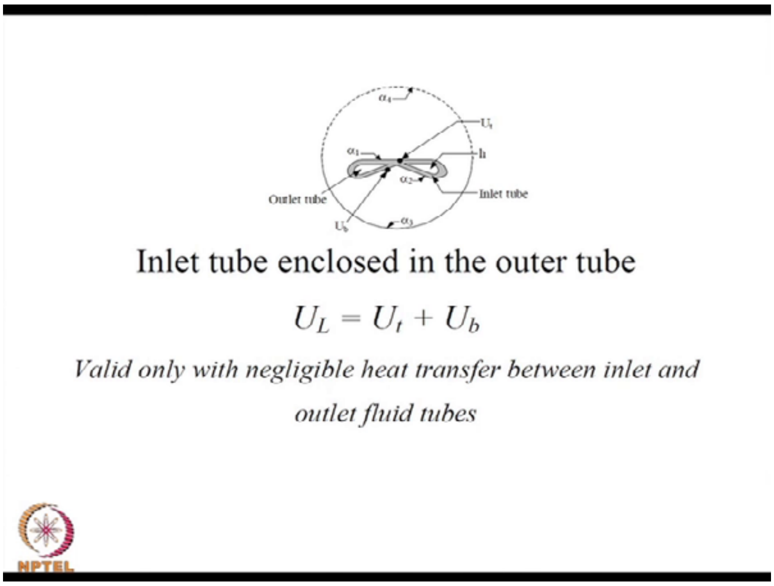

Now inlet tube enclosed in the outer tube you can see from the diagram. So, where it only with negligible heat transfer between inlet and outlet fluid tubes and again U L is U t plus U b.

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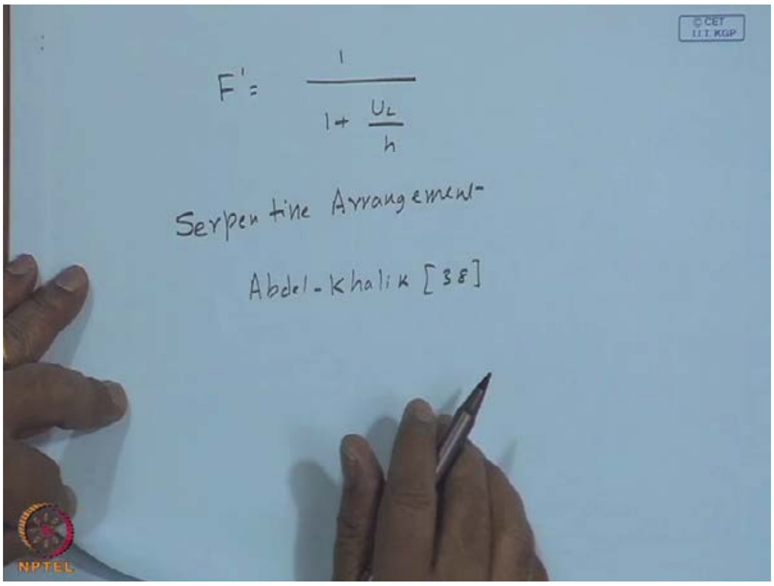

And the collector F dashed is 1 upon 1 plus U L by h. Let me show this picture for a while, so that you will see the particular slide. You have got the inner tube and the outer tube with the arrangement where U L is equal to U t plus U b. So, that itself assimilatory; this is essentially like a heat exchanger and surrounding with the cold and hot fluids.

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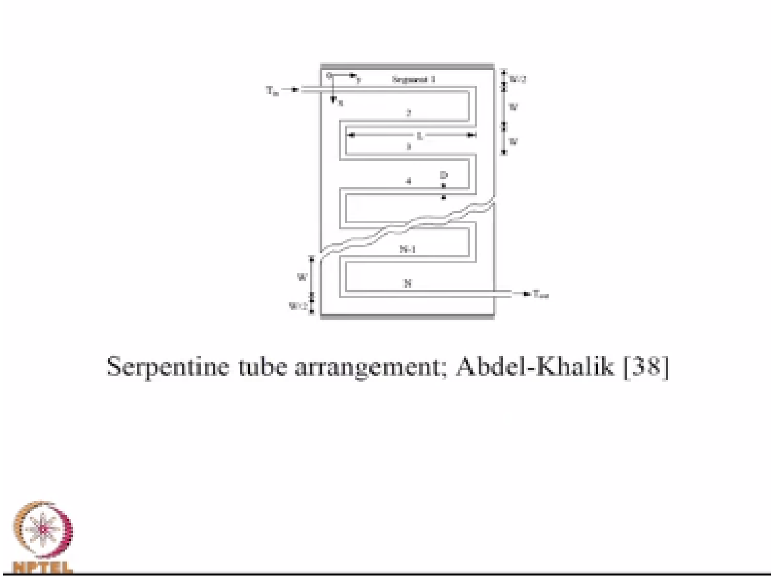

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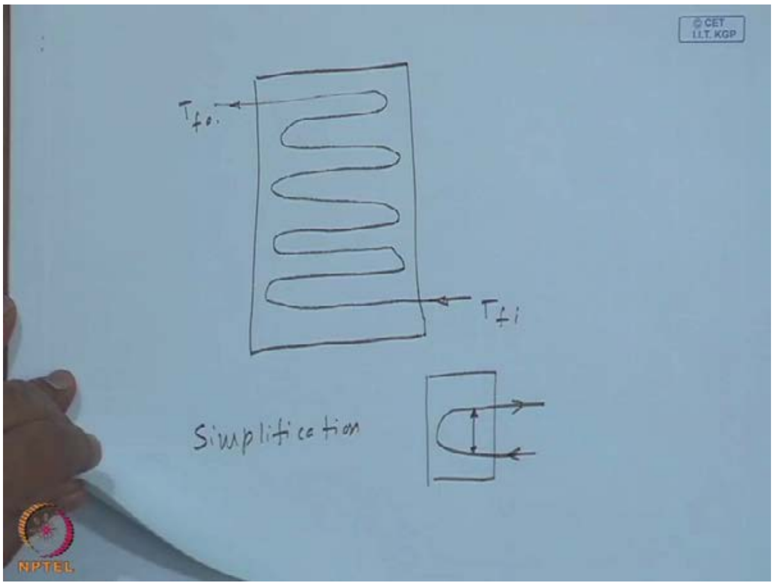

Now this is a serpentine arrangement; it is proposed by Abdel-Khalik. Before this picture can be even simply shown, this is the absorber plate, and you have a tube in serpentine fashion. So, this will be the entry point with the temperature T f i and goes out at T f o. Now this picture you can see for segment one and segment two with the appropriate dimensions, or you can refer any text book for example, by Duffy and Beckman or to see the picture in clarity. So, they have analytically solved the case of the serpentine with single bent that gave the solutions within 5 percent of numerically obtained solutions for multiple bend serpentine.

So, what they have done is simplification; it is as if one bend. So, this gives more or less for appropriate distance between the bends suitably computed if the total is l in n number of bends, each bend has got n by the number of bends, and if the entire thing had been one the distance between this will be n times the number of bends in the other case. Consequently you have to appropriately use the characteristic dimension and thereby you will get the answer for the single bent serpentine arrangement, and that gave results within plus minus 5 percent.

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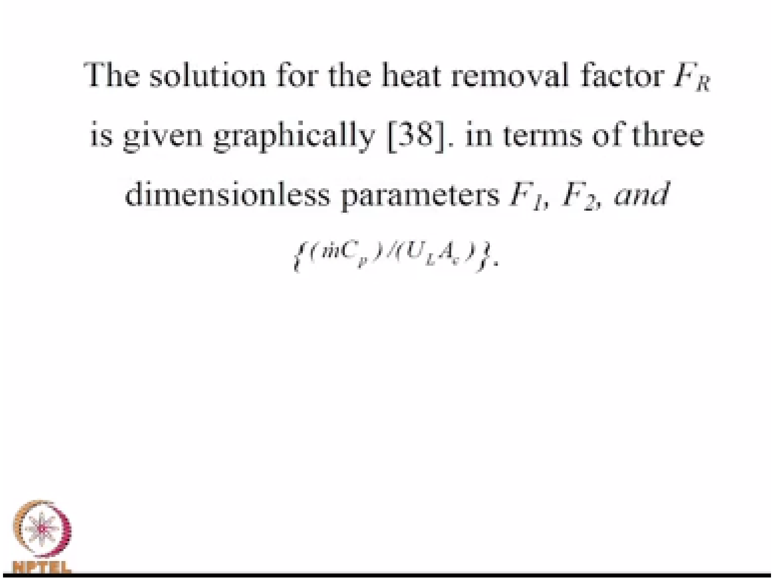

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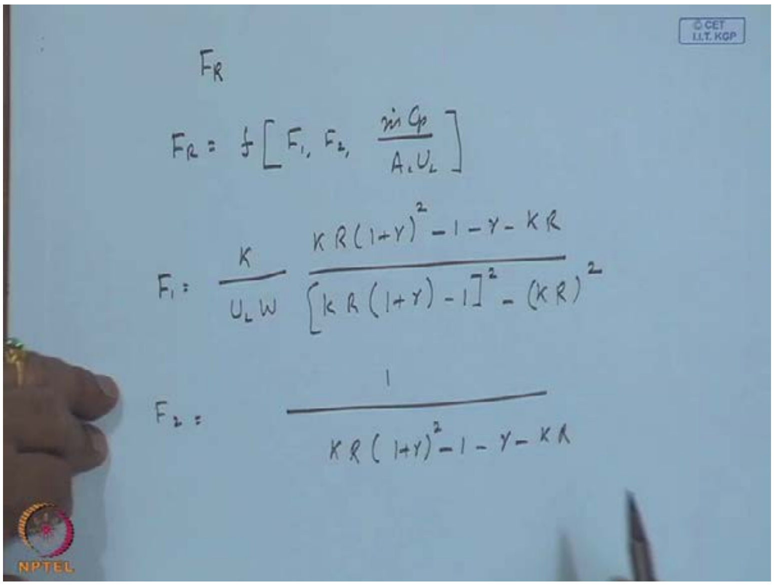

And they have heat removal factor F R is not so easy to analytically obtain. So, F R has been expressed in Abdel-Khalik as function of two dimensionless parameters F 1, F 2 and m dot C p by A c U L. This is somewhat we get in your heat removal factor all along where F 1 is defined as a kappa by U L overall loss coefficient times W into K R 1 plus gamma to the power 2 minus 1 minus gamma minus kappa R upon K R into 1 plus gamma minus 1 whole squared minus kappa R squared, and the other parameter F 2 is 1 by kappa R 1 plus gamma whole squared minus 1 minus gamma minus kappa R. I hope I have put the notation here, yes.

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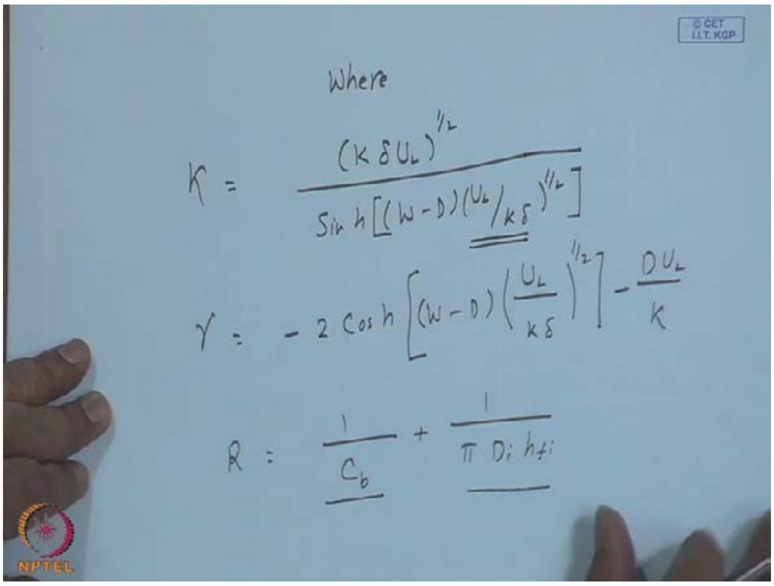

Where the parameter kappa is defined as K delta U L to the power 1 half by sin hyperbolic W minus D times U L by K delta to the power 1 half. So, this crosses here and gamma is minus 2 cos hyperbolic W minus D times U L by K delta to the power half minus D U L by kappa and your R is bond resistance if C b is the bond conductance plus the convective resistance pi D i h f i. Now though these parameters have been given different symbols kappa, gamma you can identify this is some kind of a fin efficiency parameter. In fact, it is a fin efficiency parameter, and this is a consequence of the fin efficiency and the overall resistance remaining components will compress due to bond conductance and then the internal convective heat transfer resistance.

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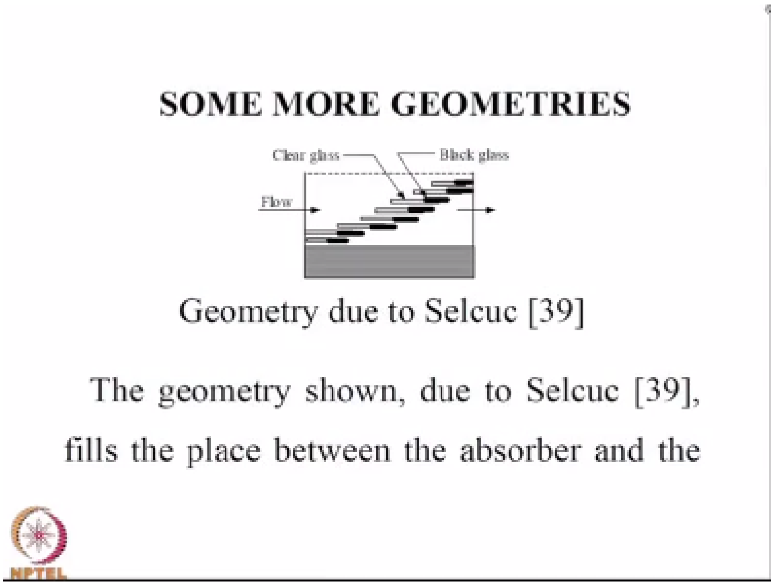

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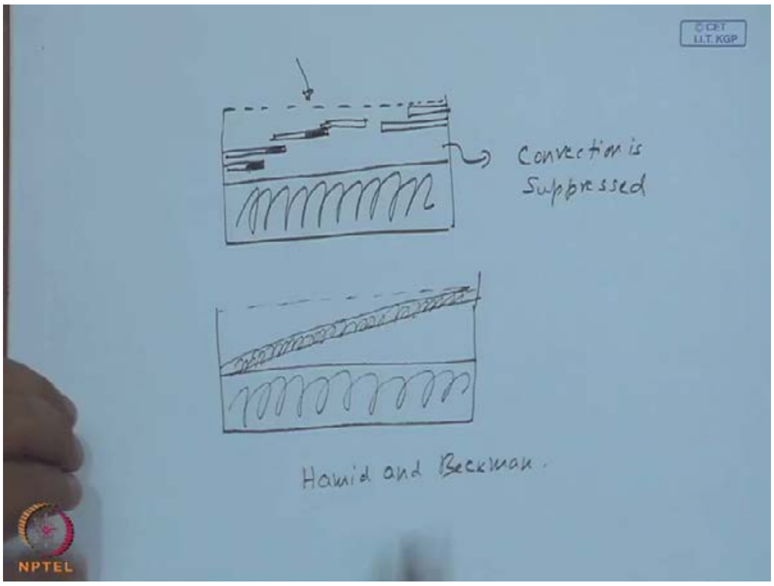

There are some more geometries for declining for air flow the search has been to improve the heat transfer coefficient and improve the absorption mechanism, and this is one proposed by Selkak. This is bottom is insulated and you have got plates; then another here like this up to here again last then this may protrude a little more with a black painted portion and a transparent portion one overlapping the other, so that the transparent portions will be transmitting the solar radiation falling on the top surface whereas the black one will be absorbing the solar radiation.

And this achieves because you have got a large number of baffles you may call it; convection is suppressed. Consequently your top loss coefficient will be lower, and now this is another matrix arrangement; it is somewhat similar in idea, you have got the insulated thing. So, the whole thing is. So, this is a sort of matrix. In other words it may be a kind of a thick wire mesh or maybe even a porous medium, and this is due to Hamid and Beckman, but all these configurations in general have higher pressure drop.

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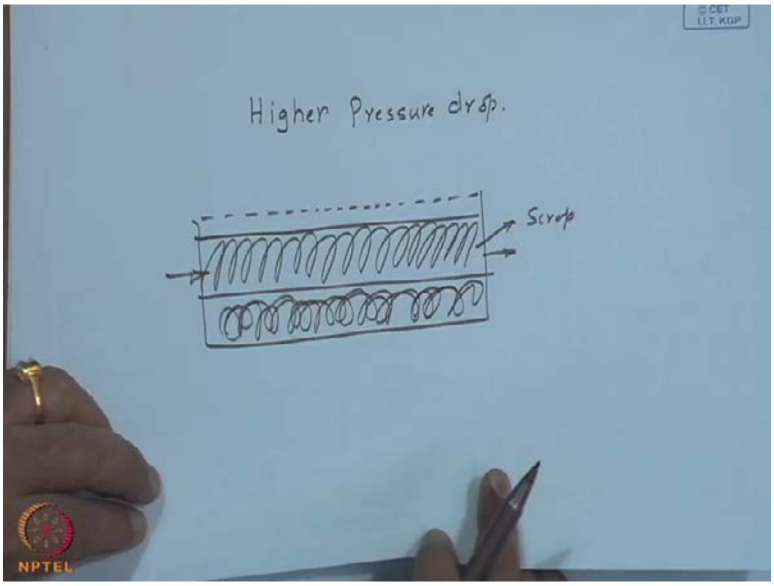

In fact, it is almost a thumb rule that you cannot enhance heat transfer coefficient without enhancing the pressure drop; the other way around is perhaps possible. You can increase the pressure drop and though not gain the corresponding increase in heat transfer. So, that is like you can imagine a pipe, you put a plug at the end of it, the pressure drop will be enormous, but there will be no significant improvement in the heat transfer. So, this is a penalty one has to pay and however, the design depends and the success depends upon playing on the non-linearity between the increase in heat transfer coefficient and increase in the pressure drop.

In certain regions or certain zones or ranges you have a higher increase in heat transfer coefficient than the corresponding increase proportionately to the pressure drop. So, that is where your design consideration comes into the picture. Indeed air collectors have also been suggested to be of this form; this entire thing is not insulation now it is a scrap and then bottom insulation. So, to distinguish I will put a double spiral and the flow is through this; of course, you can have one glass cover.

Now this has got the advantage thoroughly the fluid will be going up and down, and there will be heat exchange better heat exchange. At the same time you have the disadvantage of the heat capacity will be very large, the collector to get heated to that warm up temperature that we were talking it will be larger, and pressure drop will be enormous. We have not talked though I will not discuss very much about this particular arrangement evacuated tubular arrangement.

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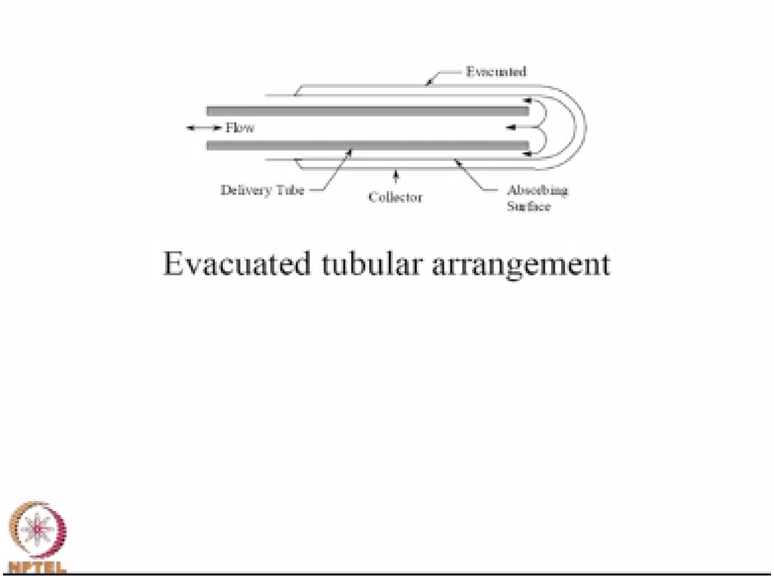

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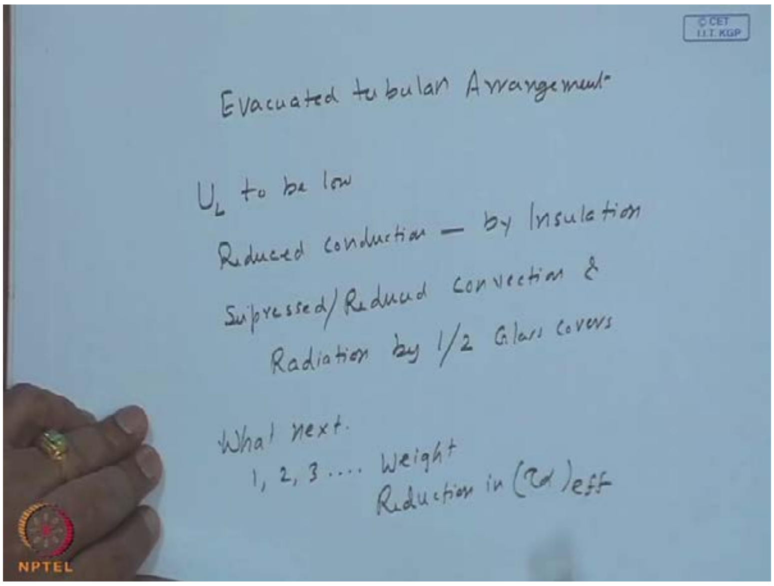

When we were first discussing the design philosophy of flat plate collectors we wanted that U L to be low. We achieved this by reduced conduction from the bottom by insulation then suppressed or reduced convection and radiation by 1 or 2 glass covers. The question comes what next? What can I do if I want to further reduce? Now, one can go 1 glass cover, 2 glass covers, 3 glass covers, so on and so forth, but they have their own disadvantage of weight and reduction in transmittance absorptance product effective. So, there is a limit to the number of glass covers, and these are the issues that do not directly come in the theory but which we have to discuss and do well to remember.

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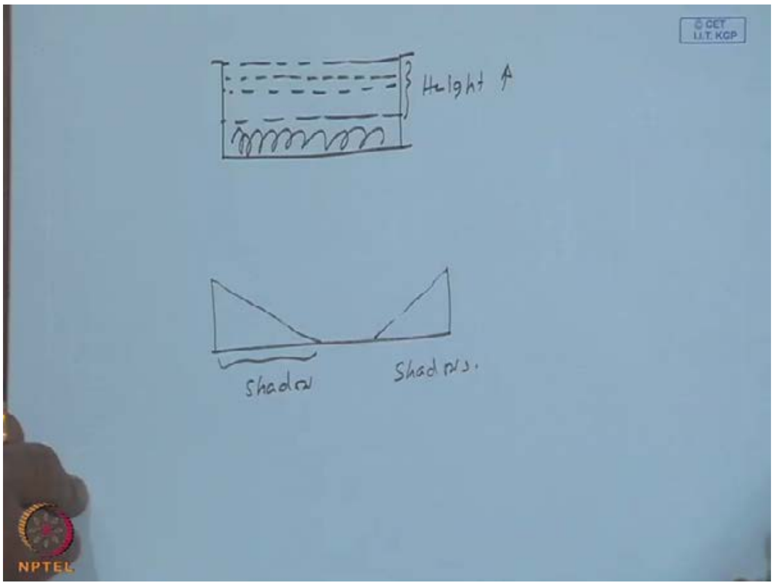

That if you are having a reduced tau alpha effect and also you have larger number of glass covers one consequence is you have one glass cover, two glass covers, third, then an absorber plate let it be liquid heater or whatever. Now with this, this height keeps on increasing and when it is not juice out it will cast a shadow this box which could be significant even if the collector is facing juice out. So, mornings sometime to the left let us say and afternoon sometime to the right there will be shadows because of the box height. Then maybe 10 percent, 20 percent of the absorber will be ineffective. So, this is one consequence one has to face by continuously increasing the number of glass covers thereby increasing the height of the collector now. So, one of the solutions that we have to improve the heat loss coefficient U L improve heat loss coefficient in this context means reduction in the heat loss coefficient.

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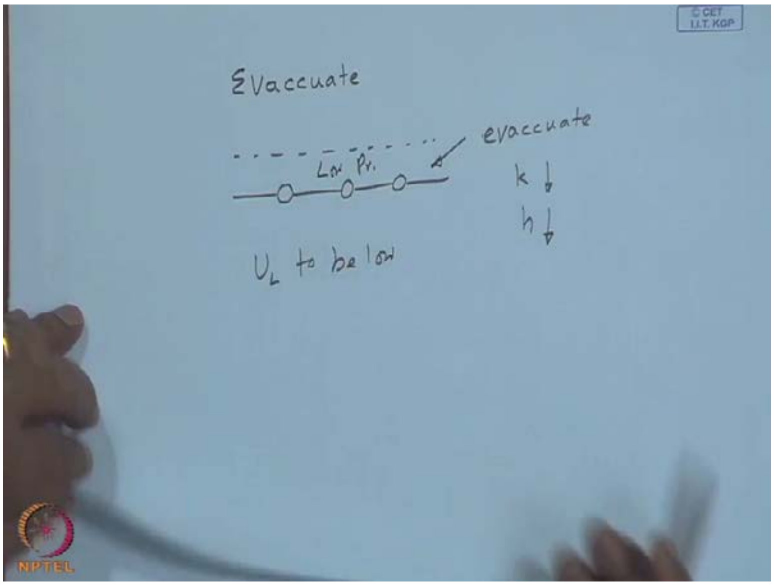

So, what we can do is evacuate between the absorber and the glass cover so that k is extremely low. So, convective heat transfer coefficient is low. So, your heat loss will be low thereby achieving U L to be low. So, this is one method. The problem will be this is a large volume for a flat plate collector. So, maintaining a low pressure through evacuation and ceiling can be a problem. Then if it collapses for some reason the glass is likely to break because the low pressure region over here and there if there is a leakage there will be a loss of vacuum; consequently again your overall loss coefficient will increase.

So, it is not practicable to maintain a completely sealed evacuated flat plate collector though there have been attempts. So, people started using the evacuation as shown in the previous arrangement only with the evacuated a tube is evacuated so that just like your tube light it is practically evacuated. So, one can have an absorber tube inside and an evacuated tube outside. So, this evacuation is more common in the case of concentrating collectors which we shall be doing in the next lecture, but meanwhile can we do anything for the flat plate collectors?

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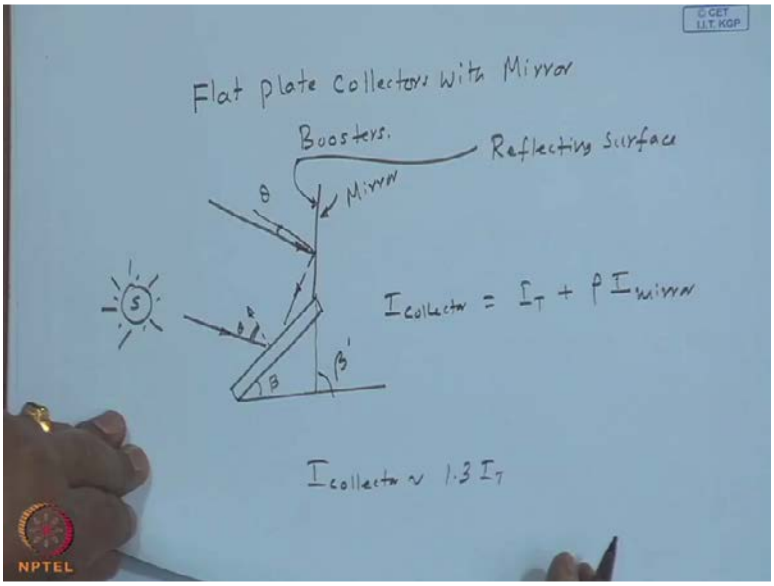

Now one solution is use the flat plate collector in conjunction with mirror boosters; that is you enhance the radiation incident on the flat plate collector by suitably attaching a mirror to the flat plate collector. Suppose this is your flat plate collector at some slope beta and here I attach a mirror this being the reflecting surface, I will take it over here. If this is the outer normal let us say that this is the suns ray, area is sun. So, this is my angle of incidence. So, the same ray parallel falls on the reflector and this may be incidentally it is coinciding with the normal, but this will be reflected onto this.

So, if you attach a mirror not only the radiation received by I collector will be equal to I T, that we have estimated number of times, plus rho of the mirror into whatever is falling on the mirror. Now you can if I extend it this may be beta dashed. So, I can express this is a surface with a slope beta dashed and I can have of course, in this case there maybe very small theta nearly normal; if it is nearly normal there will be no reflection. One can choose the appropriate angle depending upon the declination and the latitude of the location. So, the point is without absorber without other parapet area this may improve I collector now may turn out to be 1.3 times I T. So, you have a 30 percent higher incident radiation with only one mirror, but if the cost is less than let us say the 30 percent of the solar collector cost the mirror is worth it.

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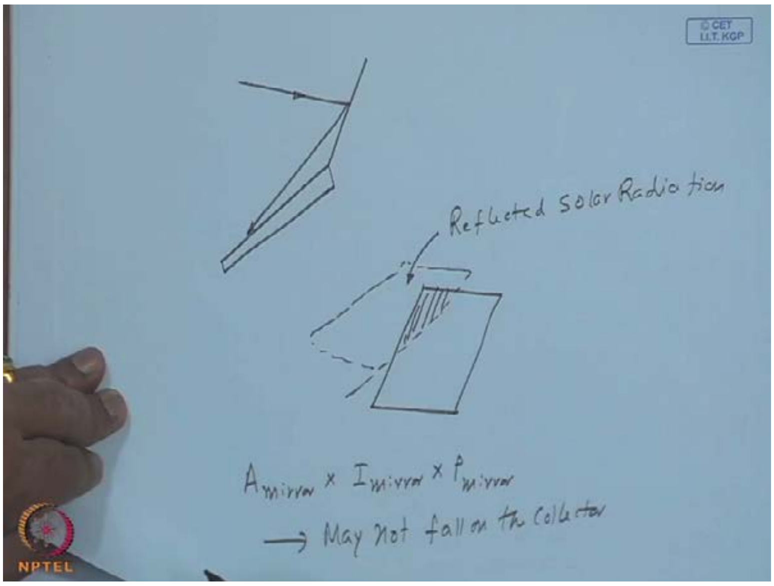

However, when you are talking about mirror boosters you have to think that the practical situation is not so nice as that a solar suns ray falls over here and then reflects onto this. So, depending upon the time of the day my reflected ray if I show this to be the collector in some view, and this may be the reflected solar radiation. It may not exactly fall area to area of the collector and the corresponding mirror. So, if there is an area A mirror multiplied by I mirror multiplied by rho mirror may not in general shall not. So, this will be a useful technique at a particular time period. Usually you orient it such that the maximum amount of reflected radiation falls on the collector surface at noon time taking advantage of the high intensity.

So, that is what we do by mirror boosters. Now in this case this is the only area that is getting an enhanced solar radiation because of mirrors reflection. This is in general may be considered as a beginning of concentration. In other words we are trying to have a higher intensity of solar radiation on the collector surface by reflecting onto it from another area; in other words the collection area is larger and the received area is something less than that. So, you have got a higher intensity or you might call it in general a concentration. So, this serves as the beginning of concentration, but flat plate collectors with mirror boosters are also quite common.

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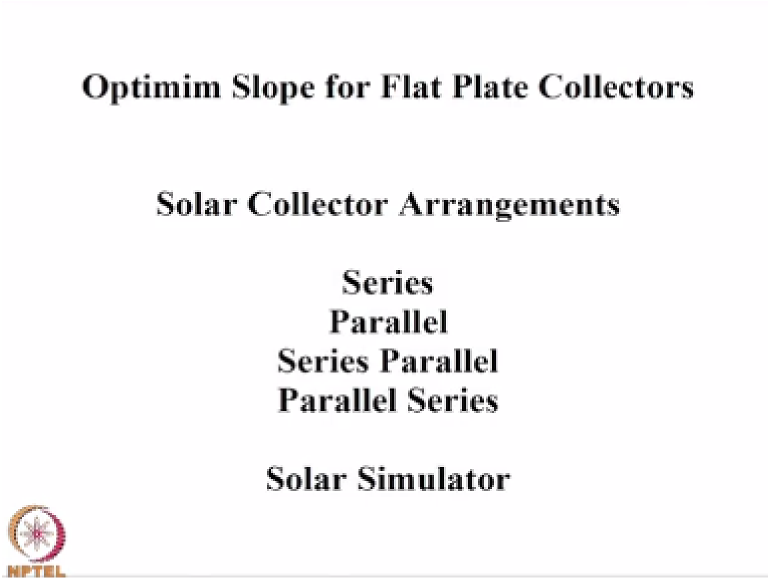

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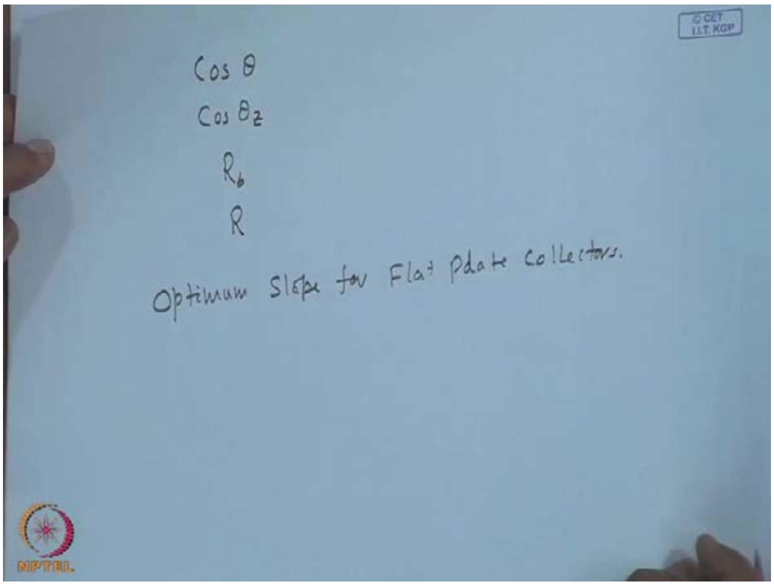

Now we have been talking so much about angle of incidence for the surface and for the horizontal surface and the direct radiation tilt factor and for the overall tilt factor. So, it is about time we consider about optimum slope for flat plate collectors. So, these topics may not be very specifically written in most of the books. In fact, they have not been but it depends upon how you look at it what it is meant by optimal.

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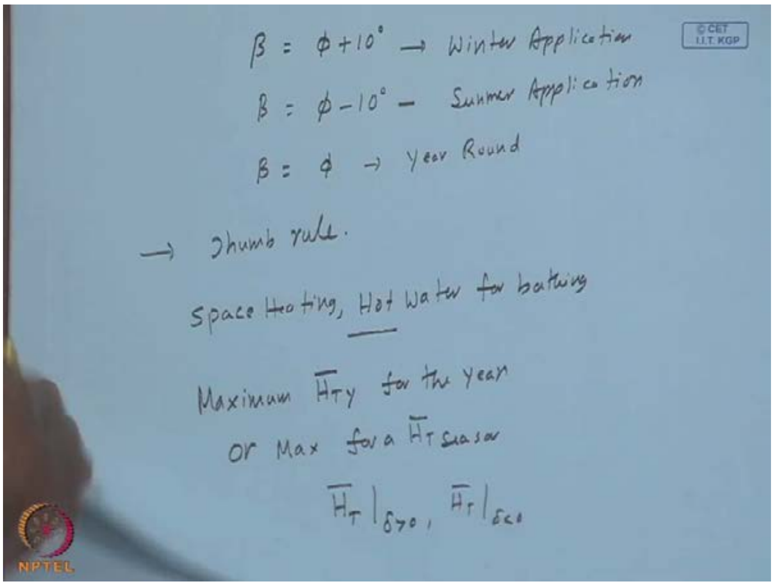

Because often it is stated that your beta is phi plus 10 degrees for winter application in general, and beta is phi minus 10 degrees for summer application. So, we make an engineering guess that beta is equal to phi for year round. So, this is some sort of a thumb rule. So, winter applications I may have space heating; if you talk in terms of Indian climate Indian habit hot water for bathing, generally hot water is not used for dish washing, etcetera in this. So, we have to find out and rather define what exactly we mean by optimization. So, one way is maximum H T for the year or max for a H T bar season. We can says that for example, maximum H T bar for delta greater than 0 or H T bar for delta less than 0 or you may say that max H T bar for any month 1 to 12.

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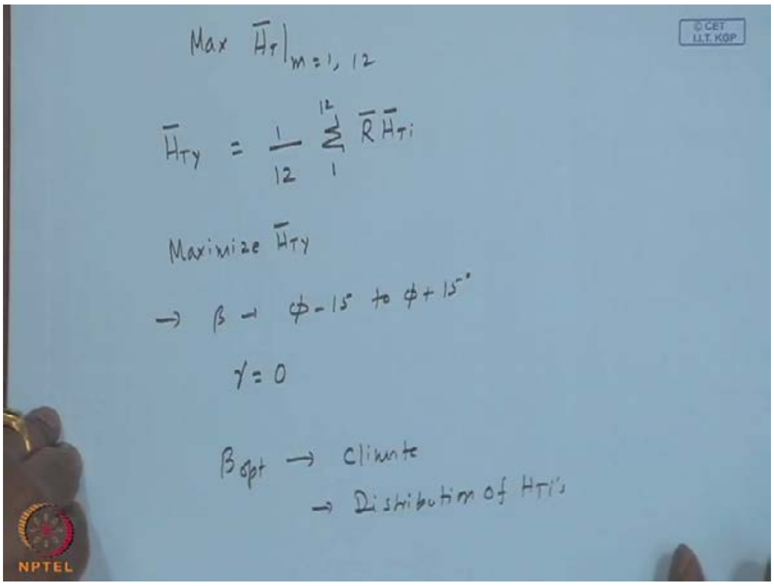

So, technically we can find out H T Y total or average does not matter 1 upon 12 sigma R bar for the month H T i bar for the month and 1 to 12, maximize H T bar Y. So, what you do is start with beta something like phi minus 15 to phi plus 15 because we got a thumb rule it is about 10 degrees. So, I go minus plus 15 degrees over the latitude and assume of course, because my best orientation is gamma is 0, and we will try to compute. And now you will realize that this optimum beta opt beta depends upon the climate meaning here by distribution of H T i's.

That means it is not essential that June has the maximum solar radiation; monsoon may coincide in June, July, august, though they may be favorable from the declination point of view, and you have different types of climates. So, one can actually calculate 12 calculations sum it up with the monthly average values, and then pick up the best beta; still it comes within beta is equal to phi plus minus 15 degrees for depending upon your optimization needs. So, we shall continue this in the next lecture, because some of the topics that I thought were left out in dealing with the flat plate theory of the collectors. We will talk about solar collector arrangements, etcetera in the next lecture.