Solar Energy Technology
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Lecture - 17
Theory of Air Based Solar Flat Plate Collectors (Contd…)

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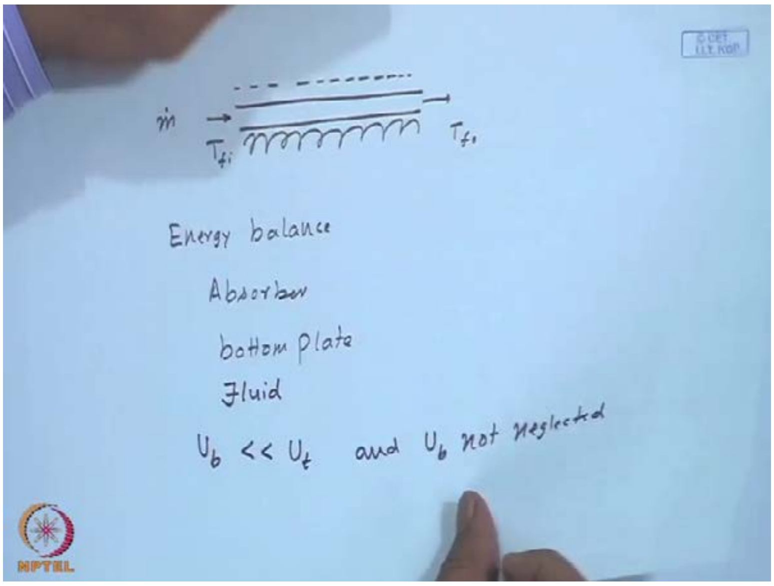

In the last lecture, we considered a solar air heater, of typical configuration, which consists of a duct, and one glass cover, and then bottoms insulated. If it flows at a rate of m dot, entering at T f i and exiting at T f o, we considered the energy balance, on the absorber bottom plate, and the fluid. So, two cases we considered, U b to be less than U t, and U b not neglected. You will get in terms of a overall loss coefficient, which is expressed in terms of U t and U b, and other heat transfer coefficients.

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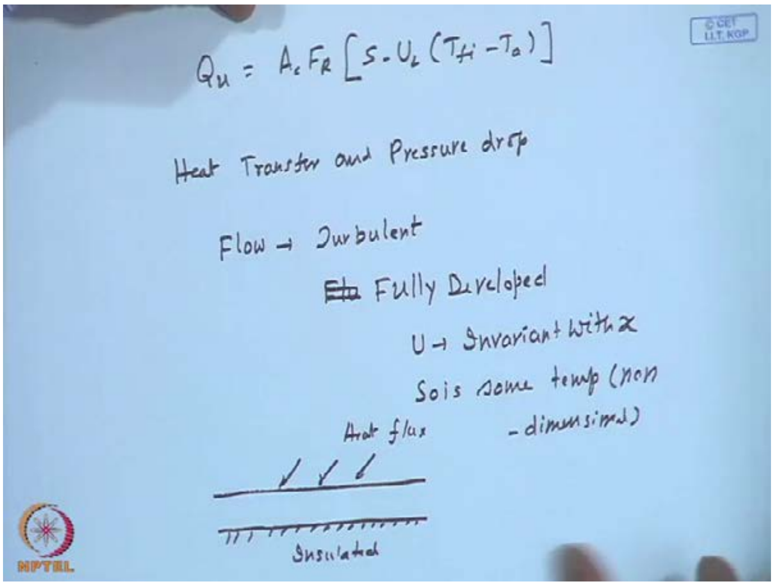

And finally, Q u can be put in the same form, as A c F R into S minus U L into T f i minus T a, though calculation of U L will depend upon, the thetas coefficients and the top loss coefficient, and the bottom loss coefficient. Subsequently we try to calculate, the heat transfer, and the pressure drop, and flow is assumed to be turbulent conditions, fully developed, which we have defined or in U invariant with x, and so is some temperature non-dimensional, and this is a case of, one of the walls of the duct being subjected to a heat flux, and the bottom being insulated.

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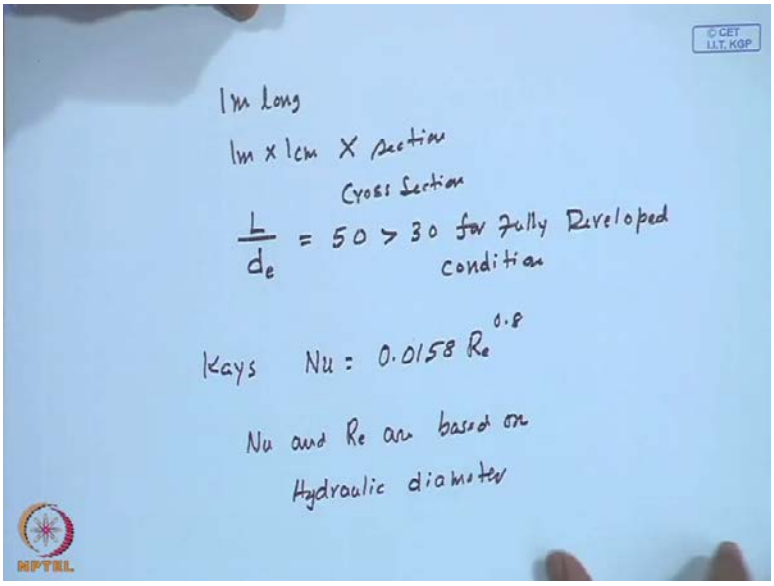

We found, for a case of, let us say 1 meter long, by 1 meter by 1 centimeter cross section. This is cross section; a L by d e will turn out to be about 50, which satisfies greater than 30, for fully developed condition. There are two correlations; one is due to Kays, where the Nusselt number is expressed as point naught 158 R e to the power 0.8, where N u and R e are based on, hydraulic diameter.

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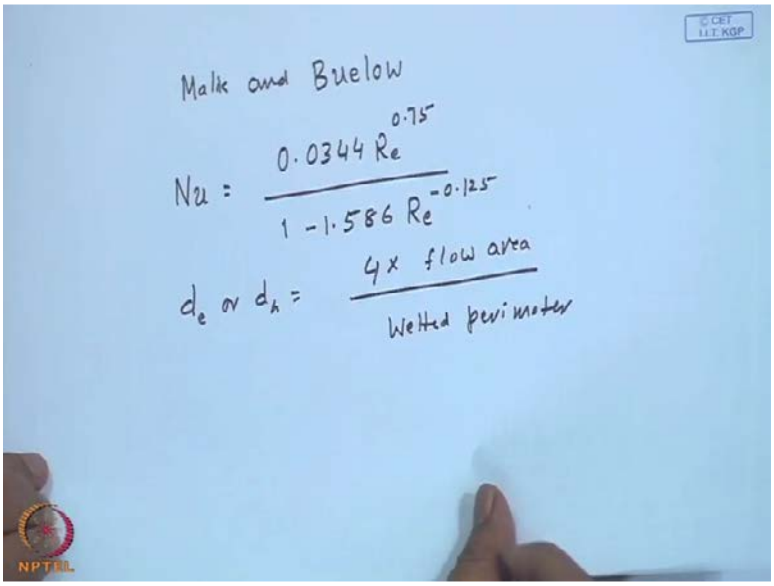

Another commonly used correlation is due to Malic and Buelow, which gives Nusselt number. So, of course, the equivalent diameter or the hydraulic diameter, which we have already defined, as d e or d h is 4 times the flow area, by wetted perimeter.

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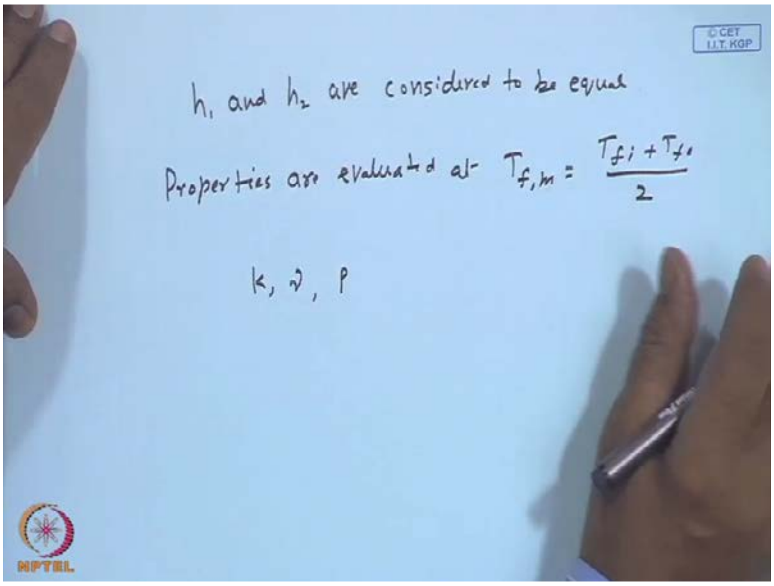

And we also said h 1 and h 2 are considered to be equal, also the properties are evaluated at T f mean equal to T f i plus T f o by 2. If the fluid inlet temperature is T f i and the exit temperature is T f o, the mean temperature is T f m, given way just the arithmetic mean T f i plus T f o upon 2. So, the property values like thermal conductivity k, kinematic viscosity U, and if necessary density rho, all of them are calculated for the fluid, at the temperature, corresponding to T f f.

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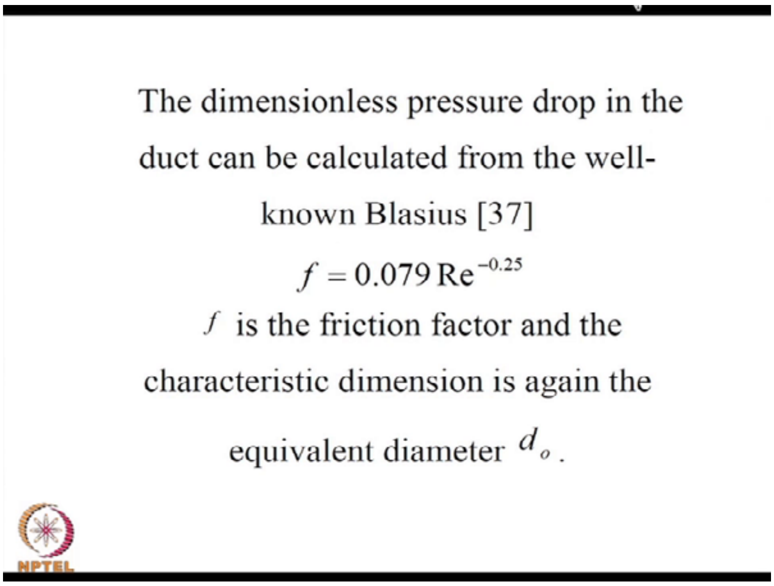

Now we come to more important thing; first we are considering the air heaters, we saw the liquid heaters. The advantages for the air heater is in the direct application of hot air, which the solar, is likely to meet very conveniently, because the higher temperatures are not, very high temperatures are not required; something like 40 to 60 70 degree centigrade is over good enough, for make quite a few applications. Then secondly, air compared to liquid in general, your heat transfer coefficients are lower.

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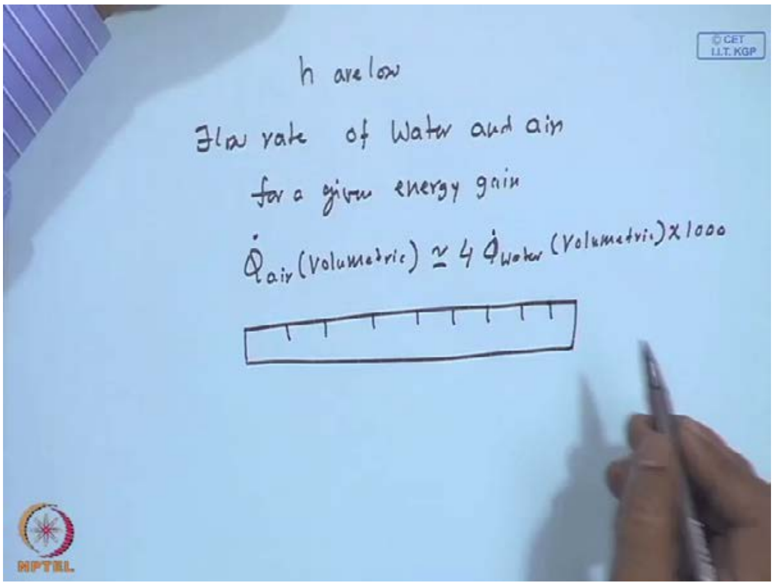

Relatively you can say that, if the Nusselt number is the same, since the thermal conductivity of air is considerably lower, than the thermal conductivity of liquids or water, you have a lower h consequently, it operates at a higher delta T. In other shift, the air is to be at 60 degree c, probably the absorber temperature will be 80, compared to a 70 or a 65 for a liquid based liquid heating system. In addition to compensate that there are other methods, which we will briefly touch up on in the later part of the lecture, and the if you consider the flow rate, of let us say water, and air for a given energy gain, at least approximately, Q dot air volumetric, will be approximately 4 times Q dot water volumetric, times thousand you can see these specific heats of water and air, they have a ratio of about one fourth. The specific heat of air will be one fourth that of water, and the density is 1000 that of water.

So, if you calculate for a given m C p delta T, you need to have a volumetric flow rate of about 4000 times, or a mass flow rate of 4 times, that of a corresponding liquid or water leaking system. So, that is one reason you do not have tubes, in the case of wave collectors, most of the time they are ducts. So, in the absence of a high heat transfer coefficient, there will be many techniques, some body may put fins or obstructions or turbulence, breakers or though breakers, to enhance the heat transfer coefficient, but right now this is not our objective, that again will increase the pressure loss there by, in spite of the fact it may gain a comparable energy as that of a liquid heater, you may have to spend more pumping power, and pumping power is a higher graded energy, which will require a 4 times or 3 times the thermal energy, through a coal burnt or somewhere etcetera. This is one aspects, one has to keep in mind while design the air collector systems, which will again complete it later.

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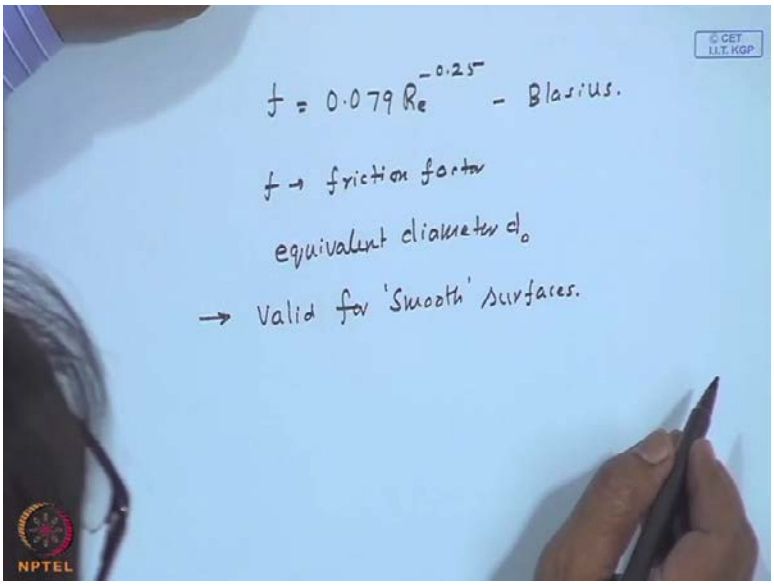

Now the friction is calculated from the Blasius formula, so this is pressure drop, this is f is the friction factor. This is due to Blasius, the famous one fourth power law. This is also at equivalent diameter d or d naught. Now this is in turbulent flow category, valid for smooth surfaces, so this is what we have over here. So, we have methods to calculate or the formulae to calculate the heat transfer coefficients in the air ducts, and the friction factor and hence calculate the pressure drop in the air duct, and find out the pumping power needed, and compare with the energy gain, and make sure that the energy gain is significantly more than the pumping power required. So, the configuration that we have considered, is a duct in a box, and then one glass cover.

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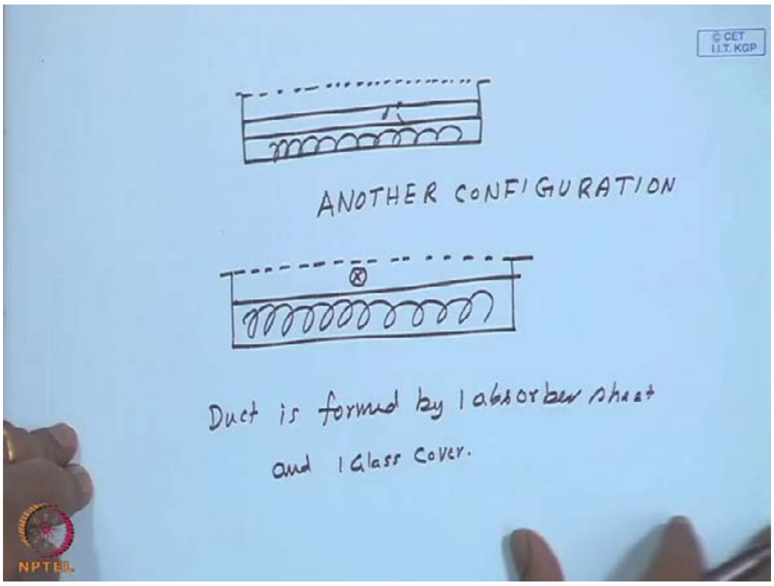

So, the observing energy or here is transferred to the fluid, then also by radiation, and again convection to the bottom, and then some loss from the bottom. So, you may call it to cut down the cost, or anyway rectangular passage is needed, a simplified configuration is designed, another configuration; that is let us call it like that. One glass cover, one absorber plate, and insulation, the flow is, perpendicular to the plain of the paper. In other words, the duct is formed, by one absorber sheet, and one glass cover; obviously, if you put them side by side.

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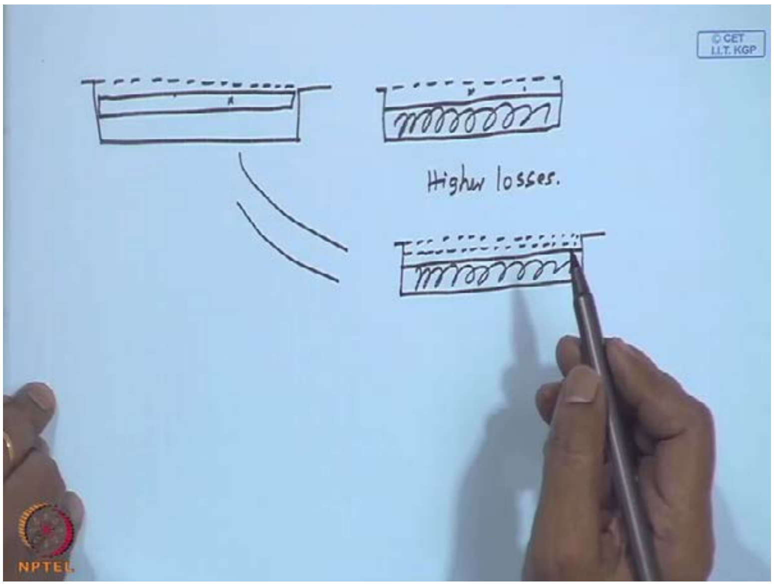

This is the first configuration, and this is the second one, with only one absorber, flow is through this, and flow is through this; obviously, here the higher losses. This beam hot air is directly in contact with the top radiation and convection losing surface glass cover .Whereas, here it the absorber then there is free convictive loss, instead of a force convection loss, so this is expected to be better. So, this may become comparable to something like this, only one absorber plate, formed between one glass cover and another glass cover. These two may be equivalent, whereas, this may be slightly inferior. However, there are many issues, whether one glass cover or two glass covers from the weight point of view, transport point of view, and maintenance point of view. So, this is what we had discussed in detail. The top loss coefficient will not be the overall loss coefficient, if the heat transfer fluid comes in direct contact with the heat losing surface. This is one such case, because technical, apparently the loss from the absorber also goes through the fluid, which is the useful energy gain.

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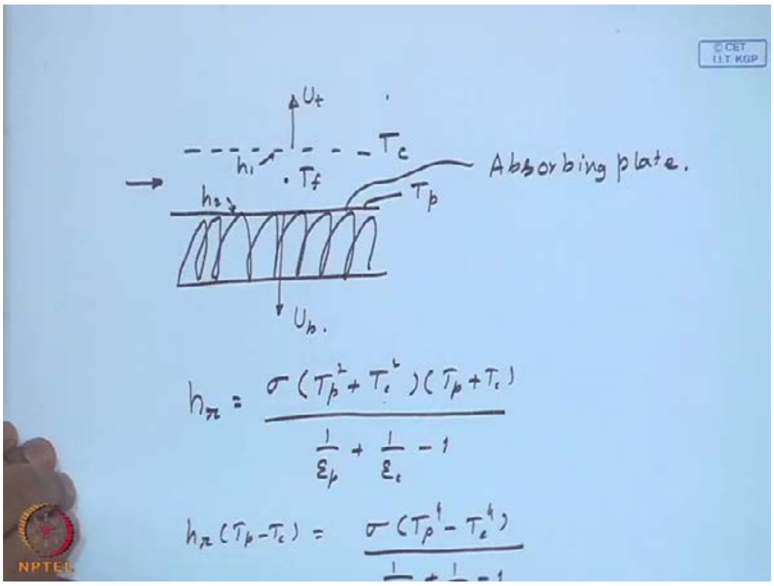

So, we will show one such configuration, which I have already shown. This is the insulation, this is the top glass cover, at a temperature of T c, this is at T p, the fluid is at T f with h 1 and h 2 as heat transfer coefficients, it is flow is something like this, and this is at U t, and you have got a U b, and this is my absorbing plate. So, we can write down straight away, the radiative heat transfer coefficient between the plate, and the absorber will be sigma times T p square plus T c square times T p plus T c by 1 upon epsilon p plus 1 upon epsilon c minus 1. This is nothing, but h r into T p minus T c, is equated to sigma times T p to the power 4, let me write down h r into T p minus T c equal to sigma into T p to the power 4 minus T c to the power 4, by the normalized (( )) epsilon p plus 1 upon epsilon c minus 1. If you do that you take T p minus T c at another side, you will get h r of whatever written here. So, how does the thermal network look like?

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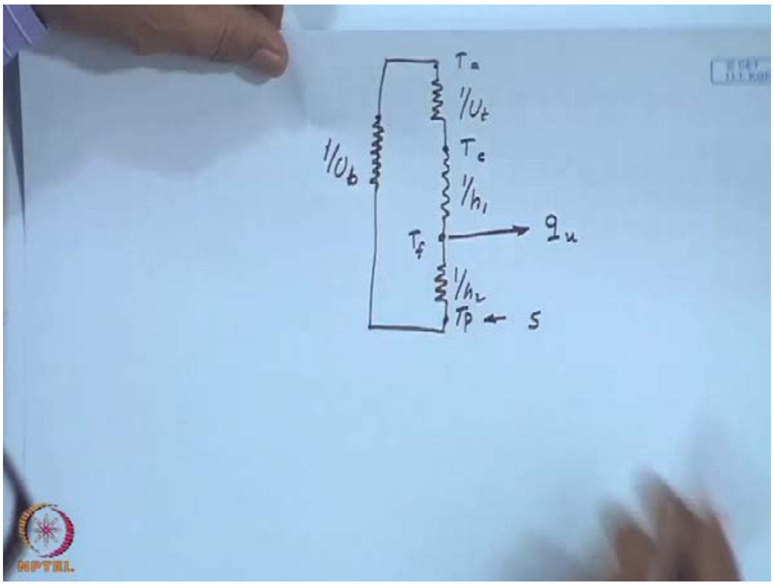

So, let this be the fluid temperature T f, from which useful energy gain comes. Then we have got 1 upon h 2, using by convection, to the absorber at T p. Then from here, to T c the cover temperature, with 1 upon h 1 as a resistance, and then T a with a resistance of 1 upon U t. Of course, you have got a S absorber energy over here, the loss is from here to the here, which is upon of course, with a resistance of 1 upon U t.

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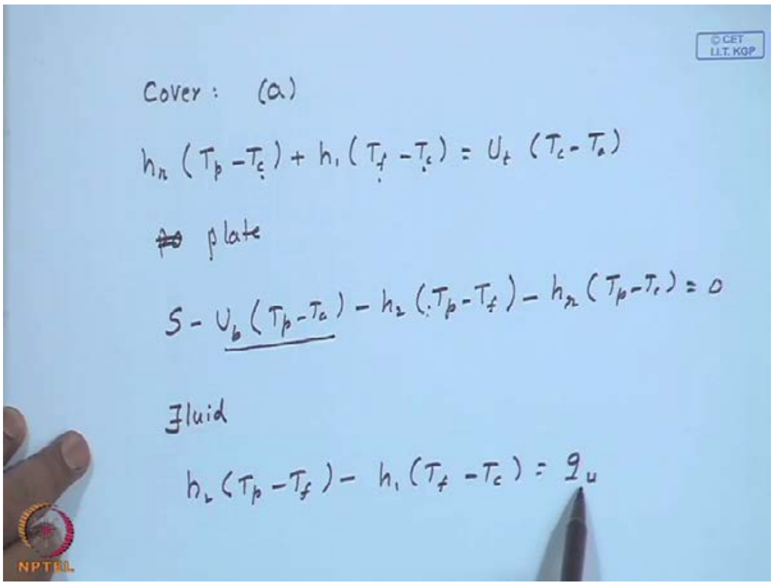

Now, you have the energy balances or this is U b on the cover, h r times T p minus T c plus h 1 into T f minus T c should be equal to U t into T c minus T a. So, by radiation it is from the plate to the cover, and by convection from the fluid to the cover, assuming this is what the cover is receiving, and it is lost to the environment given by U t into T c minus T a. Then plate this we will call it an equation a, on the plate, absorbing g s minus bottom loss U b into T p minus T a minus h 2 into T p minus T f. So, it is a loss apparently, or gain if T f is higher T p minus T c should be equal to 0. So, this is the absorber energy, out of which bottom loss is going this much, and this is from the plate T p to the fluid is deceived. So, this is gone out of the incoming, this is actually the useful energy gain minus the radiative loss from T p to T c. Then the fluid h 2 into T p minus T f minus h 1 into T f minus T c should be equal to q u. So, this receives from the plate temperature T f p to T f, and looses from the fluid temperature T f to the cover temperature T c, but net should be equal to the useful energy gain q u.

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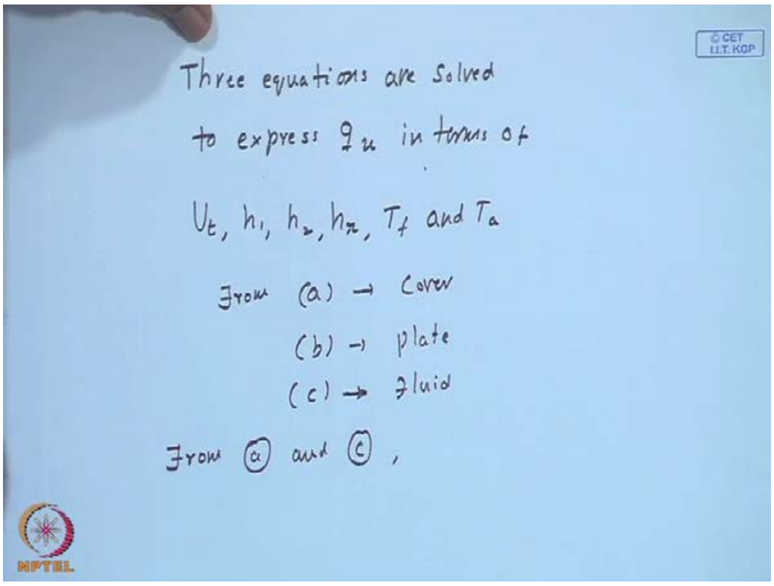

So, these three equations, are solved in terms, or to express Q U in terms of, U t h 1 h 2 h r T f and T a. So, from a, that is the cover, and b the plate, and c the fluid, just for our easy reference.

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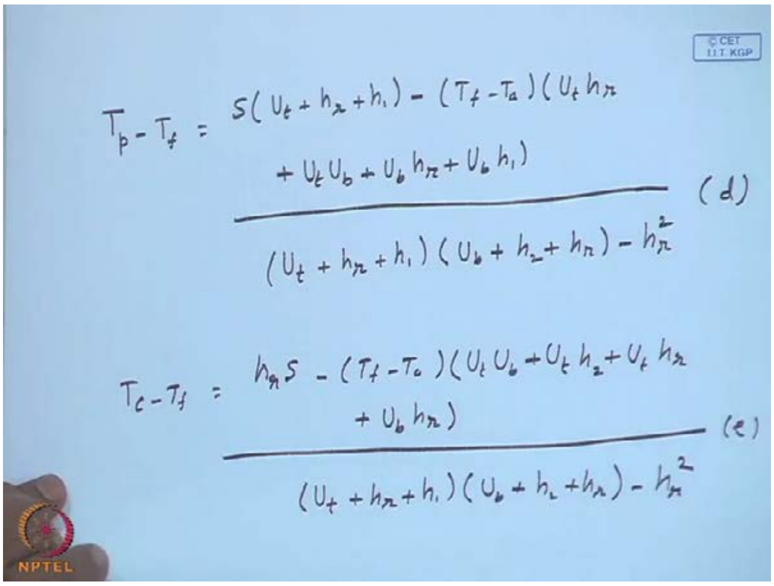

So, from a and c, you will have long equations T p minus T f equal to S times U t plus h r plus h 1 minus T f minus T a times U t h r plus U t U b plus U b h r plus U b h 1 upon U t plus h r plus h 1 times U b plus h 2 plus h r minus h r square. So, this we will call it d. So, T c minus T f equal to h r into S minus T f minus T a times U t U b plus U t h 2 plus

U t h r plus U b h r by U t plus h r plus h 1 times U b plus h 2 plus h r minus h s square this we will call it e. You may be wondering all these long equations, whether they can be remembered. It is very difficult to remember, and I will also strongly suggest you please work out the algebra, and check these things, because I have the benefit of seeing it on the computer screen while copying, but then with so many subscripts there may be a mistake, and U t U one U h all they look little confusing, but I try to be as careful as possible, but never the less, you can check it, with either standard text books or you work out there may be one or two differences, that you can easily figure out.

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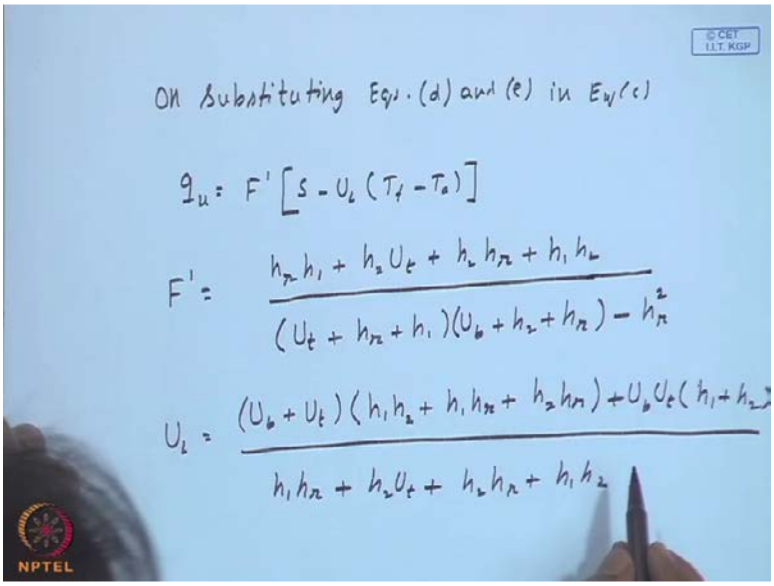

So, on substituting, for example, you can always refer the text book by Adolph and Beckmann, nevertheless nor to work out because the details are not given in most of the books, because this is a laborious algebra. So, what really matters is your q u, is F dashed times S minus U L into T f minus T a, where F dashed is h r h 1 plus h 2 U t plus h 2 h r plus h 1 h 2 upon U t plus h r plus h 1 times U b plus h 2 plus h r minus h r square and you will overall loss coefficient U L is another big equation U b plus U t times h 1 h 2 plus h 1 h r plus h 2 h r plus U b U t times h 1 plus h 2 by h 1 h r plus h 2 U t plus h 2 h r plus h 1 h 2. So, this will be a good to solve, and difficult to remember. So, consequently most of the time, from student's point of view, this type of a question will be more suitable for a open book exam, rather than a memory test.

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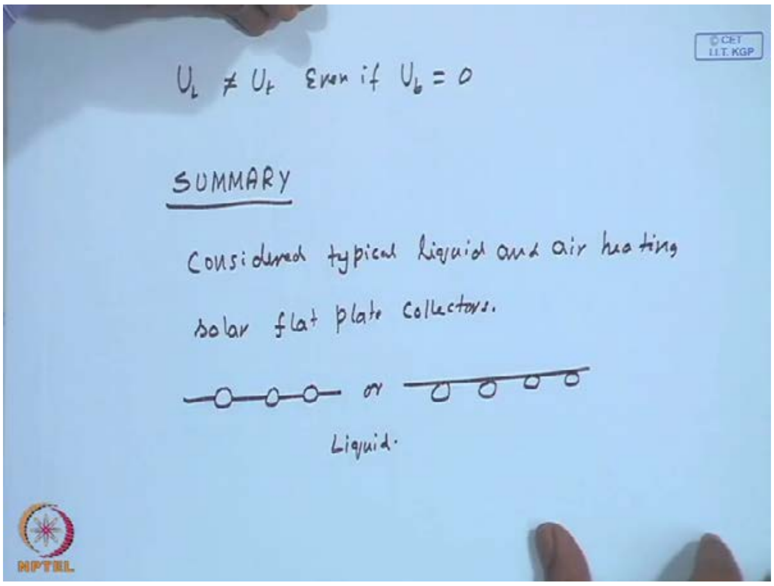

Now, you can see from this equation U L, is not equal to U t, even if bottom loss is 0. So, this is where it comes, that the fluid is directly coming in contact with the top of glass plate, where from the loss is taking place, and whatever the fluid is receiving, if you look at from the plate point of view, it is the U t into something, or a heat transfer coefficient into T p minus T f which is also the useful energy gain. So, if you want to have a summary, of the flat plate collectors, we have considered typical liquid, and air heating, solar, flat plate collectors; one is the fin, and the tube type of absorber or like this liquid.

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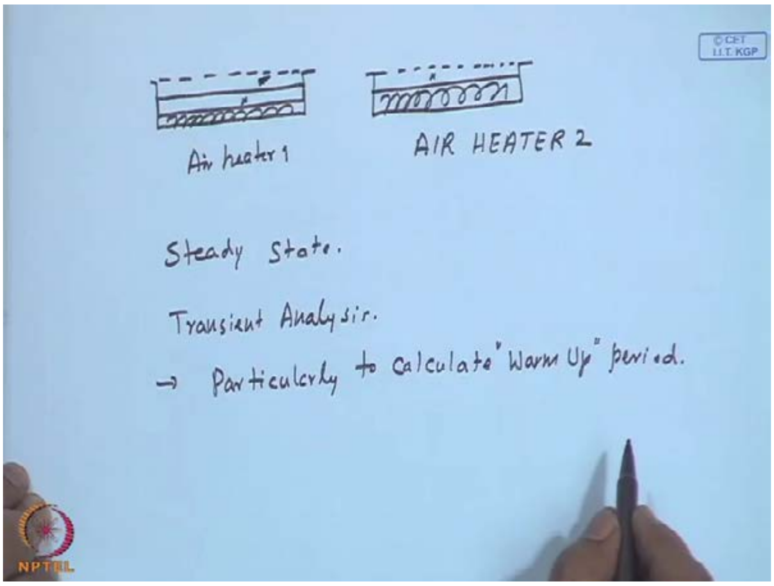

For air ,a duct with one glass cover, in the bottom insulation, and the next configuration was, with only one absorber heat and one glass cover, and the flow channel being perpendicular plane of the both, sorry c f, and here between these two this is insulated. So, this is air heater one, this is air heater two. So, first we did it with the frame work of steady state analysis, then we made transient, analysis. This is particularly to calculate warm up period.

The basic idea is the collector covers absorber, they have to reach certain temperature, in order that they are able to give energy at the desired temperature from the fluid coming out of the collector, otherwise the temperature it is lower, the fluid cannot be heated up to the temperature. In addition, you briefly consider the concept of critical gradiation level, where the useful energy gain is 0, for a certain temperature of the absorber or the inlet fluid temperature, consequently the solar radiation intensity has to be above the critical level, in order that it supplies the energy at the delivered minimum temperature desired, before that the collector should get heated to their respective temperatures for the cover and absorber.

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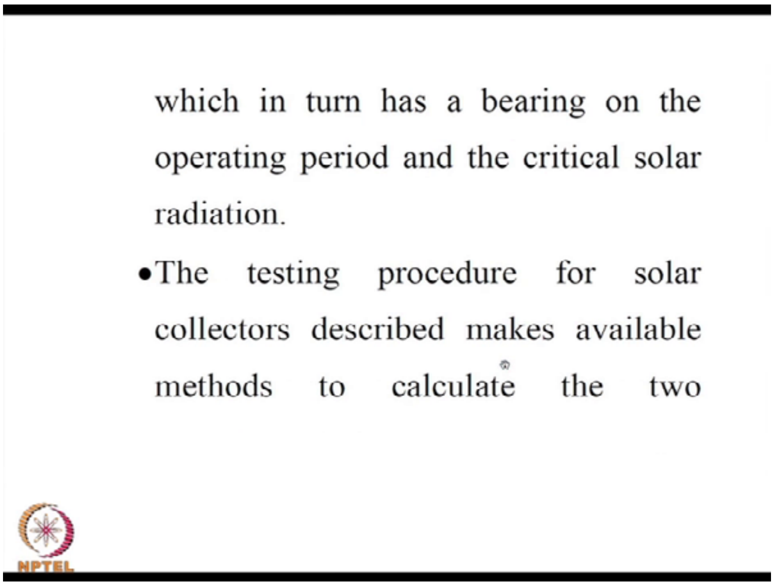

So, this in general has a bearing on the operating period. One thing we will consider, in detail when we talk about the utilizability concepts, you may wonder.

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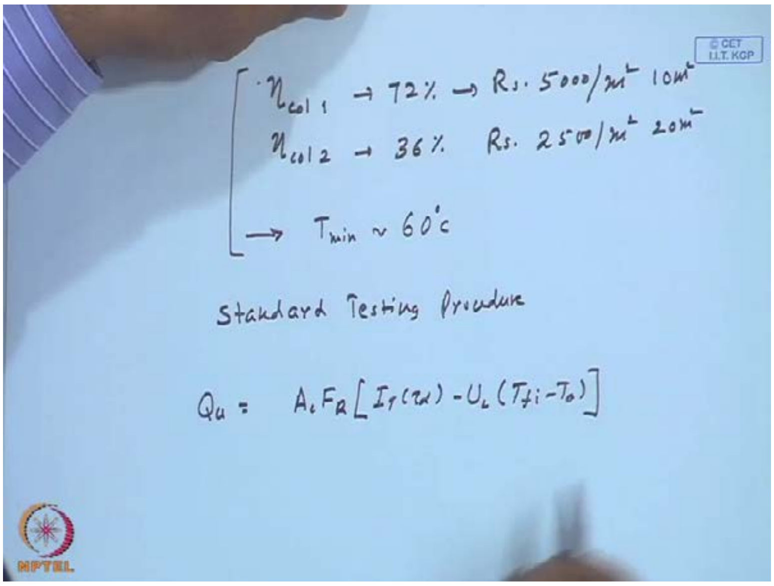

Let the efficiency of a collector one be 72 percent, efficiency of the collector two be 36 percent. So, now this is let us say R s 5000 per meter square, this is R s 2500 per meter square. I have deliberately concocted these numbers, if the efficiency is half, the cost also is half. So, if I require 10 square meters of this, this I may require 20 square meters, which may be approximately the same cost, except the second we may require higher piping, higher land area etcetera, but somehow we can discount it the cost, and you may say it even only 2000 rupees, and the additional piping cost even if it is considered, they will be comparable cost, now do you go for this or that. So, apparently let us say the my initial investment is the same, for a given amount of energy apparently, or based upon the efficiency, but the issue is really, if it is required to deliver some T minimum. Let us say 60 degree centigrade.

The collector with the higher efficiency, not only delivers at higher efficiency, but operates over a higher period of time, whereas the collector with the lower efficiency will operate less period, because this will be having a higher critical radiation level than this one. So, my T 1 to T 2 operating period will be larger, consequently total energy gain will be higher, not only in proportion to the efficiency, but also because of additional time that it operates. So, this is a very important issue, which we will deal in detail, then instead of having a standard testing procedure, we have discussed, typically the solar heating insulation being more than 700 watts per meter square, preferably conducted around noon time, or keeping the angle of incidence as small as possible, or as mere normal incidence as possible, and best to measure with the a pyranometer mounted on the collector surface itself. So, now you will find that q u is A c F R into I T tau alpha minus U L into T f i minus T a.

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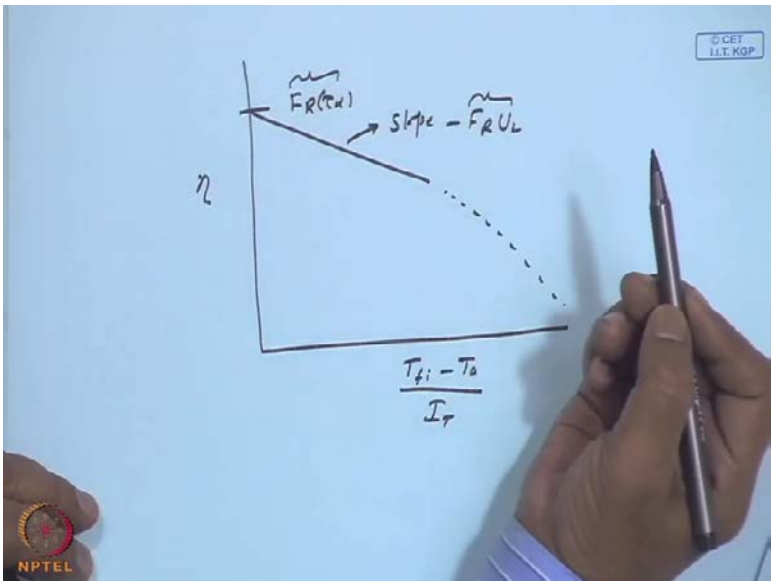

And we have determined from the efficiency equation by a T f i minus T a by I T versus efficiency one line. Of course, this is beyond the operating condition; it may not be a linear variation anymore. So, this is typically F R tau alpha, and the slope of this line, will be minus F R U L. So, you conduct the efficiency test, and you will have the collector parameters F R tau alpha, and the slow F R U L. Though there are three F R tau alpha and U L, they occur only in pair of F R tau alpha, and F R U L throughout, this course in general in solar energy.

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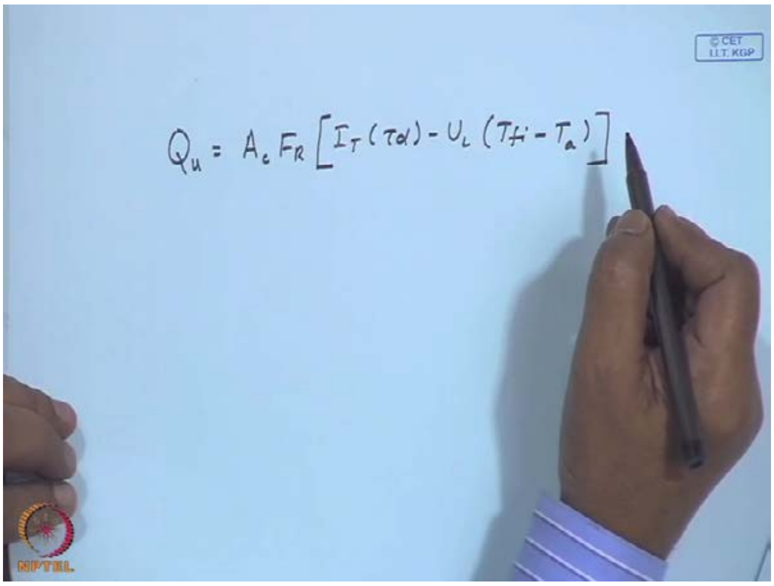

Now, this is from the this equation, which is basically derived in 1942, (( )) equation, though there have been some modifications in terms of F R F dashed etcetera. This is single most commonly used equation in the solar energy literature, and it will be used in the simulations for the collector, applying it over the time period, that is required.

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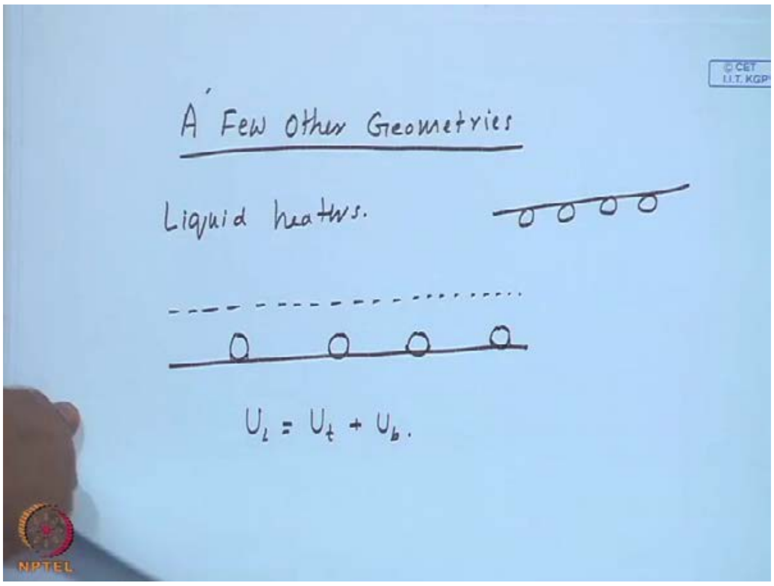

So, what we shall do now is, briefly consider few other geometries. First liquid heaters, suppose you have, like this that is the absorber, with the tubes on the top soldered or welded, with the bond, good bond, compare this, whatever we have considered earlier like this. So, some people argue that the tube is directly exposed to the solar radiation. So, that will be at a higher temperature, thereby making it more efficient, but others may say that, this is directly also will lose heat by radiation. And of course here, because it does not come into, direct contact with the heat loosing surface U L is U t plus U b.

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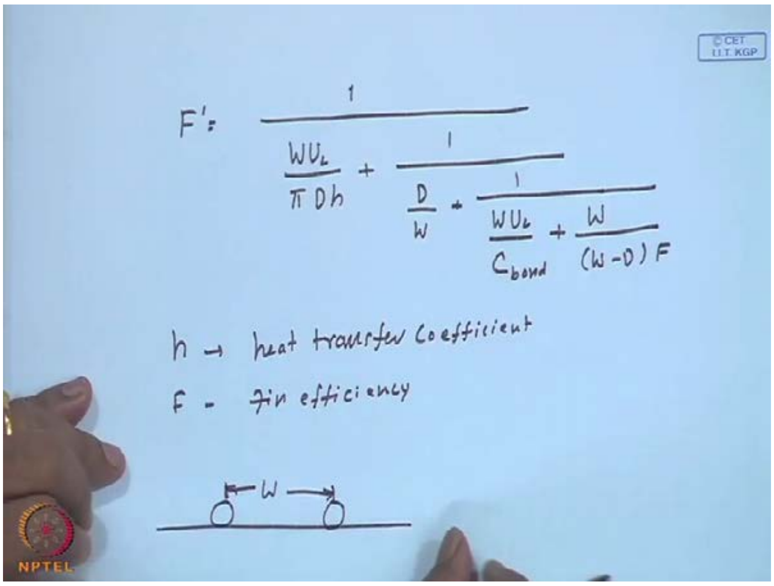

And the collector efficiency factor is given by… This is very similar to what we have worked out, the notation remains the same, what needs to be perhaps reminded is h is the heat transfer coefficient, inside the tube, and F is the fin efficiency, and F dashed even D W they remain the same, W is the centre to centre distance, between the tube and the tube. This is the way we have also defined, or when we were considering the tubes at the, below the absorber plate. So, again my fin efficiency remains the same.

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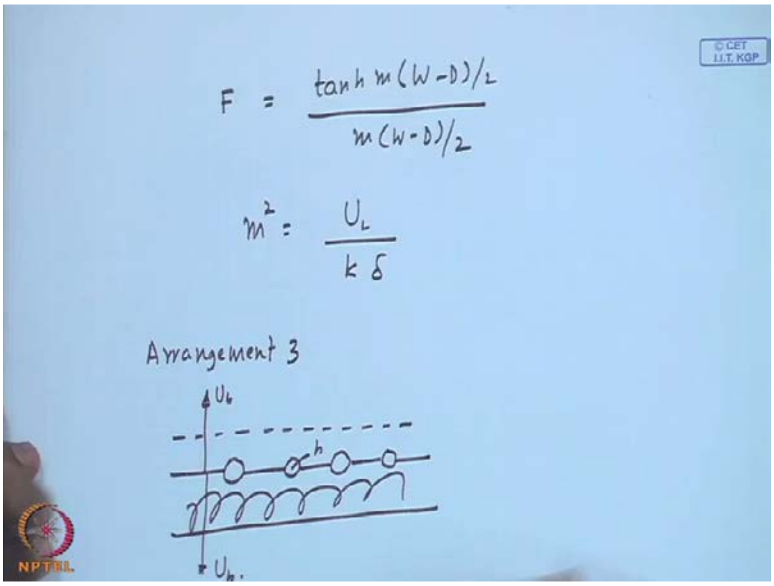

So, F dash is different expression, tan h m into W minus D by 2 by m into W minus D by 2, where m squared is U L by k delta. So, what we have done, we will call it arrangement one. This is arrangement two, and we will go to arrangement three. The regular class room heat transfer, fin and tube arrangement. This is insulated at the bottom, it may have one or two glass covers, and there is a heat transfer coefficient h, and of course, U t and U b. If you have this arrangement, U L is, though it is obvious, we will write it, because there are cases where it is not.

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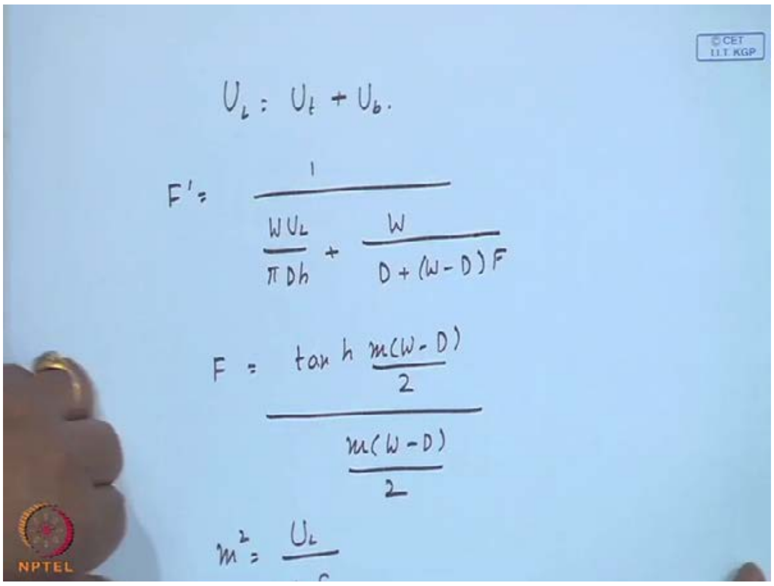

And F dashed is 1 upon W U L by pi D h plus W by D plus W minus D into F. So, F is the fin efficiency, h is the heat transfer coefficient, as we have been defining n number of times now. These are the three configurations; again F turns out to be same, so definition of F remains the same. However, your F dashed differs, for these three fin configurations.

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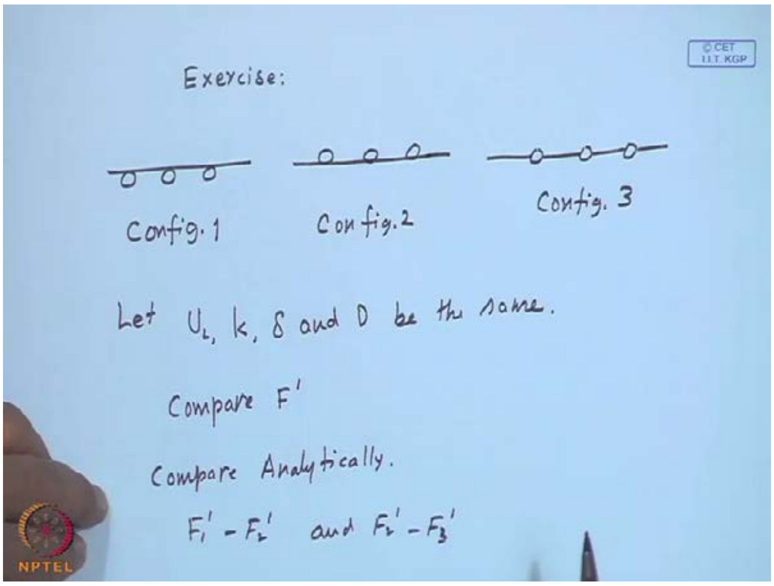

Now, it could be interesting, or you have this as an exercise; for configuration one, configuration two, configuration three. So, let U L k delta, and D be the same, so compare F dashed. So, I am having the same overall loss coefficient, same material thermal conductivity, same thickness, and same diameter tube, and but since my expression for F dash are different, the values of F dashed will be different. So, you can compare analytically. In simply, what all you have to do is F 1 dashed minus, F 2 dashed and F 2 dashed minus F 3 dashed. So, you will find out F 2 is greater than F 1, or F 1 is greater than f three etcetera, and you can say that this configuration is superior.

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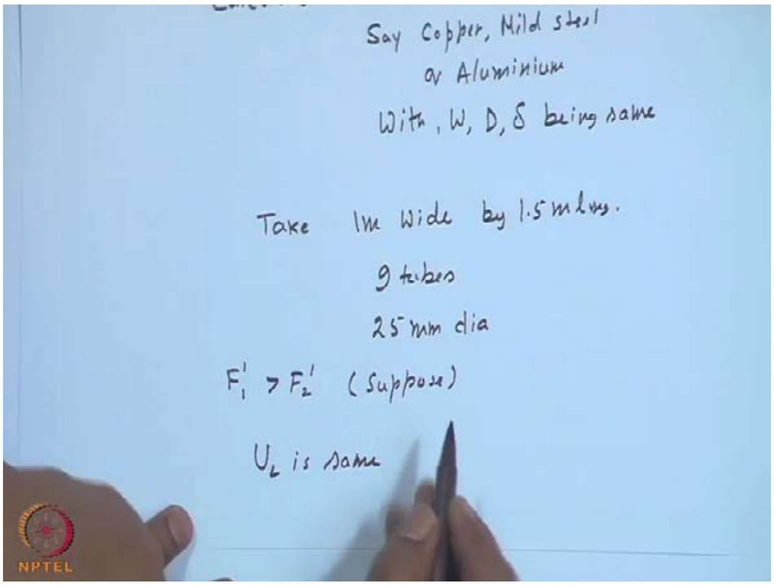

The other method is, simply calculate, for a given material; say copper, or mild steal, or steel, aluminum with W D delta being same. One of the ideas is you, go through any typical book, of course, we should solve the problems, we can a typically say take one meter wide, by 1.5 meters long, wide and nine tubes, let us say 25 mm dia. So, we accordingly you find out, what should be the number of tubes are approximately, it may be nine W and d is everything is given. So, for that you can compare which one is better. The question comes I really have no answer, because I have not done it exactly this way. So, if you find for example, configuration one of F dash is more than F dashed of configuration two suppose. So, your U L is same, K is same, delta is same, everything is same, why is this so?

Now in this analysis we find, that which geometry is better in that we are making a assumption subconsciously, same bond conductance, and same thicknesses geometry factor, W also is geometry factor, but U L is same, this need not be, because the expose variants are different, so my U L may be slightly different. So, consequently, even under those conditions, it will be nice in case you can establish; one configuration is, superior to the other configuration, whether it is analytically or through examples. So, next time we shall consider some more configurations for the air heaters that should be being as close to the theory of flat plate collectors, coming to a conclusion.

Thank you.