Solar Energy Engineering and Technology
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Lecture No. 24
Solar Air Heater

Dear students, today we will be discussing on Solar Air Heater and its performance analyzes. So, what is Solar Air Heater?

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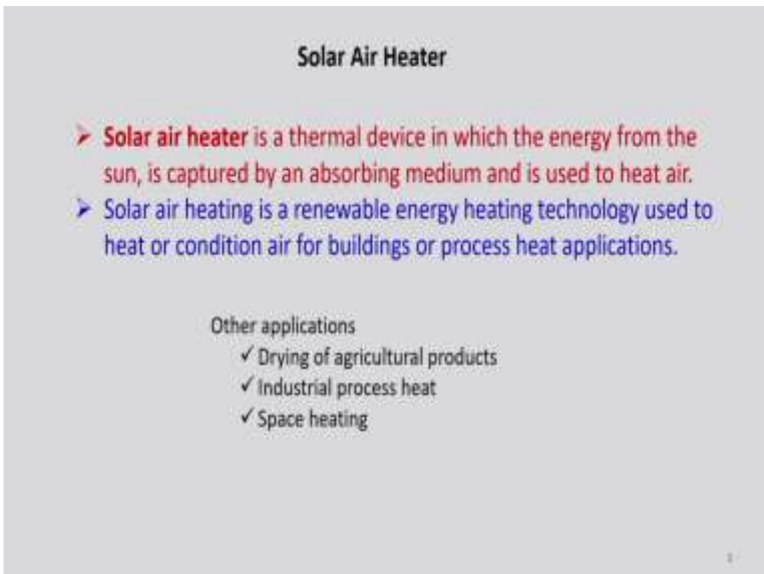

The solar air heater is a thermal device in which the energy from the sun is captured by an absorbing medium and is used to heat Air. This Solar air heating is a renewable energy heating technology used to heat or condition air for buildings or process heat application. So, other applications are Drying of agricultural products, Industrial processes and Space heating.

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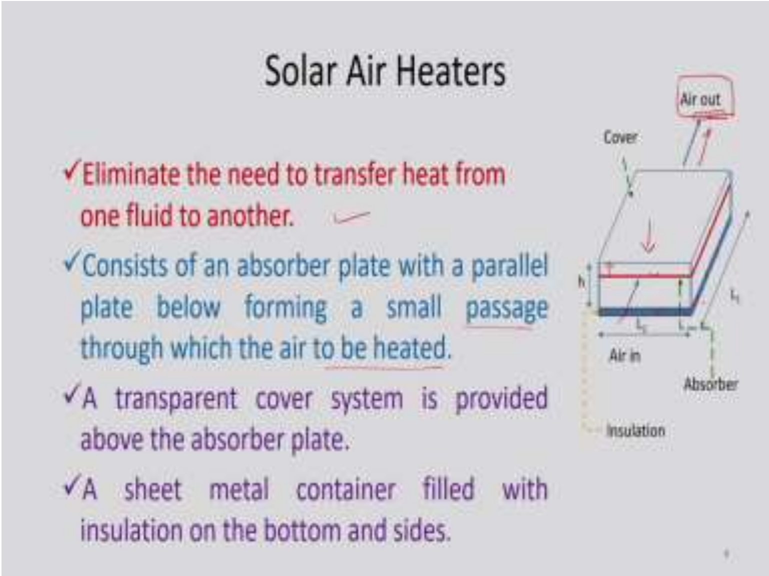

So, as far as solar heating is concerned, so, what are the different components of a solar air heaters? One glass cover at the top, then we need to have an absorber plate and then that through which air flows. So, this may be the inlet of the air and this may be the outlet of the air from where we can collect the hot air and use it for applications and also we need to provide sufficient insulation to reduce the heat losses which is generated inside the air heaters.

So, these are the insulations in the bottom side of course, we need to apply some kind of insulations into sides as well. So, this solar air heater eliminates the need of transfer of heat from one fluid to another fluid. Because in case of liquid flat plate collector what happens so, heat will be absorbed in the absorber plate, then that has to be transferred to the fluid. So, that part is not required here. So, that is why it eliminates the need to transfer heat from one fluid to another.

And as I have shown that it consists of an absorber plate with a parallel plate below forming a small passage through which air to be heated. So, this transparent cover is provided above this absorber plate for transmitting solar radiation to this absorber plate, and then finally we need a sheet metal container with insulation to hold the structure.

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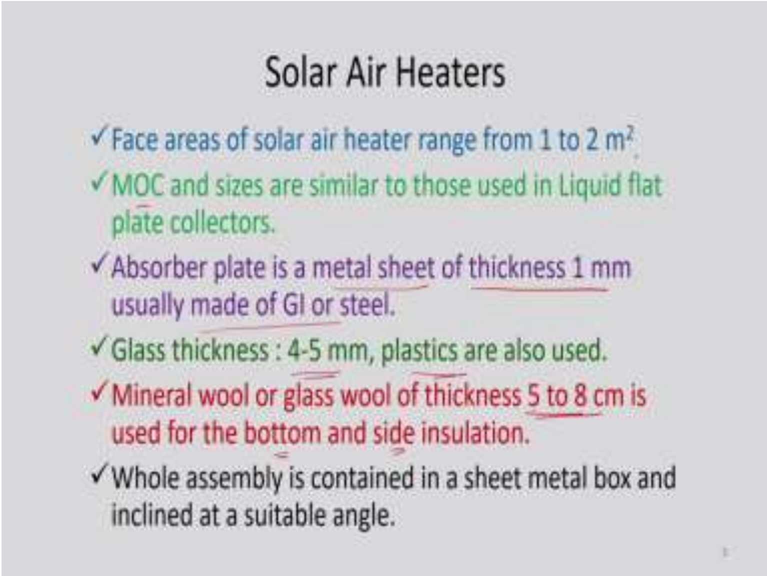

This solar air heater face area ranges from 1 to 2 meter square similar to what we have considered for liquid flat plate collector. The material of construction and size are similar to those used in liquid flat plate collectors. The Absorber plate is a metal sheet of thickness 1 mm usually made of GI or steel GI means Galvanized Iron or other material derived from steel. And this thickness of this glass is about to 4 to 5 mm.

And nowadays plastics are also used in this kind of air heaters. Mineral wool or glass wool have thickness 5 to 8 centimeter is used for reducing the heat loss at the bottom and side. And finally, the whole assembly is contained in a sheet metal box and incline at a suitable angle with this tilt angle to be maintained, which was discussed in the last class what angle will be appropriate for a certain locations.

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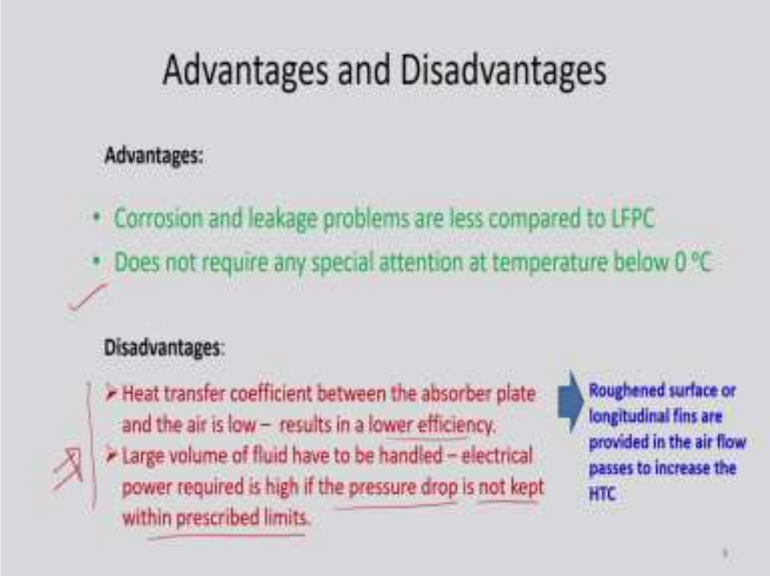

So, what are the advantages of using this Solar Air Heater if we compare with a liquid flat plate collector? So, in case of solar air heater, corrosion and leakage problem is very, very minimal. And the solar air heater does not require any special attention at temperature below 0 degree Celsius, but in case of liquid flat plate collector, we need to think about it if it goes below 0 degree and if we use in a place like Ladakh then what will happen it will freeze if we use what are in that flat plate collector.

So, we need to use different kinds of fluid so that it will not freeze if that ambient temperature goes below 0 degrees C. So, this is one special advantage of this solar air heater and what are the disadvantages, like heat transfer coefficient between the absorber plate and the air is low whose results in lower efficiency. And in this case, large volume of fluid have to be handled.

Hence, this electrical power required is very high if the pressure drop is not kept within the prescribed limits. So, these 2 are very, very important aspect we need to look into as far as design of a solar heater is concerned. And of course, we can increase the heat transfer coefficient by different means, two of the means are doing roughened surface so, that no turbulence can be created.

If we can increase the turbulence then we can augment the heat transfer coefficient and sometimes longitudinal fins are also used to increase the heat transfer from the plate to the fluid.

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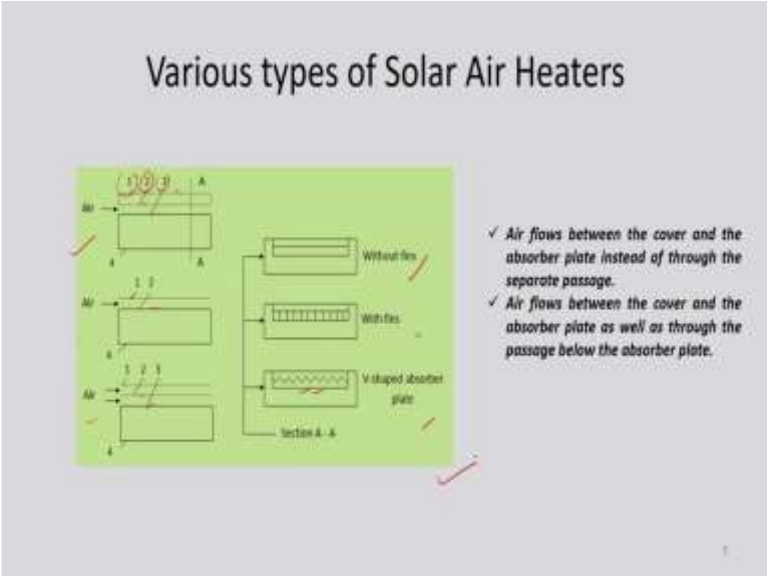

So, there are different types of Solar Air Heaters what you can see there are 3 configurations. So, in the first configurations what happens we have this glass cover 1 indicate glass cover and 2 indicates absorber plate and 3 indicates this bottom plate. So, here in the first configuration what happens, fluid flows between this absorber plate and this bottom plate and this is a glass cover. And the second case what happens we have glass cover and there is no bottom plate only absorber plate we have and in this case airflows between glass cover and absorber plate again between absorber plate and this bottom plate.

So, different types we can classify. And for all this types, we can have these kind of configurations. So, without fins, so, sometimes know we can use the solar air heater without using a single fin and sometimes we can use multiple fins in order to augment heat transfer coefficient. And also sometimes we can know use this kind of configurations to increase the turbulence and in all the cases our attempt is to increase the heat transfer coefficient between the plate and the fluid. So, that is what it is shown in this slide.

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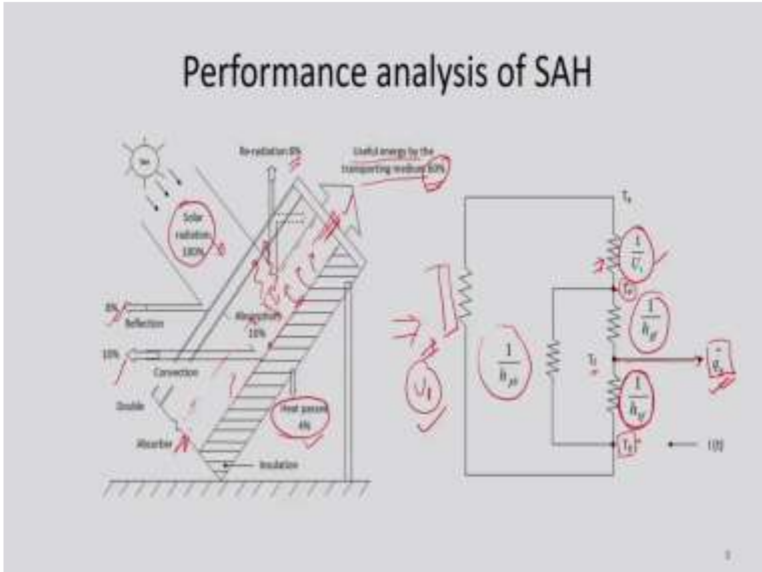

So, this slide, shows the energy flow of a solar air heater. So, here if we use double cover here, then solar air falls here through this glass cover and it is received on the absorber plate. So, energy is received here and then it is transferred to the fluid. So, as you can see if we consider this 100 % energy is coming from the solar and then some of the energy is absorbed here in the absorber itself.

And since fluid is flowing from here to here, inlet to outlet and heat will carry, so it is found that useful energy by the transporting medium carries 60 % heat and then 10 % goes to convective losses or convection losses and radiation losses will be 8 % and re-radiation once it strikes on this absorber plate it will re-radiate. This re-radiation loss will be about 8 %.

Of course, we need to estimate the amount of losses taking place from the bottom of the collector which is estimated to be about 4 %. So, all these things we can know right in terms of thermal resistance. So if we consider this qu which is useful heat gain. So, this the amount of heat which is goes out for utility that is nothing but useful heat gain and what happens when solar radiation is falling on this device.

So, radiation transmits to this glass cover that is received on the receiver again heat exchange will be there in between this absorber and this back cover. So, when heat exchange will be there then what happens, some amount of heat will be absorbed in this plate and this also contribute in increasing the temperature of this incoming fluid. So, if we consider this Tb is the temperature or say mean temperature of this back plate and T_p is the mean temperature of this plate T_p and in between fluid is flowing. So, this is the useful heat gain.

So, fluid temperature is maybe T_f at particular section or particular point. So, there will be heat exchange between this plate to this fluid and then this plate absorber plate to this fluid so, this is from back plate to the fluid and this is from the absorber plate to the fluid. So, this is the one kind of thermal resistance and top loss will be there. So, top loss will be there and this estimates the amount of losses taking place from the top of the collector.

And if we combine these two, what we will get? This is the heat transfer that is the amount of heat transfer what is know taking place here in between these 2 plates and then finally, we can estimate the amount of thermal resistance that is overall thermal resistance or what we can say total loss coefficient. So, this way we can calculate and also it tells the kind of heat transfer takes place in this solar air heater.

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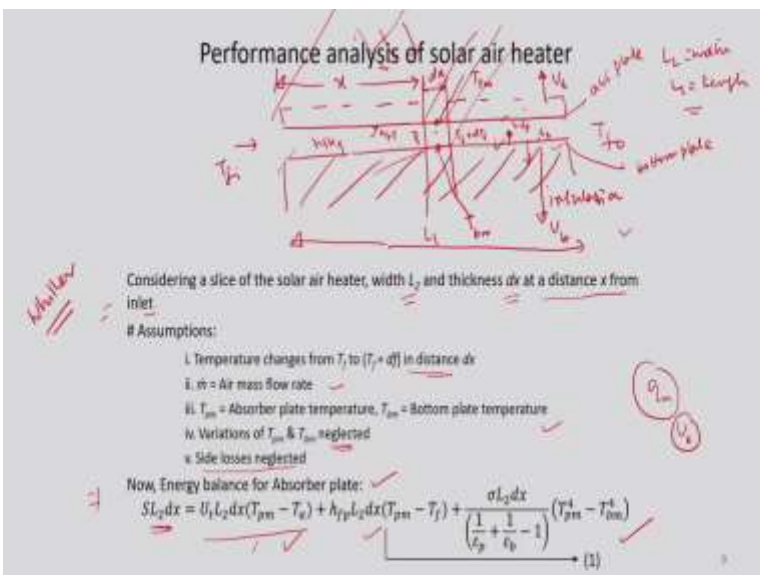

Now, let us study the performance of a solar air heater. So, we will follow the analyzes proposed by Whiller. So, we need to draw the collector first and this is a glass cover and then we will have this absorber plate and we will have in this is the back cover and of course, we will have this insulation. So, this is insulation, insulation, insulation and we will have T_{fi} we will be here T_{fo} fluid outlet temperature is T_{fo}. And this is the heat transfer coefficient h_{fp} and this is a heat transfer coefficient h_{fb} from the back plate and we will have we will consider a section here.

So, this may be dx and it will start from here and this may be T_{pm} T_{pm}. So, mean temperature of the absorber plate and this maybe we can consider T_{bm}. So, this is the mean temperature of the back plate. And if we consider T_f here, fluid temperature here if this section dx if it travels then maybe no it will have some kind of higher temperature. So, (T_f +dT_f) and maybe I can consider ε_p is the emissivity of this plate and this ε_b may be the emissivity of this plate.

And bottom loss will be there U_b and top loss I can represent by U_t. So, this part, this length is L_1 and width that way it will go so it will be L_2. So this is width and L_{2-1} is the length from inlet to the outlet. So, now we will consider a slice this is the slice and width is L_2. So, along this direction and the thickness is dx at the distance x from that inlet. So, that that is shown in the figure.

So, before we derive the expression for q_u, so, we need to assume some of the parameters like temperature changes from T_f to (T_f +dT_f) in the section dx, m is the air mass flow rate which is know constant and T_{pm} is the absorber plate temperature and T_{bm} is the bottom plate temperature and this variation of T_{pm} and T_{bm} are neglected and side losses are neglected. And also we will learn at what condition we can cancel U_b. Now, energy balance for absorber plate we can write so, this is the amount of radiation which is falling on the section what we have considered.

So, this S into this part is L L_2/dx. So, this will go something like this if we if we visualize this will go something like this. So, dx so, this, this will be something like this. So, this dx multiplied by L_2 this is the area multiplied by S to the amount of solar radiation received at that section. So, equal to some losses top losses and then heat exchange between this plate to the fluid and then heat exchange between this plate this is absorber plate already you know abs absorber plate and then this is bottom plate, bottom plate. So, this radioactive exchange will be there in between these two, two plates.

So, that way we can develop this energy balance for the absorber plate. So, this is the losses and this part is a heat transfer from plate to the fluid. And this last portion is for the radioactive exchange between both the plates.

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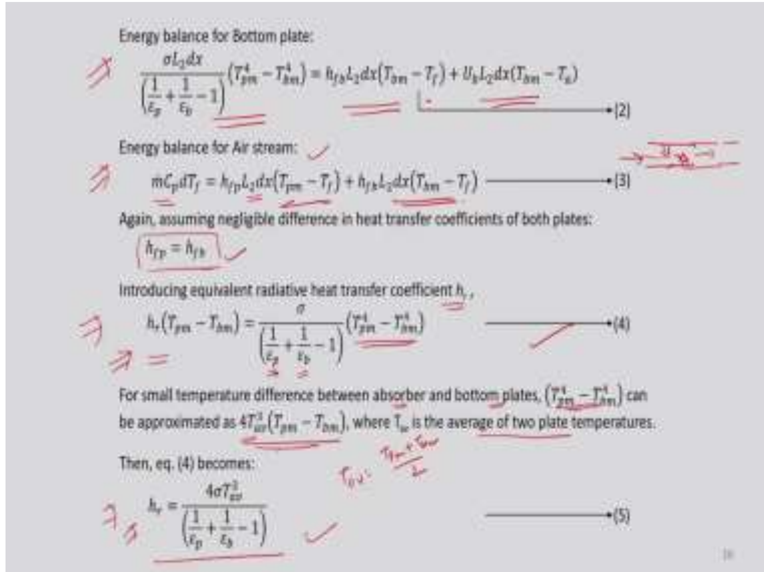

And then we are interested about energy balance for the bottom plate. Now, we are interested about this bottom plate. So, what will happen, so, these bottom plates also contribute to this fluid because already some amount of energy is absorbed here due to these exchange. So, heat will be giving to this fluid and then radioactive exchange will be there in between these two plates. So, that way you can develop. So, this is the radioactive exchange between these two plates and this is the heat exchange from this bottom plate to the fluid. And then this is the bottom losses.

So, from here we will have bottom losses. So, losses will be there and then heat exchange between the plates and the fluid. Then, we are interested about energy balance for air steam, so, air entry is there, air entry is here and then heat transfer or energy is coming from both the plates. So, that way, so, mC_p dT the amount of know heat finally, is gain is equal to $h_f L_2 dx$ is the area in that segment and $\left(T_{pm} - T_f\right)$ that is the plate to the fluid and then this is for absorber plate to the fluid and this is the bottom plate to the fluid.

So, again there is an assumption that we can assume this h_{fp} is equal to h_{fb}, this is the heat transfer coefficient between the fluid and the plate and then fluid and the bottom plate. So, now we will introduce an equivalent radioactive heat transfer coefficient $h_r\left(T_{pm}-T_{bm}\right)=\frac{\sigma\left(T^4{}_{pm}-T^4{}_{bm}\right)}{\left(\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_b}-1\right)}$.

So, $\left(T^4{}_{pm} - T^4{}_{bm}\right)$. So, this term is known as equivalent radioactive heat transfer coefficient hr. So, for small temperature difference between the absorber and the bottom plate, this temperature difference can be approximate is as $4T_{av}^3$. $T_{av} = \frac{T_{pm} + T_{bm}}{2}$. So, we can have this kind of expression. So, already defined what is T_{av}.

So, if we use this then this expression 4 because becomes something like this so, hr $h_r = \frac{4T_{av}^3}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)}$. So, this is nothing but equivalent radioactive heat transfer coefficient.

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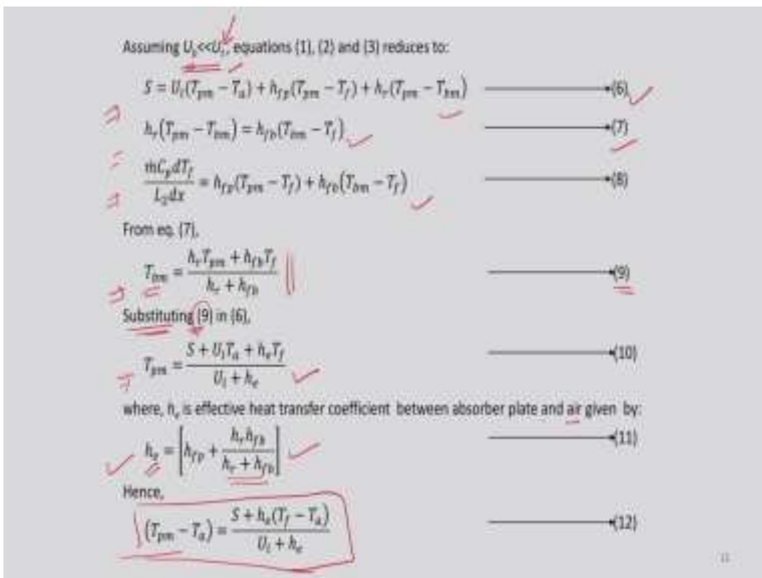

Now, assuming U_b is very, very less compared to U_t. So, this U_t is very, very high because to reduce the heat loss sufficient insulation is provided from the bottom. So, because of that this U_b can be neglected compared to U_t. So, under the condition this original equations are reduces to S is equal to this expression and than h_r would be something like this and then finally, this last expression.

Now, when we talk about the energy balance in the fluid, then this will simplify something like this, then if we use the equation 7 again to calculate T_{bm}, so, our expression will be something like this and so, this T_{bm} is equation 9. So, this if we use this T_{bm} and use the equation 6, then T_{pm}

will be something like this. So, where h is the effective heat transfer coefficient between the absorber plate and air which is given by something like this.

So, this effective heat transfer coefficient is a function of heat transfer coefficient between applied to the fluid then radiative part and then bottom left to the fluid and then this expression, then we can introduce these he in equation 10 and we can have this expression.

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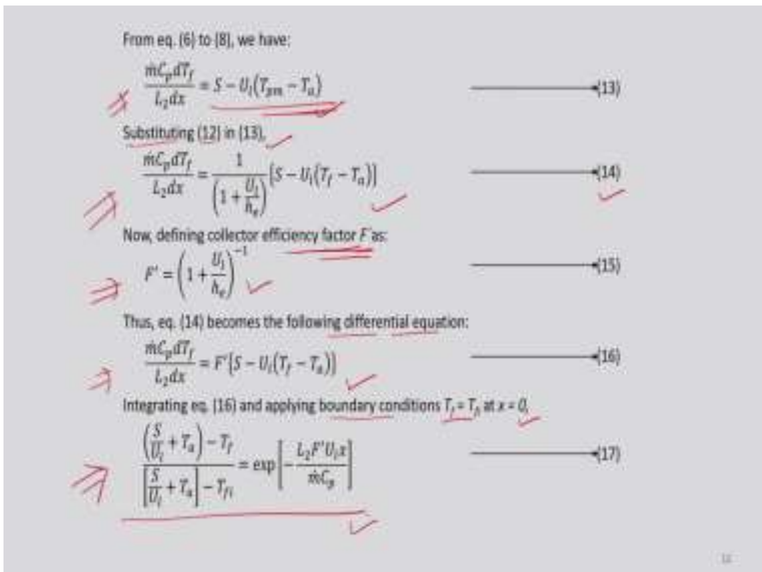

So, we will have $\frac{\dot{m}C_p\Delta T}{L_2 dx}$ is something like this, this is an energy equation for the fluid or energy balance in the fluid and then this substituting 12 in 13 what we have got in the equation 12 then we can simplify this equation and it will be something like this. Now, we can define this efficiency factor F this or collector efficiency factor F this which is nothing but this and this and equation 14 becomes the following differential equation.

So, we will get this kind of differential equation and this can be solved by applying the boundary conditions T_f is equal to T_{fi} at x is equal to 0. So, if we solve this then we will get an expression of something like this.

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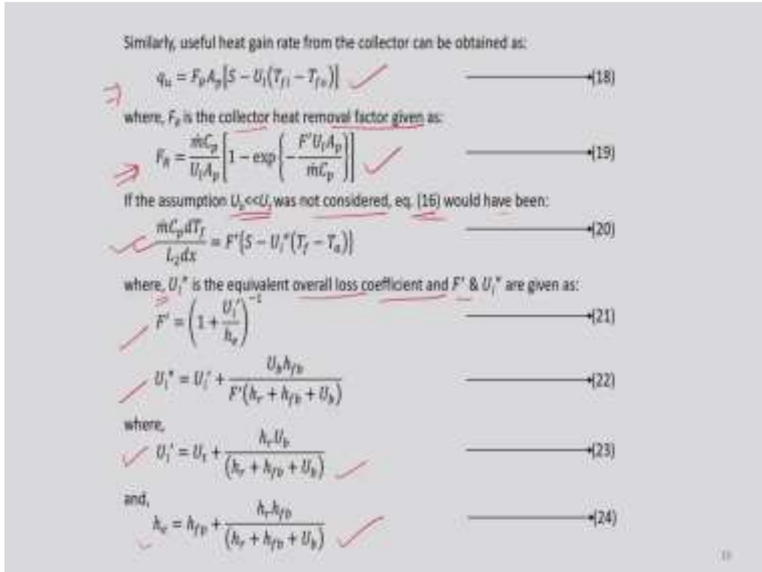

Now, similarly useful heat gain rate from collector can be calculated by using this expression where F_R is the collector heat removal factor. So, this expression is something like this which is similar to the liquid fluid plate collector what we have derived in the last class. So, if the assumption U_b is very, very less compared to U_t was not considered then equation 16 would have been something like this.

Where, U''_l is the equivalent overall loss coefficient and F' and U_l are given by this two equations and U'_l will be something like this and he will be something like this. So, we know now how to calculate F_R, how to calculate F', then we know how to calculate q_u or useful heat gain of a solar air heater.

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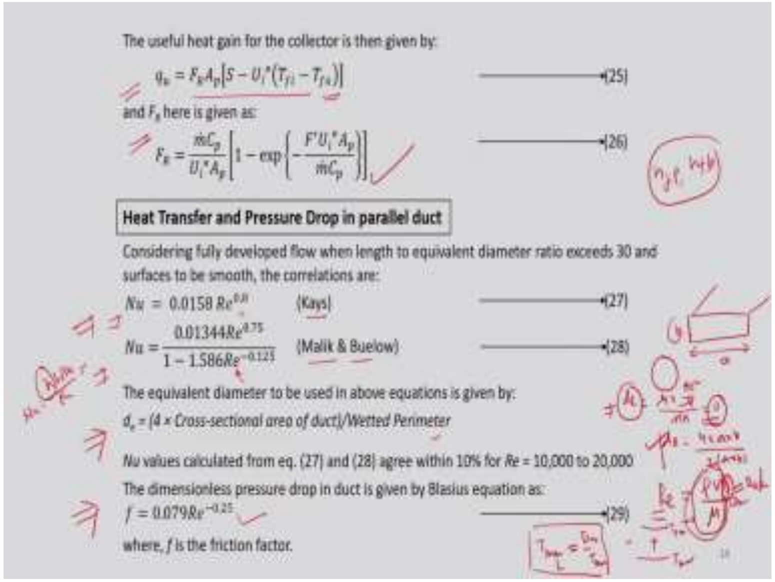

So, now this qu you can be related with T_{fi} and T_{fo}. So, this is Fr is something like this. So, as you understand in order to calculate those heat transfer coefficient like h_{fp} like h_{fb}, we need to rely on some kind of correlations. So, people have done extensive research and there are some well formulated correlations which can straight way can be used for calculation of this heat transfer coefficients.

Some of the most widely used correlations as far as this solar air heater is concerned, the correlations developed by Kays which is something like this and Malik and Buelow is something like this. And for these as you can see this Nusselt number is a function of Reynolds number in both cases. So, when we are interested to find out this Reynolds number we must know how to calculate the equivalent diameter.

So, this equivalent diameter is defined as 4× (cross sectional area of duct)/weighted perimeter. So, for example, if we consider a circular duct, so what will happen? So, what we will get d_e here? 4× (cross sectional area of duct) it is $\frac{\pi d^2}{4}$ and then we will have wetted parameter which is nothing but πd. So, these 4 goes cancel is finally d. So, for a circular pipe, so, this equivalent diameter will be the diameter of the pipe.

But in case of the section what we are considering now, this kind of section. So, if we know this b and then this is L, we must know this area, d will be 4× (cross sectional area of duct) is some maybe this was L_1 b into so, this is real on the length any anything we can consider. So, here maybe I can say a otherwise it will be confusing. So, $a \times b$ then we will have $2(a+b)$. So that way we can calculate the equivalent diameter and that diameter is required to calculate Reynolds number so, this is $\text{Re} = \frac{\rho v d}{\mu}$. So, this diameter is considered sometimes and this diameter is nothing but equivalent diameter now, so it will be d or L.

So, once you know this, then you can calculate Reynolds number by knowing these values at mean values of this plate. So, this T_{pm} and T_{bm} we need to take the mean of these two means T_{mean} is equal to (T_{pm}- T_{bm}) for any two parallel surfaces if we know that the temperature of these two surfaces then we can find out what is the T_{mean} at this T_{mean} you need to find out the property of the air. And diameter is known, then once you know this, then we can calculate what is the Reynolds number or Reynolds number.

And once you know, we can substitute there and we can calculate what will be the heat transfer coefficient because Nusselt number is known to us $Nu = \frac{hL}{K}$ or d equivalent by K. So, from that we can calculate what will be the heat transfer coefficient. Also, we need to calculate friction factor for this kind of arrangement because as you can understand here we need blower to blow air. So, if we have very rough surface over which air flows what will happen pressure drop will be there.

So, pressure drop is directly related to the amount of power consumption. So, for that we need to find out f friction factor then we need to find out pressure drop. So, this is very, very important because in solar air heater blower is one component which consumes huge amount of power. Just an example.

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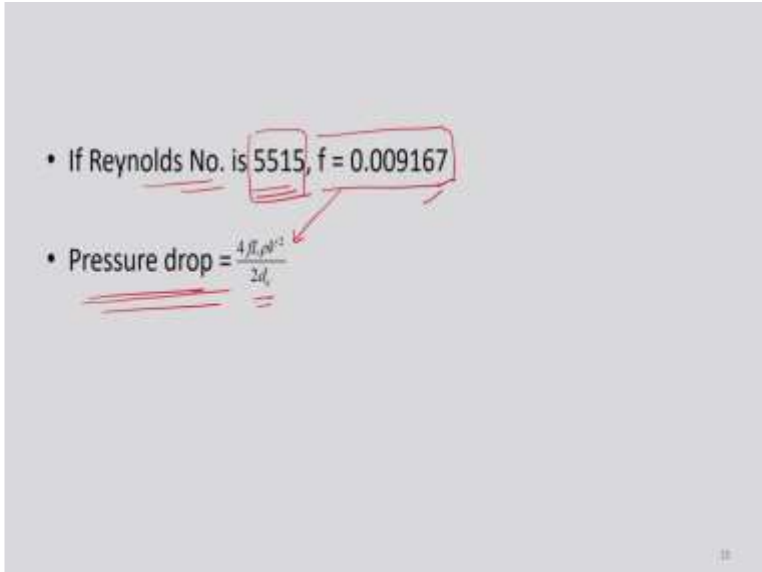

If we know a value of Reynold number for a flow then we can find out what will be the f. So, once we know this f, then we can substitute in this expression which gives pressure drop. So, this is nothing but $\frac{4fL\rho V^2}{2d_e}$. So, this pressure drop once you know then we can calculate the power requirement and all.

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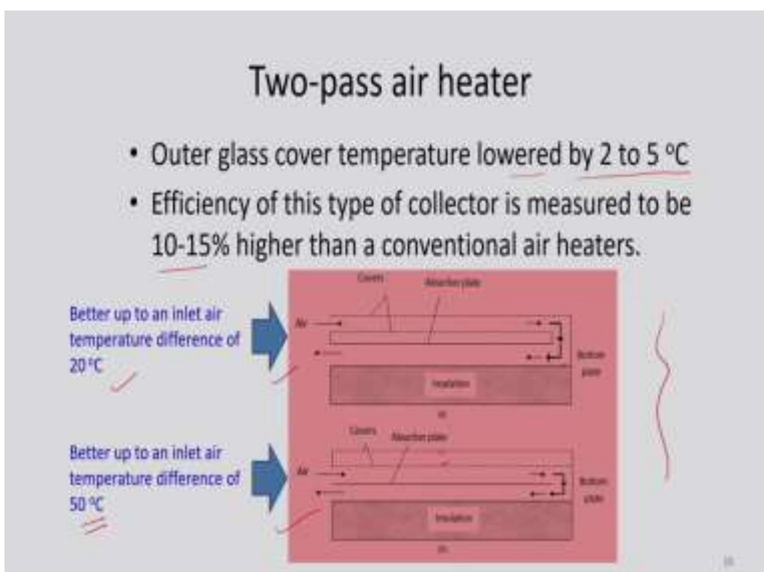

Now, let us discuss some of the experimental observations of different air heaters. So here, two air heaters are compared; in the first air heaters what happened air flows within the glass cover and then one more glass cover and under the beneath of this class cover one absorber plate is there and again air moves below the absorber plate as well. So, this is a bottom plate and the second configuration what happens these two are glass cover and air flows between glass cover and the absorber plate and an absorber plate to the bottom plate. So, it goes something like this, this is called two pass Air heaters.

So, in the first configuration this better heat up to an inlet air temperature difference of 20° has been observed, but in this case what happens better heat up or better upto an inlet air temperature differents of 50 degree C. So, as per the experimental observations, it is found that, this outer glass cover temperature lowered by 2 to 5 degree by using these configurations. And efficiency of this type of collector is measured to be about 10 to 15 % higher than a conventional air heaters. So, these are the developments.

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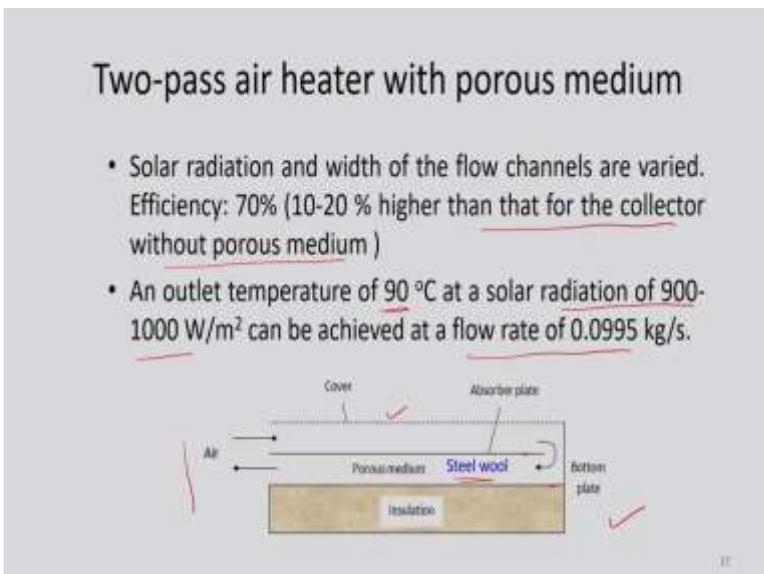

So, again here what happens porous medium is applied this porous medium is nothing but some kind of steel rules to increase the absorption of solar radiation so, that efficiency can be maximized. We have glass cover and then absorber plate and then we have bottom plate. So, this solar radiation and width of the flow channels are varied and efficiency was found to be 70 % which is 10 to 20 % higher than that of the collector without porous medium. So, in this kind of configuration, the outlet temperature of 90 degrees C at a solar radiation of 900 to 100 W/m^2 can be achieved at the flow rate of 0.0995 kg/s. So, this is one kind of experimental observations where porous medium is used to increase the efficiency of the collector.

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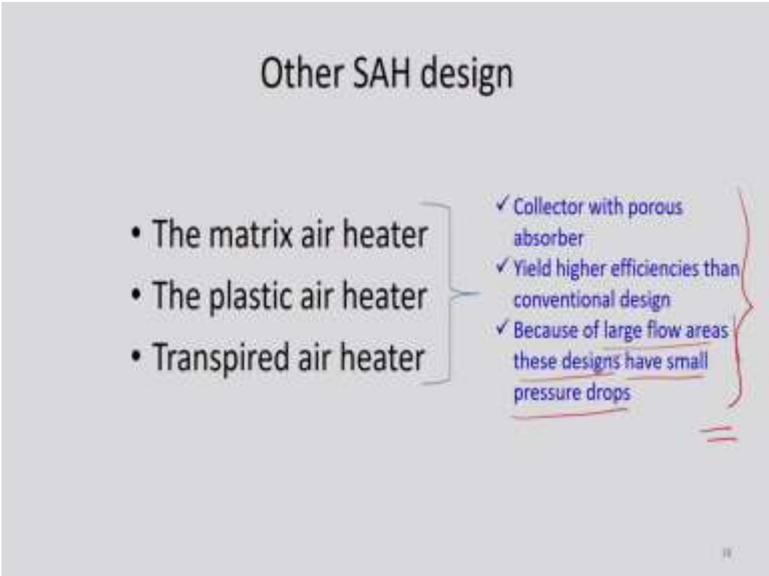

Now we will discuss some of the other solar air heater designs mostly Matrix air heater, the plastic Air heater and Transpired air heater. In all the 3 cases, collector with porous absorber plates are used and it yields higher efficiency than conventional design because of large flow areas these designs have small pressure drops. So, these are very, very important aspects of a solar air heater.

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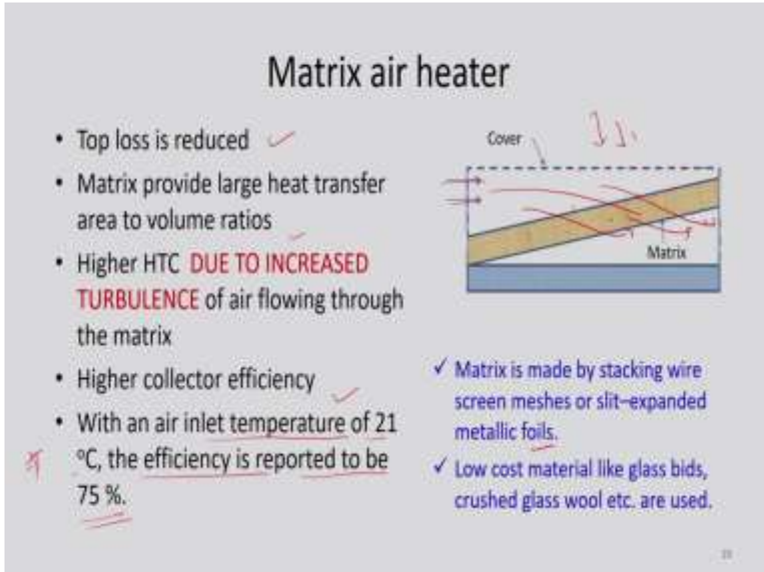

Now, let us discuss first about matrix air heater. So, as you can see its configuration is totally different than the conventional solar air heater. So, what you can see here it is a cover this is not a glass cover what is transparent the solar radiation is directly falls on these matrix absorber and air goes across these matrix. So, what is matrix here? This matrix is made by stacking wire screen meshes or slit-expanded metallic foils and normally very low cost material like glass bids, crushed glass wool, etc are used as matrix media in order to observe more solar radiations and here what happens when air moves, it gets more time to interact with the metals which is heated up by using this solar radiation.

So, in this kind configurations, it is found that top losses reduce significantly and matrix provide large heat transfer area to volume ratios and most importantly higher heat transfer coefficient due to increase turbulence of air following through the matrix, which is important, if you can increase the contact time and roughness, then of course, you can augment the heat transfer coefficient and of course, higher collection efficiency can be obtained by using this kind of configurations. So, as per their findings or researchers findings, with an air inlet temperature of 21 degrees C, the efficiency is reported to be about 75 % which is found to be quite good efficiency.

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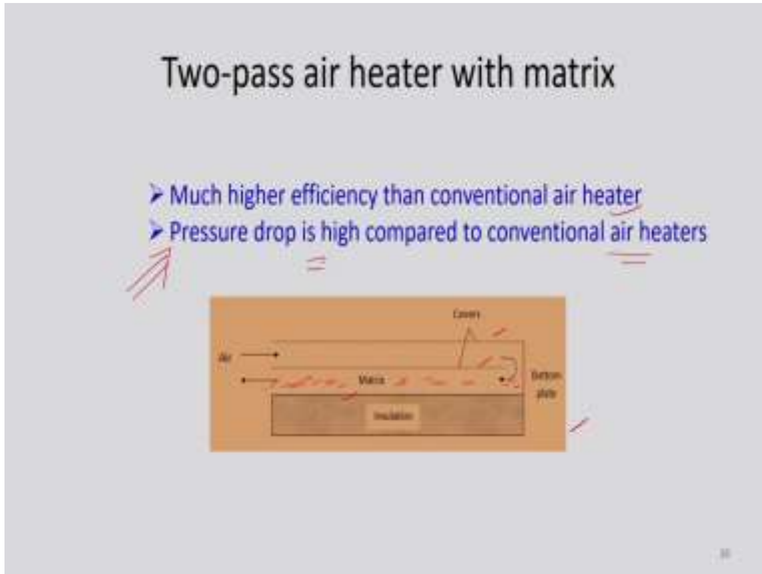

So, there are some cases where and this matrix can be used in two pass air heater. So, this is some kind of matrix in order to increase the outlet temperature of the heated air. So, this is glass cover, two glass covers and then we have matrix. So, much higher efficiency than conventional air heater can be obtained and pressure drop is high compared to conventional air heater. This is one of the disadvantages of this configuration. So, that has to be maintained properly and otherwise power consumption will be very, very high. So, pressure drop has to be maintained.

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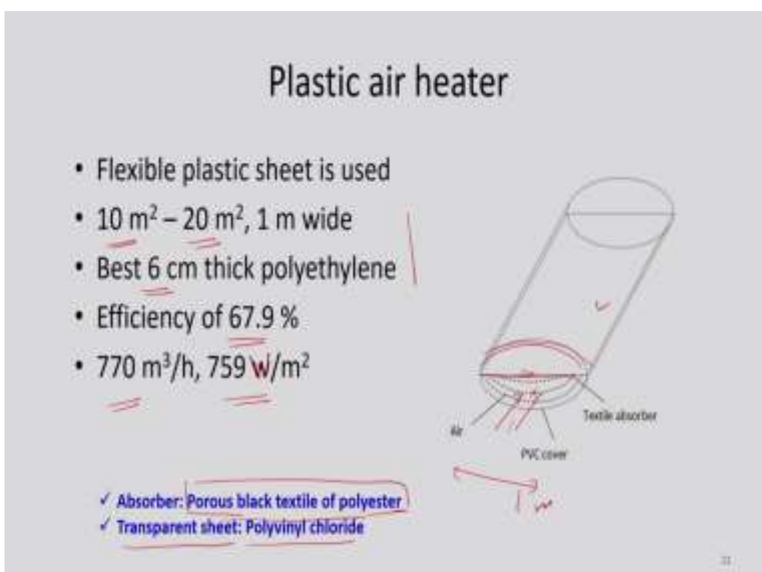

And there are certain air heaters called Plastic air heaters. So, in those kind of configurations, the absorber plate like porous black textile of polyester is used as absorber plate and for transparent sheet polyvinyl chloride is used. So, these are transparent sheets, solar radiations falls here and absorber is some kind of porous black textile of polyester, which is absorbed, it is a black surface, this is absorber plate and airflows here. So, this is an absorber this is a plastic cover.

But this is a highly transparent and airflows in between these. And it is a flexible plastic sheet, it is a very, very flexible and as per research findings its area varies from 10 meter square to 20 meter square and this wide is 1 meter, this is 1 meter and area is about maximum or about 20 meter square can be fabricated. And best thickness is found to be 6 centimeter. So, if we maintain 6 centimeter, then is the best efficiencies achieved and efficiency reported to be 67.9 % at a volume flow rate of 770 m^3/hr and then solar insolation of 759 W/m^2 capital.

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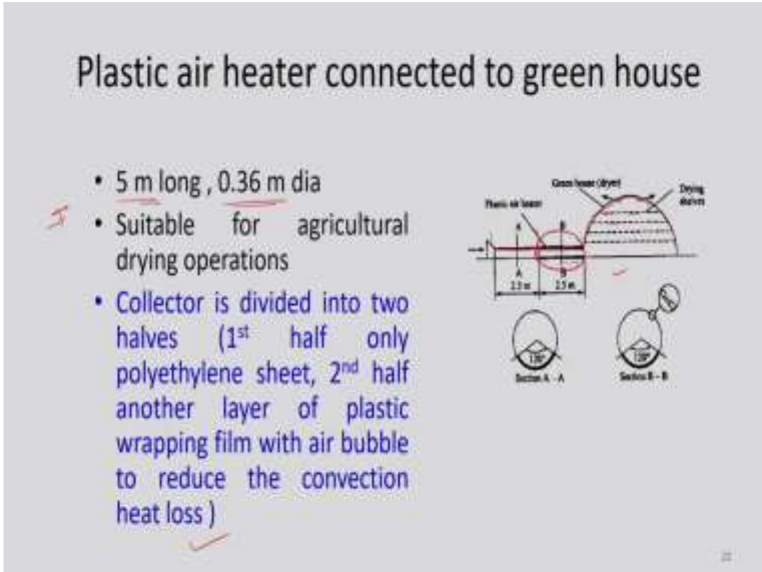

And one more plastic air heater which is used for a greenhouse has been shown here. So, here what happens there are two parts, this is one part this is the second part. In the first half or first part, only polyethylene sheets are used and the second part another layer of plastic wrapping film, with air bubbles to reduce the convective losses are done here. Then, this greenhouse dryer attached. So, there are different ways you can keep many agricultural products or other products for drying. And normally, its length is about 5 meter and diameter is about 0.365 meter. And of course, this is suitable for agricultural product drying.

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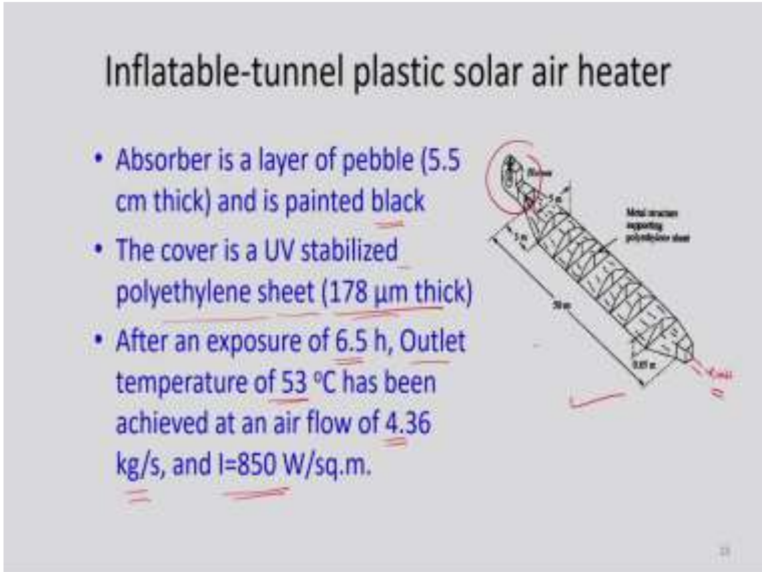

And one more solar air heater what you can see this is nothing but inflatable tunnel plastic solar heater. So, this is a blower, air is supplied from this blower and there are a number of trays where raw materials can be kept and drying can be done and this is the exit part. So, you can see length is about 50 meter people have made and this width is about 5 meter. So, this absorber is a layer of pebbles and is painted black.

So, pebbles are used and is black because of you know that has to store more thermal energy. The cover is a UV stabilized polyethylene sheets of thickness 178 micron the thickness of that sheet based on their observations they found that after an exposure of 6.5 hours outlet temperature was reported to be 53 degrees C at an airflow rate of 4.36 kg per second and insolation of 850 W/m^2.

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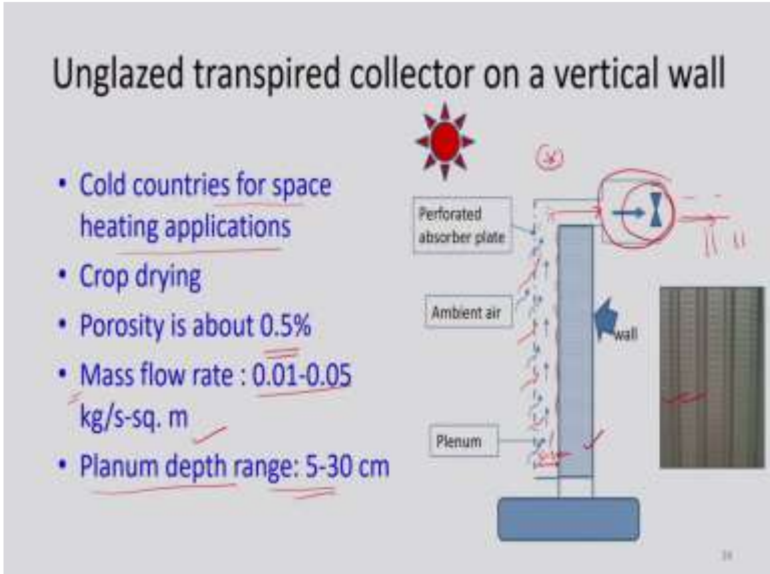

Now, let us discuss about unglazed transpired collector on a vertical wall. So, this is a vertical wall what you can see here and this is planum over which or say through which air flows and this is a perforated absorber plate. So, is ambient air will move in through this small perforations. So, one blower will be here it will suck and then air will flow and it will be distributed as per this kind of perforation devices or say ducting.

So, this kind of concepts normally applied in cold countries for space heating applications. Of course, this can be applied for crop drying and other agricultural product drying and this porosity of this absorber plate is about 0.5 % this is maintain in most of the cases. As per the investigation that mass flow rate varies from 0.01 to 0.05 kg per second per square meter and this planum rate ranges from 5 to 30 centimeters.

So, this is maybe 5 centimeters to 30 centimeter. So, this, this portion is known as planum this portion. So, this is the wall. So, air will move through this and it goes there in the header and then it will be distributed through ducts in order to maintain the room temperature.

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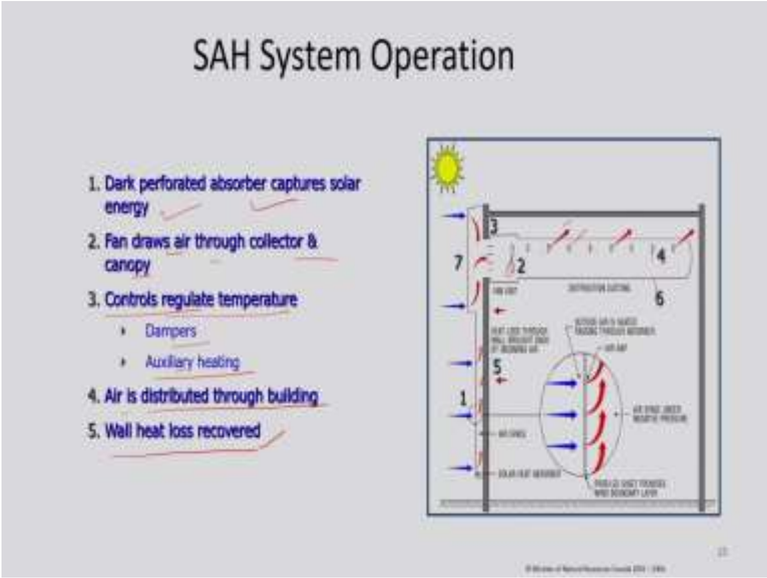

Now we can see how this ducting is done. So, once we have this then this blower will suck and then there are some holes or ducting a distribution ducting then so, this may be no this may be for one room this way for one room or maybe two holes are for one room. So, that way this can be arranged and room heating can be carried out. So, as we have said it is a dark perforated absorber captures solar energy and this fan draws air through collector.

And control regulate temperature dampers and auxiliary heating and air is distributed through buildings and wall heat loss recovered. So, normally what happens this wall heat recovery can be done by using this methodology.

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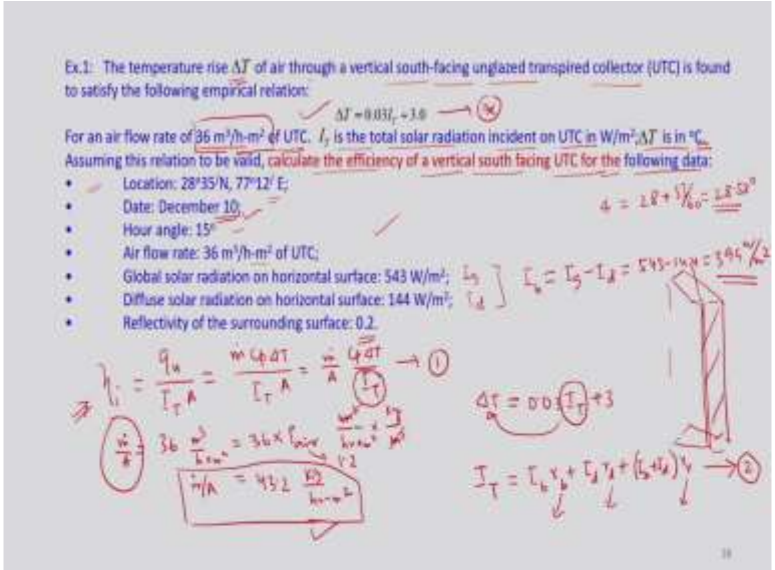

So, now, let us solve one problem related to this unglazed transpired collectors. So, the temperature rise ΔT of air through a vertical south facing unglazed transpired collector is found to satisfy the following empirical relation which is $\Delta T = 0.03I_T + 3.0$ For an airflow rate of 36 m^3/h-m^2 of UTC. This I_T is nothing but the total solar radiation incident on UTC and ΔT is in 0 C is in Celsius assuming this relation to be valid, calculate the efficiency of a vertical south facing UTC for the following data.

So, we need to find out the efficiency η_i, the location is given as 28 degree 35 minute north and 77 degree 12 minute East and date is December 10, hour angle is given as 15 then air flow rate in given, then global solar radiation Ig is given and diffused radiation is given us I_d. So, once we know these two, then we can calculate what is I_b. So, this I_b can be calculated by deducting I_d from I_g. So, it will be 543 minus 144. So, this will be 399 W/m^2 and reflectivity of the surface is given as 0.2. So, so we know what is instantaneous efficiency.

So, this can be calculated by using $\eta_i = \dfrac{q_u}{I_T A}$ this area is that area. So, this is so, this area this wall area we need to find out. So, this is the so this wall area. So, we also know what is q_u, is nothing but mC_p or $\dot{m}$ we can write is $\dfrac{\Delta T}{I_T A}$. So, normally in case of conventional collectors we place A_P or A_C but here what happens this side, this wall this wall area we need to consider this wall area, this wall you need to calculate.

So, this is given $\frac{\dot{m}}{A}$ is given $\frac{\dot{m}}{A}$ is given here is 36, then we have $\frac{C_p \Delta T}{I_T}$ this may be equation 1 and also we can simplify this m dot A. So, this is 36 $m^3/h\text{-}m^2$ so, it will be 36 multiplied by density of air. So, it will be ($m^3/h\text{-}m^2 \times kg/m^3$). So, this will go off and then finally what we will have? So, what is the density of air is 1.2 1.2 kg/m^3. So, once we multiply these 36×1.2 it will be 43.2 $kg/h\text{-}m^2$. So, this $\frac{\dot{m}}{A}$ is in Kg.

Normally, this is volume flow so, we can write volume flow also but we can convert it to mass flow rate per area. So, this part is known to us now. So, what we need is I_T and this $\Delta T = 0.03 I_T + 3.0$. So, if we know this I_T then straight way we can calculate what is ΔT? So, if we know ΔT then we can calculate what is η_i. So, now, our next step is to calculate I_T. So, how to calculate I_T now. So already we know the expression for I_T, $I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$ we have to calculate what is r_b, what is r_d and what is r_r? Let me give a name of this equation maybe 2. Let us calculate what is r_b, r_d and r_r,

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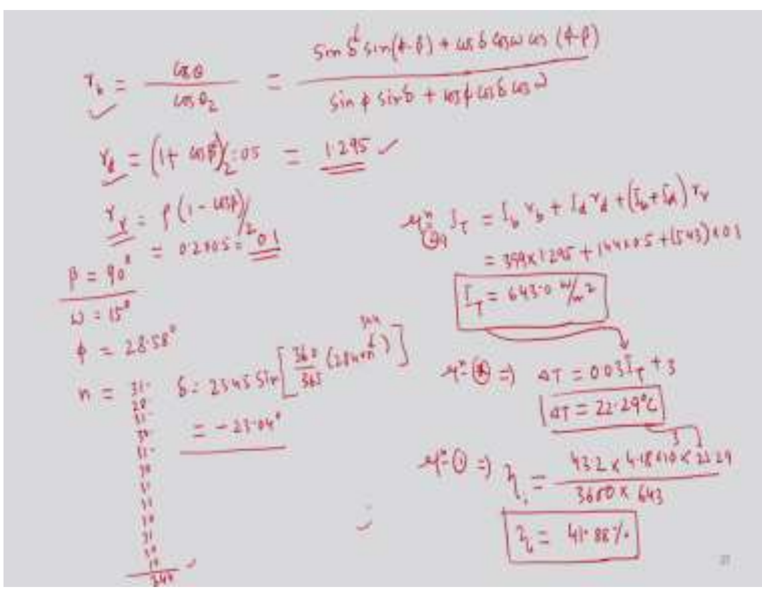

So, this r_b if we substitute those values $r_b = \frac{\cos\theta}{\cos\theta_z}$ already we have done many exercise. So, before we start, we need to maybe I can write this other expression as well. So, this $r_d = \frac{(1+\cos\beta)}{2}$, then we will have $r_r = \frac{\rho(1-\cos\beta)}{2}$. So, before we start let us know the values. So, β will be here 90° because it is a vertical surface. And what will be the ϕ so, ω is given as 15° and ϕ will be we have in the problem ϕ is so, you can write here itself $\phi = \frac{28+35}{60}$. So, which will be 28.58° and December 10 is the date.

So, we need to know what is n and so, n value we need to calculate ϕ is known what is the value of ϕ 28.58, 28.58° and n will be so, we can start from January this 31 then we have 28 then we have 31, then we have 30, 31 January, February, March, April May, June, July, August September, then we have October, November, then 10 okay so, then this will be calculated to be 344. So, n is known, so, if we know n then we can calculate what is δ what is $\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right]$. So, this n is nothing but what 344. So, if we substitute then what we will get δ is equal to -23.04 °.

So, we know all those values now, so, we can calculate r_b value now. So, this rb $r_b = \frac{\cos\theta}{\cos\theta_z} = \frac{\sin\delta\sin(\phi-\beta)+\cos\delta\cos\omega\cos(\phi-\beta)}{\sin\phi\sin\delta+\cos\phi\cos\delta\cos\omega}$. So, if we substitute those values here, then what we will get so, this r_b value will be 1.295 those all values are known to us δ is known minus 22.4, then ϕ is known ϕ is 28.58, β is 90. So, that way we can substitute here and we can do the calculation and this r_b is found to be 1.295.

And r_d just to substitute the value of β here β is 90 cos 90 is 0, so 1 by it will be 0.5. So, it will be 0.5 so, here it will be 0.5×0.2 so, this will be $\rho = 0.2\times0.5$ it will be 0.1. So, now, we know r_d value, r_r value then r_b value so, what we can use, we can calculate I_T, this equation 2 what we have given the name. So, this equation 1 in equation, equation 2 implies $I_T = I_b r_b + I_d r_d + (I_b + I_d) r_r$. So, Ib value we already know what is the value of I_b

calculated which is $I_T = 399 \times 1.295 + 144 \times 0.5 + (543)0.1$. So, if we do the calculation this I_T is found to be 643.0 W/m^2 this I_T is known.

So, once we know I_T then we can calculate what is ΔT by using the equation 1, equation was not given. So, this equation may be star I can write this is star. So, equation star $\Delta T = 0.03 I_T + 3.0$. So, if we substitute this value here then ΔT will be 22.29 °C . So, ΔT is 22.29 °C. So, once we know this ΔT, then we can go back to the equation 1, equation 1 implies we will have η_i is equal to mass flow rate $mC_p dT$. So, m what we have calculated here is 43.2. So, this is 43.2. So, we need to convert to second. So, it will be 3600. So, it will become kg/m-s^2.

So, this $\frac{\dot{m}}{A}$ is know now, then I_T what we have calculated is 643 and we will have Cp is 4.18×10^3 and then we will have ΔT so, this ΔT is here 22.29. So, now, if we do the calculation, so this eta is found to be 41.88%. So, this efficiency is found to be 41.88%. So, what we have shown here, so, in case of transpired unglazed collector or say unglazed transpired collector, if this radiation parameters are given then we can calculate what will be the efficiency of the collector.

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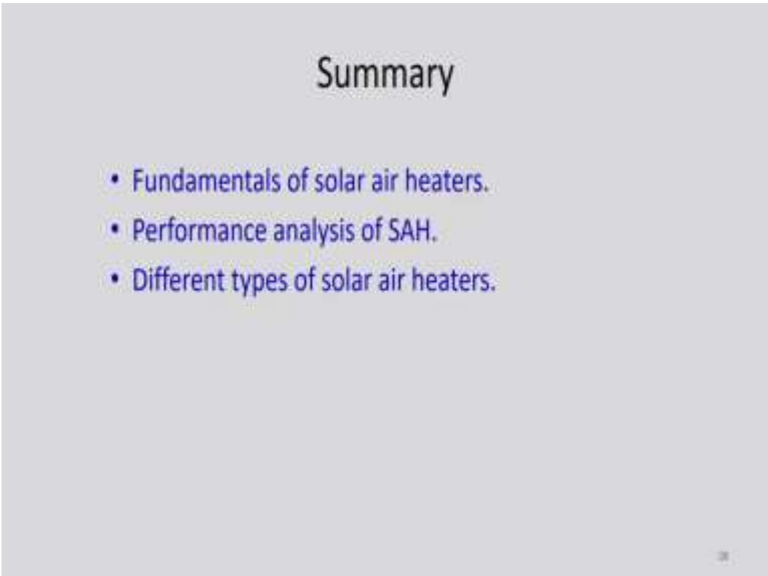

So, what we have learned in this presentation. So, we have basically learnt about the fundamentals of solar air heaters. What are the advantages of using the Solar Air Heaters and what are the disadvantages of using this solar air heaters and also we have analyzed performance systematically and also we have seen the functioning of different solar air heaters and the research trends. And finally, we have solved one numerical exercise to strengthen the understanding how to calculate efficiency of a collector. So, thank you very much for watching this video. Thank you.