Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture -07
Non-concentrating solar collectors – Part III

Hi everyone, today in renewable energy engineering solar wind and biomass energy system we are going to continue his studies lecture on non-concentrating collectors.

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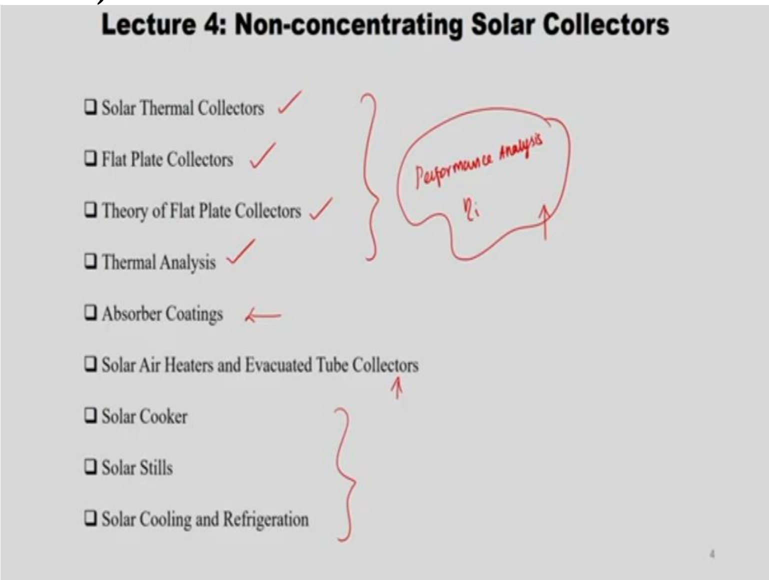

Yesterday we had seen about solar thermal collectors, Flat plate collectors, Theory on flat plate collectors, Thermal analysis and also we had done performance analysis to calculate the instantaneous efficiency of the Flat plate collector. And then we summarized what are all the advantages and disadvantages of Flat plate collectors. So, among that one special case of absorber coatings, we are going to see today and solar collectors and evacuated tube collectors on the application side, we are going to see solar cooker, solar stills, solar cooling and refrigeration.

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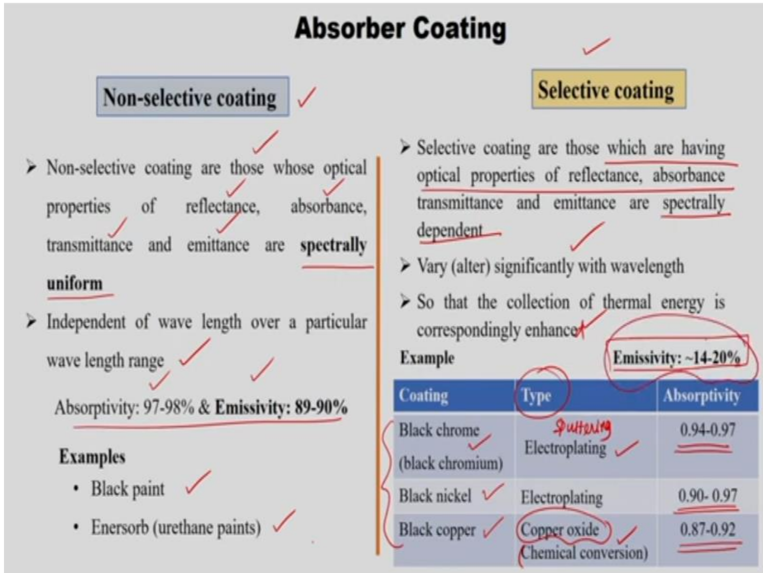

The first one absorber coating, we are going to see the 2 main categories are non-selective coating and selective coating, the difference between these 2 is in non-selective coating, so, we do not differentiate the properties of reflectance, absorbance, transmittance and emittance based on any spectral variation. So that means, the properties of reflectance absorbance, transmittance emittance are spectrally uniform.

So, we take absorptivity and emissivity almost in the same range. So, they are independent of wavelength over a particular wavelength range, the examples are normal black paint and Enersob. So, this is nothing but urethane paint. So, here we are not taking any special effort to select the selectivity of the absorber surface. On the other hand in selective coating, so, these coatings, the properties of reflectance, absorbance, transmittance and emittance are spectrally dependent.

So that means, based on the wavelength, we have the flexibility to select what should be the absorptivity and what should be the emissivity or based on emissivity and absorptivity values for the particular collector we can choose the surface as a selective coating. So, it varies significantly with wavelength, so that the collection of thermal energy is correspondingly enhanced. So, the emissivity here if you see absorptivity and emissivity both are almost the same.

But here in the case emissivity is decreased with around 14 to 20% the emissivity is taken around 14 to 20%. The type of coating or type of selection what we do the method with which how do we apply this selective coating technique. So that may be of electroplating and sometimes sputtering as well and chemical conversion method. So, example is copper oxide is selectively coated on the absorber plate. So, the method used is chemical conversion.

So, otherwise electroplating and sputtering also we use, the black chrome, black nickel, black copper everything comes under the category of selective coating. So, if we use blank chrome the absorptivity is 0.94 to 0.97. The black nickel will have the variation of 0.9 to 0.97. Black copper will have the variation of 0.87 to 0.92 all of them the emissivity comes out 14 to 20%.

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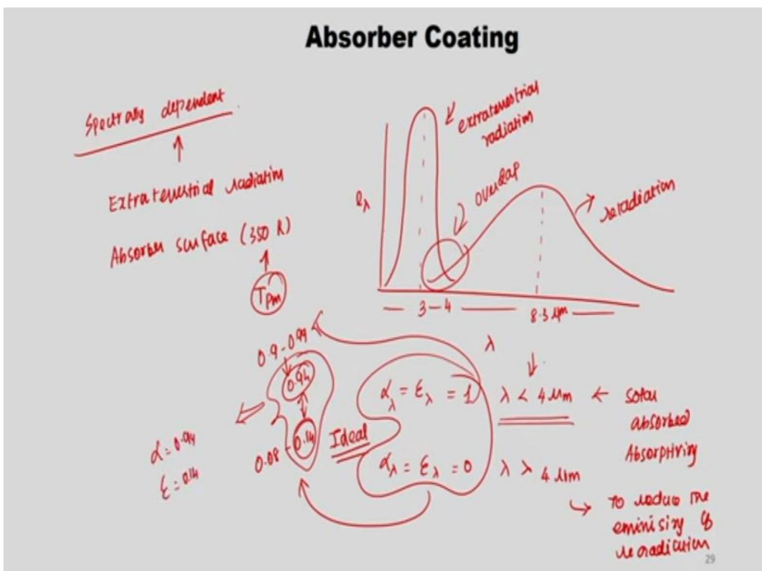

So, this variation of selective coating so, we said that they are spectrally dependent. So, the research says that how do we first select that spectrally dependent variation. So, there are 2 things to be considered one is normal extra-terrestrial radiation; the second one is the absorber surface. So which is about 350 Kelvin plate temperature, this is the normal plate temperature we would get in the absorber plate.

So, by comparing these 2 the study says that, if we plot lambda which is nothing but wavelength versus e-lambda. So, this is something for extra-terrestrial radiation which is to be absorbed and there is radiation which is reradiated from the absorber surface. So that is coming around the wavelength of 8.3 micrometer. So, this maximum lies around 3 to 4. So, this is lambda. So, there is absolutely not much of overlap.

So, based on this it is decided that when we choose alpha and epsilon which is nothing but absorptivity and emissivity. So that should be unity when wavelength less than 4 micrometer. So that is where your solar radiation is absorbed. So, we have taken care of absorptivity at the same time this is the re-radiation of long wavelength. So, in such case alpha at lambda and epsilon at lambda should be 0 at lambda greater than 4 micrometer.

So, this is to reduce the re-radiation losses, to reduce the emissivity of re-radiation. So, whether that is possible to get alpha epsilon around 1 at the wavelength of lambda less than 4 micrometer and alpha epsilon equal to 0 at the wavelength of greater than 4 micrometer, whether it is possible it is ideally only possible in practical case, so, this should be nearer to 1, so, around 0.9 to 0.99. So, this cannot be 0.

So, the maximum what we could get till now was 0.08 to 0.14. So, this is where we take nominally, so, 0.94 and 0.14. So, based on this spectral analysis, so, this value is chosen. So, from this we need me supposed to design a material which would give alpha around 0.94 and epsilon 0.14. So that is the way so, this particular type of coating material has been selected using electroplating sputtering and chemical conversion etcetera techniques.

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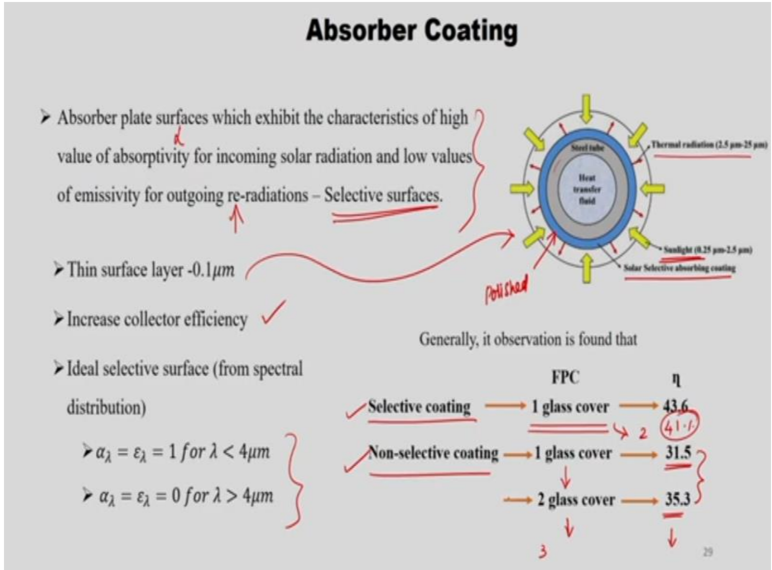

The next we are going to see the definition of selective surfaces. So, absorber plate surfaces s which exhibits the characteristics of high value of absorptivity for incoming solar radiation and low values of emissivity for outgoing re-radiation. So, those were called selective surfaces. So, if you see here, so, this is the steel tube, this is inner wall, outer wall. So, outer wall of the steel tube is given with the solar selective absorbing coating.

So, the radiation of sunlight will come around 0.25 micrometers to 2.5 micrometer. So that will be absorbed by this selective surface coating and when thermal re-radiation happens between 2.5 micrometer to 25 micrometer, the emissivity part of the selective coating can take care of that. So, normally the tube surface is polished and cleaned and then this thin layer of around 0.1 micrometer thin layer is kept on the outer side of the tube to enhance the absorptivity.

So, this obviously increased the collector efficiency because we were emissivity values decreasing and absorptivity values increasing. So, obviously, it increases the collector efficiency. So, this we have discussed why it is 4 micrometer, spectral distribution in the spectral distribution, why we have selected these 2 ranges and this we have already seen selective and non-selective coating.

What is the difference, but here one thing to be observed us when selective quoting is done, so, we need not go for more number of glass covers, more number of glass covers if you go to reduce the convection losses, but it also contributes the transmission of solar energy into the absorber plate. So, while selective coating is being applied, if you go for more and more number of glass covers, the efficiency would obviously decrease.

For example, if you increase the glass cover from 1 to 2, the efficiency would be decreasing around 2 percentage this comes around 41 percentage in the same time, if you are using non selective coating then it is advisable to go for one more glass cover, 1 glass cover to 2 glass cover in that way the efficiency increases from 31.5 to 35.3. But, if you increase more number of glass cover again more than 2 then there may be a reduction in efficiency as well.

Because this number of glass covers should be chosen the tradeoff between how much solar radiation it transmits to the absorber plate and how much convection losses it contributes. So, based on these 2 parameters, the number of glass covers can be chosen for non-selective coating, but selective coating 1 glass cover is enough for all 3 applications whatever we have been discussing in past 2 lectures.

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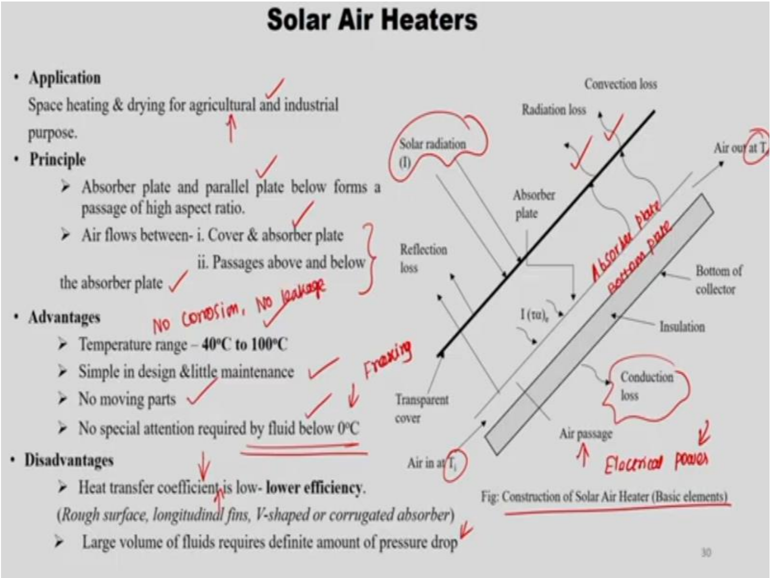

The next one is solar air heaters, the application wise solar air heaters are being applied in space heating, drying for agriculture and industrial purpose. So, mostly the agricultural products are being dried by using solar air heaters the principle is absorber plate and parallel plate below forms the passage of high aspect ratio. The absorber plate this one for example and this figure so, this is bottom plate. So, where your bottom installation starts.

So, this passage is nothing but your passage. So, absorber plate and the parallel plate below forms a passage of high aspect ratio for the fluid to flow. The air flows between cover and absorber plate and passages above and below the absorber plate. So, these are flow off air based on that there are many varieties, but here in this particular figure, we will discuss about only this passage and in successive slides we will see what are all the other categories of flow passages are available in the solar air heater.

So, here if you see, so, this is the bottom of the collector where insulation is kept. So, through which there may be a conduction losses, the air passages between absorber plate and the bottom plate. So, this is T i initial inlet temperature and T naught at outlet temperature. So, there are 3 kinds of losses happens one is radiation losses from the absorber plate and convection losses and from the cover you may get deflection losses as well.

So, this is the solar radiation incident on the glass cover and transmitted to absorber plate. So that is all this is a basic construction of solar air heater. Advantages side that temperature ranges around again 40 degree to 100 degree same as that of a liquid flat plate collector. They are simple in design and little maintenance is required. Relatively same with the liquid flat plate collector and no moving parts there also we are same in the page of liquid flat plate collector.

No special attention required by fluid below 0 degree. So, this cannot be achieved in liquid fluid flat plate collector, why it is? Because the freezing happens if we use the water. So, there we supposed to use anti freezing material or if you are using such anti freezing mixtures then you need to frequently change the fluid. So, here that is not required, advantages side this one and disadvantages side we have the heat transfer coefficient to worry about.

So, this is low which leads to lower efficiency to enhance this heat transfer coefficient. So, we use normally rough surfaces, longitudinal fins, v-shaped or corrugated absorber plates and another disadvantage side is the large volume of fluids to be handled. So which requests particular amount of pressure drop because, when you are blowing the air in between the absorber plate and bottom plate, so, you are obviously using electrical power.

So, more and more pressure drop happens inside, you drop more electrical power to flow the air between the absorber plate and bottom plate. So that basically when you are passing the air you require more power if you are not maintaining your pressure drop at a particular level. So, in that way it is a taking much of electrical input and another advantages wise if you see the corrosion properties also advantages here, so, no corrosion and no leakage problem as well. So, only thing we need to worry about us the pressure drop and then the low heat transfer coefficient.

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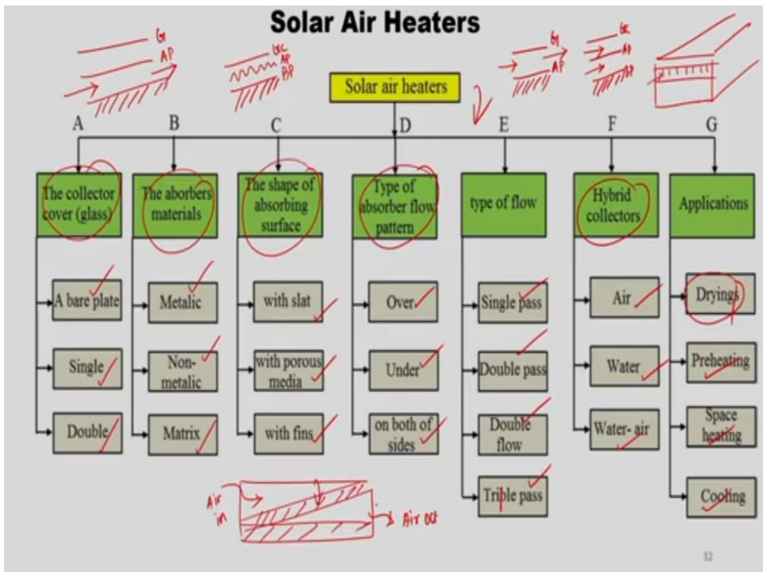

So, if you see here the solar air collectors various kinds are there, we are not going to discuss in detail, but we will see the based on the glass collector cover bare plate can be there and single and double glass cover, based on the absorber material metallic, nonmetallic and matrix type. So, this I have already told so, matrix type what do you have is instead of absorber plate? So, you have an insulation here. So, you have porous matrix. So, this is your air in, this is air out.

So, since it is passing through the porous matrix, so, the turbulence increases in that way heat transfer increases and that way efficiency. The shape of absorbing surface with slat, porous media, with fins etcetera. Based on a type of absorber flow pattern it may go above, under or both sides. So, just we have seen us here the air flows below the absorber plate. Based on type of flow single pass, double pass, double flow and triple pass.

So, there are varieties and based on the hybrid collectors air can be allowed, water can be allowed and, the air-water also can be allowed. And application side mostly for drying and preheating space heating and cooling applications. So, before moving on to ETC we will also see certain basic configurations. So, what we have seen us the glass cover the absorber plate APS absorber plate and then this is the bottom plate?

So, here air passage happens. So, another way maybe this is the glass cover, this is absorber plate AP. So, through which the flow happens. So, below absorber plate you will have insulation. So, other than that, so, you have glass cover, you have absorber plate and then you have a bottom plate where insulation starts. So, your air can flow both above and below the absorber plate. If you see the normal collector, so, this is the glass cover, this is absorber plate and this is kind of 3d.

So, here you can have for example, here we have seen where is that fin material, fin tube. Here the shape of absorbing surface. So, you can have fins over here in the absorber plate, so that you are heat transfer is enhanced or instead of this this type of absorber plate, you have a glass cover and you have a bottom plate where your installation starts. So, instead of flat absorber plate, you can have this corrugated type of absorber plate as well.

So, there are different designs there are various designs, various shapes. So, you are requested to follow Sukhatme and Nayak solar energy engineering book, for further details on solar air heaters. Already we have spent much time on liquid flat plate collector. So, if you go in detail then it may extend to next lecture as well.

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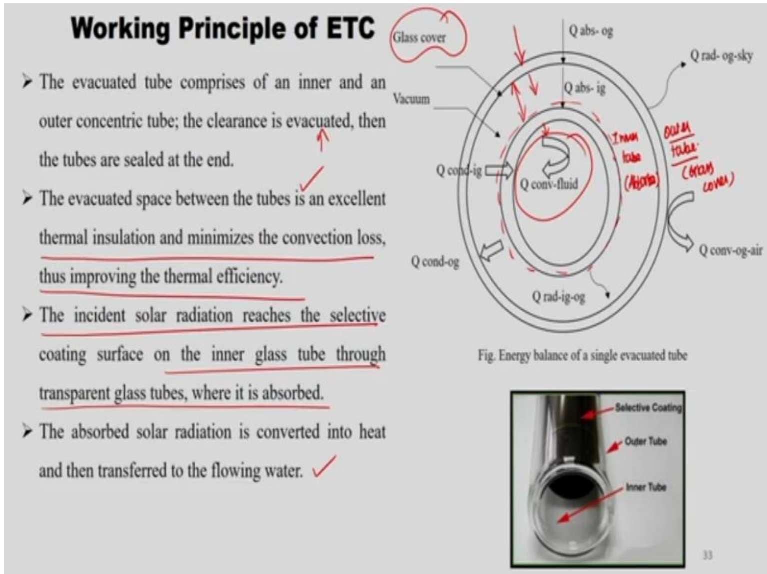

So, next what we are going to see is evacuated tube collector? The evacuated tube comprises of an inner and an outer concentric tube: the clearances evacuated, so then the tubes are sealed at the end. So, this is the arrangement where you where fluid is flowing inside the inner tube. So, this is inner tube, so, this is outer tube. So, in between there is a vacuum the air gap in between the inner tube and outer tube is totally evacuated.

So, in that way, so that outer tube this is considered as a glass cover. So, the inner tube is nothing but an absorber. So, this is glass cover, the fluid flows inside the absorber tube. So, the evacuated space between the tubes is an excellent thermal insulation which minimizes the convection losses, those improve the thermal efficiency this we are well known by now, if you reduce the conduction losses obviously, thermal efficiency increases.

The incident solar radiation reaches this selective coating surface on the inner glass tube. So, the selective coating happens to be here the outer surface of the inner glass tube which is nothing better absorber through the selective surface on the inner glass tube through transparent glass tubes where it is absorbed. So, the solar radiation incident on the glass cover then it is transmitted to the inner tube which is coated with the selective coating material then from there the fluid takes solar energy.

The absorbed solar radiation is converted into heat and then transferred to the flowing water. So, if you see here this is the exact evacuated tube. So, this is inner tube and that surface your selective coating is then outer tube is nothing but a glass cover.

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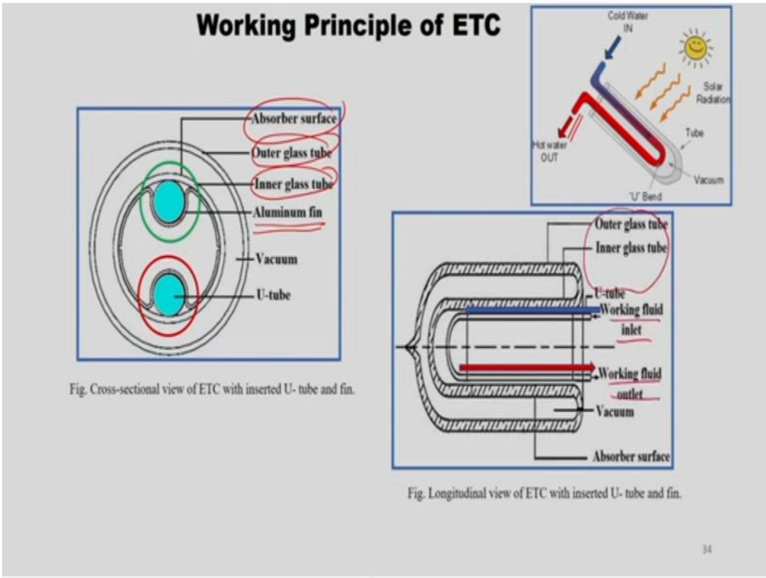

Working principle of ETC is same. So, here you have a glass cover you have an absorber tube. Absorber tubes coated with the selective coating material and to remove this air in between these 2 tubes, the 2 ends are closed and vacuum is maintained between the 2 tubes. So, here if you see this is the absorber surface that is outer surface of the inner glass tube, this is outer glass tube which is nothing but a glass cover inner glass tube which is nothing better absorber.

If you want to enhance the heat transfer coefficient further you can add aluminum fin in outside the tubes so that is where aluminum fin is given and the space between them is vacuum and this is U-tube because the ends are connected. So, here if you see this is what exactly happens. So, this is vacuum this is U-bend of the tube. So, the cold water comes in and it gets heated by the absorbed solar radiation and due to thermal syphon flow the hot water is out the side.

This is the cross sectional view, the longitudinal view of ETC inserted you tube and fin. The same story here but this is the working fluid inlet and this is working fluid outlet. This longitudinal view, this is cross sectional view, this is longitudinal view.

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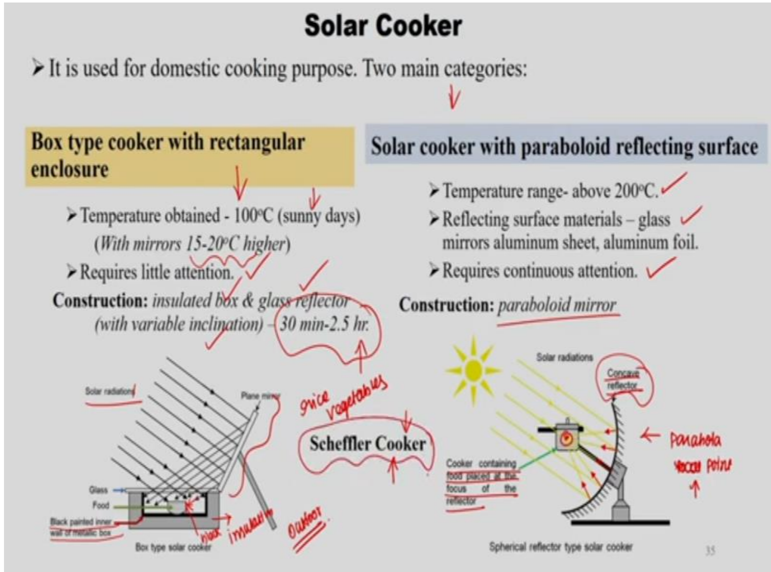

So then we are into applications which; is the first one what we are going to see is solar cooker. It is used to for domestic cooking purpose, there are 2 main categories we have discussed in short in our first lecture itself, but here we are going to see a little bit detail. The box type solar cooker with rectangular enclosure that is first category, second category is solar cooker with parabolic light reflecting surface.

In box type solar cooker the temperature of tenders around 100 degrees centigrade during most sunny days. But, here if you see this is the plain mirror if you enhance the incident radiation the temperature also increases a bit higher. So, around 15 to 20 degrees in that way if you use such kind of plain mirrors then you would be getting 100 to 120 degrees centigrade. The construction wise if you see this is the black painted inner wall of the metallic box. So, this is metallic box insulated this is insulation.

So, inside this box there is a black painted inner wall of metallic box and the food is kept in the container. So, if this container is also of black then that that would be good for absorptivity and above one is glass cover. So, if you see this plane mirror, the solar radiation hits on the plane mirror and that way it is reflected inside the box type solar cooker, in a way it can directly reflected to the food container as well or it can reflected inside the black painted metallic box.

So, in that way the enclosure gets heated in further food material kept in the container. The container gets heated on foot material kept in the container gets heated. The construction wise it needs 1 insulated box and glass reflector with variable inclination angle, normally it takes 30 minutes to 2.5 hour and also it is kept in outdoor. But if you are ready to spend this many of hours, obviously rice vegetables can be cooked with these kind of box type solar cooker.

And the second one is solar cooker with paraboloid reflecting surfaces. So, this is the construction. So you have a concave reflector. So based on this focal point, so that particular point you keep your cooking material cooker containing food placed at the focus of the reflector, this is the paraboloid and based on the parabola, focal point there is a calculation. So based on that calculation the focal point is decided were your cooker is kept.

So temperature range achieved is 200 degrees centigrade and reflecting Surface Materials are glass mirrors, aluminum sheet and aluminum foil and it requires continuous attention because here it requires little attention why it is so, because you need not change plain mirror frequently, but here the due to this focal point problem. So, you are supposed to change this concave reflector based on the solar radiation. So that adjustment needs a continuous attention.

The construction is paraboloid mirror is required so, here you would require the glass reflector that is plain mirror. There is this called Scheffler cooker so, in this you need not to t keep your tracking system and as well as the cooker material in the outdoor. The tracking system can be kept outside and the cooker can be kept inside the kitchen. So this is the recent design proposed by Scheffler, so it is called Scheffler cooker.

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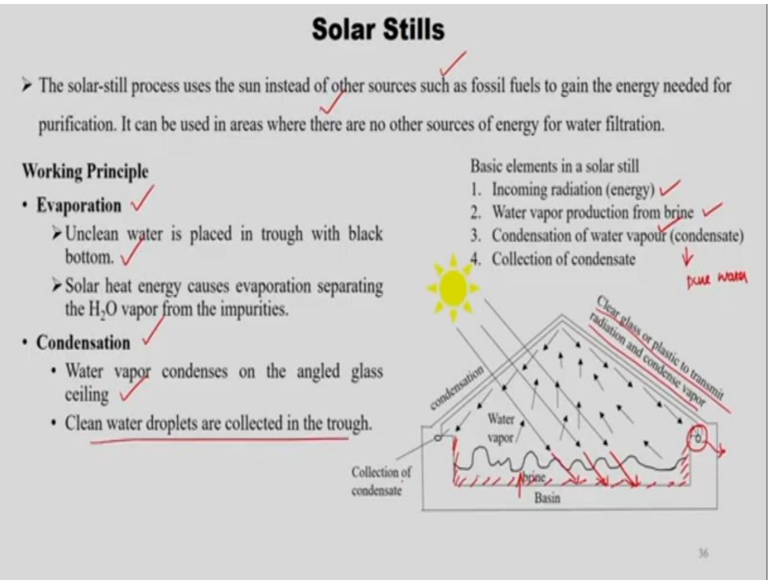

The second major application is solar stills. So it is being used for water purification. The solar still process uses the sun instead of other sources such as fossil fuels to gain the energy needed for purification, it can be used in areas where there are no sources of energy for water filtration and the basic elements are incoming solar radiation and water vapor production from brine and condensation of water vapor. So, this is a pure water and collection of condensate.

Working principle wise it uses 2 basic principles of evaporation and condensation. Unclean water is placed in the trough with black bottom. So, this is black bottom. So that the incident solar radiation gets absorbed, inside the basin and solar heat energy causes the evaporation of separating the water vapor from the impurities. So, here basically what we have is water with impurities kind of brine solution you have water plus salts.

Once the once it absorbs the solar radiation the water starts evaporating and it hits the glass dome, the clear glass or plastic to transmit radiation and condensate the vapor. So, when it hits the glass cover it gets condensed due to the outside environment and the condensate is collected here. Water vapor condenses on the angled glass ceiling the clean water droplets are collected in the collected collection trough.

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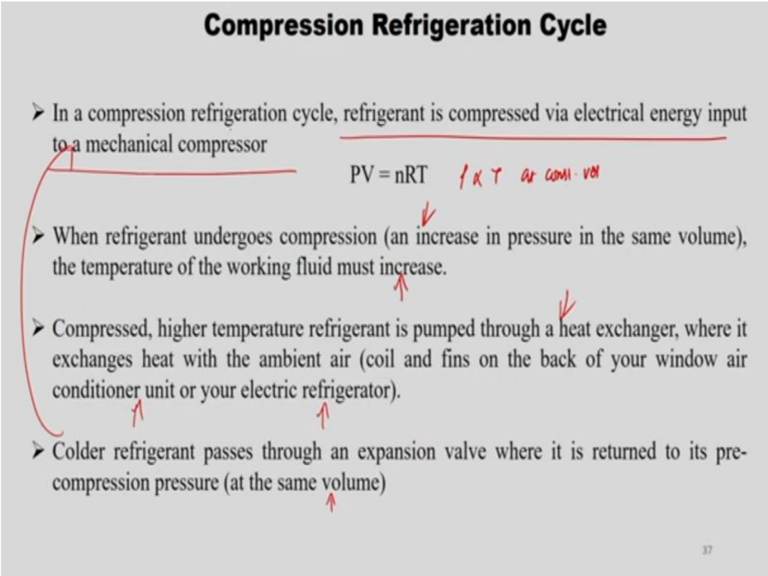

So, the next one is we are going to see the solar cooling cycle. Before going into solar cooling cycle we will see what compression refrigeration cycle, how it works is and which component is replaced by solar energy. In compression refrigeration cycle that refrigerant is compressed via electrical energy input into your mechanical compressor. So, it works based on this ideal gas law principle, P is proportional to T at constant V.

When refrigerant undergoes a compression and increase in pressure in the same volume the temperature of the working fluid or refrigerant must increase. So, to do this compression we are using the compressor which uses the electrical input. So, once it is compressed to higher temperature refrigerant is pumped through the heat exchanger, but where it exchanges the heat with the ambient. So that is nothing but your cold surface.

So, coil and fins on the back of your window or window air conditioner or you can see the same concept in your electric refrigerator as well. So, once it loses its heat then colder refrigerant passes through an expansion wall. So, to make it low pressure refrigerant, where it is returned to its pre compression pressure that is lower pressure at the same volume. So, these are all the 4 processes involved. One is compression then compressed high temperature air goes to heat exchanger that is nothing but the evaporator.

So, where it exchanges its heat then while coming out it comes out as a low temperature high pressure refrigerant. So, again the pressure is reduced in the expansion valve. So, there it reduces its pressure then low temperature, low pressure and then it goes to compressor where its pressure is increased to higher value. So, this is the basic process involved in the normal compression cycle, it has compression, evaporation, condensation and then expansion.

Before going into solar refrigeration cycle, we will review about what is normally done in compression refrigeration cycle. In a compression refrigeration cycle, refrigerant is compressed via electrical energy input to your mechanical compressor. So, the principle here is P is proportional to T at constant volume. When refrigerant undergoes the compression, so that is nothing but an increase in pressure in the same volume.

The temperature of the working fluid must increase after getting compressed to higher temperature refrigerant this is pumped through the heat exchanger, where it exchanges the heat with the ambient air. So, this is normally happens in your air conditioner unit or in refrigerator unit you must be seeing the coils and fins back of your refrigerator. So, after that the colder refrigerant passes through the expansion bar, where it has returned to its pre compression pressure which is nothing but at constant volume again this cycle goes on for refrigeration effect.

So, instead of this particular mechanical compressor, we are going to replace this one as a thermal compressor. So, that we do not require any electrical input.

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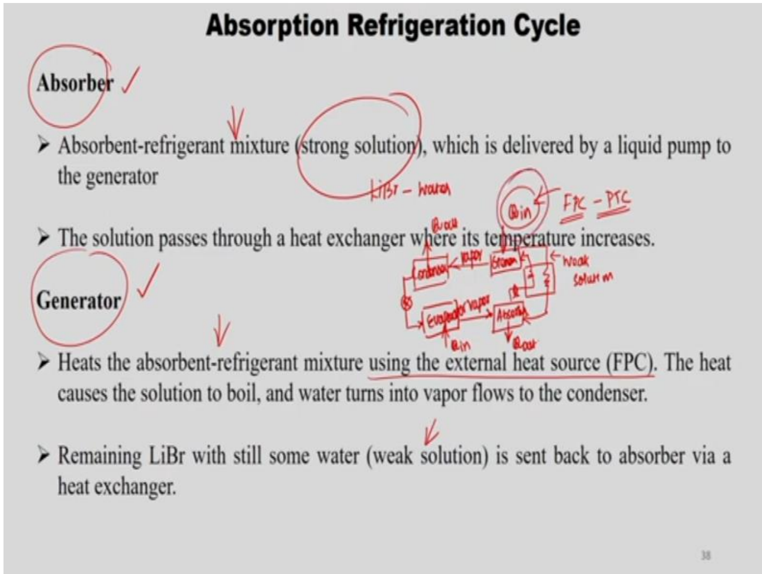

That is what is being done in absorption refrigeration cycle. So, here there are 4 components absorber, generator and condenser and then evaporator. So, if you see here absorber this is the new one here and generator is new one here otherwise same operator condenser pretty much similar. In absorber, the absorbent refrigerant mixture usually a strong solution of salt and water they are not common absorption mixture uses Li Br lithium bromide, salt and water solution.

So, this is delivered by a liquid pump to the generator that is next to component. So, when the solution passes through the heat exchanger where its temperature increases, so, here we have the absorber, the solution passes through the heat exchanger to the generator. So, here in absorber the heat is released, in the generator you are supposed to give the heat in. So, in absorber heat out.

So, what happens in absorber refrigerant make sure that is nothing better strong solution is delivered by a liquid pump to the generator the solution passes through the heat exchanger where its temperature increases with the out coming weak solution from the generator. And next one in generator what happens it heats the absorber refrigerant mixture using an external heat source. So, there comes our flat plate collector or any PTC also parabolic trough collector also based on the temperature that we are going to see.

The heat causes the solution to boil and water turns into vapor flows to the condenser. So, this vapor flows to the condenser. And reminding Li Br with the still some water which is called us weak solution is sent back to the absorber via heat exchanger. That is what we said. So, this is supposed to be called as weak solution. So, it exchanges its heat so that half of the heating of our strong solution is done by a weak solution.

So, once it the vapor reaches the condenser so, what happens in the condenser it loses its heat the condenses the water vapor coming from the generator this liquid condensate is now directed to the evaporator through an expansion valve. So, if you see there is the expansion valve. So with which is given to the evaporator. So, from the evaporator the vapor is again generated and goes to absorber.

This is what happens in the absorption refrigeration cycle which absorbs the heat from the cold space due to evaporation of the refrigerant at low pressure. This creates the cooling effect, vaporized to refrigerant then flows back to the absorber where it mixes with the weak solution of Li Br which already came from the generator. So, in condenser heat is going out. In evaporator it takes the Q in from the space to be cooled. So, this is what normal absorption refrigeration cycle. So here to give the Q in the generator because this Q in is given by the space to be cooled. So, this Q in is provided by the solar collectors.

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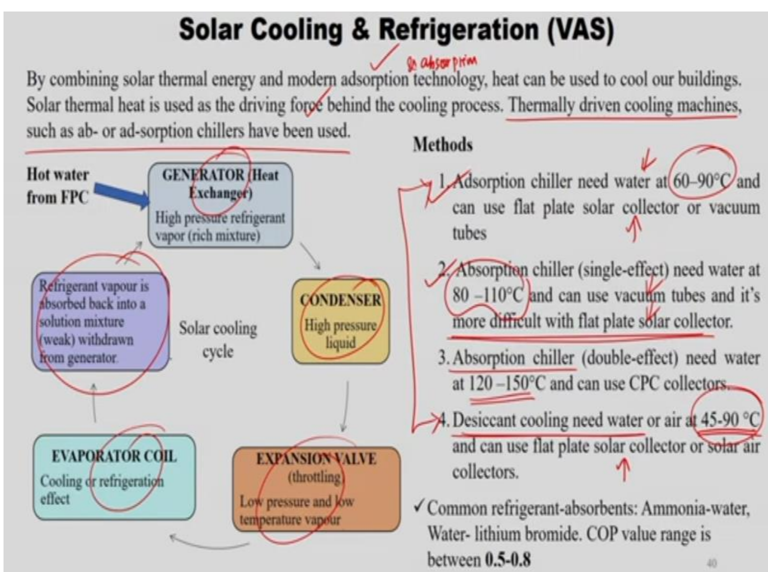

So, by combining the solar thermal energy and modern adsorption technology or absorption technology as well as heat can be used to cool our building. Solar thermal heat is used as the driving force behind this cooling process thermally driven cooling missions such as adsorption or absorption chillers have been used. Nowadays, if it is an adsorption chiller, it needs water at 60 to 90 degree. So, we can use flat plate collector or vacuum tubes which is nothing but ETC.

If you need absorption chiller of single effect, single effect in the sense here what we have seen as one only one set of components. So, such kind of single effect cooling if you want to produce then you can use the flat plate collector which bit of difficulty because it needs a water to be evaporated at 80 to 110 degrees centigrade which can use vacuum tubes comfortably, but if you use flat plate collector, if it is not able to provide the heat to evaporate the water at 110 degree.

Then it may be a problem and we have also seen in the flat plate collected is not only the water, you can use some of the phase change fluids as well which will be able to provide the temperature needed which is nothing but 80 to 110 degree centigrade. If absorption chiller of double effect is to be used, this needs the water around 120 to 150 degrees centigrade. So, in that case it can use CPC collectors which is nothing but compound parabolic collector or cylindrical parabolic collectors.

If the desiccant cooling need water or air at 45 to 90 degrees centigrade. So, very much you can use FPC and solar collector. So adsorption chillers as well as desiccant cooling you can comfortably use a FPC because it requires the temperature of 60 to 90 or 45 to 90 but when you are using absorption chiller of single effect or double effect based on the temperature requirement you can choose either ETC or FPC with phase change fluids.

This is again given to make you understand, what is generator what happens in the generator and condenser and expansion valve and evaporator coil and this is nothing better absorber refrigerant vapor is absorbed back into solution mixture with the with the drawn from the generator. This we have seen in detail in previous slide as well.

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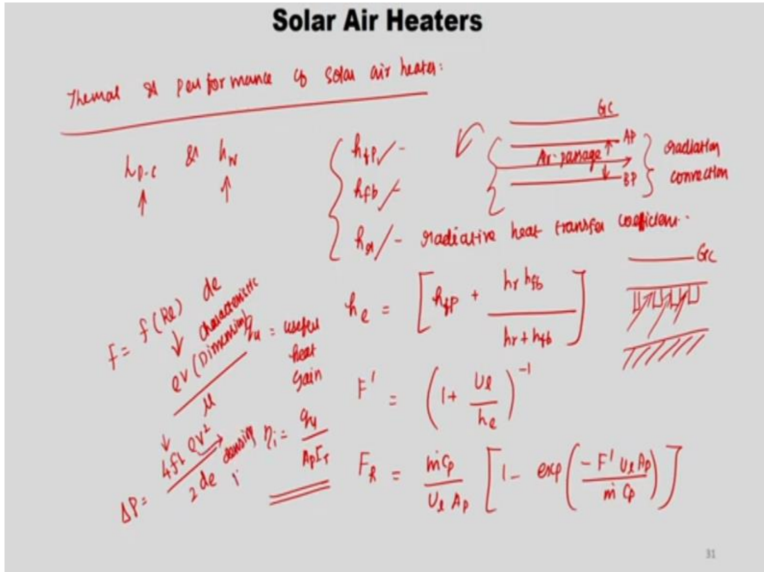

So, if we want to discuss about the thermal and performance analysis of solar air heater. We can see not in detail, but briefly there we used h pc and h w. So, this is for outside surrounding air, this is heat transfer coefficient between plate and cover system. So, here also we use 2 heat transfer coefficient h fp and h fb. So, what is p? This is the absorber plate. So, this is the bottom plate and in between the air is flowing.

So, this is the air passage it should be 2 way. So, this is our passage. So, h fp and h fb, one is fluid to bottom plate and other is fluid to absorber plate. Other than that you would be having h r which is nothing but radiative heat transfer coefficient. Using these 3 there is another heat transfer coefficient which is effective heat transfer coefficient. So, this is nothing but h fp + h r, h fb upon h r + h fb. So, after calculating h e then F dash should be calculated.

So, these are all you know. So, what is F dash what is a for u l upper h e inverse then once you calculate the F dash then F r. F r is nothing but m cp, u l A p into 1 minus exponential of minus F dash, u l, A P by m dot cp. So, once you know F r then you are supposed to calculate the Q u which is nothing but useful heat gain. So, it is almost same useful heat gained. So, whatever we discussed for liquid flat plate collector applicable here as well, for performance analysis.

But, the thing is how you calculate the heat transfer coefficient basically radiation and convection losses. How do you calculate radiation and convection losses? So, there you need to you need to handle 2 fluids oneness between plate and cover that is air and in the absorber plate, absorber tubes water is flowing, but here you are handling only air side heat transfer coefficient because the fluid itself air. So, absorber plate, bottom plate and radiative heat transfer coefficient.

So, collectively combined as an effective heat transfer coefficient from that F dash, F r then Q u So, from that eta i nothing but Q u upon A p, I t. So, this is all is derived for this basic design. So, where you have a glass cover, so, below which you have an absorber plate and then you have a bottom plate where insulation happens. So, between the bottom plate where insulation starts and absorber plate air flowing, so, this is glass cover.

So, for this basic simple design, so, these are all the performance analysis, but if you have as I said earlier this is glass cover, this is absorber plate you have a fins attached to it through which your air flows then this is your bottom plate then all have to be changed based on it because the effective area for the fluid flow will change. So, this may not be applicable. So, this is done only for basic design. So, in that way you can do analysis for solar air heater as well.

So, it is not only the instantaneous efficiency of the air heater is important you suppose to calculate the pressure drop as well as I said earlier the blower is used to send the air inside the passage so, we need to be careful about the pressure difference for that you are supposed to calculate friction factor which is again the function of Reynolds number. Reynolds number rho v characteristic dimension I will just put characteristic dimension.

So, here it is an equivalent diameter upon mu. So, Reynolds number to be calculated from there you calculate the friction factor and then you use the formula of pressure difference which is nothing but 4 FL rho v square upon 2 d e that is equivalent diameter, this is friction factor. So, this is nothing but density. So, v is velocity. So, using this you are supposed to also calculate the pressure drop along with your instantaneous efficiency to analyze the performance of the solar air heater.

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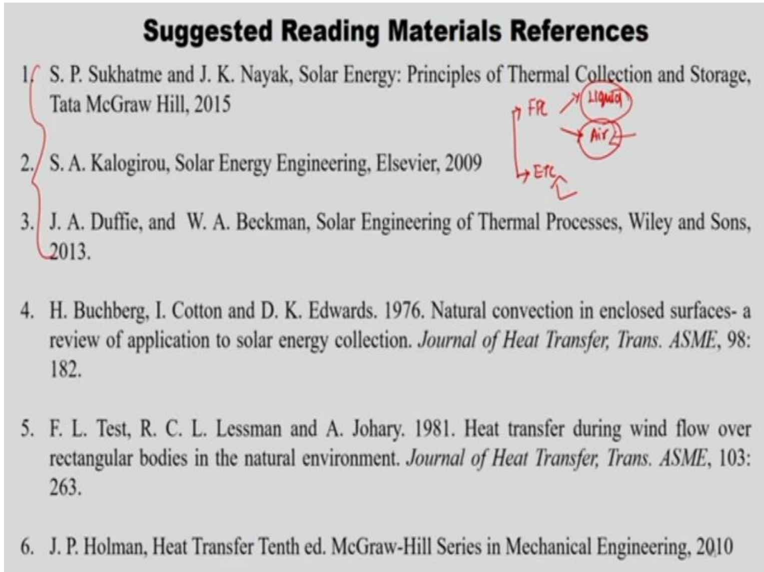

So, these are suggested materials. So, these 3 are books you can refer because here we discussed flat plate collector both liquid as well as air type and an evacuated tube collector on non-concentrating collectors. So, liquid flat plate collector we discussed extensively even thermal analysis, performance test, performance analysis etcetera. We will do problems in lecture 6. How to calculate instantaneous efficiency of the given collector system and air collector?

We discussed few Types but however, there are a large variety of solar air collectors are there. And another reason why we have not discussed in detail is that air collector mostly used to for agricultural drying purpose or agriculture material drying purpose and industrial heating as well, but most of the time it is a seasonal application only during harvesting or when you really need in industry if you see heating there may be a temperature requirement may be high.

So, in that case, you were concentrating collectors would serve better and because of these reasons solar air heaters will not find applications throughout the year. So, because of that reason, we have not discussed in detail. In ETC the advantages we have reduced the convection losses in that way the efficiency is higher. So, these 3 books you can further refer if you want to get to know anything in depth about your collectors as well as solar air heaters as well as evacuated tube collector. Thank you.