Solar Energy Engineering and Technology
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Lecture 33
Solar Energy Applications

Dear students, today, we will be discussing about solar energy applications. Basically, we will be discussing about solar thermal applications.

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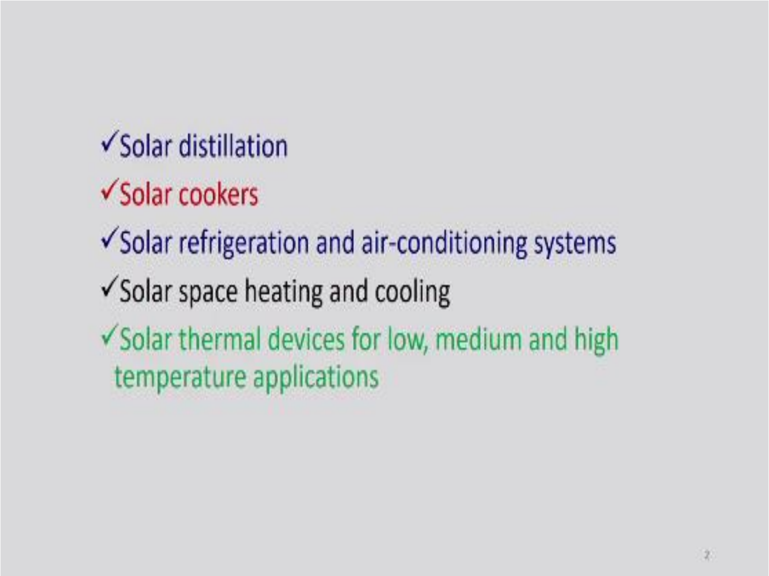

Start with solar distillation followed by solar cookers, solar refrigeration and air conditioning systems, solar space heating and cooling, solar thermal devices for low medium and high temperature applications. So, without delay let us start solar distillation and what is the need of solar distillation. So, before we understand the need, let us study few important issues.

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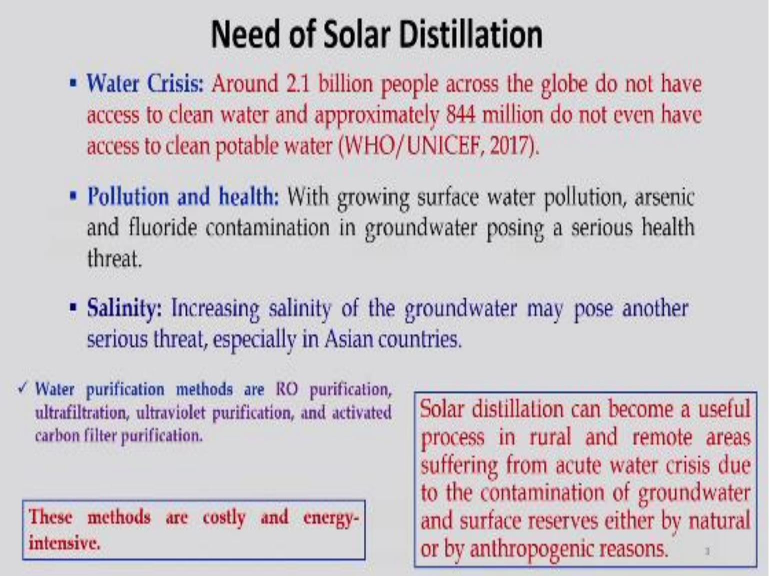

First issue is water crisis. As per World Health Organization, around 2.1 billion people across the globe do not have access to clean water and approximately 844 billion do not even have access to clean potable water. And second important issue is pollution and health. With growing surface water pollution, arsenic and fluoride contamination in groundwater posing a series health threat.

And third issue is salinity. Increasing salinity of the groundwater may pose another serious threat, especially in Asian countries. So, there are many purification methods normally adopted like RO purification, ultrafiltration, ultraviolet purification and activated carbon filter purification; these are common in the market. So, these methods are costly and energy intensive what we can see.

So, now we need a solution which can be affordable by the rural mass. So, we need a technology for that. So, now we can realize the need of a low cost solar distillation system, which is known as solar distillation. This solar distillation can become a useful process in rural and remote areas suffering from acute water crisis due to the contamination of groundwater and the surface reserves either by natural or by anthropogenic reasons.

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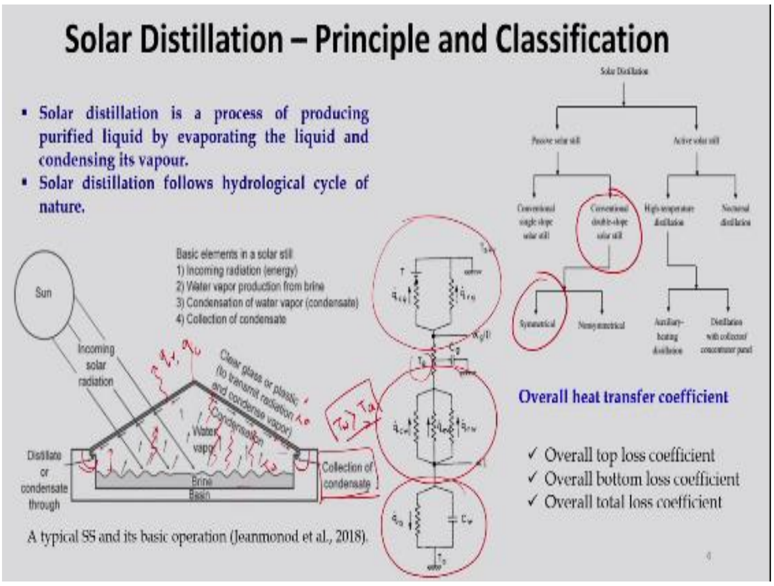

So, now let us discuss about principle and classification of solar distillation. Solar distillation is a process of producing purified liquid by evaporating the liquid and condensing its vapor. The solar distillation follows hydrological cycle of nature. So, this solar distillation can be classified broadly into two classes; passive solar still and active solar still. Again this passive solar still can be classified into two categories, called conventional single slope solar still and conventional double slope solar still.

Again further, this conventional double slope solar still can be classified into two categories; symmetric and non-symmetric. Under active solar still, we will have two categories; high temperature distillation and nocturnal distillation. And under high temperature distillation again, we have two categories, one is auxiliary heating distillation and other one is distillation with collector or concentrating solar collector.

So, what are the different elements of a solar still? Like we need incoming solar radiation from where energy is coming and that will be utilized for evaporating water from a solar still then water evaporation, production from brine then condensation of water vapor. So, finally we need to collect the condensate. So, what we can see here in the figure, so this is nothing but a typical solar still which is of this class; like conventional double slope solar still and it is a symmetric one.

So, what we can see here, it is a symmetric, because if you cut it here, so both side will be similar or identical we should say and this is glass cover. Sometimes plastics are also used for this purpose. So, sunray or energy from the sun comes here and strikes the brackish water. Of course, we will have an absorber plate at the base of this solar still and above it, we will have brackish water.

So, we need to maintain some height, say 5 to 6 cm from the water level to the start of this slope. So, when solar radiation is falling in the solar still, what will happen? This water present in the solar still will evaporate and it will strike on this glass cover. So, as soon as it strikes, what will happen? It will slip because when solar radiation is received here, so may be what we can water temperature here and maybe we can say it is ambient temperature.

So, this T_w is more than ambient temperature and this will evaporate and strike on this glass cover and it will slip off and finally this can be collected in the collector point. So, while analyzing, there are many components involved in this solar still. Because there will be losses, from the top of the glass cover. It may be radiation losses and then it may be convective losses.

And same amount of energy which is going through this glass cover and striking on this absorber as well as this water, it will evaporate and then it will condense; because temperature here in the glass cover is different than what is outside the glass cover. And finally this condensate can be collected for different applications. This may be applied for removing heavy metal present in groundwater or may be this water can be used for battery used in solar PV system, because we need distilled water for batteries.

Also we can see here, this is thermal resistance diagram showing the different losses. So, up to here, this is T_g is glass, so this is the glass cover and then above it, there are some losses convective and radiative losses and then evaporation losses will be there and then from the bottom, we will have bottom losses. So, this information are required while we are interested about heat transfer analysis, which includes overall top loss coefficient, overall bottom loss coefficient and finally overall total loss coefficient.

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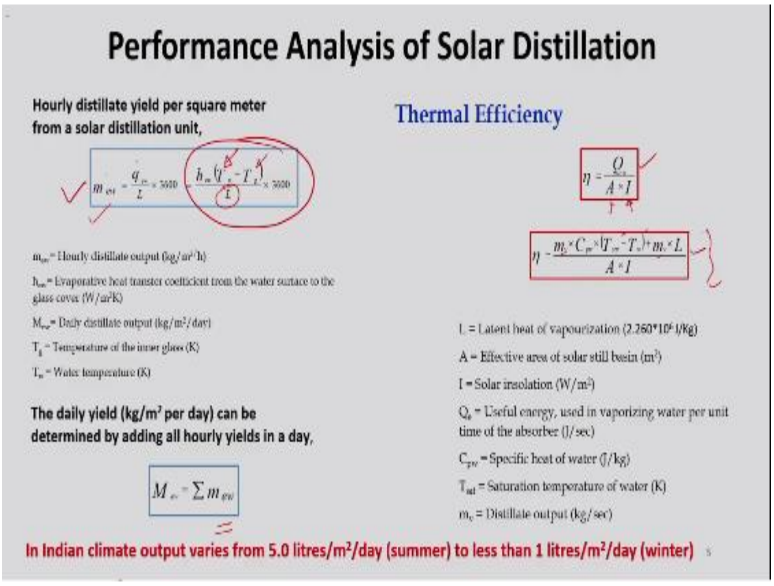

Now, let us study the performance analysis of solar distillation. So, if we are interested about hourly distillate yield per m^2 from a solar distillation unit, then we can use this expression. So, this is the hourly distillate output which is in kg/m^2-hr. So, this is the expression. If we know evaporative heat transfer coefficient from the water surface to the glass cover and then water temperature and glass temperature and if we know this latent heat of evaporation.

Then straightaway we can calculate hourly distillate output. So, sometimes we might be interested to know daily yield. So, if we are interested for daily yield, then we have to sum up the distillate generated per hour. Now as far as thermal efficiency is concerned, we can apply this expression for investigation of thermal efficiency of a solar still or distillation unit. This Q_e is the useful heat gain and A is the area of the collector and I is the solar intensity.

So, we can expand this $Q_e = m_v C_{pw}(T_{sat} - T_w) + m_v L$; because latent heat of evaporation or vaporization need to be considered in the study. So, since we know the values of all this temperature and m_v which is nothing but distillate output and here m_v is in kg/s. So, dimensionally this will be dimensionless and η will be in percentage. So, in Indian climate, output of this solar distillation unit various from 5 L/m^2-day which is in summer.

And in case of winter, a very low value of distillate output has been observed which is less than 1 L/m^2-day. So, there is a need of investigating the different operating parameters which influences the performance of a solar distillation. Of course, we need to know the other design parameters.

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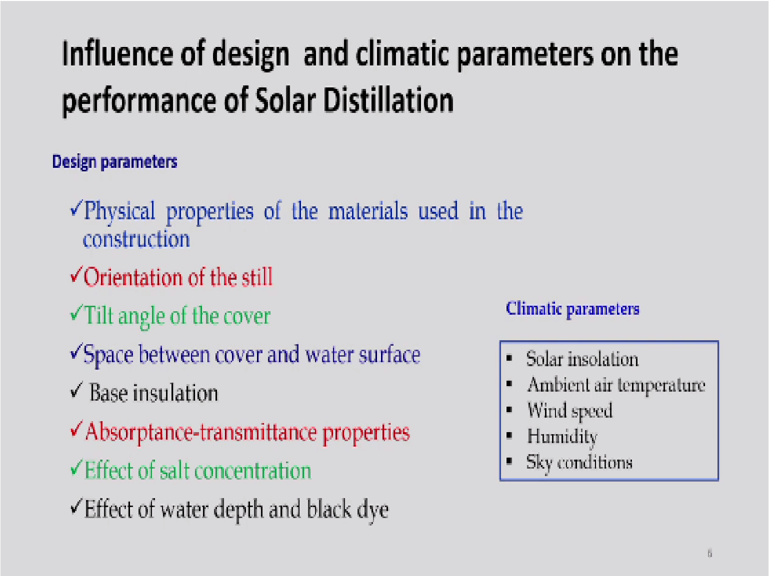

So, now we will study, the influence of design and climatic parameters on the performance of solar distillation. So, what are the design parameters? First is physical properties of the material used in the construction, orientation of the still. So, we have to be very particular about the orientation of the still, tilt angle of the cover, space between the cover and the water surface; if it is very large then it will be very difficult to evaporate.

So, we need to optimize the height between the cover and the water surface, then base insulation, absorptance transmittity or transmittance properties and effect of salt concentration then effect of water depth and black dyes. Because black dyes are applied to maximize the absorption of solar radiation. So, normally this brackish water these are saline water, that is why it is called salt concentration or it tells about salt concentration.

And what are the different climatic parameters which influences the performance of solar distillation like solar insolation which is primary, then ambient air temperature, wind speed, humidity and sky conditions.

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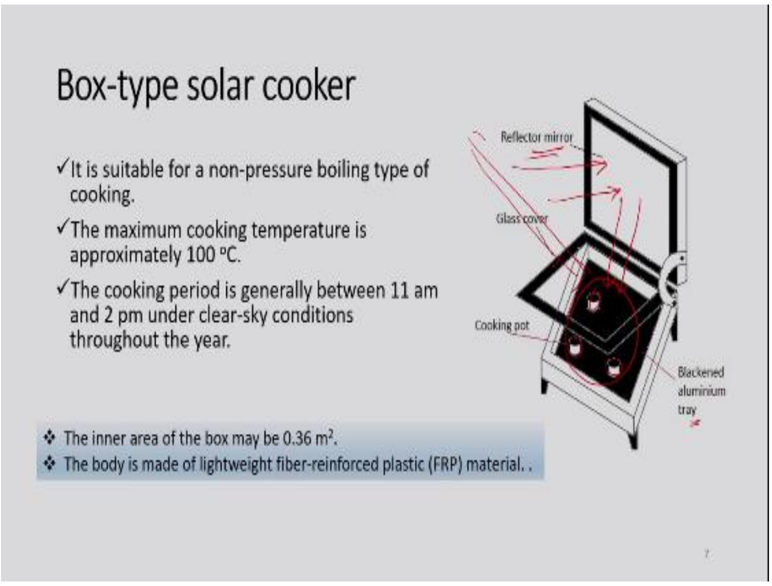

Now, let us move to the box type solar cooker. So, what is solar cookers and what are different components? So, as we can see, by using solar energy we can cook food. So, the device used for this purpose is nothing, but solar cooker. So, here we can see different components like we will have blackened aluminum trays here and then we will have this kind of pots. These are cooking pots, where rice and all is introduced and it is packed.

And these are glass cover and then reflector mirror. So, solar radiation falls here directly and some of the solar radiation which is striking on this reflected or reflector mirror is also contributes in rising the temperature of the substance which is placed in the trays and sufficient number of insulations are provided to reduce the heat losses. So, in this kind of systems, a maximum of 100 ^{o}C can be obtained.

So, this kind of cookers are suitable for cooking of variety of food items where solar radiation is significant. So, it is suitable for a non pressure boiling type of cooking. The maximum cooking temperature is approximately 100 ^{o}C. The cooking period is generally between 11 am and 2 pm under clear sky conditions throughout the year. The inner area of the box may be about 0.36 m^2. The body is made of light weight fiber reinforce plastic, which is known as FRP material.

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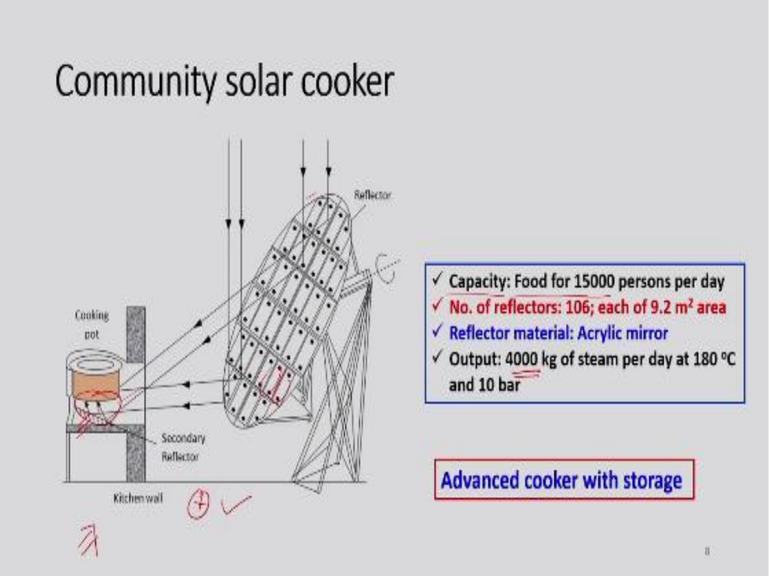

So, there are community type solar cookers. What happens here, there are set of reflectors. So, solar radiation received in the reflector, it is reflected to this surface and where intense heat is generated and pot is placed here for cooking. And this is called secondary reflector here after receiving the energy from the large reflector. So, this kind of systems are quite popular in community cooking in different places.

So, for example, its capacity varies. So, for example, this solar cooker can be employed for cooking of food for group of people like about 15,000 persons per day. So, number of reflectors required is about 106 to meet that kind of demand and each of the reflector is having an area of 9.2 m^2 and this reflector material is acrylic mirror. So, this reflector materials and this output is something like 4,000 kg of steam per day at 180 ^{o}C and 10 bar.

So, that much of steam is generated and that much of steam is capable to prepare cook for person like about 15,000 per day. So, one more invention is cookers with storage. So, what is the disadvantage of this kind of community cooker? We cannot store energy. So, this is valid when sufficient solar radiation is received at the particular location and only day time cooking is possible.

But if people are interested about cooking at night by using this kind of solar cooker, then this kind of technology will not work. So, we need some kind of storage device when excess energy is generated and that can be utilized at night for cooking of foods. So, that falls under advanced cooking or advanced cooker with storage.

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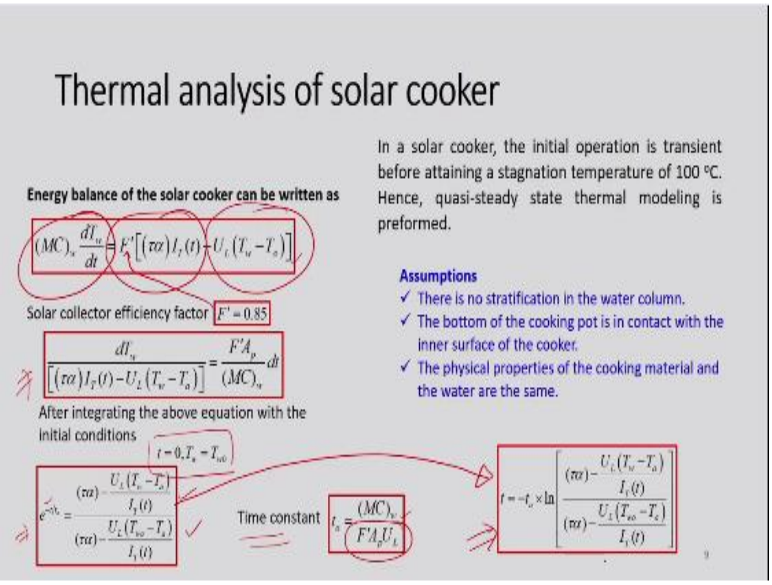

So, let us pay attention about thermal analysis of solar cooker. So, in a solar cooker the initial operation is transient before attaining a stagnation temperature of 100 ^oC. Because it will maintain at 100 ^oC. Hence, quasi-steady state thermal modeling is performed in this case and there are some assumptions. So what are assumptions? Like there is on stratification in water column, that means temperature is uniform in the vessel throughout.

The bottom of the cooking pot is in contact with the inner surface of the cooker, that we can understood now. The physical properties of the cooking material and the water are the same. So, these are the assumptions used for the analysis of solar cooker. So, if we are interested to develop energy balance of the solar cooker, we can write straightaway. So, this is the amount of energy utilized and this is the amount of energy received and this is the amount of energy lost from the cooker.

So, solar collector efficiency factor is normally considered to be 0.85. So, this is F′ is something called solar collector efficiency factor. With a very involved way, we can simplify this expression to this expression. So, we have not done anything, just we have reorient some of the expressions so that our analysis becomes easier. And after integrating the above equation with initial conditions at t = 0 and $T_w = T_{wo}$ which is the initial temperature.

So, we can develop this expression which is very very straightforward. So, we can get this kind of expression, and we can define time constant which is $t_o = \frac{(MC)_w}{F^{'} A_p U_L}$. Also we can express this expression in terms of t. So, after what time it will be steady state. So, we can modify this expression and it will be something like this. So, if we know these values T_w, T_a, I_T, U_L, $(\tau\alpha)_{av}$, that is absorptivity and transmissivity average term and t_o, we can calculate the time at which it will attain quasi steady state position.

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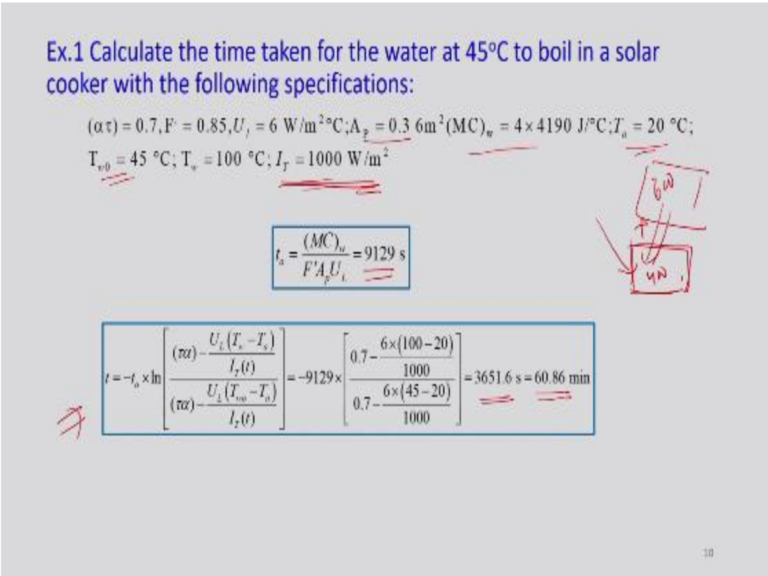

Now, let us take an example to understand what we have discussed now. Calculate the time taken for the water at 45 °C to boil in a solar cooker with the following specification. So, $(\alpha\tau)$ = 0.7 and F' =0.85, U_L = 6 and A_P = 0.36 m^2, $(MC)_w$ = 4 × 4190 J/ °C and T_a is given as 20 °C, T_{wo} = 45 and T_w is 100 and I_T is 1000.

So, when it says 1000, that includes both the component. One component is coming from the reflector, it is reflector and another component is directly falling on the absorber. So, here may be it is reflector may be 600 and may be here is 400. So, (600 + 400) = 1,000 W/m^2 is the total amount of radiation received by the blackened surface of the solar cooker. Now straightaway we can calculate what is time constant first.

So, we know the expression for t_o, then we can substitute those values which is given to us in this problem and what we can get the value of t_o = 9129 s and then we can calculate the time.

So, time taken for water to boil. So, if we substitute then what we will get, this will be something like this and it will be about 1 hour. So, in 1 hour time, we can cook the food, if the initial water temperature is 45 ^{o}C.

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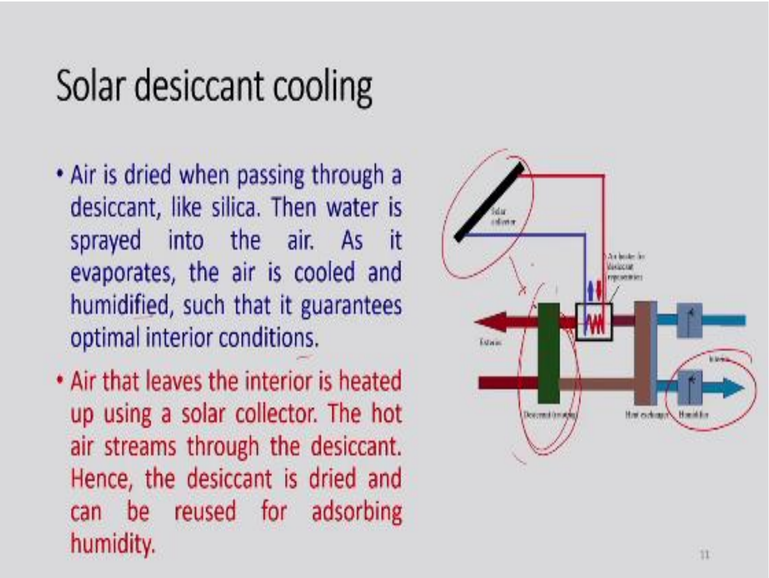

Now, let us discuss something about solar desiccant cooling. So, here what happens, we have to use some kind of descant like silica gel and air is introduced and moisture is trapped then we have to have heat exchanger and then we need to use humidifier and while coming back then we have to use solar collector; because we have to regenerate the material used for desiccant. So, what happens air is dried when passing through a desiccant like silica.

Then water is sprayed into the air as it evaporates, the air is cooled and humidified, such that it guarantees optimal interior conditions. So, here interior conditions and while coming back, air that leaves the interior is heated up using a solar collector, what you can see here. The hot air stream through the desiccant, this hot air and this is a desiccant. So, hot air streams through the desiccant and hence the desiccant is dried and can be reused for absorbing humidity. So, for regeneration, this solar collector is used here.

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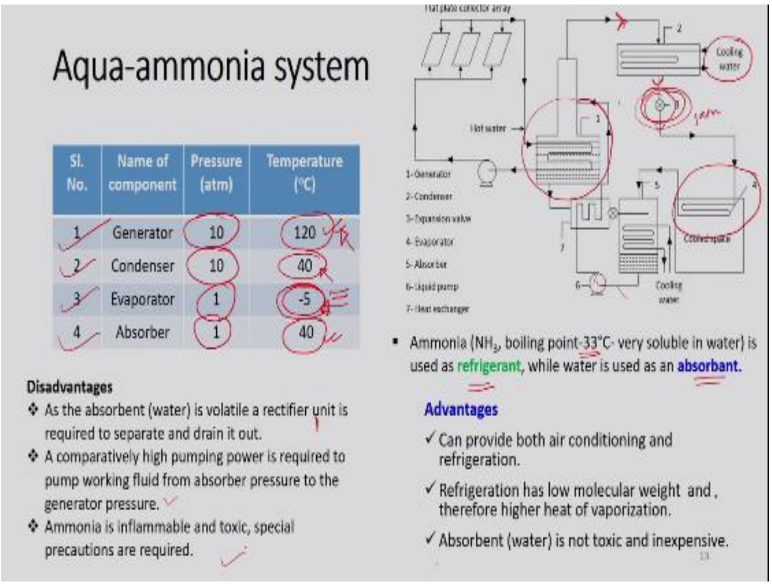

So, now we will discuss two very important technologies for utilization of solar thermal energy for providing refrigeration and air conditioning. So, first let us study aqua ammonia system. So, here in this system there are four components; generator represented by 1 condenser 2, evaporator 3 and then absorber here. And you can see, the pressure at the generator is 10 then condenser is 10, evaporator is 1 and then absorber, this is in atmospheric pressure.

And temperature you can see for generator is 120, condenser is 40 and evaporator is -5 and absorber is 40. So, from this table, what we can conclude, so we need a source of energy which is close to 120 ^{o}C. In condenser, cooling will be there, so temperature drop will be there. This evaporator is the key thing, because this temperature we are going to maintain in the evaporator where space cooling is required or refrigeration effect is required.

And then absorber is at 40. So, let us see the schematic of this plant. So here, what happens, these are the solar collectors. So, this are connected in series and parallel based on the requirement of the temperature and this 1 represents the generator, then 2 is condenser, 3 is the expansion valve and then this is the evaporator, where space cooling is required. And then we will have this absorber.

And then we will have liquid pump and it will pump back to the generator. So, in this case, in aqua ammonia system, we will use ammonia and water solution here. Here, aqua ammonia solution will be there, so why ammonia, because boiling point of ammonia is about -33 ^{o}C, which is very soluble in water and this principle is applied in cooling of room or cooling of space.

So here, ammonia is the refrigerant and then water is the absorbent. So here, ammonia and water is mixed when heat is supplied from the solar system, so heat is used to evaporate the refrigerant. Because this boiling point of ammonia is -33 ^{o}C. At very low temperature, it will evaporate and very high pressure, it will move on through this line and it will introduce in the condenser where water is provided for cooling.

But it happens at high pressure about 10 bar and then in the expansion valve, what happens, pressure will be reduce from 10 bar to about 1 bar. But you must know, here vapor will move, but after condenser, we will have liquid. But pressure will be remained fixed, but when it flows through the expansion valve, then what will happen, pressure will reduce to 1 atmosphere and then it pass through this evaporator where space need to be cooled.

What happens, this latent heat will be applied for cooling. So, this hot air or energy associated with hot air will be used here and then cooling effect will be provided. Then low concentrated solution will pass through this system and then it will pump to this generator again and it will work in a close loop. So, this kind of system can be applied for both refrigeration and air conditioning.

As you can see here, we can maintain temperature up to -5 ^{o}C. So, what are the advantages associated with aqua ammonia system, let us discuss. This aqua ammonia system can provide both air conditioning and refrigeration; that is the first thing and second thing is refrigeration has low molecular weight and therefore higher heat of vaporization; and third advantage is absorbent is water, is not toxic and inexpensive.

It also has some disadvantages, as the absorbent water is volatile; a rectifier unit is required to separate and drain it out. This is one additional thing we need to do as far as aqua ammonia refrigeration system is concerned, a comparatively a high pumping power is required to pump working fluid from absorber pressure to the generator pressure. The ammonia is inflammable and toxic.

So, special precautions are required for ammonia. Now, let us learn something about lithium bromide water absorption cooling system.

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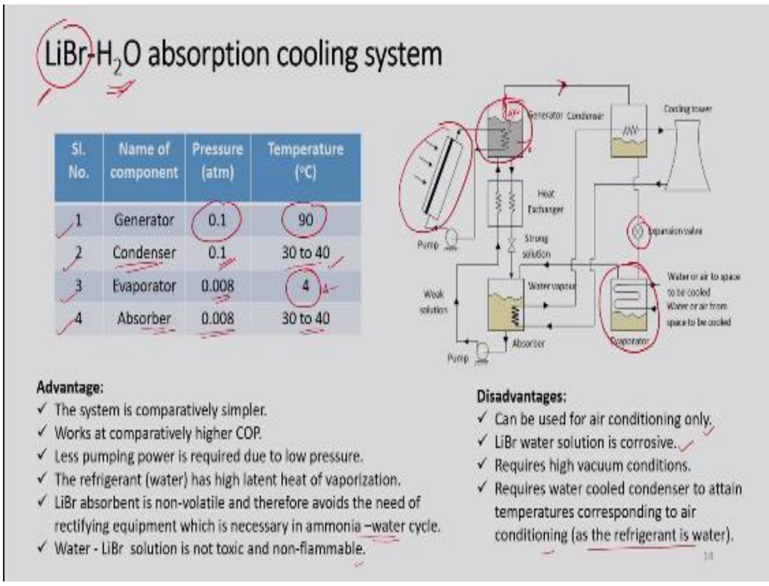

Here what happens is reverse. So, in the earlier case, ammonia was refrigerant and H_2O was absorbent and now it is reverse. Lithium bromide is absorbent and H_2O is the refrigerant. Also we can have a look about the components and its working pressure. You can see the significant difference. In serial number 1, if you consider generator, you can see, pressure is about 0.1 atmospheric at low pressure.

So, if we can maintain at low pressure then at lower temperature, we can get the evaporation of water. That is why, its temperature is 90. At serial number 2, condenser, pressure is maintained at about 0.1 and temperature varies from 30 to 40 and evaporator, pressure is very, very low, 0.008 atmosphere and see temperature is 4. So, this is the reason why you cannot use it for refrigeration.

At serial number 4, we will have absorber. Again its pressure is about 0.008 and temperature varies from 30 to 40. So, let us have a look about the working. So, this is the solar collector, from where heat energy is generated by utilizing solar energy; and this component is known as generator. So, here since it is maintained at lower pressure, so it will evaporate at around 90 ^{o}C.

Then it moves to the condenser, so cooling will be there; then it will be converted to liquid and then in the expansion valve, it will expanded and pressure will be reduced, and then it goes to the evaporator, where space need to be cooled. And again it goes to the absorber and again it will be pumped to the generator through this heat exchanger. So, there are some advantages of utilizing this lithium bromide water absorption cooling system.

What are the advantages? The system is comparatively simpler. It works at comparatively higher COP, less pumping power is required due to low pressure. The refrigerant has high latent heat of vaporization, lithium bromide absorbent is non volatile and therefore avoids the need of rectifying equipment which is necessary in ammonia water cycle. Water lithium bromide solution is non toxic and non flammable.

So, these are the advantages associated with lithium bromide water absorption cooling system and disadvantages are, this system can be used for air conditioning only. So, lithium bromide water solution is corrosive. That is very, very important and it requires high vacuum condition. Again we need to invest some kind of devices, or some kind of system for maintaining the vacuum and it requires water cooled condenser to attain temperature corresponding to air conditioning. So, as in the refrigerant in water.

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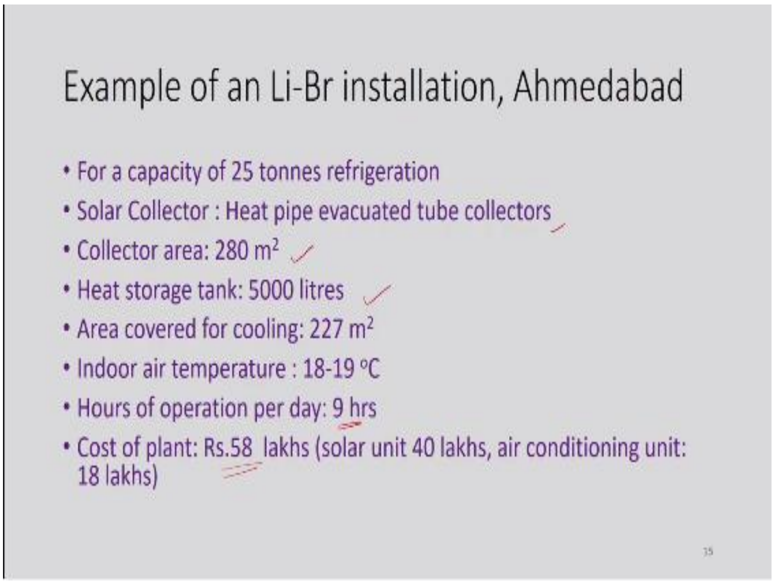

So, let us take an example which has already been installed in Ahmadabad. So, for a capacity of 20 tonnes refrigeration, the amount of solar collector required and investment required can be seen here. So, solar collector type is heat pipe evacuated tube collectors and collector area is about 280 m^2 is required for 25 tonnes of refrigeration and heat storage tank capacity is about 5,000 L and area covered for cooling is about 227 m^2.

Indoor air temperature is about 18 to 19 ^oC and hours of operations per day is 9 hours and cost of the plant is 58 lakh which includes solar unit is 40 lakhs and air conditioning unit is 18 lakhs, which are costly system.

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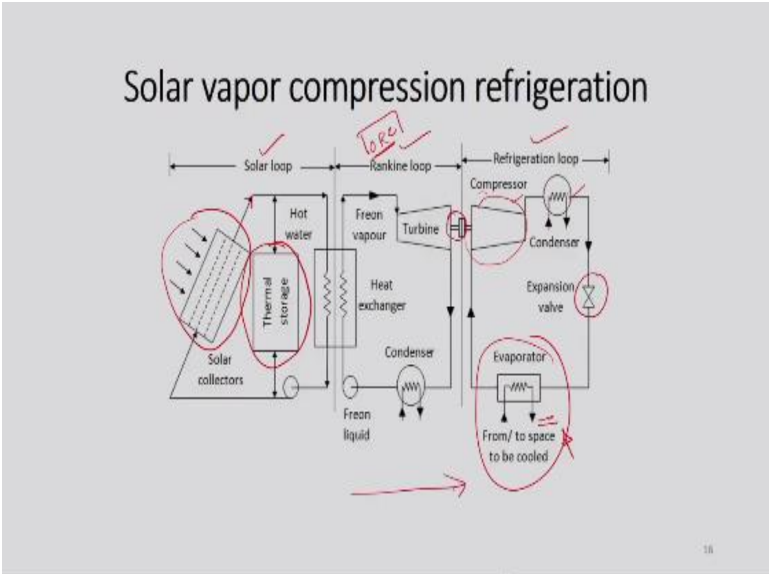

So, now let us discuss about solar vapor compression refrigeration system. So, we can use the solar thermal technology for vapor compression system also. So, what we can see here, there are three loops. The first loop is for solar, second is for rankine and third is for refrigeration. So, solar radiation is falling in the collector and hot water is generated and this hot water is utilized for generating electricity by using rankine cycle or this is called organic rankine cycle, ORC, because organic fluid is used here.

Like Freon or ammonia, that kind of fluid and then this electricity, what is generated, is used to run this compressor of the vapor compression refrigeration system. And it has many components, compressor then we have condenser, expansion valve and then evaporator. And the evaporator is installed to a place where space to be cooled. So, if this collector is generating access energy then storage can be done.

So, once storage is done then this stored energy can be utilized when sun is not available and perform the similar work for generation of electricity and finally providing refrigeration effect.

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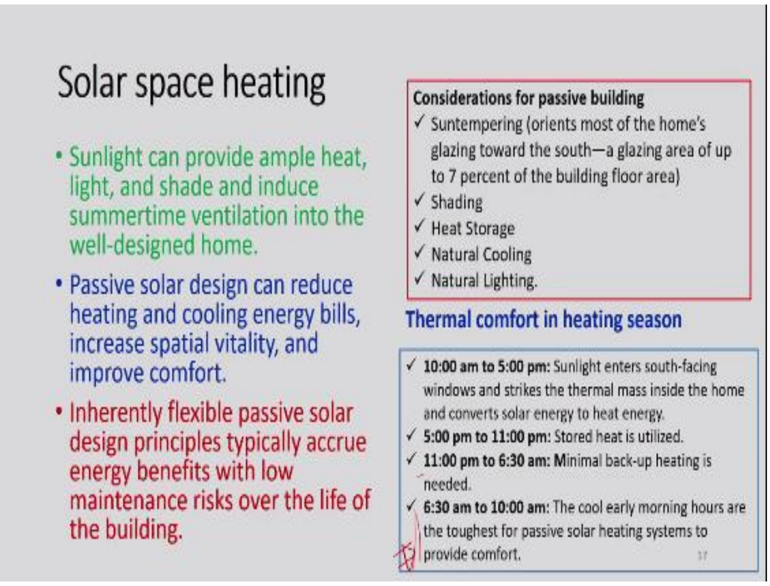

So now, let us discuss about solar space heating. The sunlight can provide ample heat light and shade and induce summer time ventilation into the well designed home. The passive solar design can reduce heating and cooling energy bills, increase spatial vitality and improve comfort. Inherently, flexible passive solar design principles, typically accrue energy benefits with low maintenance risk over the life of the building.

So, there are some considerations for passive building like sun tempering, shading, heat storage, natural cooling and natural lighting. So, sun tempering means orients most of the homes glazing towards the south. A glazing area of up to 7 % of the building floor area normally considered for this purpose. And of course, all other parameters need to be seen while designing a passive building.

Also let us pay attention about thermal comfort in heating season. Normally, there are four time zones people have classified to know the energy distribution. From 10 am to 5 pm, sunlight enters south facing windows and strikes the thermal mass inside the home and converts solar energy to heat energy. From 5 pm to 11 pm, no solar energy is there. Here, what happens, this stored energy is utilized from 11 pm to 6:30 am. Minimal backup heating is needed, sometimes electrical systems might be required to maintain the comfort.

From 6:30 am to 10 am, the cool early morning hours are the toughest for passive solar heating system to provide comfort. So, for this, there is a need to do research. How this can be maintained? Or may be alternate material which can store more energy and that can be provided when required.

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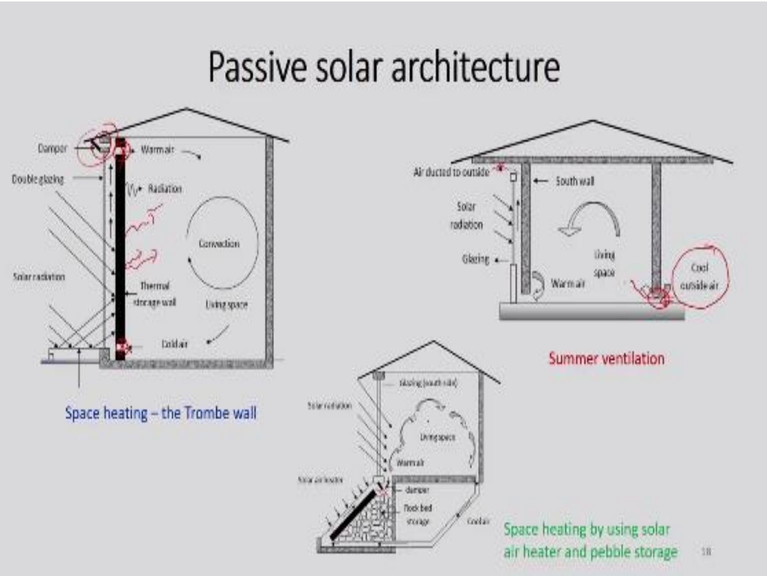

Now see about passive solar architecture. So, let us study first this Trombe wall, which is very, very famous for maintaining room comfort. So, what happens here, components are, we need double glazing, we need a storage wall. This may be concrete wall or may be stone wall or that kind of material which can store more thermal energy. That means, heat capacity of the material should be more.

That kind of material should be used and of course, black paint has to be done in order to maximize the solar radiation absorption. So, this is the room, we need to maintain the room temperature at a suitable level. So, these are the vent, these vent, this vent, this vent; these are very, very important. So, what happens, our primary target is to maintain comfortable temperature inside the room.

Here what happens, cold air is introduced and it move up, because of this density difference. And then, since this wall is received solar energy through this glass cover and then we will have reflectors, so that it can be maximized and it move up and goes in. So, amount of air required to circulate can be controlled by using this vent, can control it and also amount of water to be introduced can be controlled here.

So that way, room temperature can be controlled at a suitable level. So, in day time, even though, this air is circulated, this wall is also radiating and also convection heat transfer take places. But at night, these two vents are closed. So, only this wall will radiate and convective heat transfer will take place to maintain the temperature of the room. So, also sometimes, if we do not want more heat to introduce, then this damper can be used to control it.

Now we can see one more configuration, where we can maintain summer ventilation. So, what happens on a summer day, it was too hot, so we have to remove the hot air from the room. So, if you consider this is the room and glazing is here as solar radiation is falling here. So, this cold outside air we have to see, where to maintain this vent; because cold air has to introduced. If hot air is introducing, then our purpose will not solved.

Cold air has to be introduced through this hole and it will pass through and then it will move through this hole and it will goes off from the room. By doing so, we can maintain the room temperature at a suitable level. Also, we have one more configuration, so this is for space heating by using solar air heater and pebble storage. You can see here, these are the rocks and pebbles.

So, as you know this heat capacity of this pebbles are very, very high; so those pebbles can store more energy per unit volume. So, solar radiation is falling here and this is the absorber plate of the solar air heater and then air is coming from the room and it goes through this line and it passes through the channel between the glass cover and the absorber plate and through this damper, it will introduce here in the living room.

So that way, this energy can be distributed and room temperature can be maintained as per requirement.

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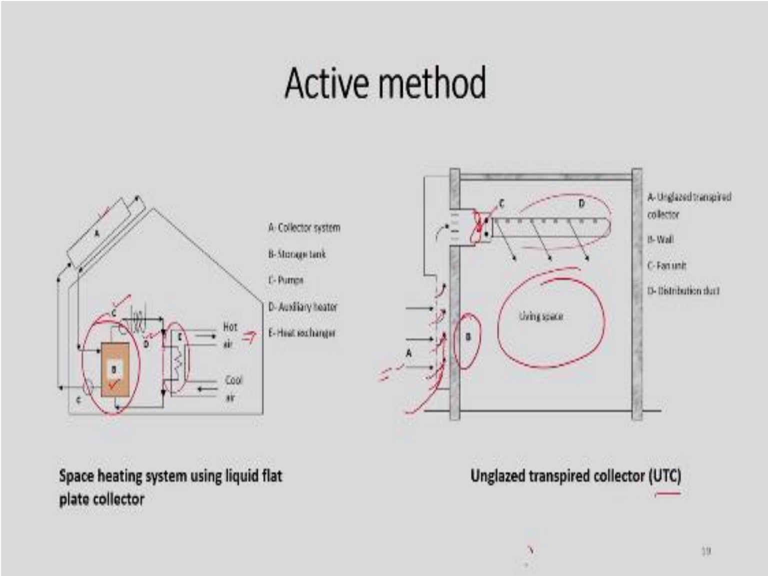

So, the kind of methodology what we have discussed, these are passive systems. We do not have to spend any energy or running any motors or running any blowers. So, now we will discuss some other technologies where we need to apply some kind of devices like pumps, motors et cetera to maintain the room temperature at a suitable level. So, this configuration is for space heating system using liquid flat plate collector.

So, this is a liquid flat plate collector and what we can do, we can store energy here, whenever we have excess energy and based on the requirement, this stored energy can be utilized by connecting a secondary line and heat exchangers. So, this A is for collector system, then B is storage tank, then C is pump, then D is auxiliary heater, this is auxiliary heater, if the storage is not sufficient, then we can provide an auxiliary heater for providing heating effect as per requirement.

And will have heat exchanger, this is the heat exchanger, because heat has to be exchanged. Cold air introduced, pass through the heat exchanger and then finally hot air is supplied and that is maintained as per the requirement or the suitability of the owner. Also, we will have one more configuration known as unglazed transpired collector, that is UTC. So, here what happens, we will have a wall which is blackened.

And then this is a transpired collector and air is flowing through this perforated glass and we will have fan here. So, what happens, fresh air will move because of this density difference and it will pass through this; what is called distribution duct and it is distributed in the living space. So, A here is unglazed transpired collector and B is the wall. It is blackened surface and we will have, what is called fan, this is the fan unit and this is distribution duct.

So, this can be controlled the amount of air to be circulated in the room based on the requirement. So, electronics are also involved. So, that can be controlled and this kind of system has already been in practice for several years in many western countries. So that way, room temperature can be maintained in active mode.

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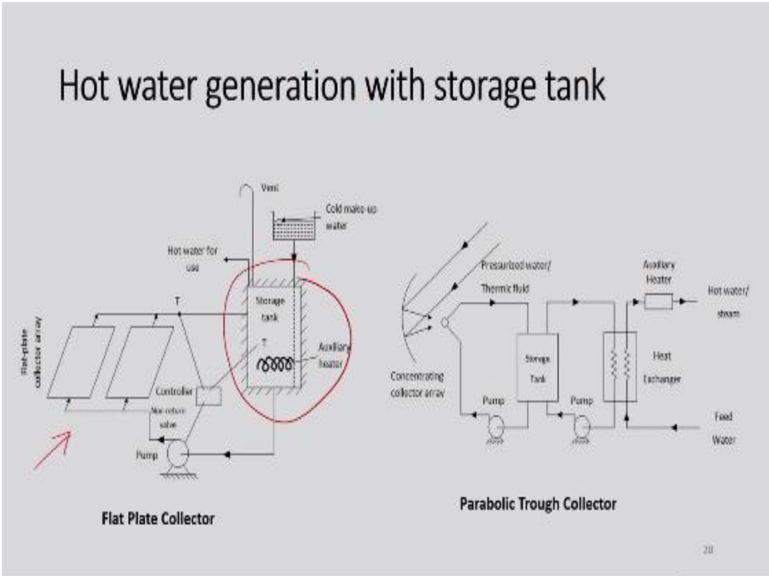

Also, we will discuss about something about hot water generation with storage tank. So, by using this flat plate collector, we can generate hot water and we can store in insulated tank and whenever required that can be collected. So, we can get temperature close to 120, 130 based on the number of collectors used and connected in series and parallel. And also we can go for parabolic trough collector for generation of hot water which can be applied in many processes like in dairy farms and process heat for other applications.

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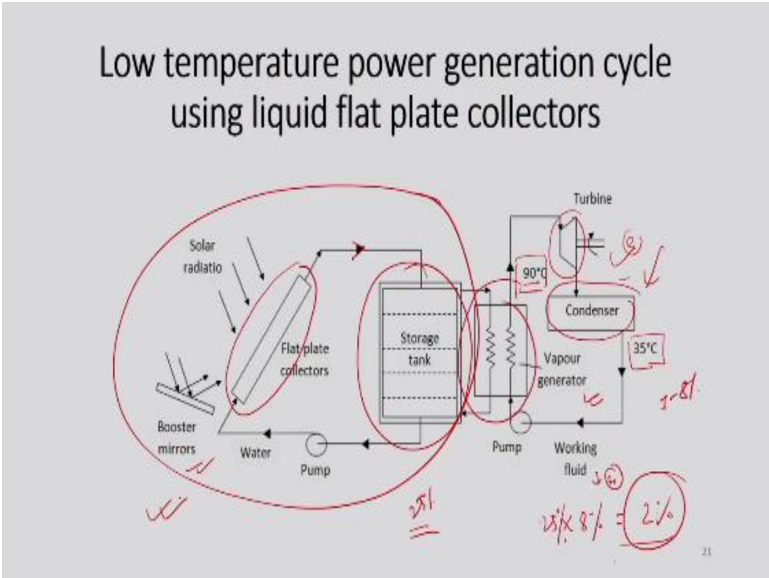

Let us learn the low temperature power generation cycle using liquid flat plate collectors. So, here what happens, we can have a flat plate collector and also we can boost the temperature by using this booster reflector. We can increase the temperature and generated hot water can be stored in a storage tank and by utilizing a heat exchanger and using a secondary cycle, we can generate electricity.

So, this cycle working fluid is normally like Freon and other organic fluids are used. So, this is circulated in this loop. So, when this fluid come into contact with this hot water, it will evaporate and pressure rise will be there, which will be expanded in the turbine and by connecting a generator, we can generate electricity and then eject of this turbine has to be condensed and it will be circulated again and again in a close loop.

So, as you can see here, this temperature before entry to the turbine is 30 and the condenser is 35. So, this kind of systems, so if you consider this loop, this conversion efficiency is about 7 % to 8 %. In case of this collector system, its efficiency about 25 %. So, if we talk about this overall efficiency, it will be about (25% × 8%), so it will be about 2 %.

So, what we can see here, even though these configurations are not so efficient, but practically these are very, very important, because this kind of systems are not emitting any greenhouse gases and we can decide based on the requirement.

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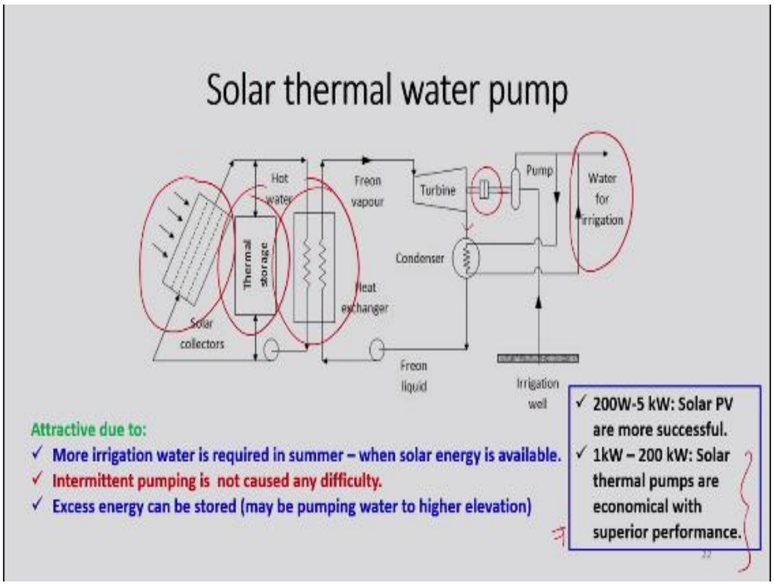

Also, we can use solar thermal energy for water pumping. So here, similar configurations we have. So, we have flat plate collector, we have storage tank and of course, we need to have a heat exchanger to exchange the heat from the water to the working fluid used in the organic rankine cycle and we can generate electricity. So, once we have generated electricity, that can be used to pump water and part of the water can also be used to condense the fluid coming out from the turbine.

And this water pumping can be applied in irrigation and other systems, where pump work is required. So, why this kind of system is quite attractive, because more irrigation water is required in summer, when solar energy is available. The intermittent pumping is not caused any difficulty, because solar radiation is fluctuating, so that is intermittent. So, this intermittent pumping is not caused any difficulty.

So, excess energy can be stored, may be pumping water to a higher elevation and whenever required, that can be channelized and re energy can be generated. So, for small scale, say about 200 W to 5 kW solar PV powered water pumping are quite successful, but for large scale, say in the range of 1 kW to 200 kW, solar thermal pumps are economical with superior performance, that we should keep in mind. For large scale, we should go for solar thermal pumping system and for moderate requirement, we will go for solar PV powered water pumping set.

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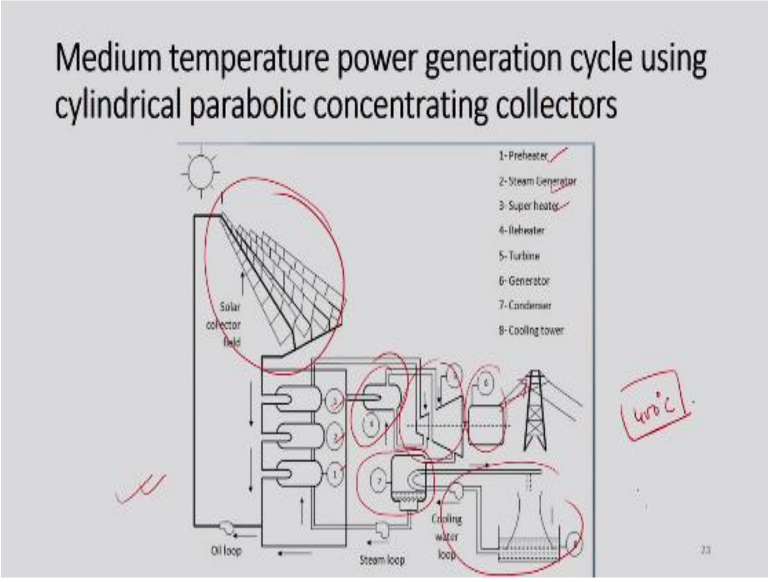

So, as far as medium temperature power generation cycle is concerned, we can go for cylindrical parabolic concentrating collectors. Or we can say, this is solar collector field and here, we will have this 1 is for preheater, 2 is for steam generator, 3 is for super heater and then we will have regenerator, then it will go to the turbine and then we will have generator and then we can distribute the energy in the grid line and we must have a condenser here.

And then for condensing, we need cooling tower. And this is circulated again and again. So, this is a schematic for functioning of a cylindrical parabolic concentrating collector. So here, we can generate thermal energy as well as electrical energy. So, maximum temperature we can go up to 400 ^{o}C, for this kind of system.

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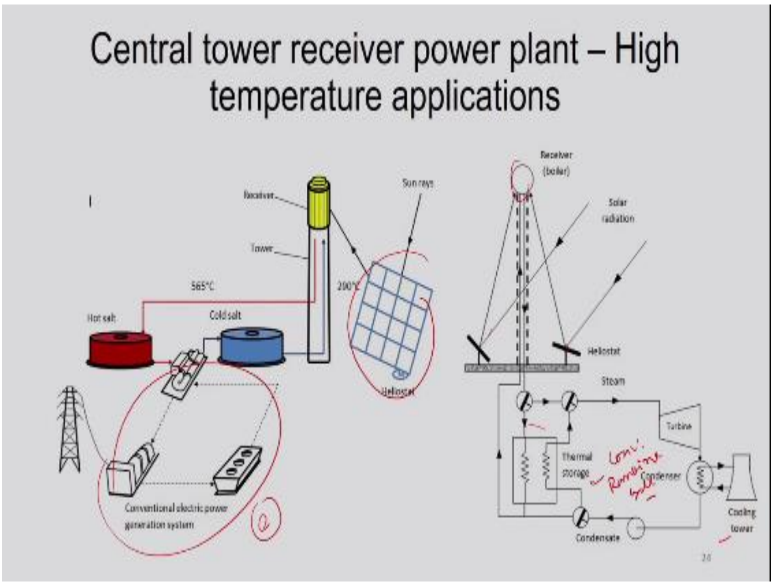

Also, we have learned about central tower receiver power plant. So, these are high temperature applications, so we can go more than 400 ºC; may be 700 ºC, 800 ºC, that kind of temperature we can go and we can generate electricity by using this thermal energy. So, as we have already studied this kind of technology, maybe I will just briefly tell about the functioning of this kind of technology.

So, solar radiation is received by these heliostats and is reflected to this receiver and in this receiver normally what happens, this cold salt is introduced and it is heated up and that is collected and by utilizing heat exchanger, we can extract the heat and this should run in a conventional rankine cycle and we can generate electricity. So, that is what it is shown, these are the heliostat.

Solar radiation falls here, is reflected to this point and then this salt is circulated and heated salt is collected and then heat exchange will be there and then we will have this conventional rankine cycle rankine cycle for electricity generation.

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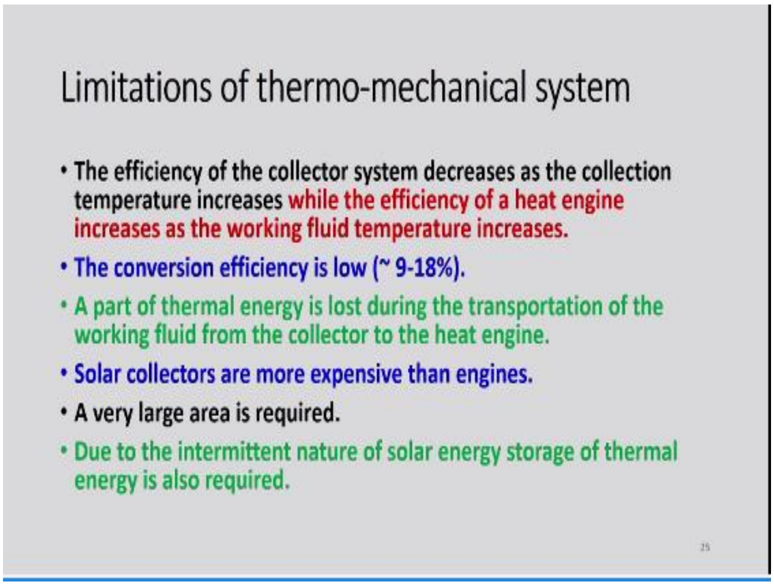

Now what are the limitations of this thermo-mechanical systems, let us study. The efficiency of the collector system decreases as the collection temperature increases. While the efficiency of the heat engine increases as the working fluid temperature increases, this is interesting. The conversion efficiency is low, in this kind of system. A part of thermal energy is lost during the transportation of the working fluid from the collector to the heat engine.

The solar collectors are more expensive than engine, that we must agree. A very large area is required as we can realize now. Due to the intermittent nature of solar energy, storage of thermal energy is also required and with time, this storage material degrades. So, that is a concern, for this kind of thermo mechanical system.

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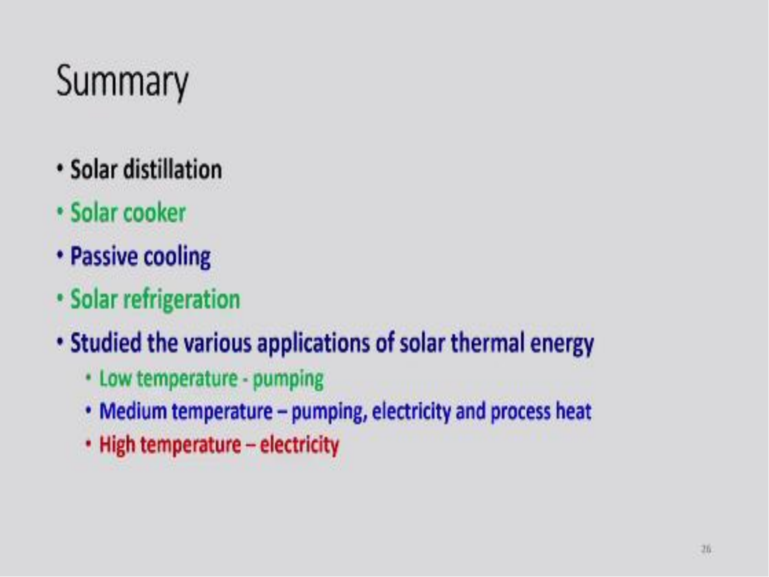

So, now let us summarize, what we have discussed today. We have discussed solar distillation, what is the importance of solar distillations and how performance of solar distillation can be investigated and it is working. We have also discussed solar cooker, we have discussed the analysis and also we have solved one numerical problem to understand the facts. We have learned passive cooling system.

Solar refrigeration and studied the various applications of solar thermal energy, like for low temperature pumping, medium temperature pumping, electricity and process heat generation and high temperature is for electricity generation. I hope you have enjoyed this lecture. Thank you very much for watching. Thank you.