Renewable Energy Engineering – Solar, Wind and Biomass Energy Systems
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Lecture - 08
Concentrating Solar Collectors

Hi everyone, today we are going to discuss about lecture 5 on concentrating solar collectors in renewable energy engineering, solar wind and biomass energy systems.

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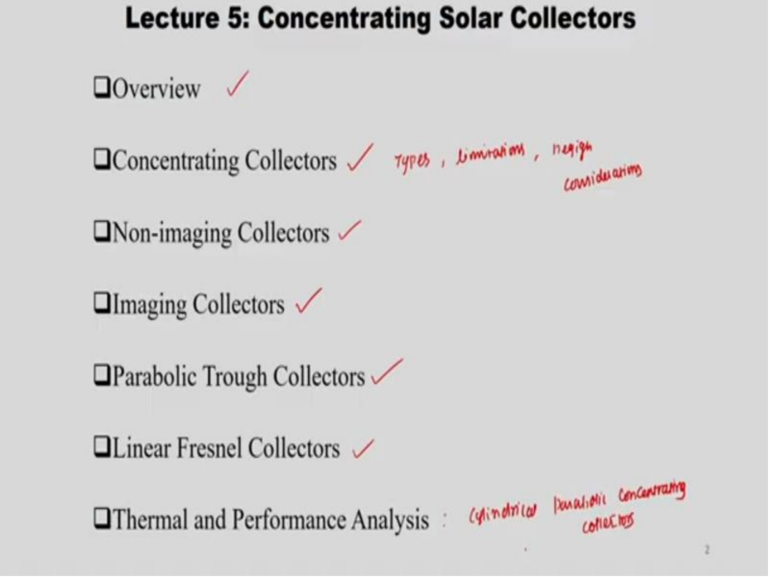

The content goes like this, the overview of concentrating solar collectors and specifically see about concentrating collectors. So what are all the types available and any limitations and using them also design considerations. And then imaging non imaging collectors and concentrating collectors then we review about parabolic and linear fresnel collectors and we do that mullen performance analysis only for cylindrical parabolic concepts concentrating collector.

As we said already for concentrating collectors we need extra optical system which concentrates solar energy for the solar collector. So in a way we are here adding one more extra optical system, but we are not going to discuss in depth about optical system, we are going to discuss concentrating solar collector in terms of its types, varieties available and also in terms of thermal point of view.

So there are many orientations with which you can arrange these concentrating collectors, but if you want in depth knowledge about optical system, you are requested to refer the references given here to understand better.

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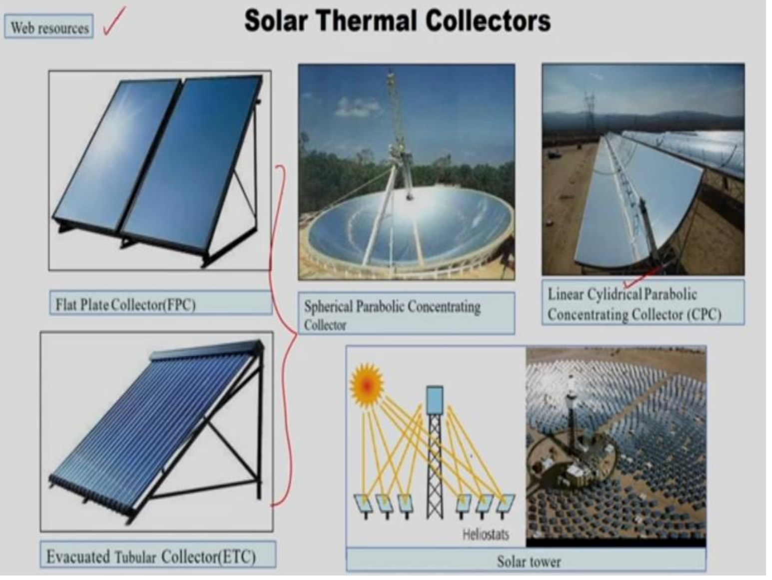

As we have seen in the last lecture of non concentrating collectors, the FPC and ETC comes under that category, both beam and diffusive radiation is collected by the absorber plate and it is used for transferring that collected radiation into working fluid in a way for further thermal applications. But when in terms of concentrating collectors, there are 2 main categories one is point concentration and another one is line concentration.

The linear cylindrical parabolic concentrating collector comes under line concentration category and solar tower comes at a point concentrating category. So here the heliostats are kept to reflect the suns radiation to a point. So here the cylindrical parabolic shape will do the same. Reflection of solar radiation and further given to the absorber tubes which is linear throughout the cylindrical parabolic shape reflector. These all figures were taken from various web sources, the same slide had been used in the non concentrating collectors as well.

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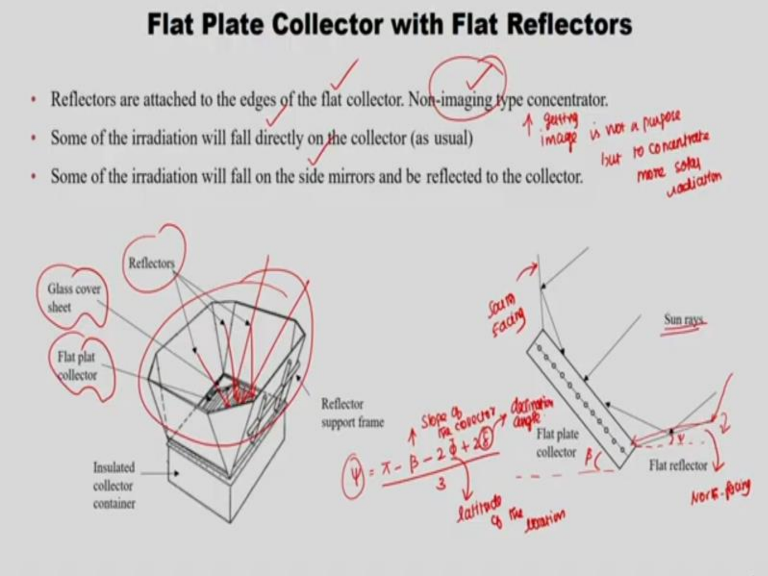

So before moving on to proper concentrating collectors, we are going to see how the flat plate collector can be enhanced to concentrate more solar radiation. So, one such category is this. So, where reflectors are attached to the edge of the flat plate collector, so these collectors are non-imaging type. So here the image is not a, getting image is not a purpose but to concentrate more solar radiation.

So we are not interested in image of the radiation. So that is done by the reflectors which are kept above the normal FPC collector. Some of the radiation will fall directly onto the collector as usual, what you have seen in FPC and some of the radiation will fall on the side mirrors and be reflected to the collector. So this is that arrangement. So these are surrounded by reflectors.

So if you see this box, this box is nothing but a FPC. So above one is glass cover then below which you have a absorber plate as well as the absorber tubes. Below one is the insulated box, insulated bottom plate and this is the reflector support which supports the reflector which is kept about the FPC collector. So some of the radiation directly falls onto FPC and some of the radiations will fall into a reflector and then reflected back to the collector.

So if you see this cross section, this is the flat reflector. So this is normally north facing, this is south facing, this angle also some of the researcher given a formula. So this is psi, this particular psi is equalent to pi - beta – 2phi + 2delta upon 3. So this is slope of the collector, this is beta slope of the collector, so this is phi which is nothing but latitude of the location; delta is nothing but declination angle, particular day of the year.

So you can calculate side accordingly and you can fix the flat mirror. So as we said earlier the sun rays some of them directly falls and some of the falls on this reflector and reflected back to the absorber plate of the collector. One thing we need to make sure is whatever the solar radiation hits on the extreme edge of the reflector should also reflected back to the collector. So that is the check but however, maximum possible way we can do it to take care of this particular fact anyway, this we will discuss in further slides.

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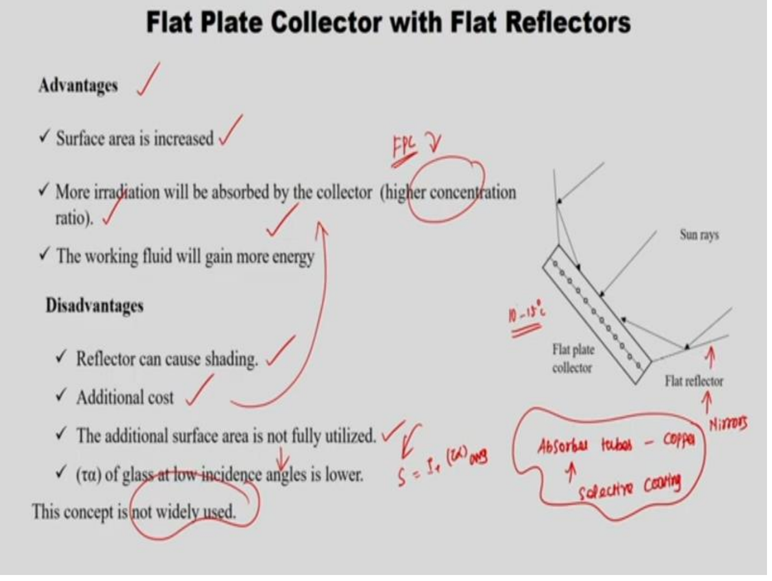

Advantages side the surface area is increased obviously because you are providing 2 more flat reflectors and more radiation will be absorbed by the collector because of high concentration ratio, high concentration ratio in relative to FPC. FPC we do not make any extra effort but here compared to FPC, the concentration ratio is bit increased because we have added more surface area and working fluid will gain more energy obviously we are getting more radiation. So in a way it gets more energy.

Disadvantages side, though we said it increases the surface area for the collection, it also can cause shading effect and additional cost. Additional cost in the sense the addition of reflectors may cost additionally, but one thing we need to remember here, this may go to advantages as well because if we see the absorber plate, tubes etcetera made up of copper and also sometimes we use selective coatings to absorb radiation.

So for that if you are whatever the energy we are gaining, so if you are gaining same energy here by providing reflector then it may be advantages one as well because the reflector is just but the mirrors. So this is the trade off, how much energy we are able to gain with or without reflectors? Because reflector material is mirror, but here if you want to gain more energy you need to use selective coating etcetera.

So cost is nothing but a trade off. And then additional surface area is not fully utilized as I said it is advantage also and disadvantage also. So if you are not taking care of the fact that all energy reflected is gained by the collector, absorber surface then you may not be using this additional surface area fully. And tau alpha product that is transmissivity, absorptivity product of the glass at low incidence angle is lower, if the tau alpha is lower, obviously S is nothing but I T tau alpha average.

So in a way you are getting minimum energy absorber by a absorber plate. So this concept is not widely used because we have dedicated concentrating collectors with low to higher concentration ratio. So in such cases this may not be required by providing additional reflectors probably you will be increasing some 10 to 15 degree temperature. So for this you may not make such an effort.

And also since it is a non imaging collector, but you may require sun tracking as well you need to change according to the sunrays but maybe occasionally or sometimes frequently. So based on which design you use. So because of all these complexities just to increase 10 degree temperature then why need to go for such a design. So that is a decision one user need to take. So then proper concentrating collectors.

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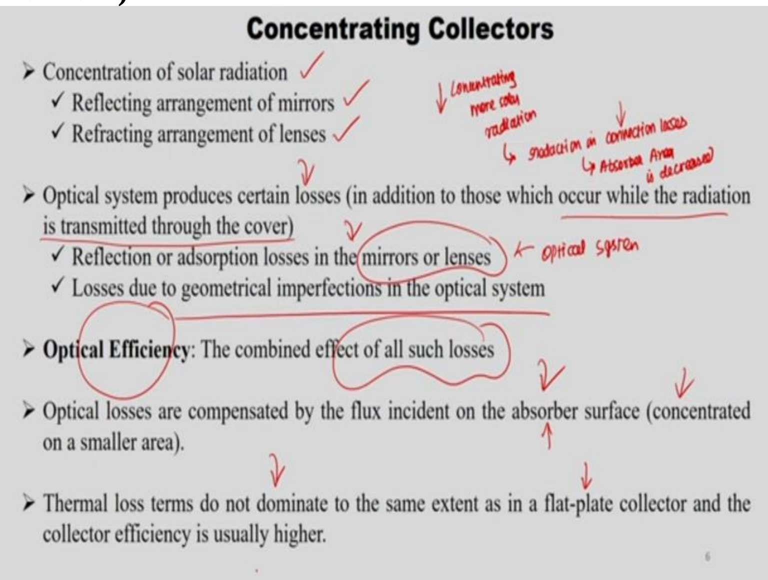

So here the concentration of solar radiation is done by 2 mechanisms one is reflecting arrangement using a mirror and refracting arrangement using lenses. So here the optical system produces certain losses as well. It is not that I am adding the optical system to concentrate more solar energy. So whenever you are going for advantages side, the disadvantages side is associated with the losses.

So already here the concept is you are not only concentrating more solar radiation, in a way you are reducing the absorbing space as well. Reduction in convection losses because you are absorber area is decreased. So when you are happy about reducing the convection losses, you are introducing an optical system with its own losses. So in addition to those occur while radiation is transmitted through the glass cover, you are again adding some more optical losses.

So that is due to reflection or absorption losses in the mirrors or lenses which are used in the optical system. Second one is the losses due to geometrical imperfections in the optical system. You have seen the spherical and cylindrical and cylindrical parabolic or proper parabolic there are many shapes. So each has its own advantages and disadvantages, you are introducing one more losses due to geometrical imperfections in the optical system as well.

Even though you are introducing the optical system you need to track the sun right because in concentrating collectors, we use only the beam radiation. You are adding geometrical imperfections in the optical system as well. So these losses to calculate these losses we supposed to calculate optical efficiency of the system as well. So here also there is a trade off. So already you have convection and reradiation losses.

So you are having glass cover as well as the absorber space to reduce the absorber space and gain more energy we are introducing the optical system. So one need to do tradeoff between this optical losses and whatever losses already you had due to convection and reradiation. So using that trade off, if you want really the higher temperature and higher concentration ratio for your thermal applications, you can go for concentrating collectors.

So if your thermal application requests low temperature then you can happily go for non concentrating collectors either ETC or FPC. So these optical losses compensated by the flux incident on the absorber surface. So as I said earlier, this is concentrated on a smaller area. So thermal loss terms do not dominate to the same extent as in the FPC because you were absorbers surface area is decreased.

So you would not get the thermal losses whatever you got it you FPC and the collector efficiency is usually higher. So this optical loss is also relatively low compared to the thermal losses, what you had experienced in FPC? The collector efficiency is higher in concentrating collectors.

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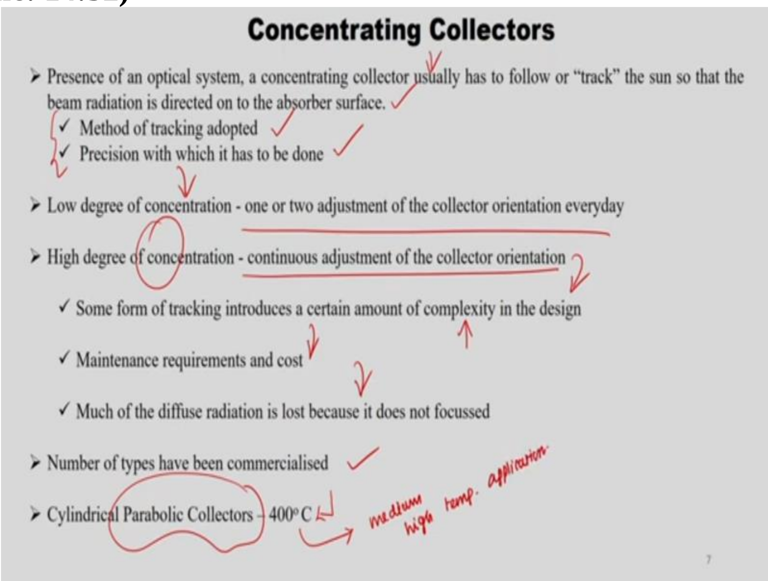

In the presence of optical system the concentrating collector usually has to follow or track the sun, so then the beam radiation is directed on to the absorber surface. So here we are concentrating only on beam radiation, to get beam radiation all the time or throughout the day, so we suppose to track the sun. So the method of tracking adopted and the precision with which it has to be done, these 2 are the design considerations one has to think while designing the optical system.

And if you require low degree of concentration then one or 2 adjustment of the collector orientation every day is enough, but if you require higher degree of concentration then continuous adjustment of the collector orientation should be done. So this how we can achieve some form of tracking introduces a certain amount of complexity in the design? So it cannot be done manually. So you need to introduce the mechanical system which tracks the sun and with the continuous adjustment throughout the day.

You are adding certain complexities in the design of the optical system and maintenance requirements and cost is high because of this extra optical system with some mechanical design to track the sun. And much of the diffusive radiation is lost because diffusive radiation is also being used in FPC but here we are only concentrating on beam radiation, diffusive radiation also lost.

For example, the location which does not have much of beam radiation and which does have diffusive radiation high that place it may not be a wise idea to use concentrating collectors. So there are number of types have been commercialized till now, the most familiar design which was tried is cylindrical parabolic collector which gives about, around 400 degree centigrade temperature. So this is very much desirable in medium and certain high temperature applications.

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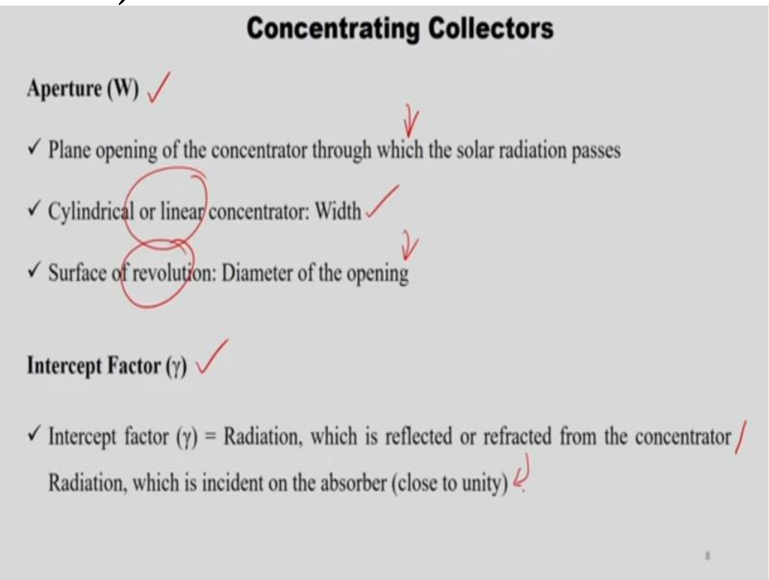

So next one is, there are 4 terminologies we would be using in concentrating collectors that we are going to see. One is aperture. So this is nothing better plane opening of the concentrator through which solar radiation passes. So if you have cylindrical or linear concentrated then width is used as a aperture, if you have surface of revolution then diameter of the opening is used as a aperture. Second one is intercept factor, it is a ratio between radiation which was reflected or refracted from the concentrator to the radiation which is incident on the absorber. So normally it should be close to unity.

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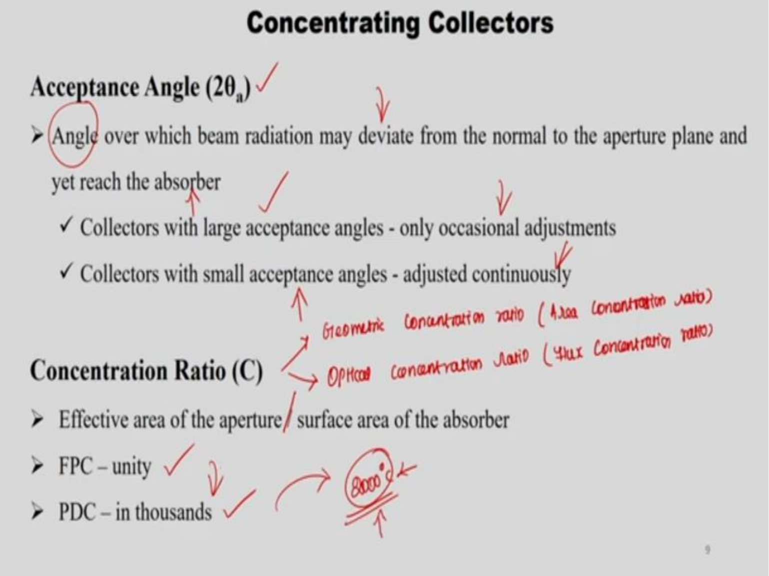

Next one is acceptance angle which is 2 theta a, the angle over which beam radiation may deviate from the normal to the aperture plane and yet reach the absorber. As I said earlier, so we need to always make sure that the beam radiation should be normal to the aperture plane. So I mean we may not be able to track whole day. So continuous tracking adjustments are there, but still the flexible one is, you are doing 2 or 3 adjustments.

But still you are getting the solar radiation reflected by the concentrator and reaching the lesser absorber surface that is what is wanted one, so in a way under which beam radiation may deviate from the normal to the aperture plane, but still it reaches that absorber. So that is the angle is called acceptance angle, so collector with larger acceptance angle only need occasional adjustments because even if it deviates it reaches the observer.

But collector with the small acceptance angle needed continuous adjustment. So, you need to use some mechanical design. The 4th important parameter is concentration ratio. So there are 2 types one is geometric concentration ratio, second one is of optical concentration ratio. So this is sometimes called as area concentration ratio. Optical concentration is called as flux concentration ratio as well.

So this is nothing but the ratio of effective area of the aperture to the surface area of the absorber. For FPC it is unity because aperture area, absorber area, both are same for FPC for PDC parabolic dish concentrator it is in thousands. That is why it is able to even produce around 2000 degree centigrade temperature for high temperature applications, but here it is the ideal temperature.

But to get this ideal temperature then you need to have larger size PDC as well, parabolic dish collector, but certain limitations will stop you to do that, but if you use this kind of ideal concentration ratio, you may even reach up to 2000 degree centigrade temperature.

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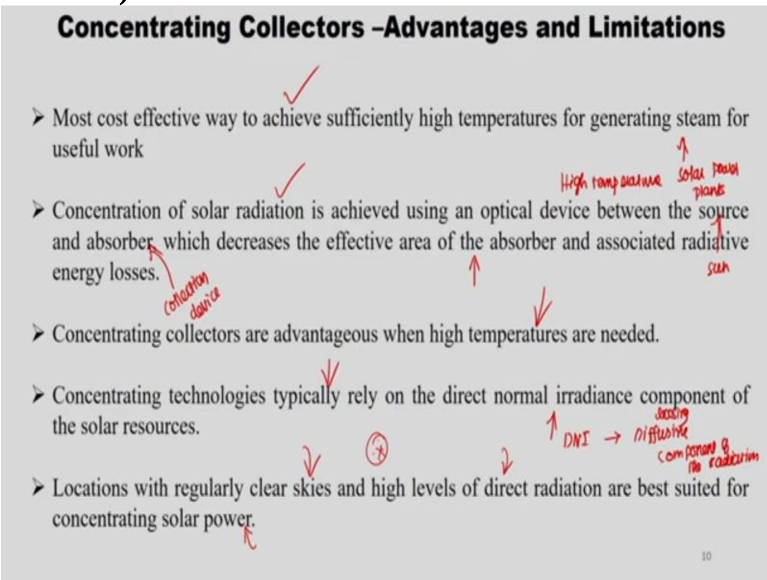

Advantages and limitations of concentrating collectors, they are most cost effective way to achieve sufficiently high temperatures for generating steam for useful work. So normally we use for high temperature power plant applications, high temperature solar power plant applications. So in a way it is a efficient methodology to use for that particular solar thermal application.

And concentration of solar radiation is achieved using an optical device between the source and the absorber, source is here sun, absorber is nothing but a collection device. So which decreases the effective area of the absorber and associated radiative as well as convection losses and concentrating collectors are advantages when high temperatures are needed. This already I told, unless otherwise you go for a high temperature application it would be a wise idea to FPC or ETC.

Concentrating technologies typically rely on the DNI, direct normal irradiance component of the solar sources in a way you are losing diffusive component of the radiation. Locations with the regularly clear skies and higher levels of DNI, direct normal irradiance are the best suited for concentrating solar power plant, this specific location is also important when you intend to use concentrating collectors for any thermal applications.

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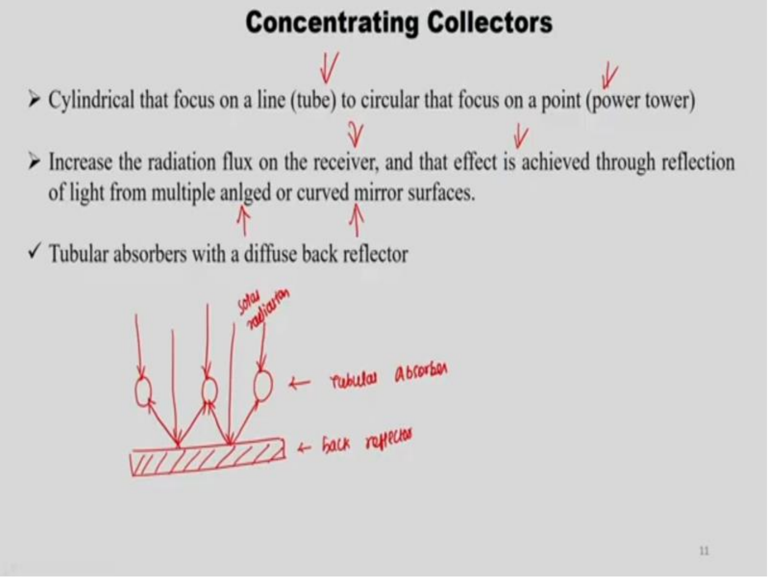

So there are various types of concentrating collectors. So here we are going to see about some 8 or 9. I request you to check the references given in this particular lecture for more designs and more varieties. So cylindrical that focus on a line which is nothing but an absorber tube to circular that focus on a point which is nothing but a power tower, there are many varieties. So increase the radiation flux on the receiver and that effect is achieved through reflection of light from multiple angled and multiple curved mirror surface.

So this is the basic working principle, so based on that there are numerous varieties of design. So here we are going to see probably 8 or 9, so the first one is tubular absorbers with that diffuse back reflector. So the design is you have a tubular absorber. So you have one back reflector. So this is back reflector. So this is your tubular absorber. So solar radiation directly comes and hits the absorber surface as well as the radiation comes to reflector and reflected back to the absorber. So this is first a design where tubular absorbers with the diffusive back reflector.

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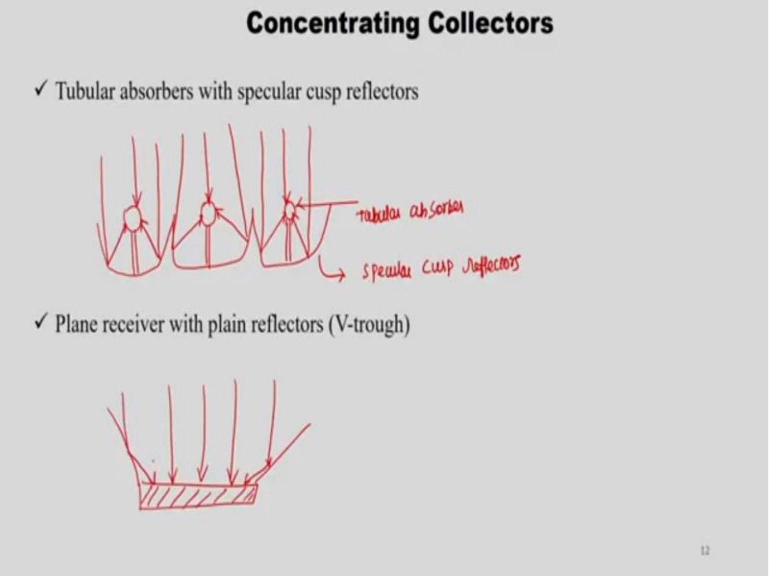

The second one is tubular absorbers with the specular cusp reflectors. So the same concept, but you have this kind of arrangement. So here your absorber is attached. So the direction, direct radiation comes and hits this is nothing but your tubular absorber, this is specular cusp reflector. So the remaining radiation comes here and reflects back comes here reflects back. They should be of same shape because I am doing it in drawing, so I did not give here the figure, so that when I am drawing you understand better, how it is thought and designed?

So the next one is plane receiver with the plane, plain reflectors, this we have already seen for FPC category. So this is your FPC, where your absorber plate is above. So here you have a 2 reflectors. So direct suns radiation comes and hits and the radiation which falls on the reflector is reflected back to the absorber. So this is plane receiver with plain reflectors.

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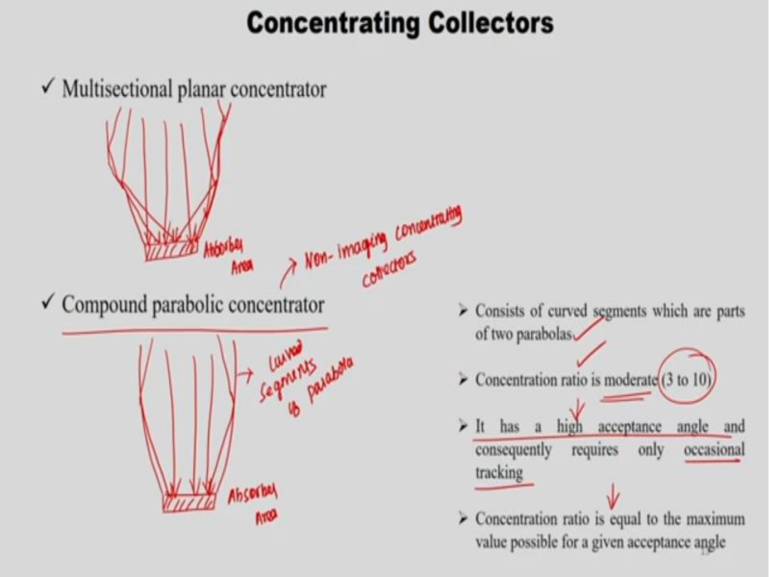

The next one is multi sectional planar concentrator. So here you have a absorber area, this is your absorber area, so instead of having one particular reflector, so you have multi sectional reflectors, kind of. So direct radiation normally comes then reflector radiation, so this comes here and the hits there then on more time comes here. So comes here, hits here then reflected back. So some directly comes in one particular section and reflected back to the absorber.

So this comes in one particular section and reflected back to the absorber. So this is multi sectional. So this is one section, this is another section, this is another section. So if you keep multi sectional then you can get more energy reflected back to the absorber and the next one is compound parabolic concentrator. So this is the non imaging concentrator, non imaging concentrating collectors very famous one.

So here you have an absorber area you have section of reflectors. So direct radiation comes directly and the radiation comes and reflected in the reflector and comes here. So this is called compound parabolic concentrator. So here are some of the points are also given consists of curved segments which are parts of 2 parabolas, in the parabola we have taken 2 curved segments. So this is segments of curved segments of parabola.

Concentration ratio is around moderate concentration ratio, 3 to 10 and it has a high acceptance angle and consequently requires only occasional tracking. So, if you go for proper concentrating collectors, imaging concentrating collectors, you might require the continuous tracking, but here you will get the medium concentration ratio of 3 to 10 without much tracking of the sun.

So it also has high acceptance angle and concentration ratio of whatever the compound parabolic collector gives which is equivalent to maximum value possible for the given acceptance angle. With this given acceptance angle, you do not require much tracking. So in that way the concentration ratio it gives without tracking of the sun, it is quite impressive. So in that way, it is being applied in much of thermal applications in place of imaging concentrating collectors.

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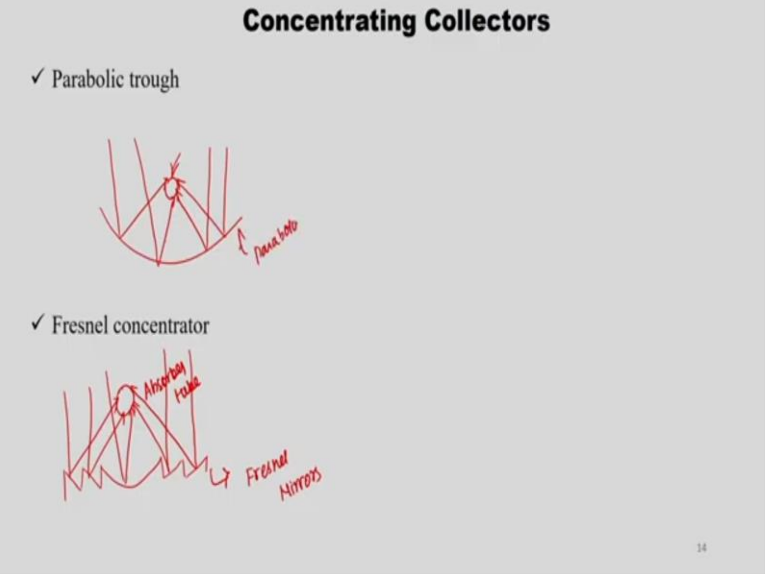

The next one is parabolic trough. So this you are now familiar with. So here you have heads back. So this is parabolic trough and then Fresnel concentrator, so Fresnel mirrors are arranged in this way. So you have a absorber tube, radiation comes, reflects to the absorber. So this is Fresnel concentrator, these are Fresnel mirrors, so this is section of parabola.

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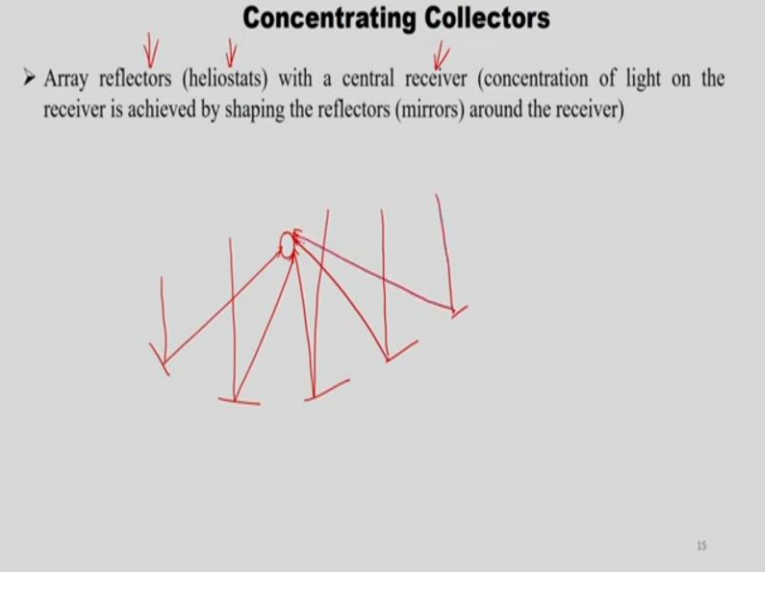

The next one is, whatever we have done here the Fresnel mirrors it is kept in one particular angle only. So here we have an array of reflectors which are nothing but heliostats with the central receiver normally, concentration of the light on the receiver is achieved by shaping the reflectors around the receiver. So the heliostats are shaped into particular direction to reflect the suns radiation into the central receiver system. So in this way, so you have differently shaped reflectors, those are heliostats. So this is that way like this.

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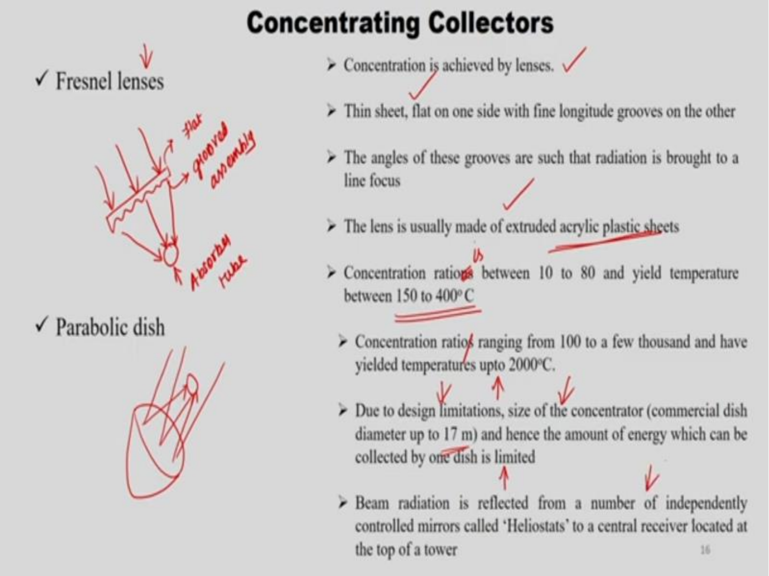

We have already said Fresnel mirrors, but that same thing can be done using Fresnel lenses as well, so how to do that? So this is Fresnel lenses, so when solar radiation comes through it, it is reflected at the point. So concentration is achieved by lenses instead of mirrors. So this is a thin sheet, flat on one side. So this side if you see it is a flat and other side it has grooves such that the radiation is brought to a line focus. So the angle of group is designed in such a way that radiation is brought to the line focus.

So this grooved assembly, so this is your absorber tube. The lens is usually made of extruded acrylic plastic sheets. And the concentration ratio is between 10 to 80 and yield a temperature between 150 to 400 degrees centigrade. The next one is parabolic dish. So you have absorber tube here. So, the concentration ratio ranging from 100 to a few 1000 for parabolic dish and have yielded temperatures up to 2000 degrees centigrade.

As I said earlier due to design limitations, the size of the concentrator till now, achieved is around 17 meter and hence the amount of energy which can be collected by one dish is limited. But if you could make the compact design then you may achieve higher temperature up to 2000 degrees centigrade. So beam radiation is reflected from a number of independently controlled mirrors called heliostats to a central receiver system located at the top of the tower.

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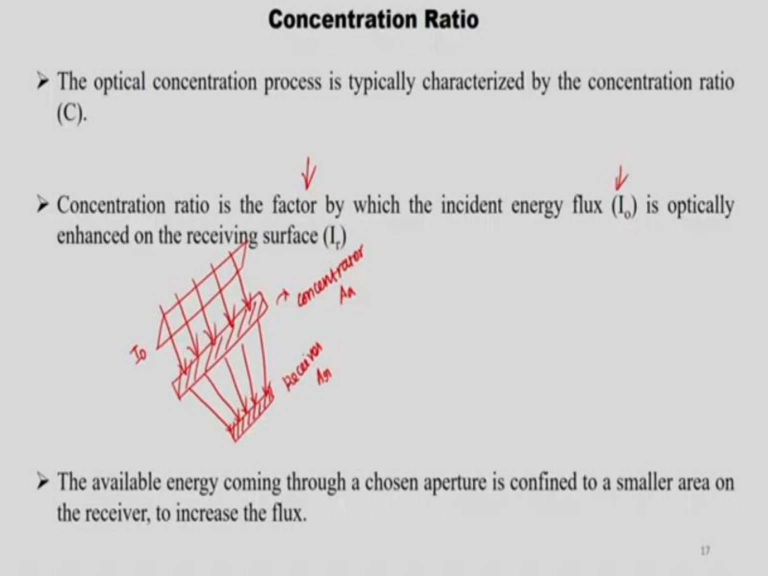

The next one is the optical concentration process which is typically characterized by the concentration ratio. So concentration ratio is the factor by which incident energy flux, I naught is optically enhanced on the receiving surface. So if you see, so this is your solar radiation, this is aperture through which your I naught is passing which is nothing but a incident energy flux.

So here you have a concentrator, so this we call it as a aperture area through which when it passes it hits on the much lesser area of the absorber. So this is the receiver or absorber, so do not get confused with the receiver and absorber terminology. So the receiver includes absorber as well. Receiver is which is receiving the radiation because it is absorbing we are sometimes tell the same as absorber as well. So this is nothing but A r. So the available energy coming through a chosen aperture is confined to a small area on a receiver to increase the flux, increase the flux in the sense per meter square how much energy you are getting?

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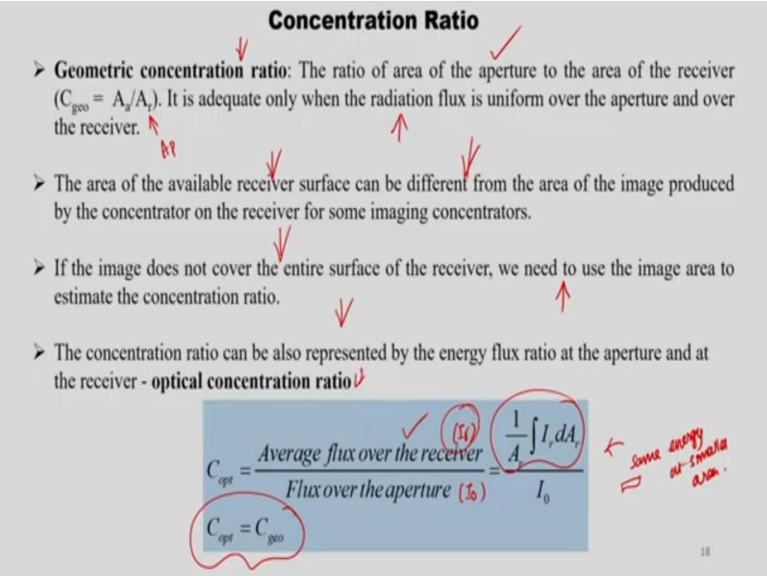

Geometric concentration ratio already I defined which is nothing but a area of the aperture to the area of the receiver or sometimes this can be said as A p which is nothing but the absorber plate or absorber tube area. It is adequate only when the radiation flux is uniform over the aperture and over the receiver. As I said earlier, if the flux what you are getting in the aperture as well as receiver if it is not same then you cannot use this definition of geometric concentration ratio.

Then you are supposed to use the definition of optical concentration ratio. So the area of the available receiver surface can be different from the area of the image produced by the concentrator on the receiver for some imaging concentrators. So non imaging concentrators it may not be a problem, for imaging concentrators, if the image produced by the concentrator on the receiver is not same as the area of the available receiver surface then you might need to use optical concentration ratio.

If that image does not cover the entire surface of the receiver then we need to use image area of the receiver to estimate the concentration ratio. So here what we are using is aperture area and receiver area, but if the image produced by the concentrator does not cover the entire surface of the receiver then we need to use image area instead of simple geometric areas, or otherwise it is a good practice to use directly optical concentration ratio.

The concentration ratio can also be represented by the energy flux ratio at the aperture and at the receiver, our aim is to get the same energy at the smaller area right, same energy at smaller area. So we can use optical concentration ratio, it is nothing but average flux over the receiver to the flux over the aperture. So this is the average flux 1 upon A r integral of I r d A r upon I naught. So this is the incident flux.

So, when optical concentration ratio and a geometric concentration ratio is similar, as I said, so this is I naught which is average flux over the receiver is radians. So when the average I r is equal to I naught then you can use C opt = C geo which is nothing but geometric concentration ratio.

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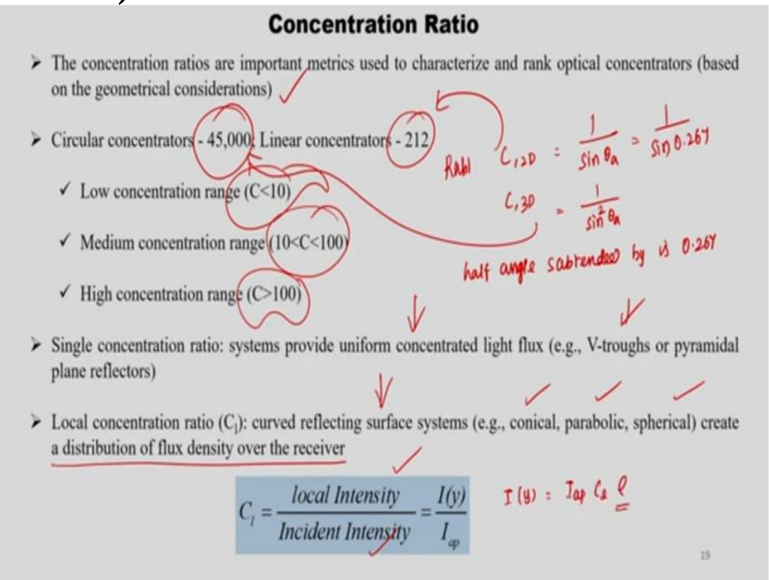

Concentration ratios are important metrics to characterize and rank the optical concentrators, based on their geometrical considerations. The ideal case is for circular concentration you can get around 45,000, for linear concentration you can get around 212. So how we have decided or we came up with this particular number is there is a researcher called Rabl. So he came up with the concentration ratio formula for planar as well as for 3d.

So he said that this is 1 upon sin theta a, so theta a, you know that is nothing but a half of the acceptance angle. So the half angle subtended by the sun is point 267 degree, if you substitute here, so this is sin squared, sin point 267 you would get for linear. So if you substitute the same angle you would get for 3d which is nothing but circular concentrators. Anyway the lower concentration ratio ranges C which is less than 10, medium concentration range is, concentration ratio between 10 and 100, high concentration range is, when concentration ratio is greater than 100.

So single concentration ratio as we said either you can use optical or geometrical for the systems, V troughs or pyramidal plane reflectors which provides uniform concentrated light flux. And some systems we need to analyze based on local concentration ratio which is nothing but local intensity upon incident intensity. So, there are curved reflecting surfaces which are conical, parabolic, spherical which create a distribution of flux density over the receiver.

So in such case you are supposed to use the local concentration ratio which is nothing but local intensity upon incident intensity. And here to calculate the local intensity which is I of y which is equivalent to I of ap into C l, sometimes it is multiplied with rho.

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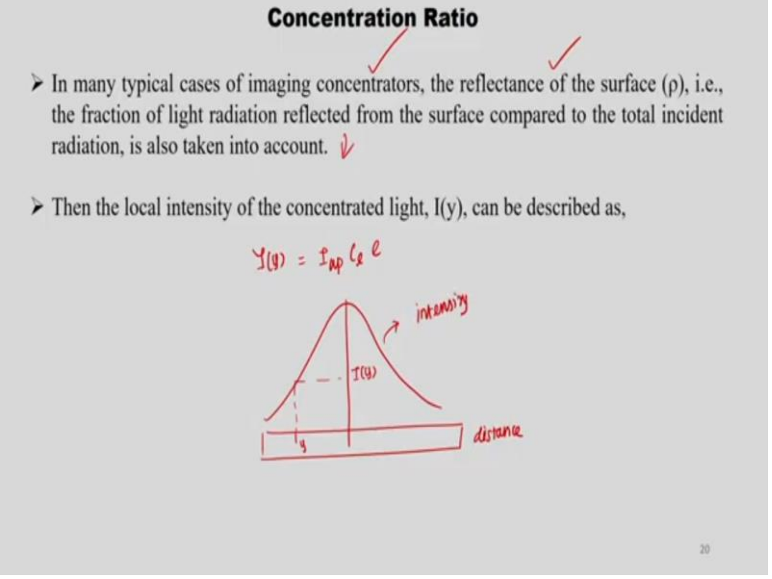

So that we see here in many typical cases of imaging collectors, the reflectance of the surface which is nothing but rho that is the fraction of light radiation reflected from the surface compared to the total incident radiation is also taken into account. So in a way I of y is calculated as I of ap into C l, local concentration ratio into rho. So how do we calculate this particular I y? So this is the distance, this is your intensity. So for example, at some point of y, you would require intensity then it is nothing but I y, this is local intensity. So this is y axis is intensity.

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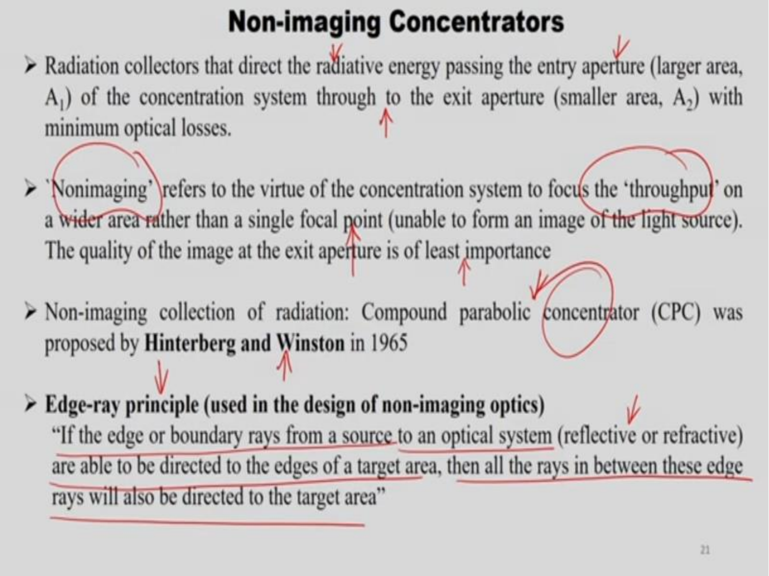

So the next one is non imaging concentrators, the radiation collectors that direct the radiative energy passing through the entry aperture which is of large area to the concentration system through the exit aperture with the smaller area which is nothing but A 2 with the minimum optical losses. This is what we suppose to do on concentration. So this non imaging refers to the virtue of the concentration system to focus the throughput on a wider area, rather than a single focal point.

So these kind of collectors they may not be able to produce the form of image of the light source, the quality of the image at the exit aperture is of least importance because that is not for the purpose this particular non imaging concentrators are designed for. So it focuses only on the throughput on the wider area rather than pointing into a single focal point and in a way it will not be able to produce the image of the light source.

So this particular idea of compound parabolic collector, CPC which is nothing but a non imaging collector was proposed by Hinterberg and Winston in 1965, from then it is widely used. It works based on the edge ray principle which is used in designing of non imaging optics, if the edge or boundary race from the source to an optical system, reflective or refractive are able to directed the edges of target area then all the rays in between these edge rays will also be directed to target area. This is the basis of energy ray principle, so with which non imaging concentrators work.

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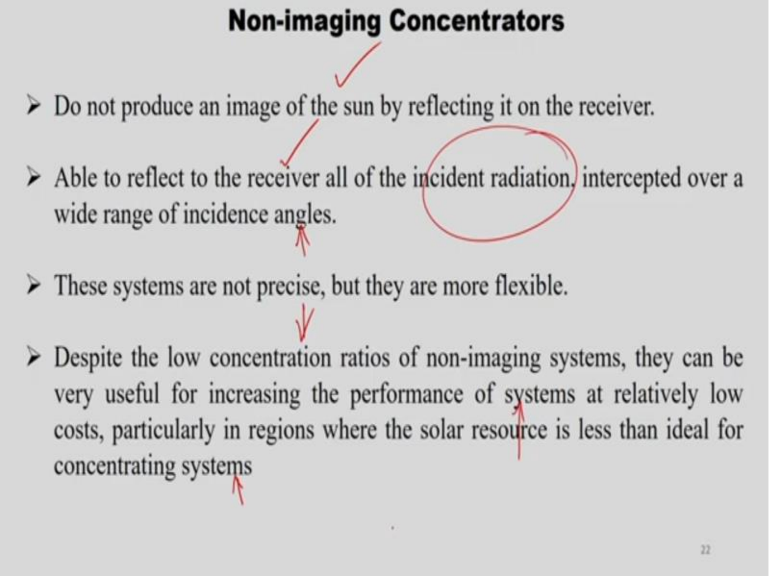

They do not produce an image of the sun by reflecting it into the receiver and able to reflect to the receiver all of the incident radiation intercepted over a wide range of incidence angles. These systems are not precise, but they are more flexible. And despite the low concentration ratios of non imaging systems, they can be very much useful for increasing the performance of the systems at relatively low costs.

Particularly in regions where solar resource is less than ideal for proper concentrating systems because it takes all of the radiation. So by concentrating collectors only targets on beam radiation. So you need more energy, but you are in a place where that particular place is not ideal for concentrating collectors then you can use non imaging concentrating collectors which is nothing but the compound parabolic concentrators.

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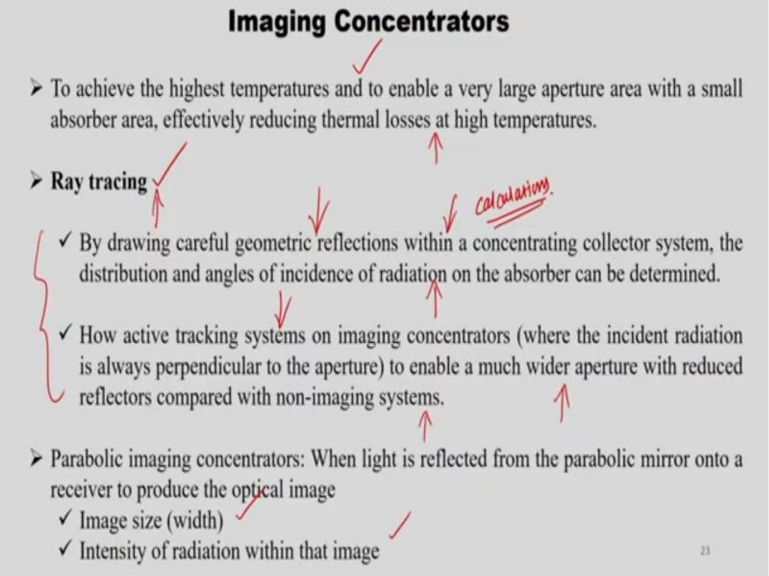

Imaging concentrators to achieve the highest temperature and to enable very a larger aperture area with a small absorber area in a way to effectively reducing the thermal losses at a high temperature, these imaging concentrators are being used. Here also the ray tracing is very much important by drawing careful geometric reflections within a concentrating collector system, the distribution and angles of incidence of radiation on the absorber can be determined.

So it involves proper calculations maybe digital calculations we can say, also how active tracking systems on imaging concentrators? This is also important because where the incident concentration is always perpendicular to the aperture, to enable much wider aperture with the reduced reflectors compared to non imaging system, so these 2 things also to be kept in mind when we do ray tracing.

In parabolic imaging concentrators when light is reflected from the parabolic mirror onto the receiver to produce optical image, 2 parameters to be calculated, one is image size which is nothing but width of the concentrator, another one is intensity of radiation within that image.

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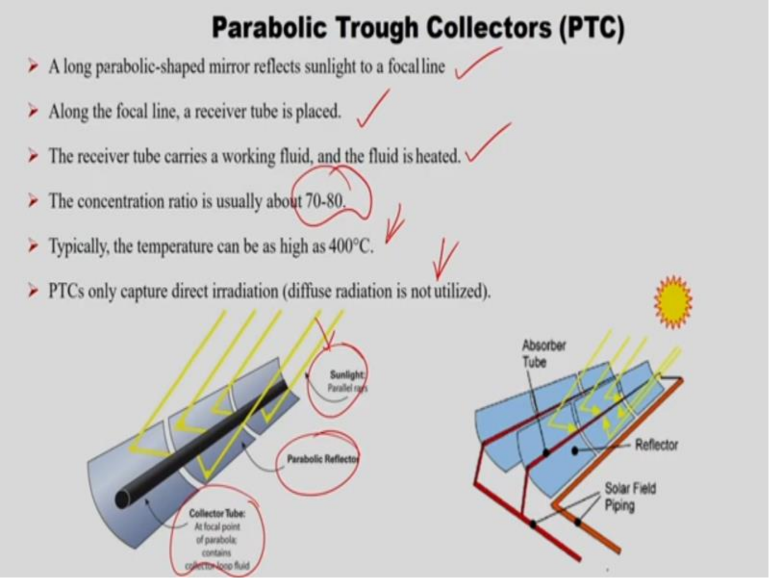

So this is PTC a long parabolic shaped mirror, reflects the suns sunlight to a focal point. So these are nothing but a parabolic reflectors. This is suns rays and this is the collector tube at focal point of the parabola which contains the collector loop fluid, along the focal length the receiver tube is kept that is nothing but a absorber tube, the receiver tube carries the working fluid and the fluid is heated.

The concentration ratio achieved by PTC is around 70 to 80, typically the temperature can be as high as 400 degrees centigrade and PTC only capture the direct radiation and diffusive radiation is not being utilized. So this is a header pipe as we said in the FPC, here also it collects all the hot fluid and goes to the thermal applications wherever we wanted.

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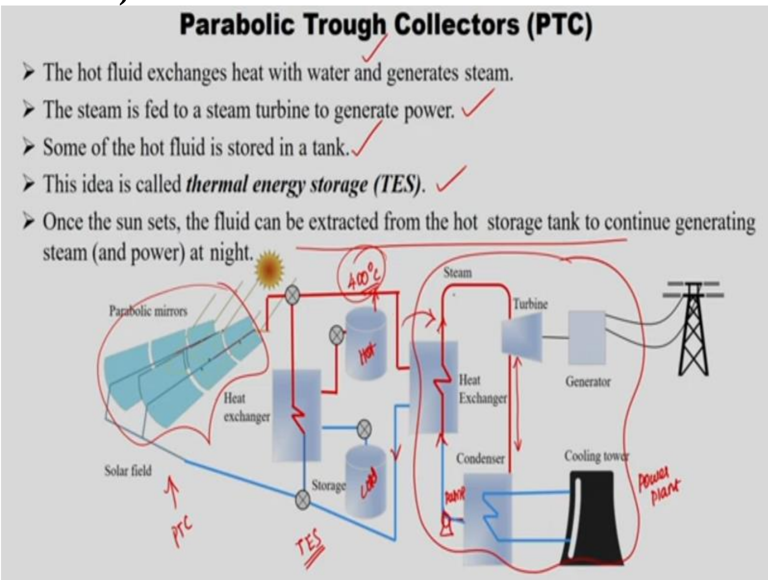

So this is in larger picture with the thermal energy storage system which is nothing but TES and this is the power plant which produces the electricity. So this is connected with the PTC, parabolic trough concentrator. So here hot fluid exchanges the heat with the water and generates the steam, the steam is fed to the steam turbine to generate power. Some of the hot fluid is stored in a tank, this idea is called thermal energy storage system, we will be seeing in next week.

Once the sun sets the fluid can be extracted from the hot storage tank and continuing generating the steam and the power at night. So first we will see this power plant. So here you have a turbine, when it rotates it creates the electricity via generator. Then after the kinetic energy being spent the fluid is sent to the condenser where it loses its heat and becomes the cold fluid and it is pumped, this is the pump, pumped back to the heat exchanger where it receives heats from outside fluid.

And it generates the steam then stainless fed again to the turbine then it generates the electricity and the slope is closed. So to convert this normal cold water into a steam so we will be using some of the hot fluid. So that is given by the parabolic mirrors. So we already said that it can create around 400 degree centigrade temperature heat transfer fluid. So which this amount of heat produced by around 400 degree centigrade temperature is being used here to convert the cold water into steam.

So once it loses its heat it becomes cold then it is again going to the parabolic mirror. So this operation continues in the day. If we want to operate the same in the night then PTC cannot provide the 400 degree centigrade temperature. So in a way it is stored. So whenever it produces excess, the thermal energy storage system is nothing but whenever you gain the extra energy you store it and you use when there is a demand for energy. So in a way it is stored in the storage tank, so this is cold, this is hot.

So the cold fluid passes through this heat exchanger and takes the heat from the PTC, the extra heat whatever is given for power generation, the extra heat can be stored in a cold fluid which is passing through it and kept in the hot tank. So whenever it is required when off sunshine hours this is being supplied to another heat exchanger to produce the steam. The same way whatever it comes, night you cannot directly fed into PTC. Then it also can be stored in the colder storage unit for getting charged using this heat exchanger through PTC.

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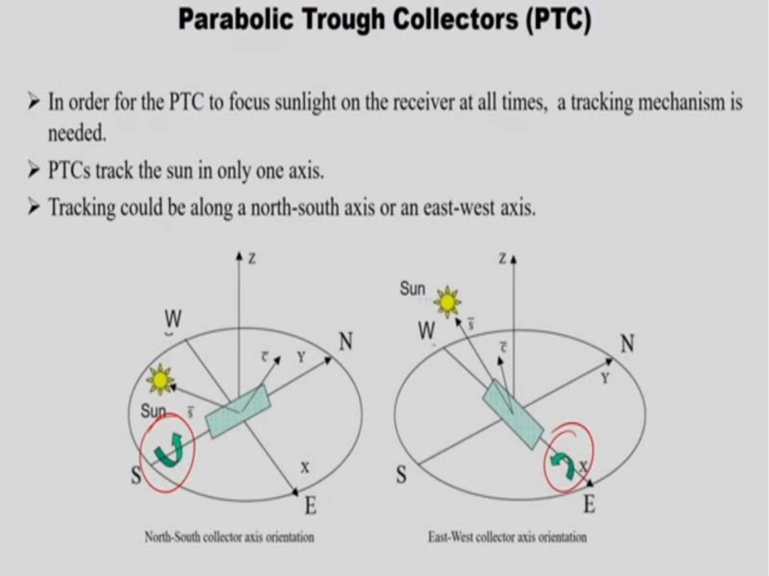

So this is the sun tracking either it can be done via north south or east west. As I said earlier, we are not going to discuss in detail about this tracking system and optical system. So we are concentrating only on thermal part of it. So I am not going into detail. So if you require some in depth details you are requested to refer the references given here.

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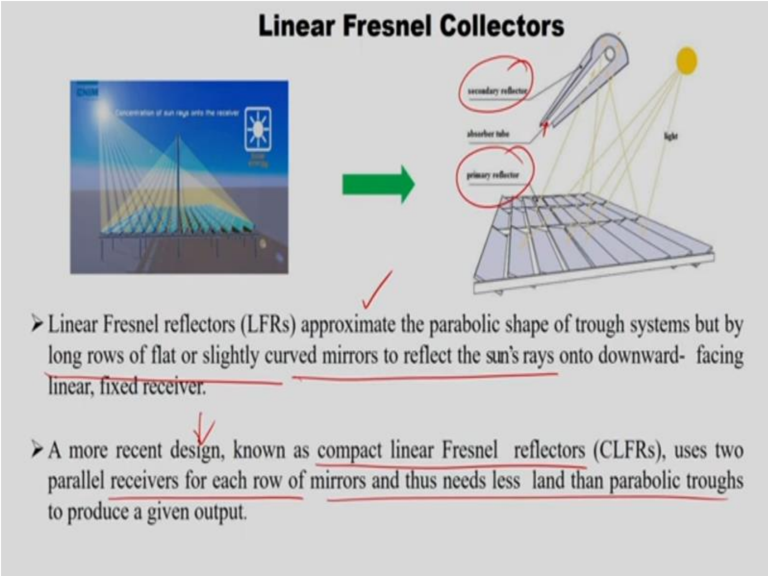

The next one is linear Fresnel collectors. So these collectors approximate the parabolic shape of trough system but by long rows of flat or slightly curved mirrors to reflect the suns rays into downward facing linear fixed a receiver. So this is nothing but absorber tube, this is secondary reflector, the primary reflectors are nothing but the Fresnel mirrors. And most recent design in this category is compact linear Fresnel reflectors which uses 2 parallel receivers for each row of mirrors.

And thus needs less land than the parabolic troughs to produce given output, instead of one receiver it may use parallel receivers for each row of the Fresnel mirrors.

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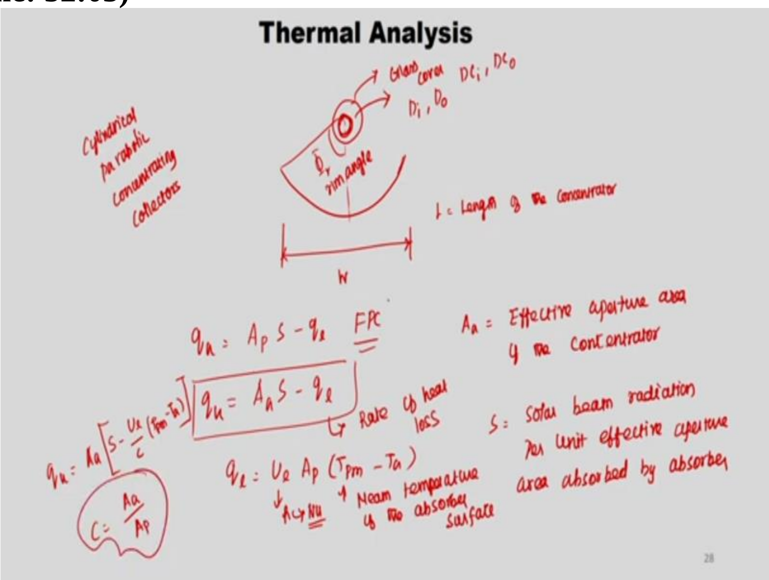

So on thermal analysis part, we are not going to discuss about in depth because here if you see it requests a lot of time to go for each kind of concentrating collectors. So in short, what we are going to see here is the cylindrical parabolic concentrating collectors. So this is nothing but width of the concentrator and l is the length of the concentrator and this is your absorber tube, this is nothing but phi r, we call it as a rim angle.

So for the absorber tube inner diameter is D i, the outer diameter is D naught, so this is absorber tube and above which there is a glass cover. So for that the diameter is DC i, cover system DC naught. We already know the useful energy this A p S – q l for FPC. So there you are plate area and aperture area is same, but here it is based on aperture area A a S – q l. So what is A a?

A a is nothing but effective aperture area of the concentrator. And q l is rate of heat loss. So S is nothing but solar beam radiation per unit effective aperture area absorbed by absorber. So q u is A a S – q l, q l is same way. You are supposed to calculate u l A p T pm – T a. So what is T pm? Mean temperature of the absorber surface. Again to calculate u l, you would require the local heat transfer coefficient h.

So that can be taken from any Nusselt number correlations. So once you know q 1 then q u is nothing but, actual q u is nothing but A a into S - u l upon c T pm – T a. This is C, C is nothing but A a upon A p. A p is nothing but the absorber surface. This is the way thermal analysis to be done here also you will have that FR factor and all.

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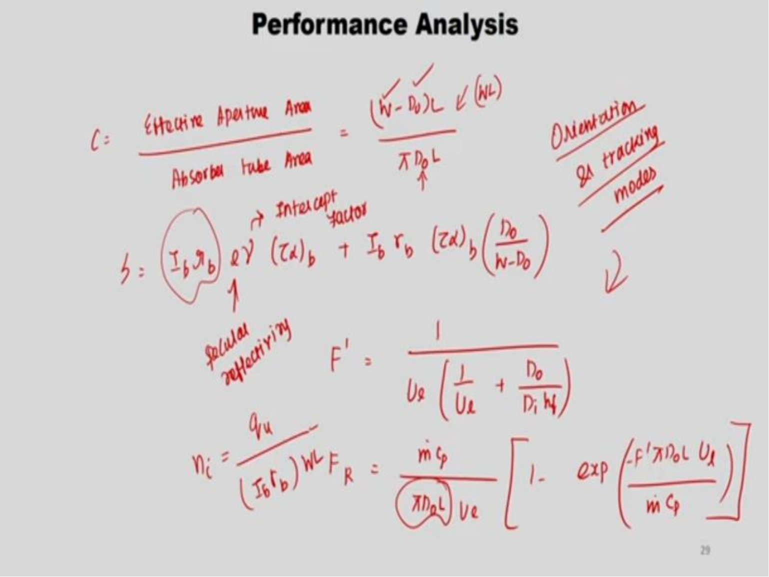

So if you want to calculate the performance analysis of same cylindrical parabolic concentrating collectors you can also do, so where your C which is nothing but the effective aperture area upon absorber tube area, so which is equivalent to W - D naught into L upon pi D naught L. So where W is width of the concentrator, this is absorber tube outside diameter, L is length of the concentrator.

So this is outside diameter of the absorber tube, L is the width of the concentrator, some books use WL as well here and what you require is the S. S is nothing but I b r b rho gamma tau alpha b + I b r b tau alpha b D naught upon W - D naught. So what is rho? rho is specular reflectivity. So what is gamma, gamma is the intercept factor and then the F dash, F dash is nothing but 1 upon U l + D naught upon D i h f and F R is nothing but m C p upon pi D naught L, this is the area.

A p, here it is the surface area of the absorber into U l, one minus exponential of -F dash pi D naught L U l upon m dot C p. So remember this performance analysis is meant for only the cylindrical parabolic concentrating collectors because we have different orientation and different tracking modes. So based on which one has to derive all this formulas for performance analysis.

Thermal analysis is that is basic the useful heat energy is nothing but whatever you are getting in the absorber minus the losses. But while getting in the absorber that calculating S then you need to include all these parameters and also here we are only concentrating on the beam radiation in a way instantaneous efficiency is nothing but q u upon I b r b into W L. So that is nothing but the area of the concentrator. So that is all about concentrating collectors.

So we will do practice problem on liquid flat plate collector. If time permits, we will do simple problems and cylindrical parabolic collector whatever we have discussed today. So that would come as a special lecture because this particular week is designed for only 3 lectures.

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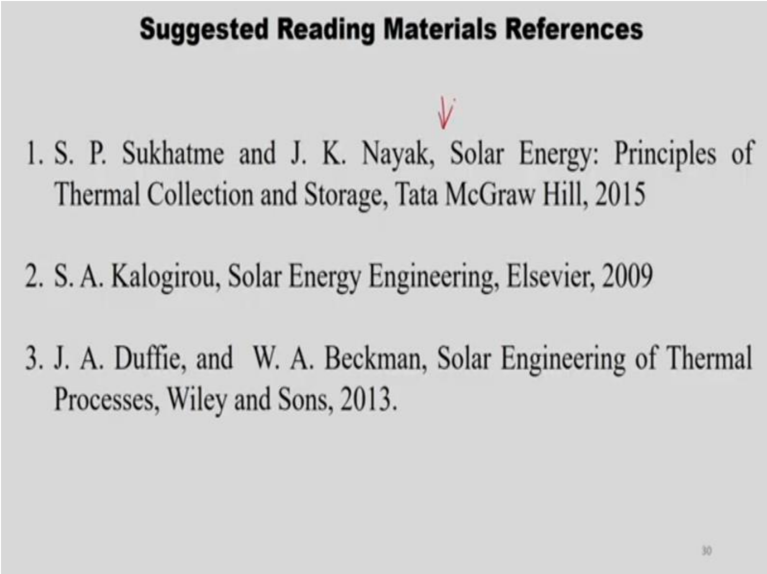

So these are references and reading materials. As I said, I have not discussed or in depth discussed about the optical system, how to concentrate the solar energy? So we were requested to refer these materials to get to know more about orientation and tracking modes. Thank you.