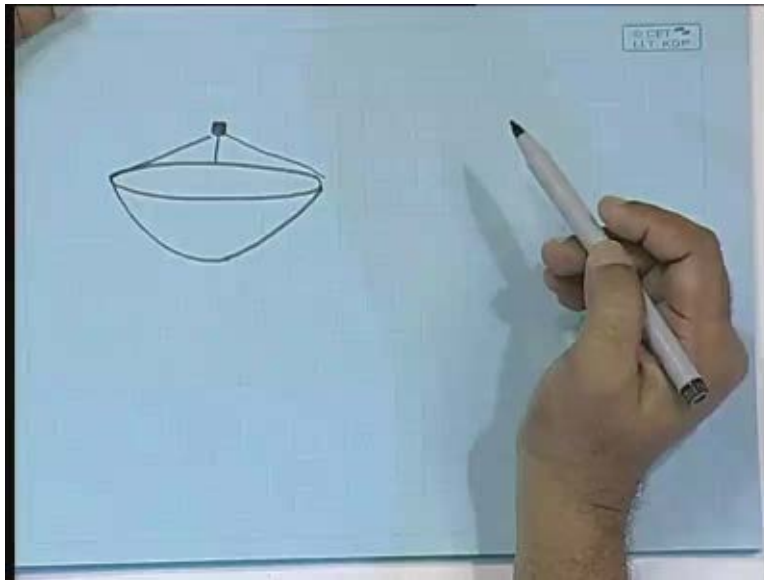


**Energy Resources and Technology**  
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**Lecture - 16**  
**Solar Concentrating Collectors**

In the last class, we were talking about the solar thermal power conversion and we had just introduced the solar flat plate collectors and we had gone into the solar concentrating collectors and we have seen that, did I say this? There are two types of collectors, concentrators, the imaging concentrators and non-imaging concentrators. Yes; so, we were essentially talking about the imaging concentrators and one important class of imaging, imaging concentrators were the parabolic concentrators.

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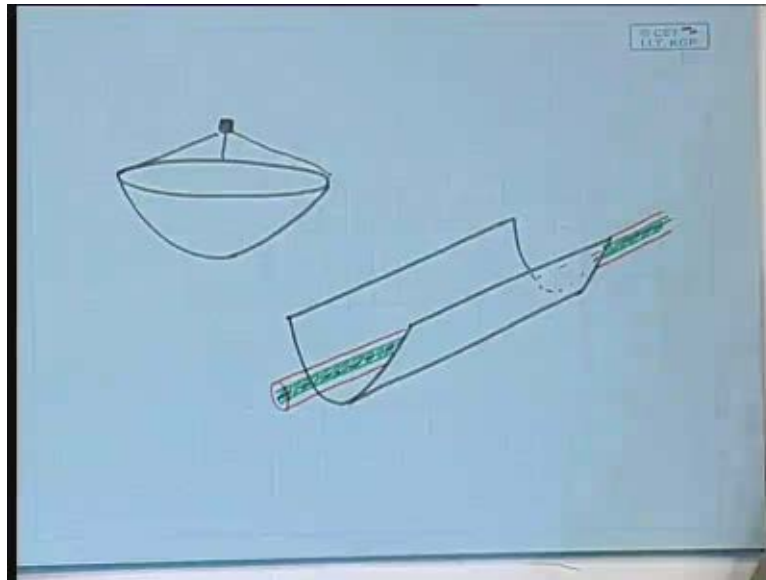


So, the structure would be, where you have the parabolic trough kind of structure and then you will have the focus somewhere here and naturally the absorber, the collector has to be placed here, which will be in the form of a copper vessel blackened on the outside and held with an arrangement something like this and the whole thing will then, will have to move, will have to track the sun, so that all the time it faces the sun, because the sun's energy is concentrated only at the focus. So, if the sun goes off, then the point at which it

concentrates also goes off and therefore, if the sun goes off the main axis, then obviously no energy will be concentrated on the collector. So, it has to have a very good tracking system.

We had also seen that a simpler arrangement can be made with a linear parabolic concentrator.

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A linear parabolic concentrator would be the situation, where you have the parabola, but you have a parabola not in both the directions. So, in that case this shape is a parabola and in this side it is a straight line, so it is a, you know parabolic cylinder kind of arrangement and naturally, the focus will be a line like so and the light will be focused onto this focal line not on a focus point but on a focal line. So, in that case, this will be the reflecting surface and the concentration will be on the focal line. Obviously, you cannot really focus on a line. It will be on a strip, because of the slight imperfections on the reflecting surface and so, you will have to make a relatively larger observing surface. This observing surface obviously can be very simply constructed out of a copper tube, copper tube of the diameter that is dependent on the expected imperfection of the reflecting surface.

If it is perfect, then it can be very narrow. If it is relatively imperfect, depending on the manufacturing process, then you will have to have a relatively larger diameter. But then, how do you make the greenhouse effect on this? Greenhouse effect means you recall that on the absorbing surface, the absorbing surface will also emit radiation and in order to arrest that, we had put in case of flat plate collector a glass plate which would not allow, which would allow the visible radiation to come in, but will not allow the infrared radiation to go out. What can be done in this case? You can have, of course put a flat plate. Very simple, you put a concentric cylinder of glass, so there would be a concentric cylinder made of glass. Let me draw in red; then, the amendment becomes very simple, that you have water flowing through this and you have some kind of a circulation system and it goes through this. The manufacturing process will be very simple and even because it is cylindrical in size, you can also withstand pressure and therefore, it is not impossible to generate steam out of this, clear.

In fact, this is the type of the concentrating system that is more popular than this type unless you are really going for very large scale power generation systems, which I will come to later. So, in case your requirement is water of a temperature something like 60 to 80 degrees, then flat plate collectors are okay. If you are trying to generate hotter water like 90 degrees or 100 degrees or steam, then this kind of collectors are better, but if you want to make a power station kind of thing, then obviously this may not suffice and you need to have more higher degree of concentration.

But, it is clear that if you have a two dimensional system that means this is a two dimensional parabola or a 3-D parabola actually, then you need to have a two axis tracking system. That means it has to be able to move this way, as well as this way, in order to have the complete tracking of the sun. In case of this, obviously you need to only move it this way, right. It is a one axis tracking system. That is why it is simpler, but even people are trying to go for a higher degree of simplicity. Just imagine that if it is a parabola with one side linear, then it can be placed either East West or North South, right. So, can you imagine what would happen if you place this one in the East West orientation and if you place this one in North South orientation? What will happen?

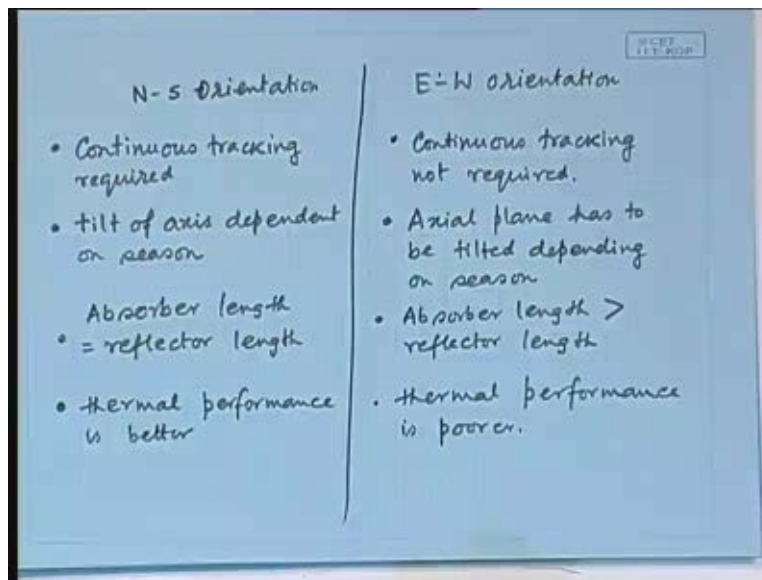
Let us first imagine that you are placing in the North South orientation. So, here is the North, here is the South. In that case, sun rises to the East and goes on and sets to the West and as a result, you need to tilt it towards this side in the morning and towards that side in the evening. So, you will need a continuous tracking system, one axis tracking system over the day, clear. Only thing is that since the sun's position in the sky, the plane in which it moves, changes with the season, therefore during the summer season it will be more or less horizontal, in winter season it will have to be more or less at an angle. So, there will have to be an arrangement of changing the tilt due to the seasonal change of the position, clear. So, for the North South orientation, you have to have a one axis tracking system that works all through the day and the tilt is decided dependent on the season.

Now suppose you orient it to the East West direction. So, in that case, imagine that here is the East, here is the West. In that case the sun rises in the East goes off and sets in the west. So, naturally all the time it is moving along the axis and therefore, you do not need tracking, right, you do not need tracking then. So, that can be a very simple arrangement where even the requirement for the tracking is eliminated. Only thing is that the plane in which the sun will move will be dependent on the season and therefore, this tilt has to be, this tilt, not this tilt, it is this tilt that has to be decided on the basis of the season. Is that clear?

Next, another issue here. In the early morning, the sun will be coming from this side and therefore, after reflection there will be a large part of the refill, of the absorber area here which will not really receive the concentrated sun light, rather some amount of concerted sun light will be received here beyond the range of the reflector. So, if you have to have an East West orientation, the absorber size has to be larger than the reflector size, which is not required in case of a North South orientation. So, the absorber, the glass sheet, all that has to be larger than the reflector size, because for most part of the day the light will actually be concentrated away, out of the range of the reflector. So, you see, here in this kind of system, you can, it is possible to avoid, even though it is a parabolic concentrator, it is possible to avoid the tracking system.

In some cases, the tracking systems can be messy. So, essentially if it is a standalone system, not much attended to, then tracking system are not very .... In many cases, you have to do it in an isolated place with not much electricity supply or unreliable electricity supply, in those cases, it is better to have a system without tracking. But, if you have it in a reasonably well attended place, then a tracking system would be better, because it has a larger concentration ratio, clear.

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So, let us enumerate the two types of tracking system, the North South orientation and the East West. So, what are the points? First in case of the North South orientation, daylong tracking is required, continuous tracking all over the day is required. In the case of the East West orientation, continuous tracking is not required. In this case, tilt of the axis is dependent on the season and in this case tilt of what will you call it, this tilt?

Student: ...

What? Yes; no, not rotation. It does not rotate, it is just tilted, tilt it and a so, actually this is the axial plane, the axial plane has to be tilted. In the first case, axis has to be tilted and in this case axial plane has to be tilted depending on season. Next point, in case of the

North South orientation, the absorber area can be the same as the reflector area or length, absorber length can be the same as the reflector length and in this case the absorber length has to be larger than the reflector length. But, which one will be better? As far as the overall thermal performance is concerned, which one will absorb more amount of energy? The first one, the North South tracking. You have the disadvantage that you have to track it all the time, but the advantage that it gets you more energy. So, the thermal performance is better. So, this is how they compare and depending on the specific situations, people chose a particular kind of orientation and then they design accordingly.

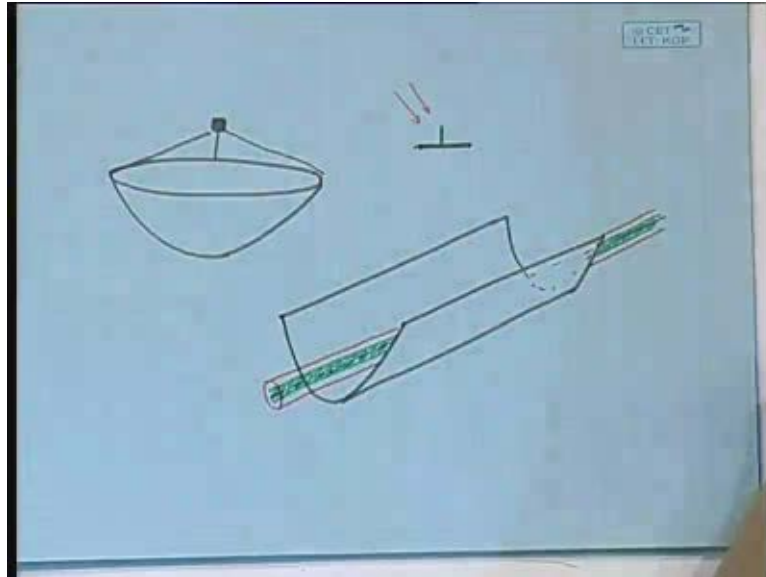
What would the reflector be made of? You see, the reflector in your home is a glass with a silver coating. Can you do this here? For various purposes, various reasons, no. Firstly how to bend a glass in a parabolic shapes? Even if you do and somehow manage to silver the other side, then the whole thing will be very brittle. I mean anything happens, it might break. So, normally these are made of simply polished steel surface. So, these are steel surface, metal surface, aluminum surface in many cases, but that is thoroughly polished, so that they are proper reflecting surfaces. So, naturally if the place is such, like a big city like Calcutta, there will be deposition of dust that reduces the reflection coefficient. Obviously, you need to clean it; it is necessary to clean it.

Now, how can you put into effect the tracking system? In this kind of system, as I told you that you will need a tracking system, in this case also you do, but if it is North South orientation, but it is a one axis tracking system, nevertheless you will need a tracking system. How to actually do the tracking system? Normally this is done by a very simple mechanism. For any tracking system it has to be a feedback controller. That means if it is going wrong, then there should be some kind of a generation of a voltage that is proportional to the extent it has gone wrong and then, on the basis of that if motor is turned and it is reoriented back to the proper position.

Now, the way it is normally done is by the use of small photovoltaic cells. What photovoltaic cells are I will come to that later, but assume that there are cells that can

generate voltage or current. In fact these actually are current sources, so that they generate current depending on the amount of solar radiation incident on it.

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So, what is done is normally if you have say, imagine that you have a, you have to have a one axis tracking system and you placed a photovoltaic panel here and some kind of a barrier there, so here is one part of the panel photovoltaic cell, it is another part of photovoltaic cell, equal size. So, normally if the solar radiation is coming from there, they will produce equal voltage, equal current. If instead, the solar radiation is coming from this side, then this will produce the full voltage, but a part of that will be shaded. As a result, unequal amount of voltage and current will be generated. So, all you need to do is to subtract these two voltages and use that as the error signal. So, depending on that voltage, depending on the voltage generated, you will have a, you will turn a motor.

In case of a two axis tracking system, a similar thing has to be done also along the other axis that is all. So, one axis the motor that actually turns it that will be governed by the error signal generated this way and the other axis also it will be the same way. This is one kind of tracking system where you actually use the feedback control. There is another type of feedback control system. Here you see, the voltage that is generated, the

difference in the voltage that is generated is exactly proportional to the error that means how much away from the exact alignment you have gone. If it comes from this side there will be larger difference in the voltage, if it is more or less vertical, then there will be smaller difference in the voltage. In the other words, I am saying that the voltage is an analogue quantity, can take any value, right and on the basis of that you turn it.

In many implementations you will find that people find this not very convenient. So, they have an implementer in which either the motor turns or it does not turn. So, in that case, all they do is simply put a very small photovoltaic cell here and a very small photovoltaic cell there, very small. Now, if the incident solar radiation falls, this will generate the voltage, this will not at all, as a result of which the motor will turn and when it turns, it turns at the same velocity. The turning, the speed of the turning does not depend on the analogue voltage that is generated. The moment it becomes vertical, both the small photovoltaic cells generates the same amount of current and therefore the difference becomes zero and therefore the motor stops. This kind of a, of an implementation you will find in our energy engineering laboratory in electrical department. Those who are energy engineering students you will see this kind of tracking system actually used. So, this is where you are actually using the feedback to obtain the position.

There are some difficulties in the sense that if there is a cloudy sky, there is no direction in which the sun comes and therefore this fellow finds it difficult to orient it. If it is cloudy sky, it is a diffused radiation and in case of diffused radiations, the difference will not be significant at all and therefore, in case of diffused radiations, this fellow cannot orient, but of course when the sun again comes out it, it immediately can readjust its position and come to the proper position.

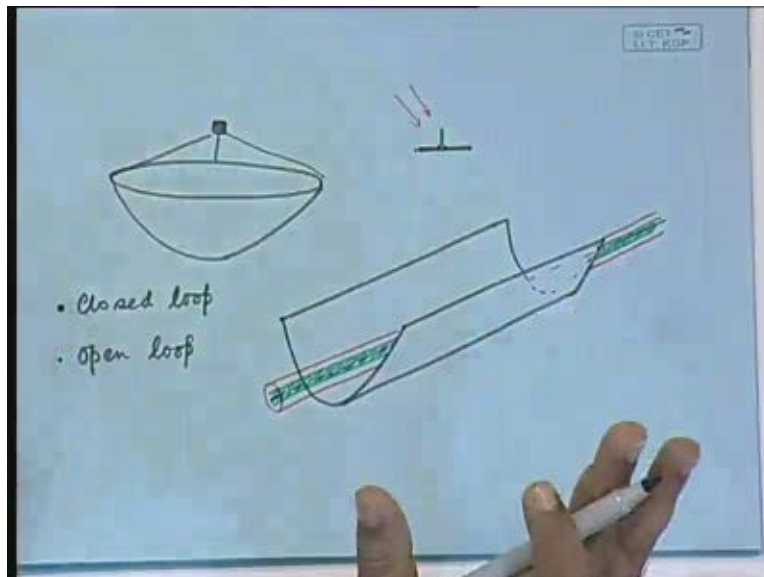
In case of relatively larger establishments, larger means where you have a more, where you can afford more sophisticated control system there another type of control system is normally implemented. Here this was the feedback control system. For the feedback control system, you do not need to know, prior to actually doing the control, where the sun is. The system finds whether the sun is and tracks it, but actually the sun's position is



known. You can easily calculate what will be the sun's position on 23<sup>rd</sup> October, say 2 o'clock in the afternoon. So, it is only a problem of proper calculation which is tractable calculations, not a difficult calculation at all and so, since you can find out where the sun is going to be, therefore, in many implementations people do not do it by feedback control at all. They simply know and therefore they orient. So, that is the open loop controller. It is not a closed loop control, open loop control where you will know where the sun will be and therefore you can pre-orient it.

Independent of whether there is a cloud cover, whether there is a stormy day, does not matter, you can still orient, because you will know where the sun is. So, how to actually find or calculate the location of the sun, this comes from simple spherical geometry calculations, that are taught in most astronomy text books. So, these are, mathematically it will be a lot calculation, all right, but conceptually very tractable, because the position of the Earth, position of the sun and everything is pretty well known. So, there are two types of tracking systems – one, the feedback control tracking that means closed loop tracking, two the open loop tracking. For the open loop tracking, you will need to have a computer, in order to compute the future position of the sun at any point of the day.

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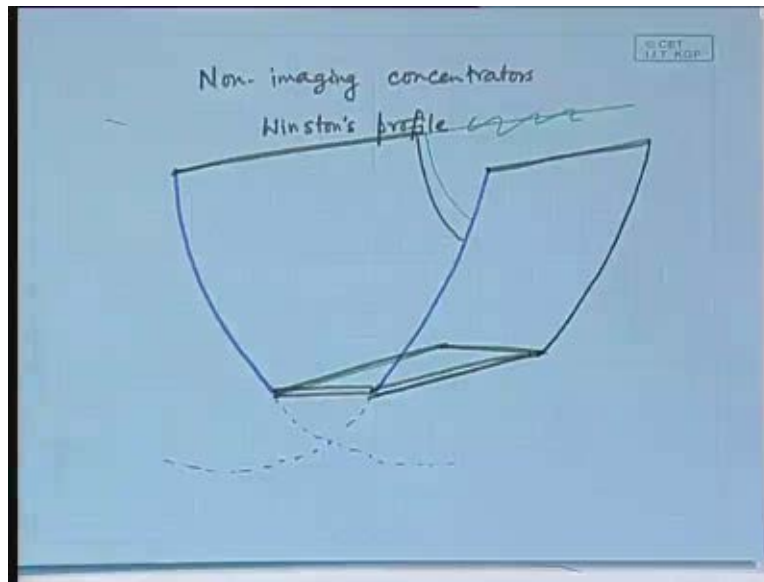


So, there are essentially two types of tracking systems, closed loop and open loop. The closed loop control system is simpler, does not require a computer. The open loop control system is more sophisticated, requires the computer, but the performance is guaranteed, because you will know where the sun will be. So, is there any question regarding these tracking systems, where you either have a two axis tracking or a single axis tracking and you either do it by closed loop control or open loop control. Understood, can we go to the next?

Well, in some situations people nevertheless do not like to have a control system. That means it has to be a non-tracking system. You have seen that it can be a non-tracking system, if say it is East West oriented, East West oriented and some seasonal positioning is done; it can be a non-tracking system. But nevertheless, the problem is that if the orientation is improper, say the **season** has passed, but this orientation has not been changed, what will happen? It will concentrate, but at a point away from the focal plane, focal line. So, out of the absorber it will not work. So, in some situations, people try to think of, can we make a reflector which, whose shape will be such that any solar radiations coming within that area will always be concentrated on to the absorber area independent of whether I track it or not. In fact, such reflectors do exist.

Let us talk about the geometry of such reflectors. Such reflectors are in general called the non-imaging concentrators. These were all imaging concentrators, because ultimately the image of the sun is produced. If you stand in front of that you will see a quite distorted, but your image; you can identify that it is me, imaging.

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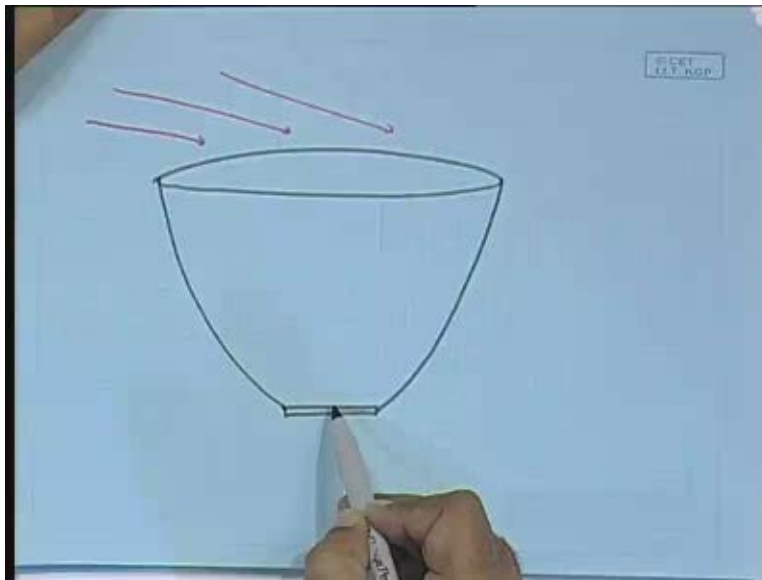
So, these will be non-imaging concentrators, non-imaging concentrators or sometimes they are called Winston's profile. Here we will consider the flat plate kind of absorber system. So, we will take this as the absorber. In that case the constructional feature is this, it has to firstly be a parabola all right, but where should the focus be? There will be a parabola going like this, another parabola going like that and any light that goes in should be absorbed by this one, should ultimately, after multiple reflections may be, but ultimately it should fall on the absorber. So, it will be a shape like this, but that shape will have the focus here. So, the one that starts from here will have the focus here. So, if you have a focus here, then you might imagine a ... and in this side you will have another reflector here, whose focus would be here. So, the .... part is not there, I am drawing for the sake of understanding how it is done.

So, these are the two parabolas. This parabola has a focus here and this parabola has a focus here, right and then if this is a circular shaped absorber, then this will also be a trough like thing. The advantage is that it can be shown that any light that goes into this range even if it is like this, then it will, after a multiple reflection ultimately be incident on the absorber area. So, this is called the Winston's profile. You might easily imagine that there can be two types of structure, one is where you have a trough kind of thing, the

other is where you have, sorry, this is wrong; okay, that is also possible. So, this will then be a, this will then be a flat plate which will retain all this specialties of the flat plate collector, except that it will have a larger concentration and therefore larger temperature rise.

So, there are two possibilities. Either you have a three dimensional trough like structure or again linear parabolic concentrator, but a non-imaging parabolic concentrator, so that all the light that enters goes in. You might possibly argue that in that case it is not necessary to have any tracking.

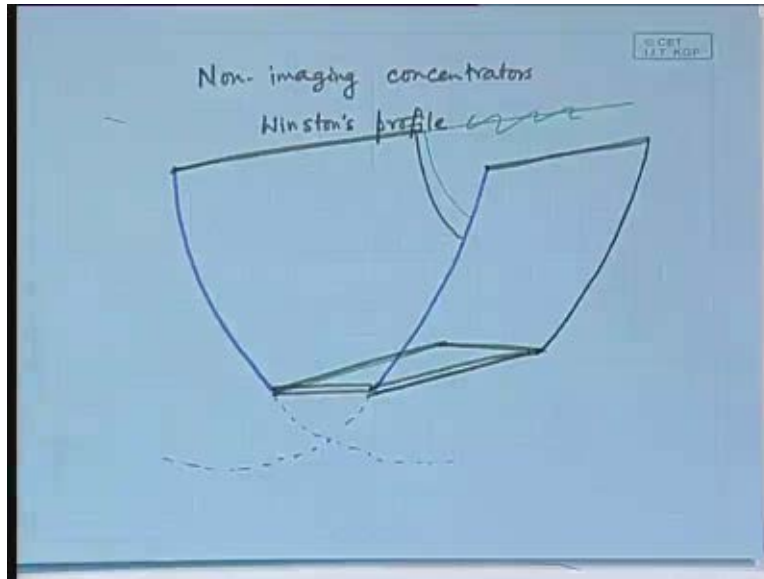
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Well, that is not quite true, that is not quite true, because supposing the, okay, let me draw another image, where I will use the ... here and this one will be a ..., fine. In that case, if the light comes from such an angle, yes, true that it will, after multiple reflection it will, come here, but what is the concentration factor. Concentration factor is the area seen by the incident light to the area of the absorber. Now, area seen by the incident light reduces, because you are seeing from a **side**. So, obviously the concentration factor reduces, the amount of the light that we intercept reduces. So, that is not really a very

clever idea. So, simply making it and keeping it just like that will not help. It has to be oriented, but in that case it becomes more logical to orient it, if you have a linear one.

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If you have a linear one, then it is logical to orient it in a ..., okay, how do you orient it, North South or East West? North South; if it is North South, this is axis. If it is North South, then East West is that way and then in the morning it will receive very little amount of light, in the afternoon it will again receive very little amount of light. That is not a clever idea. So, if you do that, then again there is a requirement of somewhat crude, but nevertheless a tracking system.

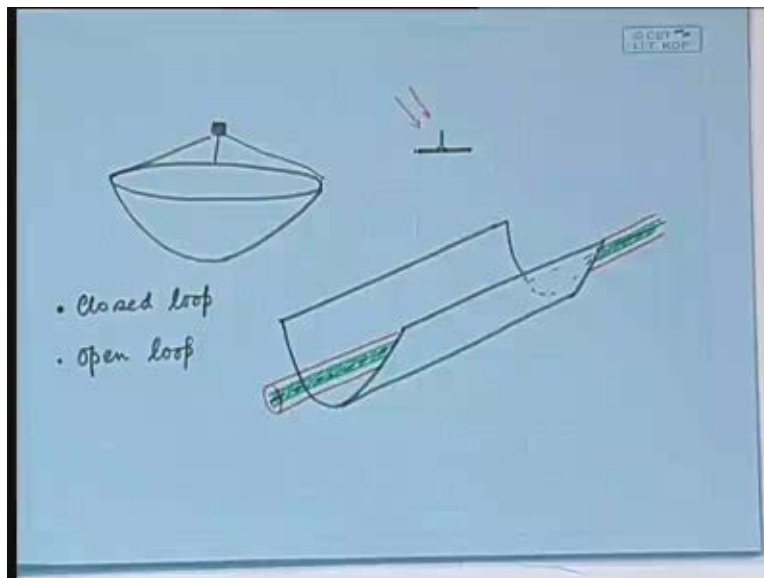
Maybe you can engage somebody to change the angle once a hour, no continuous tracking is required though, because ultimately it does concentrate, but in order to keep the concentration ratio high, maybe somebody, some attendant comes and just changes the orientation, that works or you can orient it East west. If it is East West orientation, if it is East West orientation, then also that problem is there. The length of the absorber area has to extend beyond the reflector area, but nevertheless you can do that. If you do that, then only this orientation has to be changed once a month may be. No continuous

tracking is required in either case. That is why in many situations, this kind of structure is preferred. But again, how to make, how to make?

Making this often poses a problem. You have these days' industrial methods of producing parabolic troughs, because all the TV antennas, the ones that you use in the, the service providers use, that is basically this type. So, same kind of technology can be used in order to make this. But, how to make this kind of a reflector, parabolic reflector with, you know, it is a truncated parabola. You focus somewhere here, so that sometimes poses a engineering challenge, how to produce a manufacturing system that will manufacture this kind of thing? But nevertheless, the concept is clear, right. Is the concept clear, the geometry clear? So, tracking is done, non-tracking concentrators I have done; these are the non-imaging concentrators, you do not see the image of the sun.

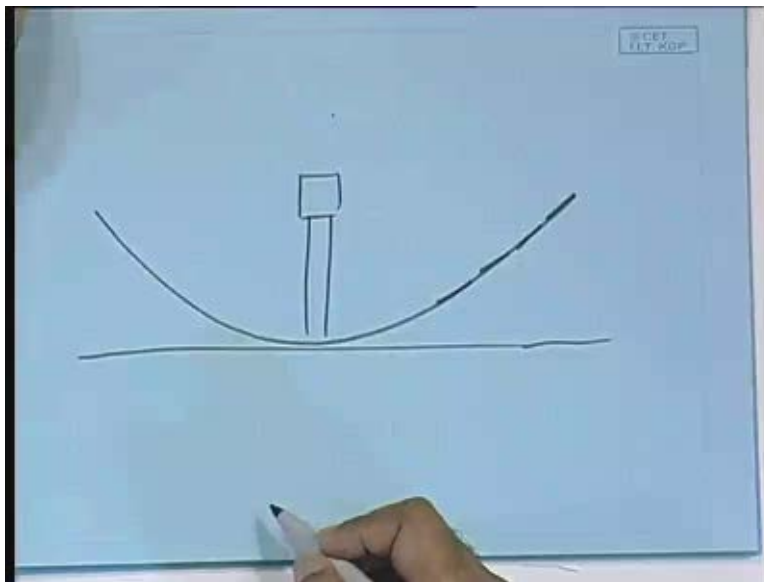
Now, all these that I have done essentially referred to relatively smaller systems. You might simply add them, for example, there are power stations where a larger number of these are used.

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That means the water comes, goes through one and at a higher temperature goes into another; it comes out at a higher temperature; finally it goes into steam and you can use that steam to generate power. So, there are, simply by multiplying this kind of linear parabolic reflectors, you can have a larger amount of collection and generation of energy. But, most of the solar thermal power stations, where your objective is not just to generate steam, hot water or something like that, rather to generate electricity, there you need to have a larger size.

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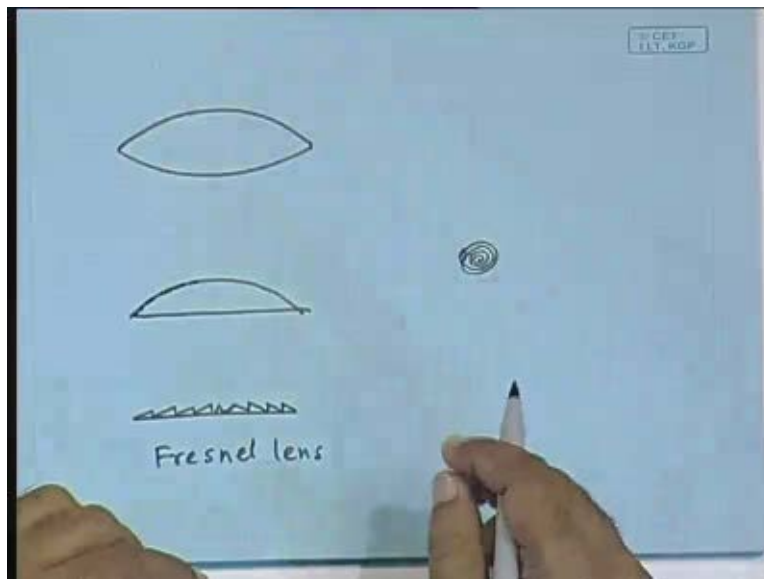


There if you have to have a reflector something like this, with a absorber somewhere here and this reflector is to span like a square kilometer, will you be able to make it? A reflector this big, a square kilometer, you will not be able to make it. Moreover, this height will be large, this height will be large. So, there are actually two types of options. One, if the natural landscape allows you to have this kind of a height, like, a valley like thing, where there was a sloping surface where you can put these absorbers and you can have a tower somewhere here, so that it absorbs there; that means the other part is not there, it is only one part of that which is used and you have placed the absorber somewhere here on top of your tower. Let us say here, you make a tower and on top of that let that be the absorber.

Such a power station has in fact been installed in Spain, but it is not difficult to see that such locations are rare, a location where this slope will be facing South, more or less a flat surface that can be oriented like this, very rare. So, something else has to be done in order to make this kind of a thing. So, what is the actual challenge? The actual challenge is that you need to have, if it is a reflector that spans over a square kilometer, it has to rise for a larger, large length. Secondly, you cannot really make a single reflector like that, it will be practically impossible. So, what to do? You can of course break it up like one here, another here, another here, another here and so on and so forth, but still the problem is that you have to elevate.

Now, there is another concept. Have you come across the Fresnel lens? Yes, what is a Fresnel lens?

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That if you have to have a lens something like this, you cannot really have, because this is feasible only in small sizes. In large size, it becomes bulky, huge thing. So, in order to avoid that, what people do is, they first say that let that be half of it, not the full, that also is a convex lens and then we would say that okay, it is not necessary to have these bulk. All that is really important are there these slopes. So, you can simply make it like so and

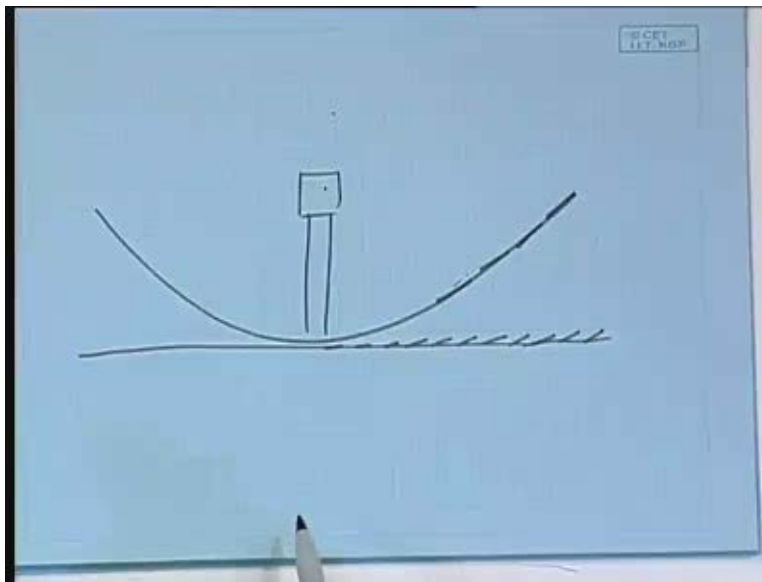


that is how you make the Fresnel lens. So, this is called the idea of the ... It is not pronounced as Fresnel, it is pronounced as Frenel, though the spelling is Fresnel. So, you have to have a, have you seen these lenses? No, you have only read in a book, concepts. Have you seen those overhead projectors, over overhead projectors where you use a transparency and that is projected onto the screen, so in that, in the seminar rooms ...

Students: Yes.

Yes; now, next time when you see that, look at the top surface of that. You will find a glass and if you look carefully, you will find the concentric, see there will be concentric lines like this and these are actually these grooves and that whole thing is like a plate, but that is a lens that concentrates on to **air**. So, Fresnel lens are actually very easy to manufacture and they are used widely. Now, in case of a large power plant, a similar idea is used, but you cannot have a lens, you have to have a reflector.

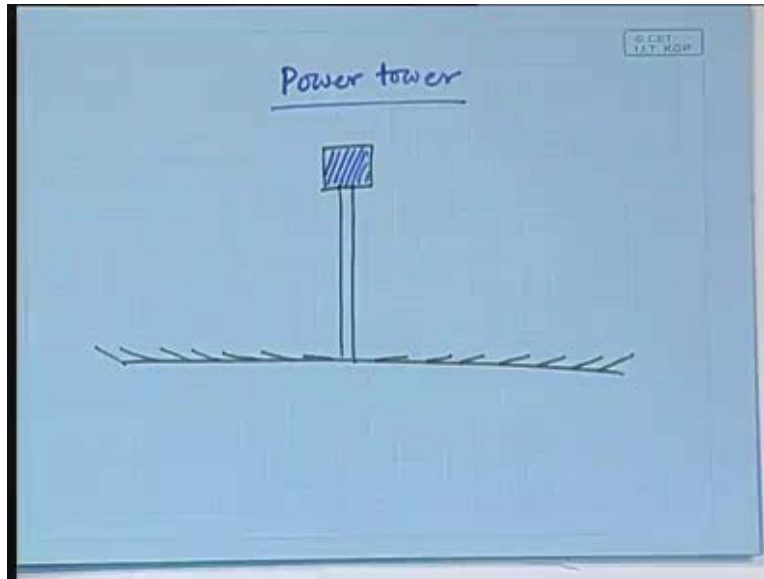
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So, in that case, this height, again you do not need, you can bring it down to this surface. Only these angles matter and therefore, you can have something like this, right. They will have the same role to play. So, these are plane mirrors. These are only plane mirrors that

are angled in such a way they all concentrate onto a center tower. In that case how will it look?

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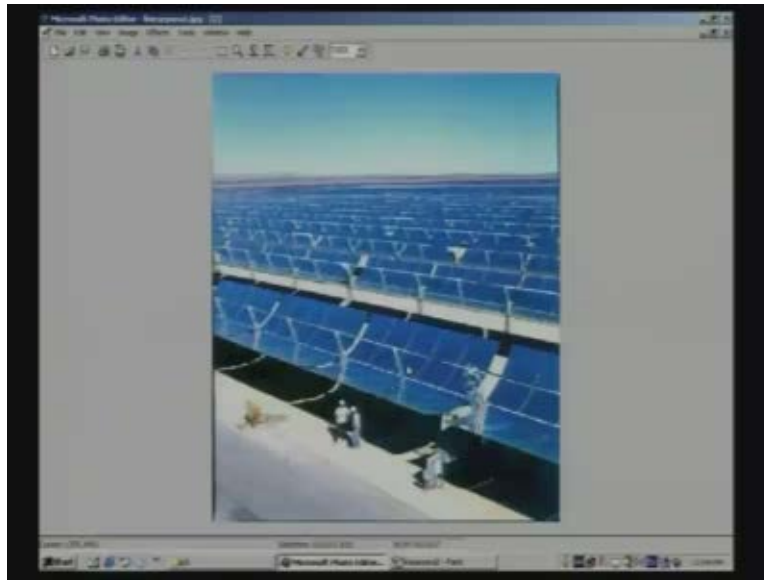


It will look like a plane in which there is a big tower. On top of it is the absorber area, outside is copper blackened and inside there will be those water walls. In the power plant, do you remember? There was the, the water walls that absorb the ... So, inside there would be the tubes that carry water that absorb the heat that is actually absorbed by the outer wall and that generates steam and that can be used to run a turbine. The turbine can be placed at the base of the tower. Now, the reflector should be something like this. As you go away, the angle has to increase. Moreover, as the sun moves, all these ... will have to be reoriented, because in case of the big one what you would have to do? If the sun moves the whole thing has to be moved and obviously, the whole thing is not constructed, the whole thing cannot be constructed, so you have the each piece. But, if you move each piece, then you can still make them concentrate on the, on the tower. So, this is essentially the, what is known as the power tower concept. So, here is the tower that acts as the absorber and these are the reflectors. There will be pretty large reflectors though and each will have to have a two axis tracking system.

Normally, these tracking systems, in such systems, it is never a feedback control system. It is always that you know the position of the sun and that gives a signal as to how to orient these individual reflectors and such systems have been installed with reasonably large capacity like 100 megawatt or so, essentially in desert areas, because that requires to cover a large amount of area, desert areas and that has, even though the installation cost is at present quite high, so it does not really compete with the existing fossil fuelled power plants.

Why is the installation cost high? Mainly because these reflectors, you know, reflectors as big as this room, each will be and that has to be, has to have a two axis tracking system, that has to stand on a platform that will make it withstand winds, windstorms, so that has to have a have a reasonably good structure and that increases the overall cost of the system. Moreover, mirrors, it themselves are pretty expensive; shiny steel surface, they are themselves pretty expensive. So, this is the concept of the power tower. In India, we do not have any of them yet, any of the power towers yet, but there are power towers. As I told you, a one sided power tower where you have a mountain, is installed in Spain. There are a couple of such power towers in USA. Europe does not have so much sunshine, so they did not go for this kind of a system, but it is basically the temperate areas like ours that may benefit from this kind of a concept. But as yet, as I told you, the technology is not matured enough to make them economically competitive with the rest of the fossil fuel systems.

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These are pictures of the things that we talked about on the computer screen. Right now, you see the picture of a whole power plant made of linear parabolic concentrators. These are the linear parabolic concentrators. Do you see the size? Here are the people standing and in comparison to that you can see the size of this linear parabolic concentrators and on the focal line you can see this absorber tube going. So, these are the absorber tubes that go along the focal line and you can see that whole field is covered with such collectors, concentrating collectors, as a result of which the total amount of energy collected is large, sufficient to produce steam and thence to produce electricity. Let us see another picture. This one is not all that good though. Let us see this one.

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So, here also you see another picture; I will put it in a slightly lower size, yes. Here are the similar large arrays of linear parabolic concentrators with these are the tubes that are going. As I told you in the class that these can either be aligned North South or East West, depending on the facilities for tracking that are available. I do not know what these particular power plants operate on, but now let us look at some of the power towers.

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Here is a, here is a power tower. You can see that these are the reflectors. These are standard flat reflectors, but very large in size. At the middle there is the tower and on top of it there is this absorber area. So, all these reflectors reflect onto this absorber area and you can see that this is a desert area in which this power station has been installed, thereby utilizing an otherwise completely unusable tract of land.

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Here is another picture of a power plant, of a solar thermal power plant, a larger picture, where these are the individual arrays of reflectors, individual arrays. As I told you, each one has to be, has to have its own tracking system and the whole arrays tracking system, the control system, is controlled from a central place located somewhere here. This is the control place, the place where the control systems are located. So, all these finally concentrate onto this area. This is the absorber area. The outside of the absorber is the place where it is concentrated and inside it, you will have those water walls, the tubes going through, the tubes that are attached physically to the outer surface, tubes that carry water to make steam and finally, the power plant is stationed at the base; power plant means that turbine, generator, everything.

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Let us look at another picture in which you have another design of the, of the power tower concept. In this case, it is not everywhere, not in all the directions; rather in one side you have the reflectors, the mirrors and in between here there is a large tower and in the other side, this side that you cannot see from this angle, here is the absorber area. So, in one kind of power tower concept, you have the reflectors in all the directions surrounding the power tower. In another concept you have it in one direction. Mainly these things are useful in the northern hemisphere where these face South, these face South and these face North. So, this way you can have different designs of the power tower concept.

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This is a standard arrangement of a linear parabolic concentrator. As you can see, here you have the parabolic reflector in this case made of standard market available material and here we have the copper pipe and the copper pipe is covered by a glass cylinder at the top which acts as the agent for greenhouse effect and this is enclosed at these two sides. The water flows and here also this is an experimental arrangement, so that at the input end we have a thermometer, at the output end also we have a thermometer and it is possible to generate steam by this means.

As you can see that this inclination can be varied and if you vary this inclination you can get it to focus to the sun. That means the sun's rays should be on the focal plane and this has to be adjusted in order to get it into the focal plane. Now, this can be either aligned in the North South direction or in the East West direction. Right now, it is in the East West alignment, so that presently depending on the time of the year, you have to have this inclination and that remains more or less fixed over the day.