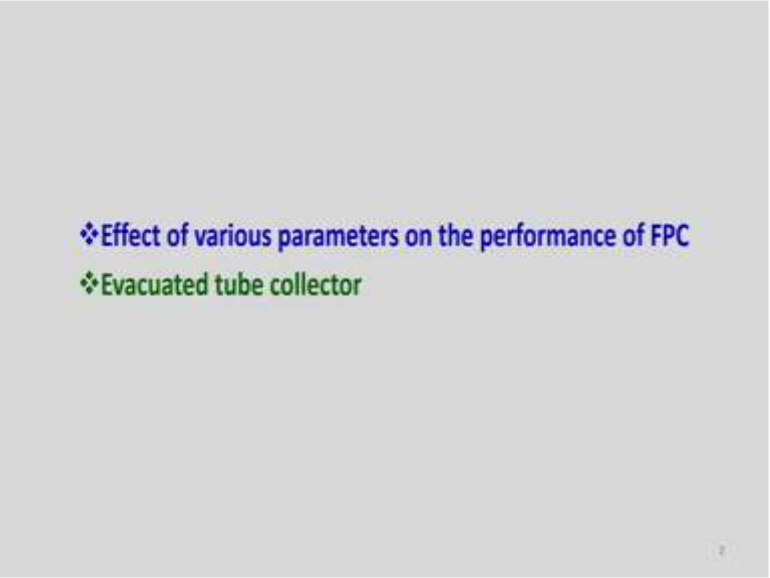
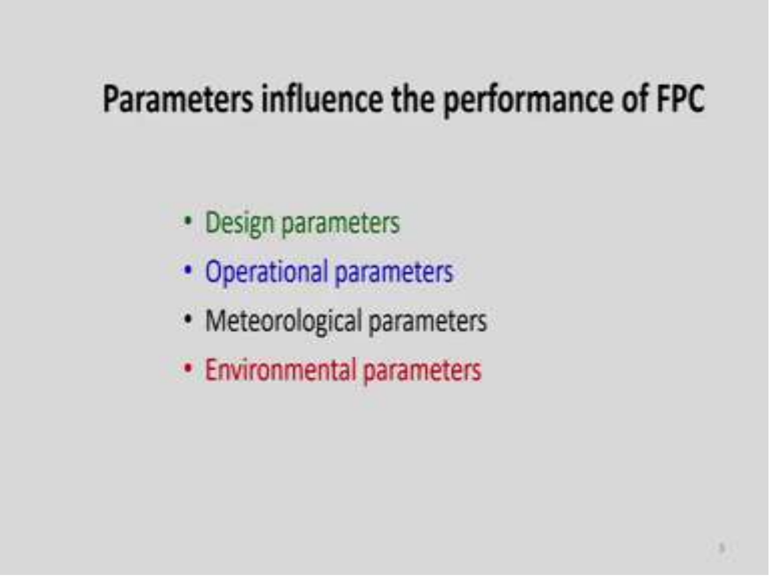
Solar Energy Engineering and Technology
Professor Doctor Pankaj Kalita
Centre of Energy
Indian Institute of Technology Guwahati
Lecture 22
Influence of various parameters on the performance of LFPC

(Refer Slide Time: 0:39)



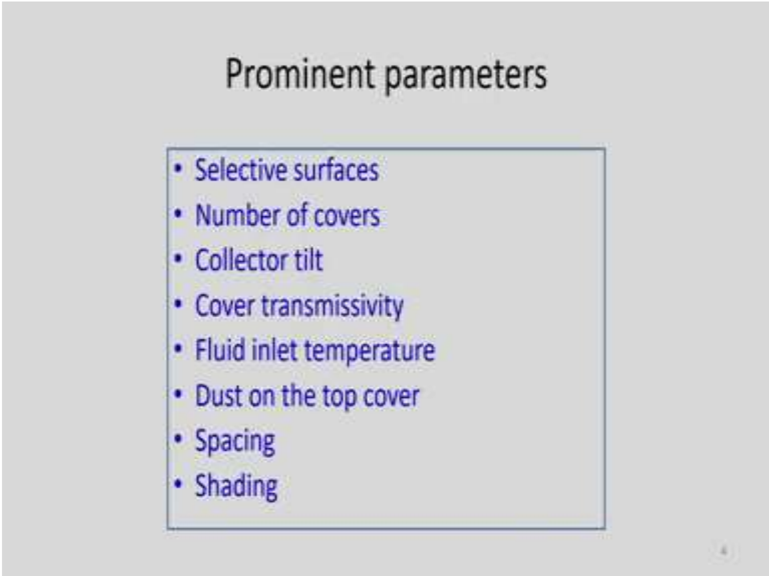
Dear students, today we will be discussing about the effect of various parameter on the performance of flat plate collector and evacuated tube collector.

(Refer Slide Time: 0:50)



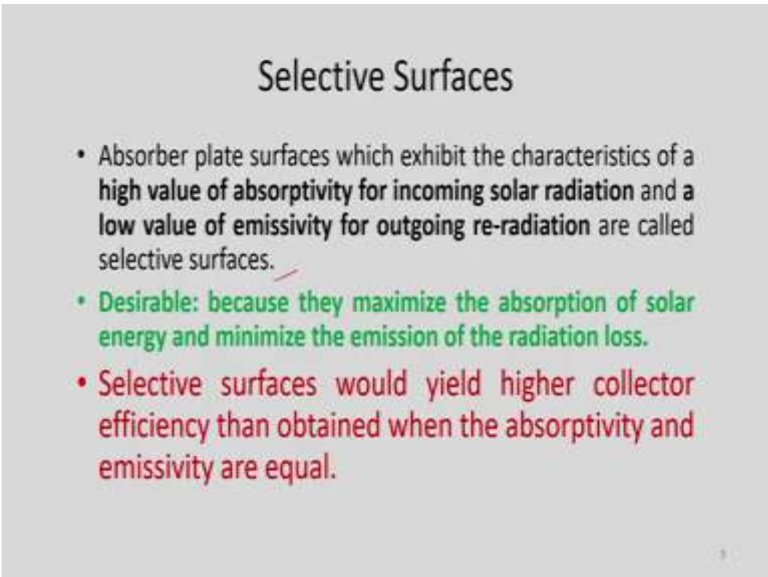
So there are different parameters which include design parameters, operational parameters, meteorological parameters and environmental parameters.

(Refer Slide Time: 0:59)



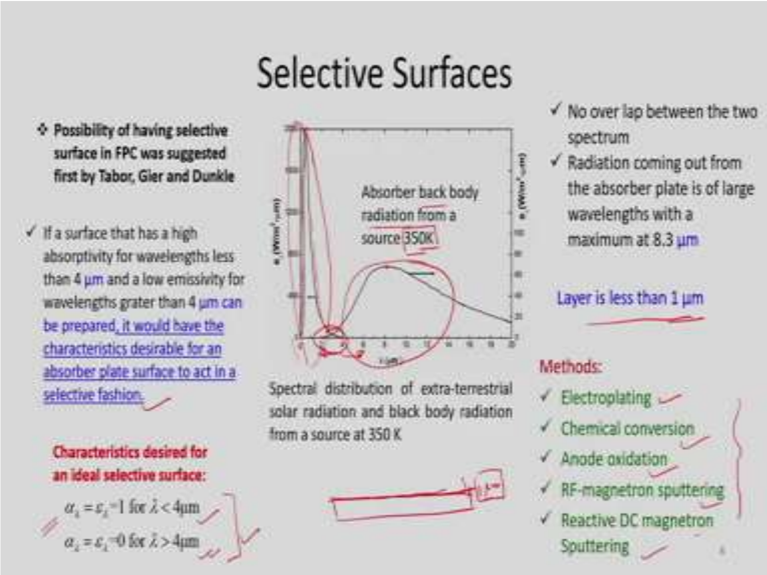
So while considering prominent parameters, we normally consider selective surfaces, number of covers, collector tilt, cover transmissivity, fluid, inlet temperature, dust on the top cover, spacing between the covers, shadings. So these are the prominent parameters which directly influences the performance of a flat plate collector. So these parameters will be discussed one by one.

(Refer Slide Time: 1:30)



So now, let us first discuss about selective surfaces. What is selective surfaces? The absorber plate surface what we understand now, what is the absorber plate so we consider now the absorber plate surface. The absorber plate surfaces which exhibit the characteristics of a high value of absorptivity for incoming solar radiation and a low value of emissivity for outgoing re-radiation are called selective surfaces. So this surface is desirable because they maximize the absorption of solar energy and minimize the emission of radiation loss. These selective surfaces would yield higher collector efficiency than obtained when the absorptivity and emissivities are equal in case of non selective surfaces.

(Refer Slide Time: 2:31)



So this possibility of having selective surface in flat plate collector was first introduced by Tabor followed by Gier and Dunkle. So what he has done, so he used to use this spectral distribution of extra terrestrial radiation and blackbody radiation from a source which is nothing but absorber plate. So if we plot it, so this peak is for the spectral distribution of extra terrestrial solar radiation.

So peak is received normally at around 3 micron and it diminishes at 4 micron and if we talk about this black absorber plate is something like our absorber plate what we are considering. So if we maintain that temperature of 350 Kelvin, so if we plot this radiation spectrum, so we will get something like this. So peak will be there at around 8.3, here is the 8.3 and very less, no overlap has been observed here.

So if the surface that has high absorptivity for wavelength, so this is the wavelength, high absorptivity of this wavelength of this range and low emissivity of this wavelength range. If we can make such kind of system, then we can maximize the absorption of solar radiation. So what we can comment on it. So if a surface that has a high absorptivity for wavelength less than 4 micron, so here less than 4 micron.

So it is more than 4 micron and this side is less than 4 micron and low emissivity for wavelength greater than 4 micron can be prepared it would have the characteristics desirable for an absorber plates surface to act in a selective fashion. So for an ideal selective surfaces what are the desirable characteristics, this absorptivity and emissivity should be 1 for wavelength less than 4 micron and this absorptivity and emissivity is 0 for wavelength greater than 4 micron.

If we can make this kind of system, then we can maximize the amount of solar radiation received in the collector system. So this layer normally less than 1 micron, the kind of layer what we are talking about, say for example, this is an absorber plate, so on the top of it this layer is placed. So this thickness of the layer is normally less than 1 micron. So this is nothing but selective surfaces.

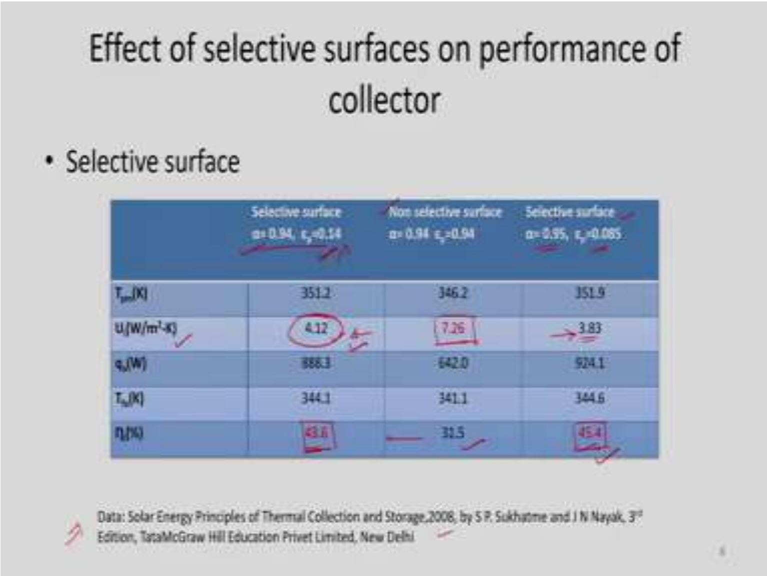
So what are different methods used for making the selective surface, maybe electroplating, chemical conversion, then anode oxidation, maybe RF magnetron sputtering, then reactive DC magnetron sputtering. So there are different methods of preparing these selective surfaces. There are host of literature, people have done research on investigation of best selective surfaces for maximization of solar radiation absorption. So it is a very good active research.

(Refer Slide Time: 6:24)

So this most of the commercialized selective surface coatings are metal dielectric composite coating known as Cermets. The Cermets consist of fine metal particles in a dielectric or ceramic matrix or a porous oxides impregnated with metal. These thin films of these composites are transparent in the high wavelength region and strongly absorbing in the solar wavelength region which is very, very important. Thus they form a selective surface when deposited on a highly reflective metal surface.

This coating developed include nickel black, black chrome and nickel pigmented alumina and this is suitable for flat plate collector applications up to a temperature of 100 degrees C. Normally, for these kind of selective surfaces absorptivity varies from 0.88 to 0.94 and emissivity varies from 0.28 to 0.49. So this is the range of these 2 parameter; absorptivity and emissivity.

(Refer Slide Time: 7:45)



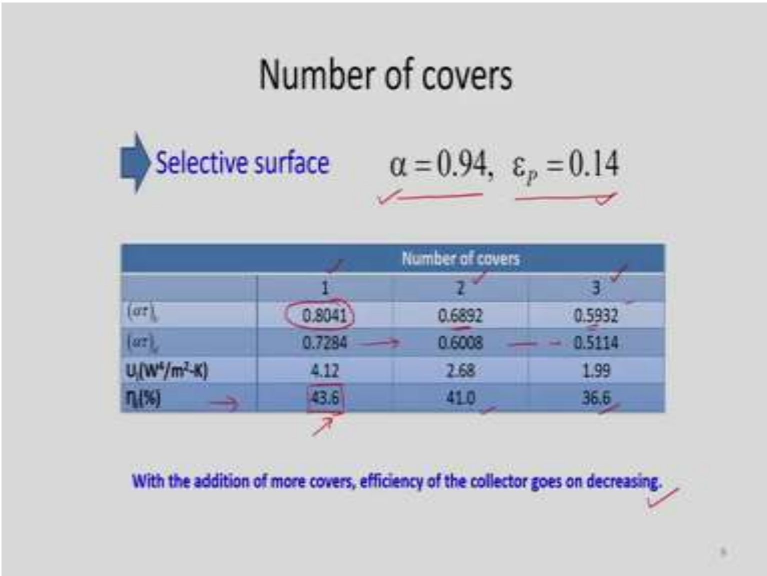
Now, let us see the effect of this selective surfaces, once we apply on the absorber plate, then what happens, what benefit we are getting, so that will be demonstrated now. So this data is an experimental observations taken from a book on solar energy principles of thermal collection and storage written by Sukhatme and Nayak. So here what is shown, 2 different selective surfaces and 1 non selective surfaces are considered.

So in case of selective surface 1, so absorptivity considers to be 0.94 and emissivity is 0.14 and selective surface 2 will have absorptivity is 0.95 and emissivity is 0.085 and for nonselective both absorptivity and emissivity are same, which is equal to 0.94. So if we see this table very precisely what we can see, in case of nonselective surface we can see the losses, this is the overall loss coefficient which is about 7.26.

But when we apply this selective surface, what we got is overall loss coefficient is 4.12. It is a significant reduction of losses. And here again, if we increase the selectivity, or if we increase the absorptivity, so we can further reduce the losses to 3.83. And if we see the instantaneous efficiencies of all the 3 cases, so what we can see here, it is 43.6 for the first selective surface, which is far higher than the non selective surfaces. And also you can see if we improve the absorptivity we can have higher instantaneous efficiencies.

So what we can conclude, by utilizing this selective surface, we can significantly improve the instantaneous efficiency of the collector. And also we can see how these losses can be reduced by applying selective surfaces over the flat plate collector.

(Refer Slide Time: 10:15)

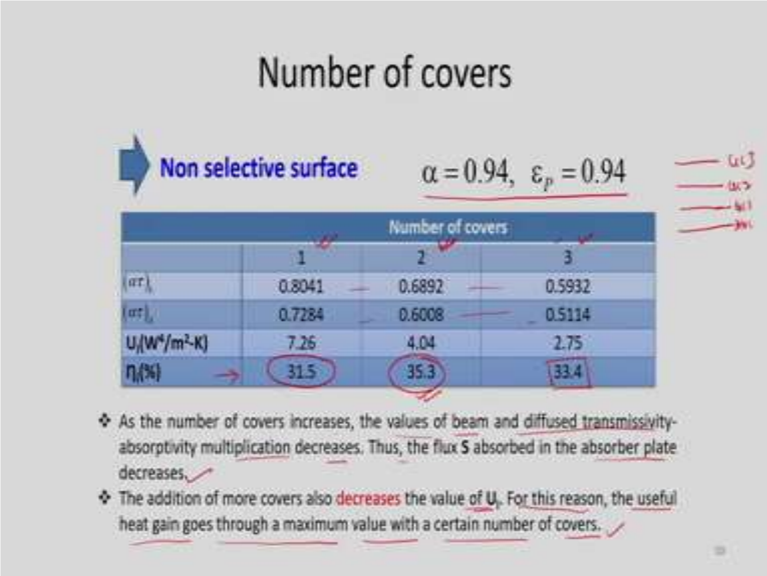


Now, let us consider the case if we increase the number of glass cover on the top of the absorber plate when we apply selective coating. So for example characteristics of the selective coating is something like absorptivity is 0.94 and emissivity is 0.14 and we have considered 3 cases, one for single cover system, one for 2 cover system and one for 3 cover system. As we can see this transmissivity absorptivity product for beam and diffuse radiation is decreasing with increase in number of cover system.

So here in case of single cover system it is 0.8041 then in 2 cover system it is 0.6892 and here you can see 0.5932 for 3 cover system. Similarly, there is a reduction of transmissivity absorptivity product for diffused radiation, as number of cover increases from 1 to 3. So if we see this instantaneous efficiency, which is found to be best for single cover system compared to double and triple cover system.

So what does it mean? So single cover system is the best when we apply selective coating, so that can reduce the maintenance cost of the flat plate collector. So with the addition of more covers efficiency of the collector goes on decreasing what we have observed in the experimental table.

(Refer Slide Time: 12:01)



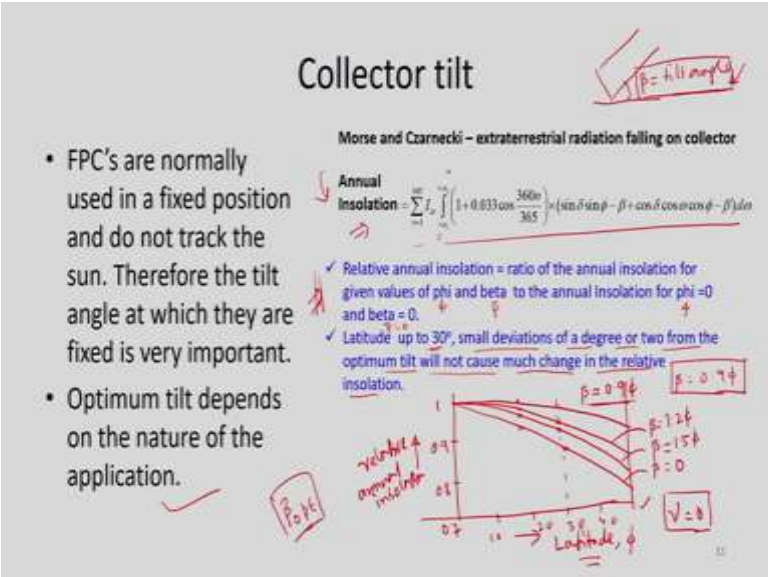
Now, let us have a look on the non selective surfaces, what happens here. So let us consider the characteristics of α, that is absorptivity is 0.94 and emissivity is also 0.944 for a nonselective case and also 3 cover system we have considered, so in the first case single cover, in the second case 2 cover system and third case it is 3 cover system. So absorber plate then glass cover 1, glass cover 2, glass cover 3. It is absorber glass cover 1, glass cover 2, glass cover 3.

So as you can see this transmissivity absorptivity product for beam and diffuse radiation as the number of cover increases, so this value is decreases. Then if we look into this instantaneous efficiency part. So it is observed that when 2 cover systems are employed, instantaneous efficiency is found to be best among these 3, which is about 35.3 percent. So if we increase further this number of covers efficiency decreases.

So in case of non selective surfaces, if we increase the glass cover from 1 to 2, then it is expected that we will get higher instantaneous efficiency. But if we increase further, so there is a decrease in instantaneous efficiency. So as the number of cover increases the value of beam and diffuse transmissivity absorptivity multiplication decreases, thus the flux absorbed in the absorber plate decreases.

The addition of more covers also decreases the value of U_l which is nothing but overall loss coefficient. For this region that useful heat gain goes to a maximum value with a certain number of covers. So that optimized number of covers need to find out. So from our investigation it is found that 2 cover system without selective surface is the good solution for getting higher conversion efficiency.

(Refer Slide Time: 14:37)



Now, let us discuss something about collector tilt. So at what angle we need to maintain for maximization of solar radiation absorption in the collector system. So what does it mean, if we make this kind of collector, we have to maintain some kind of β, this is nothing but tilt. So tilt angle. So this tilt angle is very, very important and this is a location specific and then time specific. So these FPCs are normally used in a fixed position.

No tracking is employed in case of flat plate collectors and not track the sun, therefore, the tilt angle at which they are fixed is very important. Because it will be fixed throughout the year, so when we decide what angle to be fixed for the installation, then we need to be very particular, otherwise we will be losing a lot of solar radiation. So optimum tilt depends on the nature of the application, this is also important and there are host of literature, we have developed many correlations and mathematical expression which can give the optimum value of β or tilt angle for a particular location.

So Morse and Czarnecki, they have used extra terrestrial radiation falling on a collector and they have used this expression for calculation, this is the annual insolation which will be watt per meter square and integrating with this hour angle. And then finally, the amount of solar radiation which is received in the extra terrestrial radiation can be calculated on annual basis.

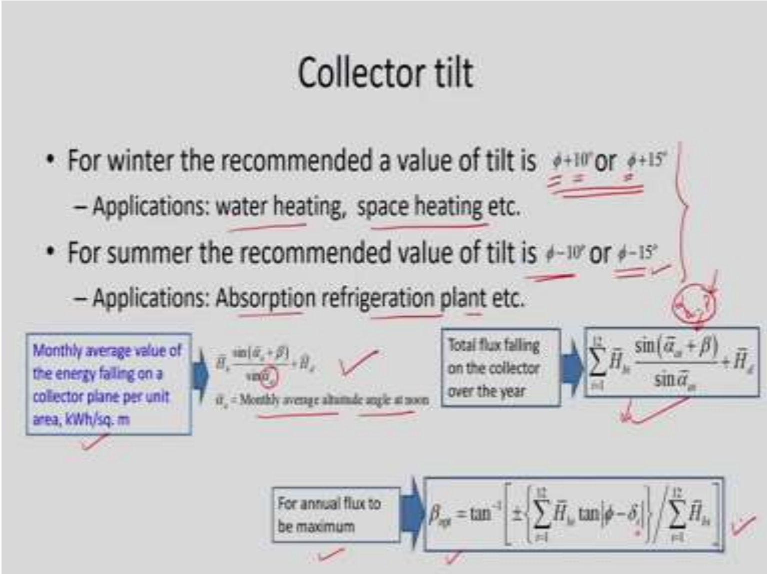
So they have defined a term called relative annual insolation which is nothing but the ratio of the annual insolation for given values of ϕ, this is ϕ and β to the annual insolation for ϕ is equal to 0 and β is equal to 0. So once we know this, then from that also we can conclude many more thing. So let us draw what they have investigated. So if we plot it in a vertical axis, maybe relative annual insulation and in the horizontal axis we will have latitude which is ϕ.

And this is valid for γ is equal to 0, which is nothing but azimuth angle. So if we have to make, so maybe we can use this coordinate 10, 20, then we have 30, then we have 40, this is something like this and maybe we can start with 0.7 here, then you have 0.8 then you have 0.9 and then we have 1. So it goes something like this, then we will have this, so this is an important observation and it goes something like this and then this goes something like this.

So these are the experimental points and maybe you can plot it here. So this first line is for β is equal to 0.95 ϕ and second plot is for β is equal to 1.2 into ϕ and in this case β is equal to 1.5 into ϕ and this is β is equal to 0. So what we can conclude here, this latitude up to 30 degrees, so this is the 30 degree, small deviations of a degree or 2 from the optimum tilt will not cause much change in the relative insolation. So this is the best one, so β is equal to 0.95 ϕ, where we can get the maximum solar exposure.

So this plot shows the variation of relative annual insolation with respect to latitude. So if latitude is more than 30, then we can see this relative annual insolation actually decreases. So there are many correlations which can be used for calculation of this β optimum for maximum solar radiation absorption in the collector.

(Refer Slide Time: 19:53)



So for winter, the recommended value of tilt is $\phi+10$ or $\phi+15$. So ϕ is known and then if we add 10 then that may we know we can consider for winter months. So what are the applications in the winter months for water heating, space heating. So these are applications in the winter month, if we have to use solar collector for this kind of applications. And for summer months, this tilt angle variation maybe we can give $\phi-10$ or $\phi-15$.

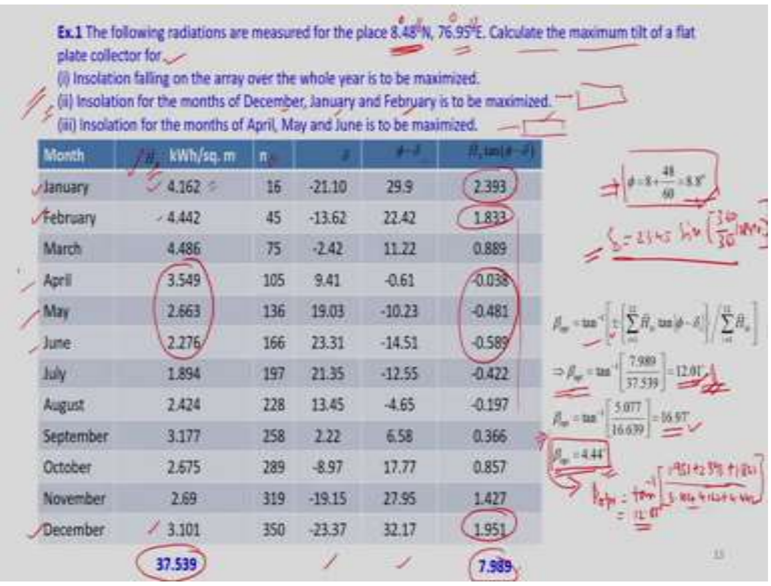
So in summer applications are absorption refrigeration plant. So once we know latitude, so from that we can calculate the β value. Now, our concern is, say for some time we are trying to install a collector system to meet the demands in the winter months. So in that particular case, we need to find out the optimal β value for maximum exposure to the solar radiation for the applications like space heating. And sometimes maybe throughout the year we are interested, throughout the year we would like to maximize the amount of solar radiation received by the collector.

And sometimes it might so happen that only summer months we are interested or people are interested for maximization of receipt of solar radiation. So for all these 3 cases, we need to find out what will be the best beta value. So how to find out. So this monthly average value of the energy falling on a collector plane per unit area can be calculated by using this expression. So this alpha a is nothing but monthly average altitude angle at noon. So monthly average altitude angle at noon.

And total flux falling on the collector over the year can be calculated by using this expression. So there are certain cases where we need to apply some other expression here. So instead of $(\bar{\alpha}_{ai} + \beta)$, sometimes we need to apply $(\bar{\alpha}_{ai} - \beta)$. So these are conditional specific. And again γ_s or γ values how these will vary. So this discussion maybe we can take up when we solve the problem.

And for annual flux to be maximum then from this expression, we can differentiate it and we can find out this optimum value which is nothing but ($\tan^{-1}H_{bi}$). So this is i varies from 1 to 12, so for 12 months, we need to find out H_{bi} value and then we need to multiply with $\tan(\phi - \delta_i)$ So δ will also vary with months and finally, summation of H_{bi} we need to consider.

(Refer Slide Time: 23:23)



Ex.1 The following radiations are measured for the place 8.48°N, 76.95°E. Calculate the maximum tilt of a flat plate collector for
(i) Insolation falling on the array over the whole year is to be maximized.
(ii) Insolation for the months of December, January and February is to be maximized.
(iii) Insolation for the months of April, May and June is to be maximized.

Month	$\bar{H}_b$ kWh/sq. m	n	δ	$\phi-\delta$	$\bar{H}_b \tan(\phi-\delta)$
January	4.162	16	-21.10	29.9	2.393
February	4.442	45	-13.62	22.42	1.833
March	4.486	75	-2.42	11.22	0.889
April	3.549	105	9.41	-0.61	-0.038
May	2.663	136	19.03	-10.23	-0.481
June	2.276	166	23.31	-14.51	-0.589
July	1.894	197	21.35	-12.55	-0.422
August	2.424	228	13.45	-4.65	-0.197
September	3.177	258	2.22	6.58	0.366
October	2.675	289	-8.97	17.77	0.857
November	2.69	319	-19.15	27.95	1.427
December	3.101	350	-23.37	32.17	1.951
	37.539				7.989

Now, let us take a problem of something like this. The following radiations are measured for the place having ϕ value 8.48 North and then longitude is 76.95 degrees East. So we need to calculate maximum tilt of a flat plate collector for 3 different cases. In the first case, insolation falling on the area over the whole year is to be maximized. So now I want to maximize the solar radiation received by the collector throughout the year. So for that we need to consider all the months.

And second case insolation for the months of December, January and February is to be maximized. And third case insolation for the month of April, May, June to be maximized. So there are logics why these months are considered because we have specific application during these summer and winter months. Actually this is degree and it is minute, this is in degree and this is minute, this is degree and this is minute. So if this is so then what you can do we can convert the entire ϕ to in degree.

And these data are given to from January to December, H_b values are given in the problems and N values we can take the middle of the month and we can sum it and delta can be find out by using the equation of what we have done already $23.45\sin\left(\frac{360}{365}(284+n)\right)$. So by using this expression we can find out the δ value for all the months. And once we know δ and ϕ is known to us then $(\phi-\delta_i)$can be calculated here and then we can multiply this term and $\tan(\phi-\delta_i)$and we can see the results of this multiplication and finally, we can add these values.

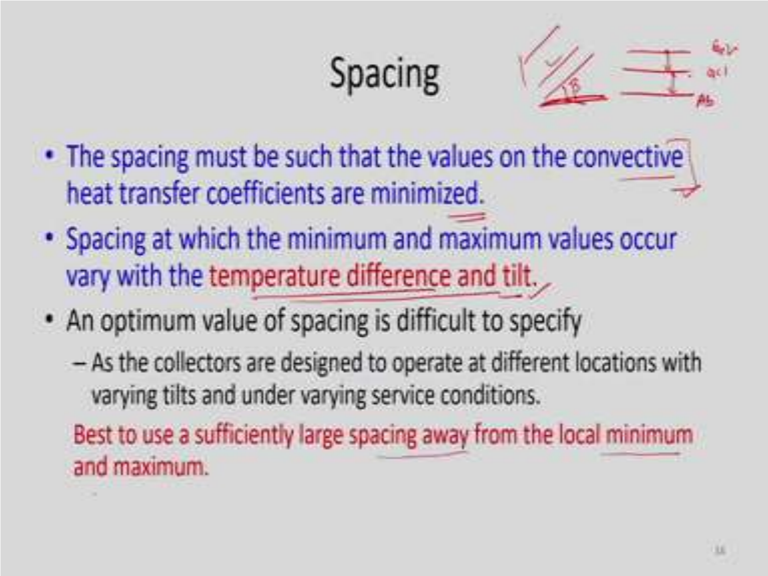
So as per the expression what we got. So β optimum for maximum absorption of solar radiation we can use this expression. So if we substitute these values, then what we will get is a 12.01 degree. So this tilt angle you need to be maintain in order to maximize the solar radiation. And what will be the optimum tilt angle for case 2, December, January and February? So here we need to find out these values, we need to find out December, January and February, what are those values. So this I can explain here.

So β_{opt} is something like tan inverse. So here positive we have to apply because this part is positive. So $\beta_{opt} = \tan^{-1}\left[\frac{1.951+2.393+1.833}{3.101+4.162+4.442}\right]$. So if we do the calculation then this optimum value will be 12.01° and for this case again we need to consider April, May and June. So for this we need to consider these 3 values, and then these 3 values.

So once you consider and of course, you need to apply minus here because it will be minus, so minus sign we need to apply here. So we will get β_{opt} is equal to 4.44. So what will can conclude from this numerical exercise. So when we are maximizing the solar radiation absorption for the entire year, then we need to keep a value of β at about 12.01, which is the optimum value of tilt angle which gives the maximum exposure to the solar radiation.

And if we are targeting for only December, January and February months application, then we need to maintain a tilt angle of 16.97° and for summer months, we need to maintain a tilt angle of 4.44. So this is a very important problem and we understand how this beta value is important for getting the maximum exposure to the solar insolation.

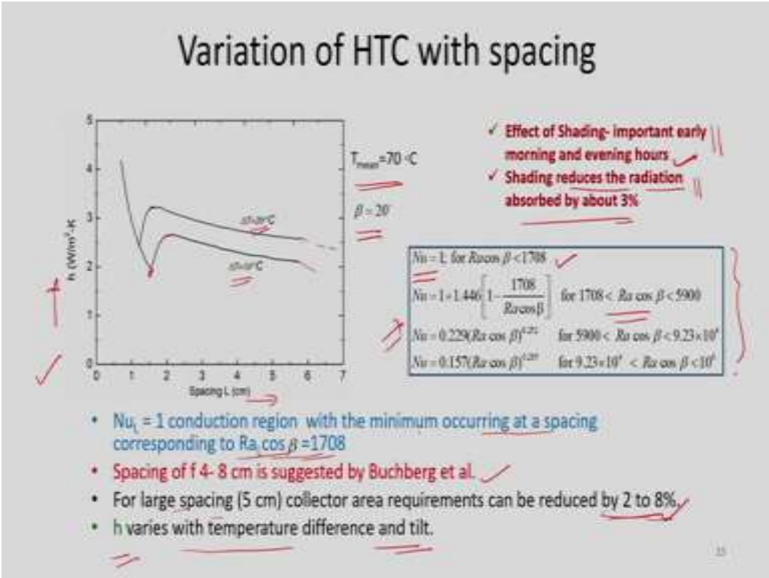
(Refer Slide Time: 28:59)



Now, let us move to the spacing between the covers. So maybe absorber plate is here, Abs, then we have glass cover 1, G_{C1}, maybe G_{C2}. So this spacing is also very very important. This spacing must be such that the values on the convective heat transfer coefficients are minimized, this is very very important. The spacing at which the minimum and maximum values occur vary with the temperature difference and tilt. So this temperature difference between this cover system and the tilt.

So this will be always installed at certain angle. So this is beta, this is horizontal. The spacing which the minimum maximum values occur vary with the temperature difference and tilt, which is shown here. An optimum value of spacing is difficult to specify as the collectors are designed to operate at different locations with varying tilts and under varying service conditions. Hence the best to use a sufficiently large spacing array from the local minimum and maximum. Let us learn what is minimum and maximum here.

(Refer Slide Time: 30:38)



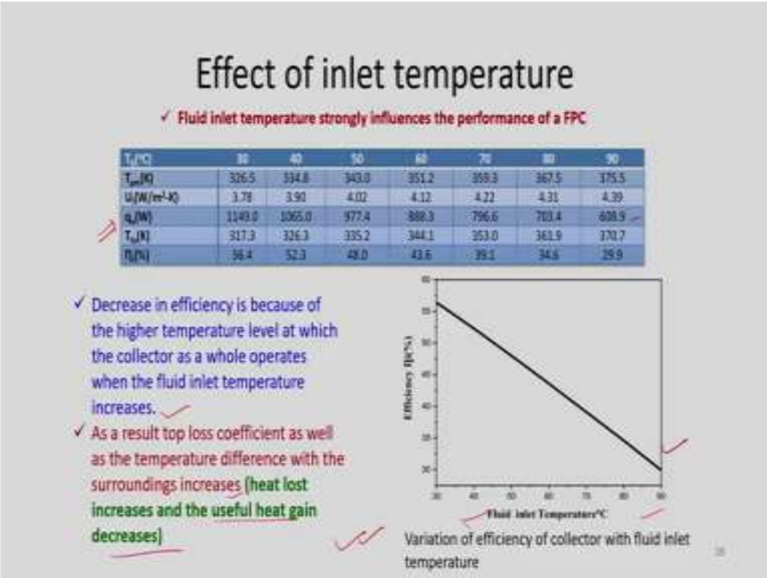
So this curve was generated based on the experiments. So it is founded when Nusselt number is 1, this conduction region with the minimum occurring at a spacing corresponding to the $R_{aL}\cos\beta$ is equal to 1708. What does it mean? So this figure shows the variation of heat transfer coefficient with spacing between the covers and this is an example when T_{mean} was 70 °C and β was 20 °C. So what happens as this space increases initially drops to a minimum and then further increase of spacing immediately jumps to the maximum heat transfer coefficient.

Then it decreases and with increase in space, finally it may come again to the below of this minimum. So that may come something like this. So the spacing of 4 to 8 centimeter is suggested by Buchberg et al, these are correlations which can be applied under different conditions. So when Nusselt number is 1, so we can use this correlation which gives the minimum heat transfer coefficient. For large spacing about 5 centimeter collector area requirements can be reduced by 2 to 8 percent, this is also one of the important observation and this heat transfer coefficient h varies with temperature difference and tilt what you can see here.

So when ΔT is 10, so its variation is something like this when ΔT was 20 so its variation is something like this. So it varies with temperature difference and tilt. So this tilt angle is very very important for capture of more solar radiation. And also this effect of shading is very very important during early in the morning and evening hours.

So because Sun will be oblique and then one of the tubes will shade the others or some part of the absorber plate shades the, some portion of the absorber plate, so that way shading is also important. So investigation of shade is really important for precise calculation of heat transfer taking place in a collector. So shading reduces the radiation absorption by about 3 percent which is estimated by many of the researchers. Now move to the next slide.

(Refer Slide Time: 33:39)

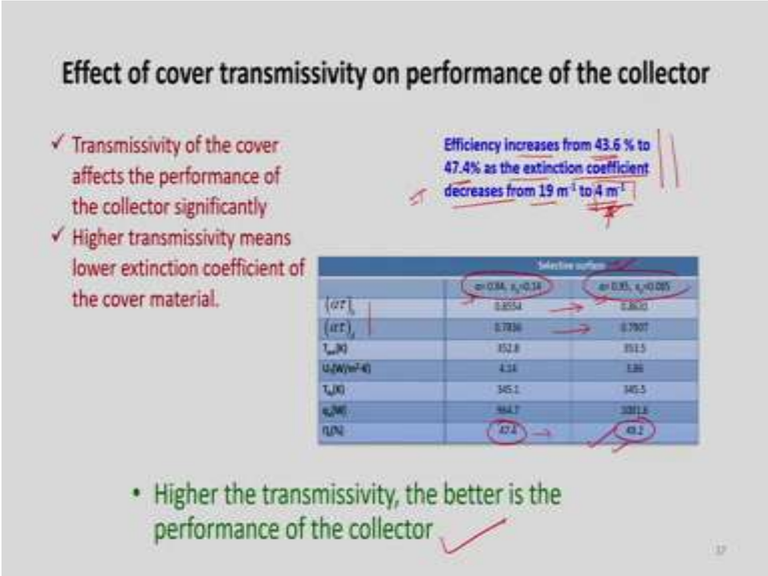


So which shows the effect of one of the most important operating parameter called temperature. This fluid inlet temperature strongly influences the performance of a flat plate collector. As you can see here, as the fluid inlet temperature increases, this efficiency is decreases. So this can be seen in this plot also. This plot shows the variation efficiency with respect to the increase in fluid inlet temperature. And other values can also be seen.

So this q_u is decreases which is nothing but useful heat gain is decreases with increase in inlet fluid temperature. So this decrease in efficiency with respect to rise in temperature is because of the higher temperature level at which the collector as a whole operates when the fluid inlet temperature increases.

As a result, the top loss coefficient as well as the temperature difference with the surroundings increases. Hence, heat lost increases and useful heat gain decreases. So temperature of the inlet fluid is very, very important as far as performance of a flat plate collector is concerned.

(Refer Slide Time: 35:14)



Now, let us study about the effect of cover's transmissivity on the performance of the collector. So this transmissivity of the cover affects the performance of the collector significantly. So you can realize now, because you know now how to develop the energy balance equation, there the role of transmissivity, you can realize how important this parameter is. Higher the transmissivity means lower extinction coefficient of the cover material, also you know, what is extinction coefficient.

So what extinction coefficient we need to maintain for higher transmissivity. So as reported the efficiency of the collector increases from 43.6 percent to 47.4 percent as the extinction coefficient decreases from 19 to 4. Normally 4,5,6 that range is suitable for flat plate collector applications. So as you can see here, 2 different selective surfaces are considered. So one for absorptivity is equal to 0.94 and emissivity is 0.14 and in the second case absorptivity is 0.95 and emissivity is 0.085.

So if you see this transmissivity absorptivity product for beam and diffuse radiation, you can see there is a rise in those values. So also you can see the increase in efficiency from 47.4 to 49.2 percent. So by increasing the absorptivity of the selective surface, we can really increase the efficiency of the collector significantly. So once we increase this, then our transmissivity absorptivity product for beam and diffuse radiation also increases. So higher the transmissivity, better is the performance of the collector that we understand now.

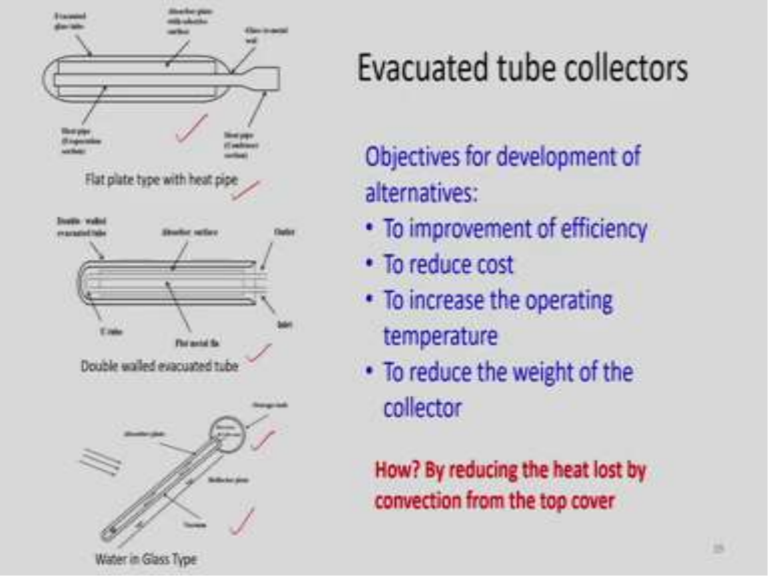
(Refer Slide Time: 37:42)

So dust which is accumulated with time on the flat plate collector as well as PV collectors are also important, because this dust is nothing but it is a resistance to the flow of photons or flow of heat. So when the collector is deployed in a practical system, dust gets accumulated over it and that reduces the transmissivity of the glass cover. That is why it is recommended that that glass cover or say PV system need to be cleaned time to time. Of course, it is recommended to clean daily but it is not possible to clean daily, but cleaning is generally done in a few days.

So because of this dust, which is accumulated over the glass cover in the flat plate collectors and on the PV modules the intensity reduces, that is why we need to multiply with a correction factor. So what is correction factor? This correction factor is the ratio of normal transmissivity to a dust laden cover to the normal transmissivity.

So in general a correction factor of 0.92 to 0.99 is considered in Indian context and this range is also varied for PV system or PV modules. Also this accumulation of dust depends on the material of the cover, maybe sometimes glass or sometimes plastics are used and tilt of the collector and frequency of the cleaning.

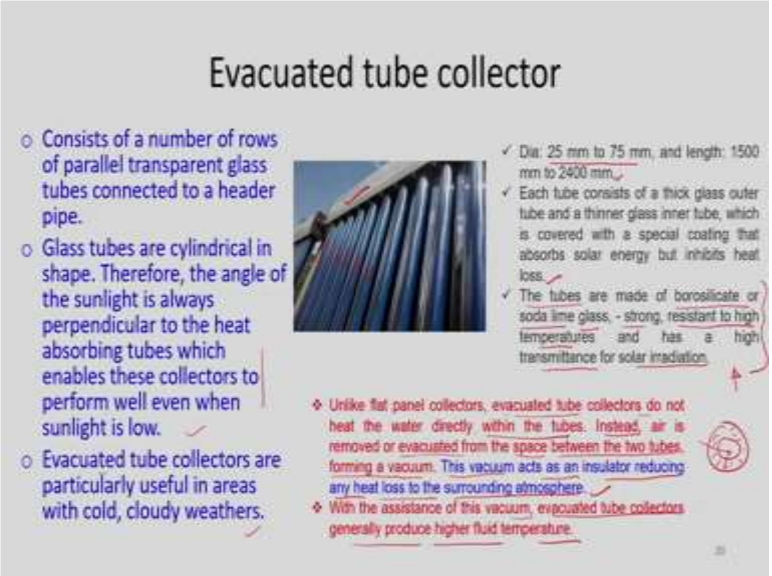
(Refer Slide Time: 39:52)



Now, move to the evacuated tube collectors. So what are the objective of development of this alternative collector? To improve the efficiency, to reduce cost, to increase the operating temperature and to reduce the weight of the collector. So how this is done, by reducing the heat lost by convection from the top of the cover system. So there are many configurations. So first configurations what we can see is a flat plate type with heat pipe. So heat pipes are used I will explain in the coming slides, how does a heat pipe work.

And then double walled evacuated tubes. So evacuation is maintained, this vacuum is maintained between the tubes so that convective heat losses can be minimized. And the third configuration is the water in the glass type, here some kind of reflectors are used to heat the fluid. And finally, this is collected at the storage tank. Let us learn in a deeper sense this evacuated tube collectors.

(Refer Slide Time: 41:13)



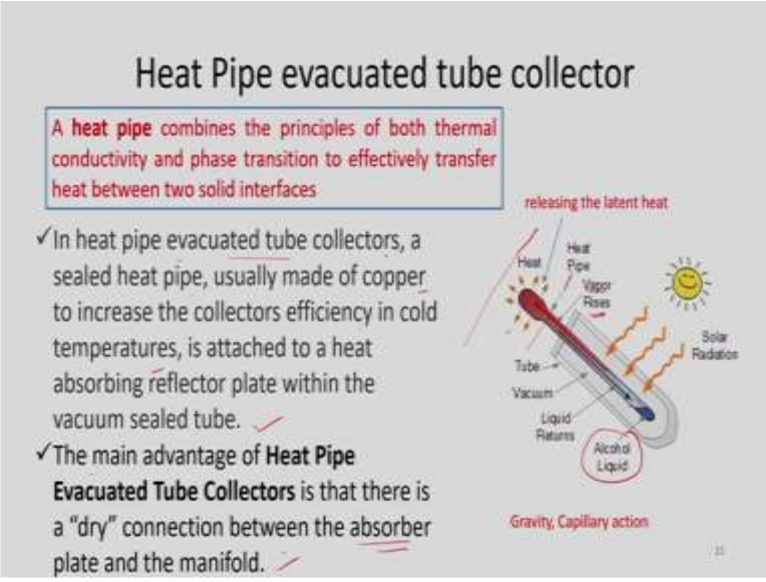
This evacuated tube collector consists of a number of rows of parallel transparent glass tubes connected to a header. So these are the headers and these are the tubes through which heat transfer fluid flows. These glass tubes are cylindrical in shapes, as you can see here, therefore, the angle of the sunlight is always perpendicular to the heat absorbing tubes which enables these collectors to perform well even when the sunlight is low.

So this is very, very important point, even though sunlight is low this evaluated tube collector will work perfectly. These evacuated tube collectors are particularly useful in the areas with cold and cloudy weathers, so that we should keep in mind. This tube diameter normally keeps in the range of 25 to 75 mm and length is about 1500 to 2400 mm. So this each tube consists of a thick glass outer tube and a thinner glass inner tube which is covered with a special coating that absorbs solar energy but inhibits heat losses.

So selective coatings are applied so that energy absorption can be maximized. The tubes are made of Boro silicates or soda lime glass which is strong, resistant to high temperatures and has a high transmittance for solar irradiation. These parameters are very, very important as far as evacuated tube collectors are concerned. So what is the difference between this collector and conventional flat plate collector?

These evacuative collectors do not heat the water directly within the tubes, instead air is removed or evacuated from the space between the 2 tubes forming a vacuum. This vacuum acts as insulator reducing any heat loss to the surrounding atmosphere. So these are the tubes, so here is this is the vacuum and since no medium is there, so once heat is introduced the heat cannot be come out. So it is an insulation. With the assistance of this vacuum, the evacuated tube collectors generally produce higher fluid temperature, which is more than flat plate collector. Sometimes we can get a temperature more than 130 °C.

(Refer Slide Time: 44:18)



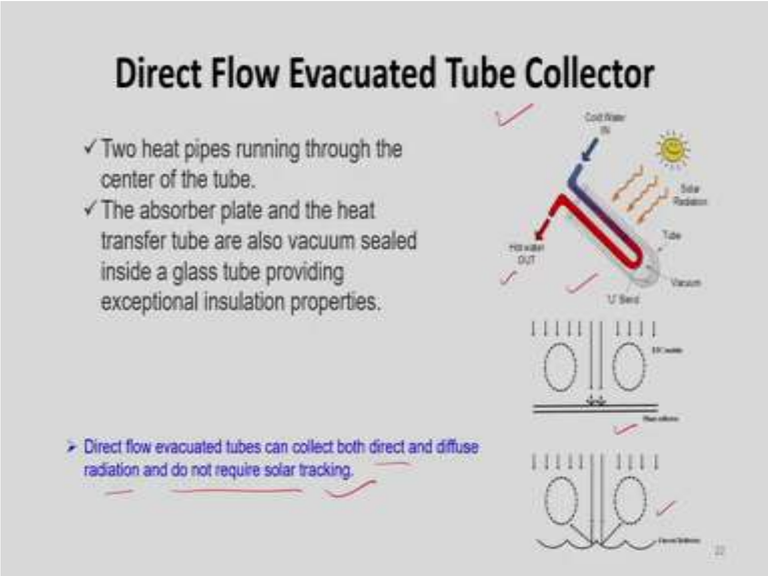
So it is seen that heat pipe technologies are used in evacuated tube collectors. What is heat pipes? Heat pipes is nothing but a heat exchanger which combines the principles of both thermal conductivity and phase transition to effectively transfer heat between two solid surfaces. So what happens if we consider this configuration. So fluid is here in this tube when solar radiation is exposed here, then this fluid will be evaporated.

And then this latent heat of evaporation will be released here in the condenser part, this is the condenser part where heat will be carried. And then once it is condensed, it will flow in the tube under the action of gravity or capillary. So this will maintain and this will be circulated again and again. So heat will be carried by this fluid and which is deposited here, where heat is collected and then it is condensed and this comes back to the original position and it moves in between the close circuit.

And this is vacuum, this vacuum is maintained, so that energy losses are minimized and this is the glass tube and liquid return is as shown here and fluid is something like alcohol like fluids. And this is called vaporizers and this is as a whole call heat pipe, this part is heat pipe, this is heat pipe. So in heat pipe evacuated tube collectors, a sealed heat pipe usually made of copper to increase the collector efficiency in cold temperatures is attached to the heat absorbing reflector plate within the vacuum sealed tube.

The main advantage of this heat pipe evacuated tube collector is that there is a dry connection between the absorber plate and the manifold. So there is no wet connection, no fluid will be contacted, so this is a dry connection. So this is a very good technology and efficiency is very, very high but somewhat costly.

(Refer Slide Time: 46:37)

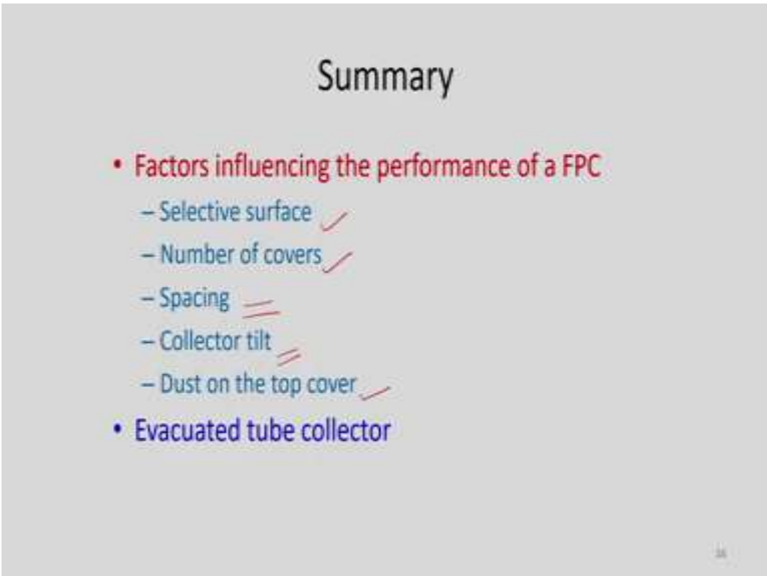


And also direct flow evacuated tube collectors are in place. So here 2 heat pipes running through the center the tubes are used. So as you can see here, solar radiation falls here. So it is a cold fluid in and hot fluid out is here, and then evacuation is maintained and it is a U tube. And of course this energy absorption can be maximized by using this kind of plane reflectors. So one more advantage is that these direct flow evacuated tubes can collect both direct and diffuse radiation and do not require solar tracking. So principle of working is same as heat pipe collectors.

(Refer Slide Time: 47:19)

There are other collectors like BNL collector, then polymer solar collectors and concrete collectors. So we will not discuss more on it. So these are the available collectors and most of the collectors in under research condition. So we can summarize what we have discussed today.

(Refer Slide Time: 47:42)



Primarily, we have discussed different factors which influences the performance of a flat plate collector. Primarily we have discussed selective surfaces, how selective surfaces can be manufactured, what are the importance of selective surfaces and what are the range of absorptivity and emissivities for selective surfaces, how we can enhance the absorption capability by increasing the absorptivity of the absorber surfaces.

Also we have seen the effect of number of covers with selective surfaces and without selective surfaces. Also we have studied the influence of spacing between the covers, also we have studied the role of collector tilt and dust on the top cover. Finally, we have understand how this evacuated tube collector works and what are the need of development of this kind of technology, of course for increasing the conversion efficiency by reducing the cost. I hope you have enjoyed this lecture. Thank you very much for watching.