Solar Energy Engineering and Technology
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Lecture - 28
Tutorial: Concentrating Collector

Dear students, today we will be discussing about a tutorial on solar concentrating collectors. So, this tutorial goes something like this.

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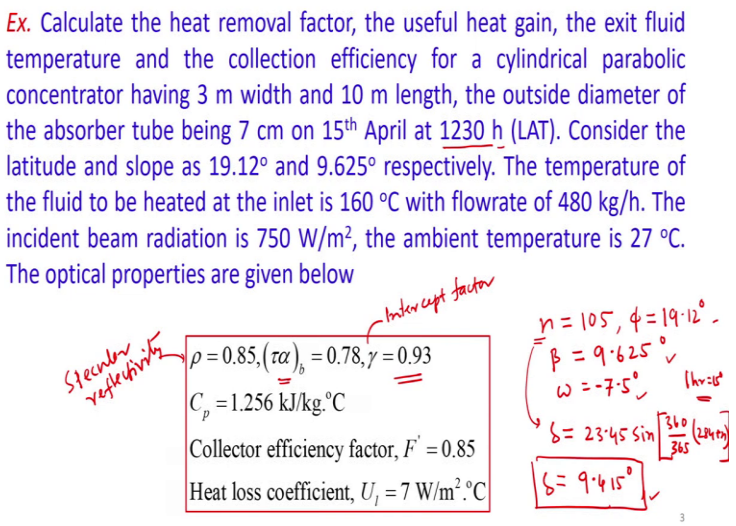

We need to calculate heat removal factor, the useful heat gain, the exit fluid temperature, and the collection efficiency for a cylindrical parabolic concentrator having 3 m width and 10 m long. The outside diameter of the absorber tube being 7 cm and that has to be calculated on 15th April at 12:30 hours local apparent time.

Consider the latitude and slope as 19.12° and 9.625° respectively. The temperature of the fluid to be heated at the inlet is 160 °C, with flow rate of 480 kg/hr. The incident beam radiation is 750 W/m^2, the ambient temperature is 27 °C. And optical properties are also given.

So, this ρ, which is nothing but specular reflectivity of the concentrator surface. And this τα for beam radiation is given to be 0.78 and γ, which is nothing but intercept factor, so this is intercept factor. Intercept factor, which is equal to 0.93. So, what is intercept factor? The fraction of the reflected radiation intercepted by the absorber tube. And ρ, what I said before is specular reflectivity of concentrator surface. And for 15th of April, n = 105.

And ϕ = 19.12° and beta, which is nothing but slope, which given as 9.625° and ω, because this is 1230 hours. That means 1 hr = 15°, 1 hr = 15° and half an hours is 7.5°. But since it is afternoon, so we will use negative sign. So, ω = -7.5°, which is nothing but hour angle. So, if we know n, then from that we can calculate what is δ or declination.

So, we know the expression for declination, which is nothing but $\delta = 23.45 \sin \frac{360}{365}(284+n)$. So, if we substitute the value of n, which is equal to 105, then this δ = 9.415°. So, declination is known. So, know now ϕ, then β, slope; then hour angle, and declination. So now, what is next, we to calculate tilt factor, because we need to find out the absorbed solar flux.

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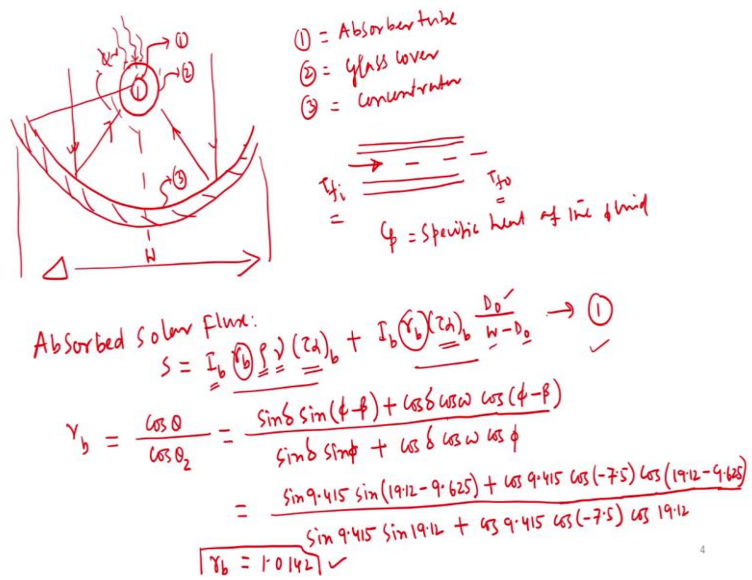

So, before we initiate the calculation, let us draw the figure first. That means cross section of a cylindrical parabolic collector. So, if we consider, this is the tube, and this is the glass cover, and concentrator is something like this. We can extend this somewhat and draw this. This is nothing but the concentrator. Solar radiation is falling here and it is going here, falling here and is reflected to this absorber. And maybe, I will name it as this may be 1, this may be 2, and this may be 3.

And we can draw this here and may be we can draw here and here. So, this part is W, which is nothing but the width, and length is towards this, it will go something like this. So here, one is nothing but absorber tube, absorber tube; then two is nothing but the glass cover, and three is concentrator. And also, we can see how this fluid flows. So, fluid is flowing inside the tube. So, T_{fi} may be the input inlet fluid temperature; so that we can do it.

So, fluid is flowing to this tube. So, may be T_{fi} one things and then T_{fo} in the other side, and like. So here, W is the aperture and length is L and also, we can define this rim angle if required. This is the rim angle, which is nothing but ϕ_r. And inlet fluid temperature is T_{fi}, outlet fluid temperature is T_{fo}. And if we consider a fluid having specific heat is C_p, this is the specific heat of the fluid.

Now, we need to find out the tilt factor. Because if we write the expression for absorbed absorbed solar flux, that means the amount of solar radiation which is absorbed in the absorber tube. So, this is the absorber tube and this is the glass cover and this is the reflector. Solar radiation is falling on this reflector that is reflected back to this absorber. Again, some component of radiation is falling directly on this absorber through this glass cover. So, we have done the entire derivation. Now, we are interested about the absorbed solar flux, which is represented by S.

So, we can write $S = I_b r_b \rho\gamma(\tau\alpha)_b + I_b r_b (\tau\alpha)_b \left(\frac{D_o}{W - D_o}\right)$. So, this is the expression by which we can calculate the absorbed solar flux in the absorber. Now, these values are known, I_b is known, ρ and then intercept factor, τα for beam radiation beam radiation. D_o, W, D_o everything is known, expect r_b, which is common in both the parts of this expression.

Now, let us calculate what is r_b. r_b is nothing but the tilt factor for beam radiation, which is defined as the ratio of the beam radiation flux falling on the tilted surface to the radiation falling on a horizontal surface. So, this is something like we have $r_b = \frac{\cos\theta}{\cos\theta_z}$. So, if we write the expression for this, this will be something like,

$$r_b = \frac{\sin\delta\sin(\phi-\beta) + \cos\delta\cos\omega\cos(\phi-\beta)}{\sin\delta\sin\phi + \cos\delta\cos\omega\cos\phi}.$$

So, we know the values of δ, ϕ, β, ω so if we substitute here, then what we will get? So, let us substitute $r_b = \frac{\sin 9.415 \sin(19.12 - 9.625) + \cos 9.415 \cos(-7.5)\cos(19.12 - 9.625)}{\sin 9.415 \sin 19.12 + \cos 9.415 \cos(-7.5)\cos 19.12}$.

So, if we do the calculation then this r_b is found to be 1.0142. So, this is nothing but r_b. So, this value is known now then we will use this value of r_b in the expression 1, which is nothing but absorbed solar flux.

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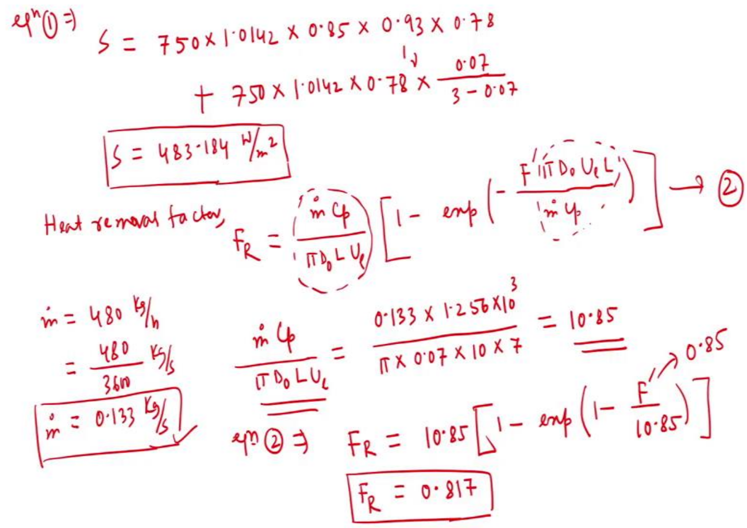

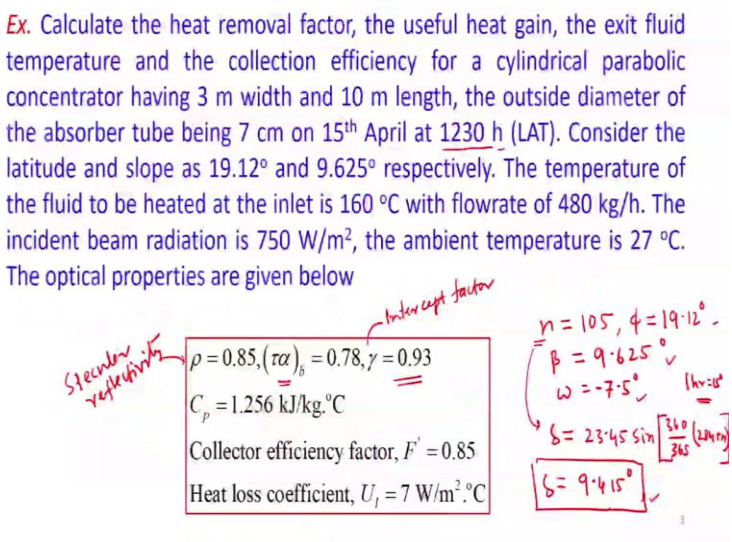

So, use the equation 1, equation 1 implies, we will have $S = 750\times1.0142\times0.85\times0.93\times0.78 + 750\times1.0142\times 0.78\times\dfrac{0.07}{3-0.07} = 483.184\,W/m^2$. So, this is the flux received. So, once we know this S, then other parameters can be calculated like instantaneous efficiency and q_u.

So, for that, again we need to calculate one parameter call heat removal factor. So, how to calculate this heat removal factor? So, heat removal factor F_R, it is normally represented by F_R. So, this is the expression $F_R = \dfrac{\dot{m}C_p}{\pi D_o L U_l}\left[1-\exp\left(-\dfrac{F'\pi D_o U_l L}{\dot{m}C_p}\right)\right]$ ok.

So, this ṁ, what is given here; so ṁ = 480 kg/hr. So, we need to convert it to kg/s. So, 480 divided by 3600, which will give kg/s. And, if we simplify it, so it will be 0.133 kg/s. This is

$\dot{m}$. So here, we have to use this kg/s, maybe we can write this as equation 2. And we can calculate this term, so this term, because this term is common here also. So, once we calculate then, it will not be so complex.

So, this term, $\frac{\dot{m}C_p}{\pi D_o L U_l} = \frac{0.133\times\left(1.256\times10^3\right)}{\pi\times0.7\times10\times7} = 10.85$. So, this value is found to be 10.85.

So now, if we use equation 2, what will happen? This $F_R = 10.85\left[1-\exp\left(1-\frac{F'}{10.85}\right)\right]$. So, it becomes very easy to calculate now. So, this F_R value, if we substitute F′, which is given as 0.85. So, if we substitute, then $F_R = 0.817$. So, F_R is found to be 0.817. So, in the next calculation, we need to find out q_u.

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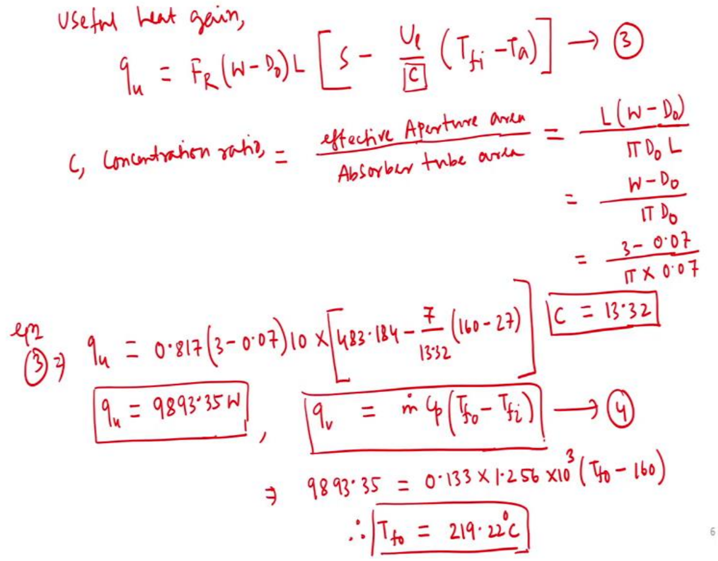

So, lets us write down the expression for useful heat gain. Useful heat gain $q_u = F_R (W - D_o)L \left[S - \frac{U_l}{C}(T_{fi} - T_a)\right]$. So, we need to find out the concentration ratio now. T_{fi}-T_a, as we know the other parameter. So, F_R, we have calculated and only unknown is C here. So, how to calculate C? So, let it be equation 3.

And C is nothing but concentration ratio, concentration ratio which is defined as effective aperture area to the absorber tube area. So, this is nothing but $C = \frac{(W - D_o)L}{\pi D_o L} = \frac{(W - D_o)}{\pi D_o}$. So, we know the value of W and D_o. So, if we substitute here, then what we will get $C = \frac{(3 - 0.07)}{\pi \times 0.07} = 13.32$.

So, we know now concentration ratio values for this configuration, which is about 13.32. So, let us calculate the useful heat gain. So, this is q_u or we can write here equation 3 implies, $q_u = 0.817(3 - 0.07)10\left[483.814 - \frac{7}{13.32}(160 - 27)\right] = 9893.35\,W$ q_u.

So, once we know q_u, then from that we can calculate what will be the instantaneous efficiency. So, how to calculate this? So, we know $q_u = \dot{m}C_p(T_{fi} - T_{fo})$. So, this maybe equation 4. So, once we substitute the value of q_u here, then from that we can calculate what will be the value of T_{fo}.

So, q_u = 9893.35 and then mass flow rate is 0.133 multiplied by C_p is 1.256 $\times 10^3$ and T_{fo}, we need to calculate. So, this expression we we have to reverse it; so (T_{fo}-T_{fi}) ok. So, it will be (T_{fo}-160). So, from here, we can calculate what is T_{fo}. So, which is found to be 219.22 ^{o}C. So, we have calculated what is T_{fo}. Now, what we need to calculate is the instantaneous efficiency.

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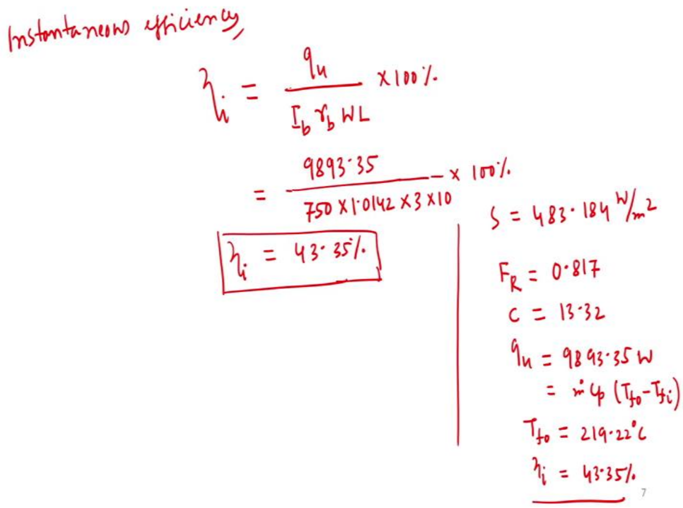

Instantaneous efficiency, η_i, which can be expressed

$$\eta_i = \frac{q_u}{I_b r_b W L} \times 100\% = \frac{9893.35}{750 \times 1.0142 \times 3 \times 10} \times 100\% = 43.35\% .$$

So, what are the parameters we have calculated? First, we have calculated S value; so S was calculated to be 483.184 W/m^2. Then we have calculated F_R; so this F_R was found to be 0.817. And then, we have calculated the concentration ratio, which was 13.32. And then, we have calculated useful heat gain, which was found to be 9893.35 W. And after calculation of these, we have used the expression, $q_u = \dot{m} C_p \left(T_{fo} - T_{fi} \right)$.

So, based on this calculations, what we have calculated, T_{fo}, which is found to be 219.22 ^{o}C. And finally, we have calculated instantaneous efficiency, η_i, which is found to be 43.35 %. So, in this problem, we have demonstrated, how this solar absorbed flux can be calculated, then how to calculate q_u. For calculation of q_u, we need the value of F_R and F′. So, F_R is nothing but heat removal factor and then, F′ is efficiency factor of the collector. So, once we know this, then we can calculate, what is q_u. Of course, we need calculate concentration ratio and after that, we can calculate T_{fo} and instantaneous efficiency.

So, this kind of problems are very, very practical. And I hope you have enjoyed this video and hopefully, you are now capable to design a solar concentrated collector. So, thank you very much.