Solar Thermal Engineering

12 Feb 2021.

→ Typical Solar Radiation intensity on a horizontal Surface is 300 – 800 W/m².

→ On a clear Sunny day for a plate with temp. that exceeds ambient temperature by about 40°C,

→ Heat loss-coefficient is around 8 W/m²°C.

→ Losses are the Same order of magnitude as Energy received.

Important:

Solar Energy is received on the Earth Surface in terms of radiation comprising mostly the visible and IR Wavelengths.

→ A blackbody intercepting the Solar radiation Can convert Solar Energy to heat which Can be further transferred to a fluid as useful energy.

Solar Energy Applications

The conversion of Solar energy into other useful forms of energy can be accomplished by three conversion processes

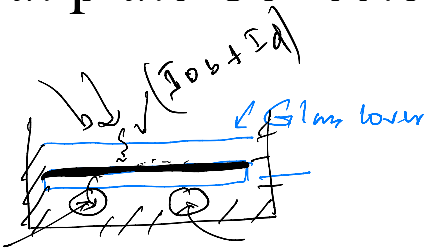
Flat plate Solar thermal collector

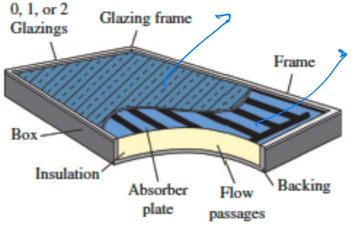
- **Heliochemical process:** This is basically photosynthesis process and it is responsible for production of fossil fuel and biomass

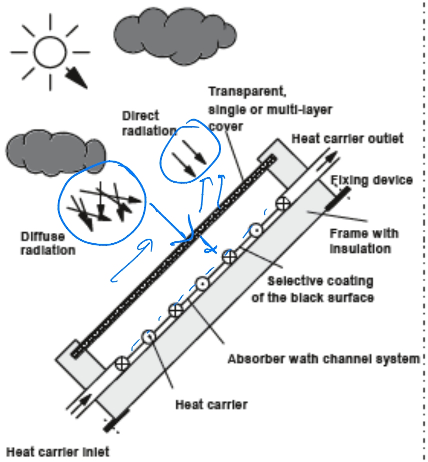
- **Heliothermal process:** In this process the solar energy is collected and converted to thermal energy or heat. Flat plate collectors or concentrators are common devices that converts solar energy to useful heat energy.

- **Helioelectrical process:** The production of electricity by photovoltaic or solar cells is accomplished by a device called Si-solar cells

Flat plate Collector and collector components







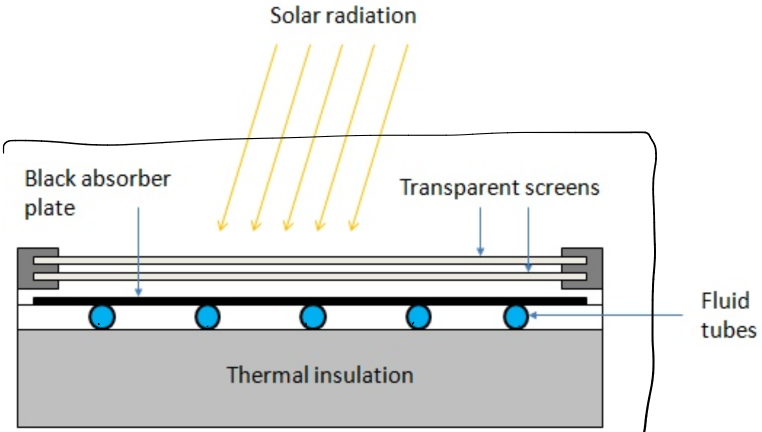
Cover
Transparent material:
- Single pane
- Solar compound pane
- Plastic plates or sheets

Box
Material:
- Aluminum
- Galvanized steel plate
- Plastic
- Wood

Insulation
Material:
- Polyurethane
- Mineral wool
- Fiber-glass wool

Absorber
black
Material:
- Metall (Cu, Al, Fe)
- Plastic (e.g. Polypropylene, Polyethylene, EPDM)

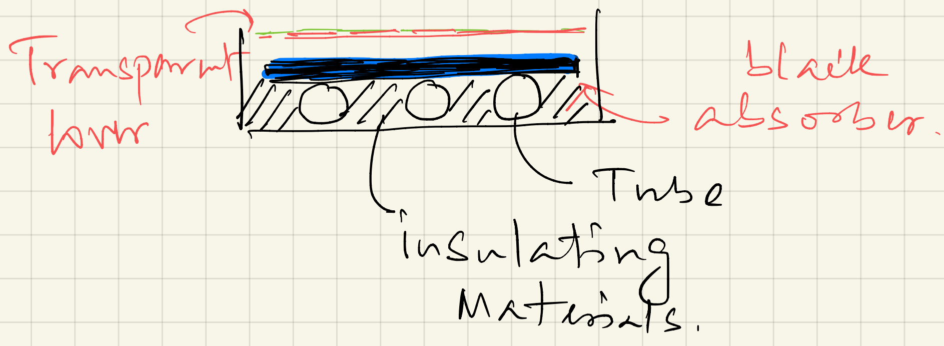
Heat carrier
Material:
- Water (with antifreeze)
- Air



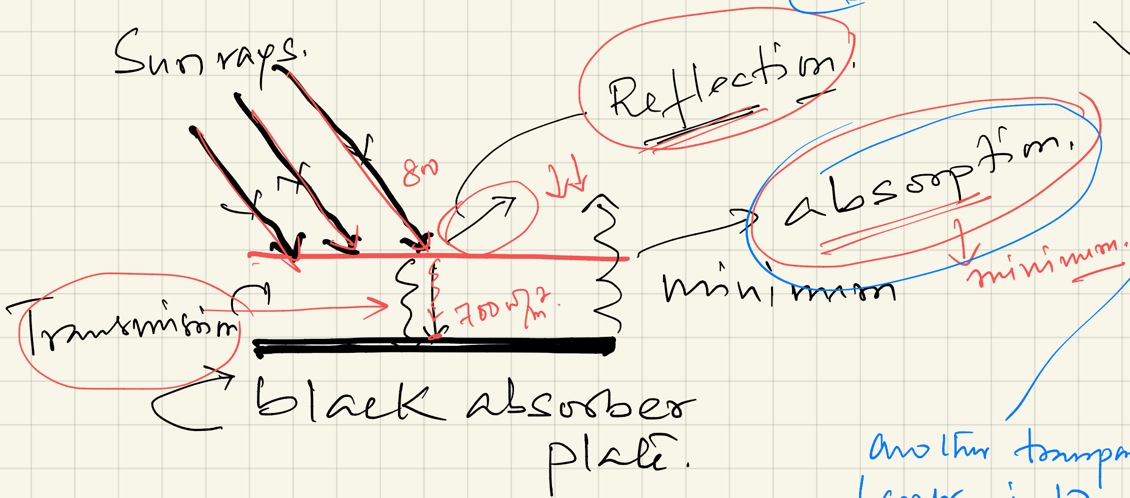
$$\eta = \frac{\text{Output}}{\text{input}}$$

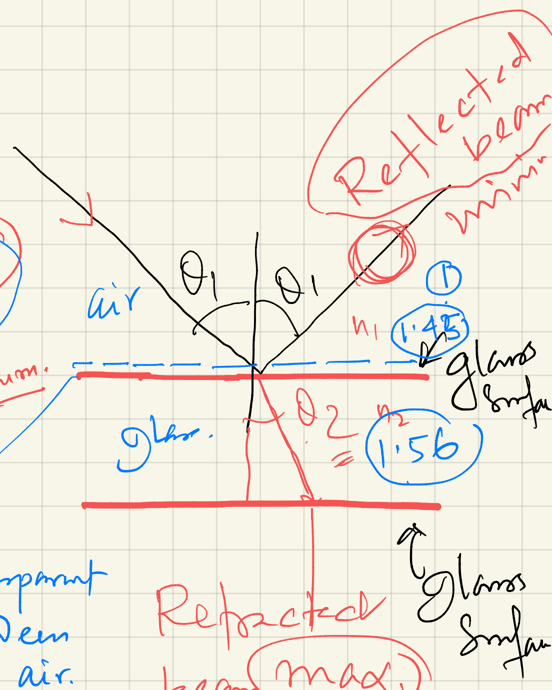
Water / gas.

- Transparent cover → Convection losses
→ Radiation losses.



Transparent cover:





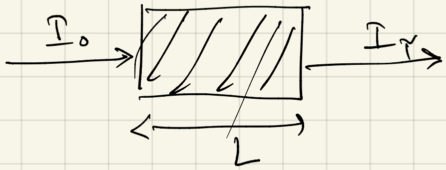
another transparent layer in between glass and air.

→ refractive index of that substance (n') should be in between Glass and Air.

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

Items	Refractive Index.
air	→ 1.0
Glass	→ 1.526
Polyfluoroethylene	→ 1.34
PVF	→ 1.45.

* Absorption should be minimum.



$$-dI = K I \, dL.$$

$$\int_{I_0}^{I_r} -\frac{dI}{I} = \int_0^L K \, dL$$

or, $\ln \frac{I_r}{I_0} = -KL.$ Extinction co-efficient.

$$\boxed{\gamma = e^{-KL}} \longrightarrow (1)$$

or, $I_r/I_0 = e^{-KL} = \gamma.$

Fe_2O_3 for an impurity.

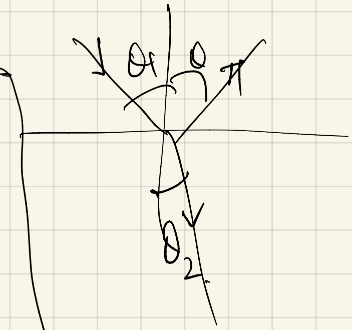
→ 5 – 10% absorption for normal glass.

Items.	Extinction co-efficient.
Glass	0.04
White Glass	0.03.
Polyethylene	1.65
Teflon	0.59
PVF.	1.4

It is worth noticing that both the Refractive index (n) and extinction co-efficient are wave length dependent. $\rightarrow$ should be defined monochromatically.

$\rightarrow$ Light waves are transverse in character and polarization is a natural phenomenon. ($\perp$ and $\parallel$)

* Surface Reflectivity are



Fraction of Reflectivity

$$\rho_\perp' = \frac{\sin^2(\theta_1-\theta_2)}{\sin^2(\theta_1+\theta_2)}$$

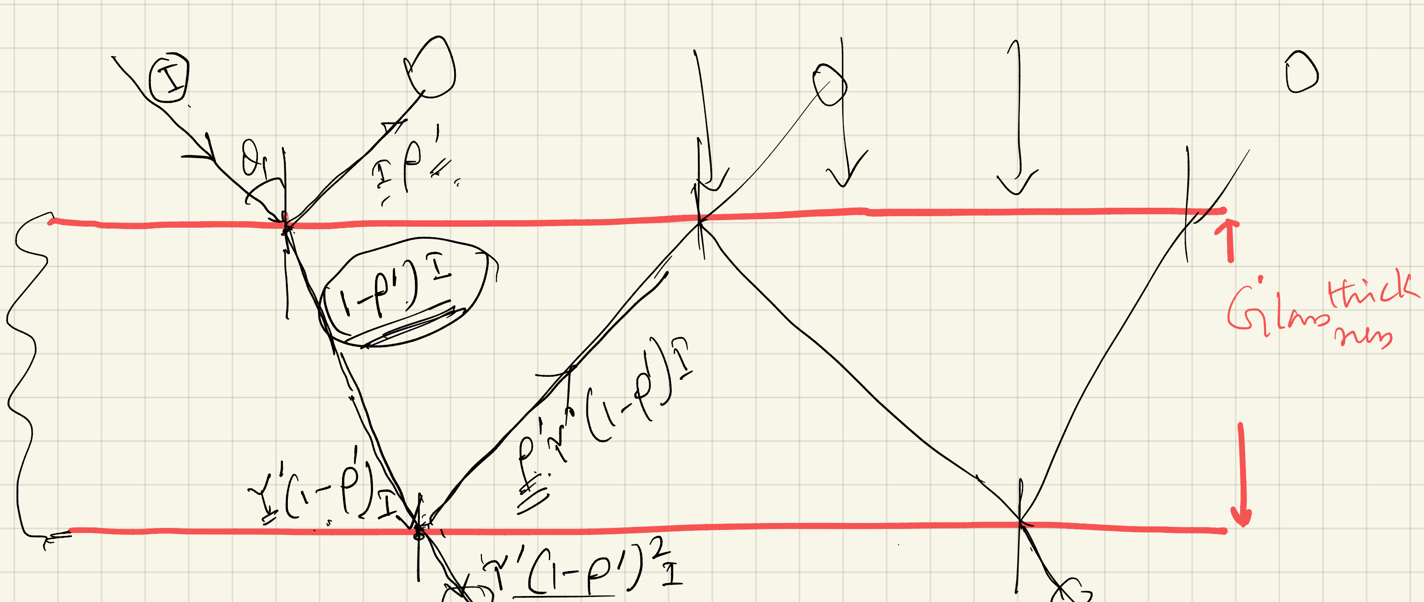
$$\rho_\parallel' = \frac{\tan^2(\theta_1-\theta_2)}{\tan^2(\theta_1+\theta_2)}$$

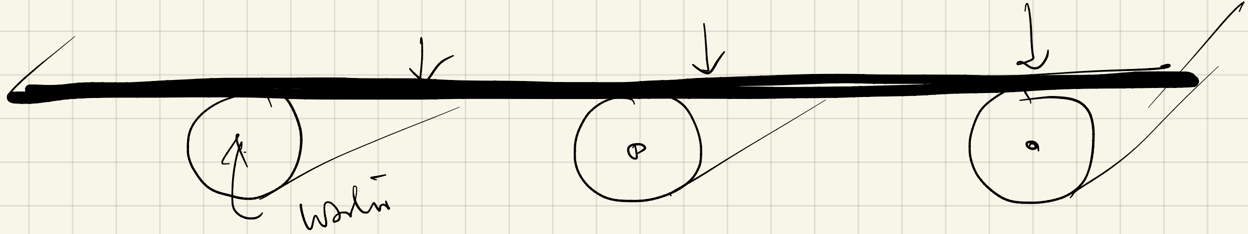
if $\theta_1 = \theta_2 = 0$ (normal incidence)

$$\rho_\perp' = \rho_\parallel' = \frac{(n-1)^2}{(n+1)^2}.$$

On the hand when $\theta_1 = 90^\circ$, $\theta_2 < 90^\circ$,

$$\boxed{\rho_\perp' = \rho_\parallel' = 1}$$





The total reflectivity $\rho(\rho', \gamma')$ of the plate is

$$\rho' + \left[\rho'\gamma'^2(1-\rho')^2 + \rho'^3\gamma'^4(1-\rho')^2 + \cdots\right]$$

$$\boxed{\rho_{\perp/\parallel}(\rho'\gamma') = \rho' + \frac{\rho'\gamma'^2(1-\rho')^2}{1-\rho'^2\gamma'^2}}$$

$\perp \parallel$

Total transmissivity $\boxed{\gamma(\rho', \gamma') = \frac{\gamma'(1-\rho')^2}{1-\rho'^2\gamma'^2}}$

At normal incidence $\rho'_\perp, \rho'_\parallel$

$$\rho = \frac{1}{2}\left[\rho(\rho'_\perp\gamma') + \rho(\rho'_\parallel\gamma')\right]$$

$$\gamma = 1/2\left[\gamma(\rho'_\perp, \gamma') + \gamma(\rho'_\parallel\gamma')\right]$$

$\boxed{\rho + \gamma + \alpha = 1}$ $\boxed{\alpha = 1 - \rho - \gamma}$

If the layer is very transparent $\gamma' \simeq 1$, $\alpha \simeq 0$,

very thin,

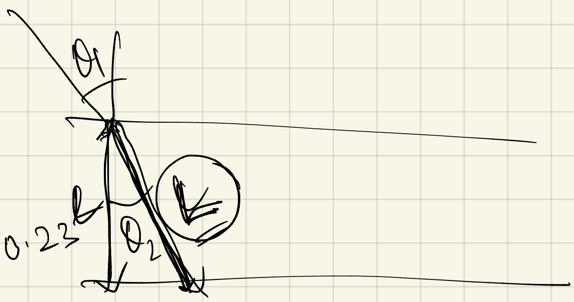
$$\rho = \frac{2\rho'}{1+\rho'}$$

$$\gamma(\rho') = \frac{1-\rho'}{1+\rho'}$$

$$\alpha(\rho') = 0$$

Problem-1

A solar energy collector uses a single layer glass cover 0.23 cm thick. In the visible solar range the refractive index of the glass is 1.526 and its extinction co-efficient is 0.1 cm-1. Calculate the reflectivity, transmissibility and absorptivity of the glass at an angle of incident 60 degree.



$n = 1.526$, $l \rightarrow$ thickness of glass $= 0.23$ cm.

$K = 0.1\ \text{cm}^{-1}$.

$\theta_1 = 60^\circ$.

$$\boxed{\rho,\ \tau,\ \alpha} = ?$$

$$n_2/n_1 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{\sin 60^\circ}{\sin\theta_2}$$

or, $\theta_2 = 34.6^\circ$.

$$\boxed{L = 0.279\ \text{cm.}}$$

Fraction of transmissivity $\tau' = e^{-KL} = 0.97$.

cm^{-1} cm.

$$\boxed{\tau', \rho'}$$

$$\rho'_\perp = \frac{\sin^2(\theta_1 - \theta_2)}{\sin^2(\theta_1 + \theta_2)} = 0.19$$

$$\rho'_\parallel = \frac{\tan^2(\theta_1 - \theta_2)}{\tan^2(\theta_1 + \theta_2)} = 0.001.$$

$$\rho(\rho'_\perp, \tau') = \rho'_\perp + \frac{\rho'_\perp \tau'^2 (1-\rho'_\perp)^2}{1 - \rho'^2_\perp \tau'^2} = 0.31$$

$$\rho(\rho'_\parallel, \tau') = \rho'_\parallel + \frac{\rho'_\parallel \tau'^2 (1-\rho'_\parallel)^2}{1 - \rho'^2_\parallel \tau'^2} = 0.003.$$

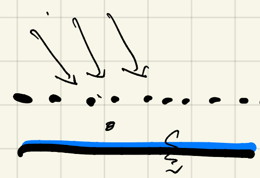
$$\text{Average} = \frac{1}{2}\left[\rho(\rho'_\perp, \tau') + \rho(\rho'_\parallel, \tau')\right]$$

$$= \tfrac{1}{2}\left[0.31 + 0.003\right]$$

$$= 0.16.$$

$\gamma' =$

$$\frac{\gamma(\rho_\perp', \gamma')}{\gamma(\rho_{\parallel}', \gamma')} \begin{matrix} = 0.66 \\ = 0.97. \end{matrix}$$



$$\text{average} = \gamma = \tfrac{1}{2}\left[\gamma(\rho_\perp', \gamma') + \gamma(\rho_{\parallel}', \gamma')\right]$$

$= ?\ 0.82.$

$$\boxed{\alpha = 1 - \gamma - \rho = 1 - 0.16 - 0.82 = 0.027.}$$

$\alpha = 0.027$ [2%]

$\rho = 0.16$ [16%]

$\gamma = 0.82.$ [82%]