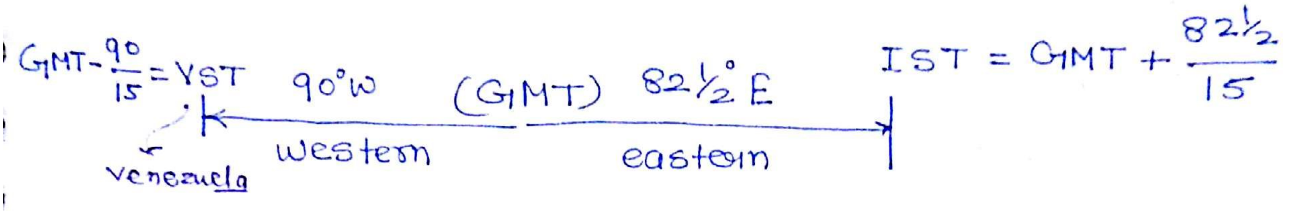
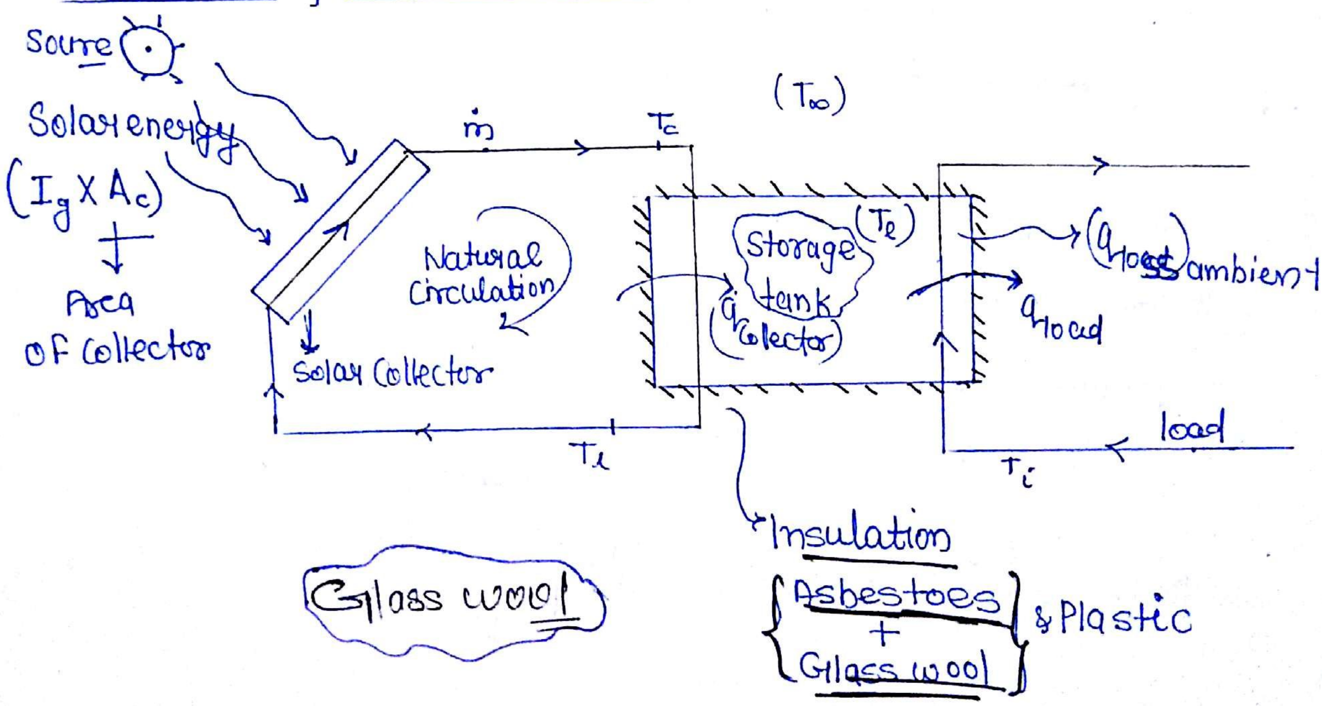
Solar thermal Energy storage system:-

The availability of solar radiation at any perticular location is intermitant, variable, and unpredictable



In order to overcome this disadvantage solar energy storage system require to ensure the smooth supply of power over a desired period of time.

Basic Configration of thermal storage system:-



In solar thermal energy storage system energy in the form of heat is added to the collecter system to the storage system

Type-1 (sensible storage device)

↳ Heating a liquid or solid without phase change.

$$E_{storage} = m\int C_p . dT$$

These are sensible storage device and the amount of store (E) is a function of temp change

$$E = m\int C_p \, dT$$

Ques. A Thermal heat storage device contains a organic liquid R-11a which is having variable specific heat C_p Given by $C_p = (0.05T + 0.2) \, kJ/kg\text{-}K$. The rise in temprature in the liquid from 20°c to 50°c. Then determine the amount thermal energy stored for the unit mass System.

Sol^n

$T_1 = 20°c = 293 \, K$

$T_2 = 50°c = 323 \, K$

$$\underset{(storage)}{E} = m\int C_p . dT$$

$$E = 1\int_{T_1}^{T_2} (0.05\,T + 0.2).dT$$

$$E = \left[0.05\frac{T^2}{2} + 0.2T\right]\Bigg|_{293}^{323}$$

$$E = 0.05\frac{(323-293)^2}{2} + 0.2\,(323-293)$$

$$E = 468 \, kJ$$

Type-2 (Latent heat storage)

↳ Heating a material which undergone <u>change of phase</u>

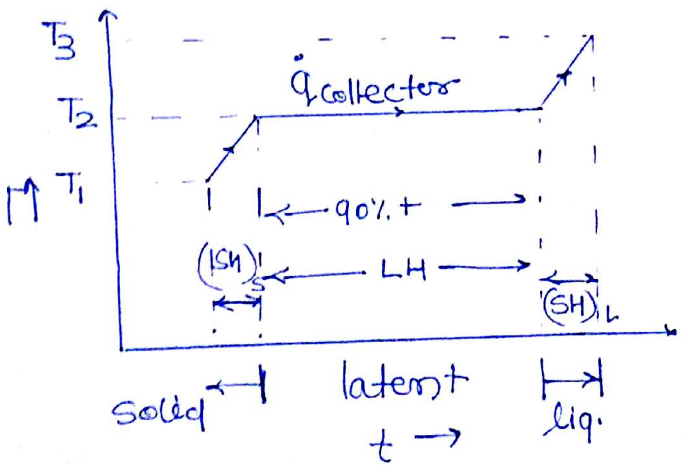
→ These devices are called as latent heat storage devices and these devices energy stored in the form of latent heat.

P.C.M. (Phase change material) → Solid $\underset{\dot{q}_{load}}{\overset{\dot{q}_{collector}}{\rightleftharpoons}}$ Liquid

$$E_{stored} = m \times (LH)$$

LH – latent heat

In case of practical application there is a chances that some heat may be stored as sensible heat



Practically

$$E_{stored} = \underbrace{m\int_{T_1}^{T_2} C_p \cdot dT}_{\text{Solid}} + \underbrace{m(LH)}_{\text{latent}} + \underbrace{m\int_{T_2}^{T_3} C_p \cdot dT}_{\text{liquid}}$$

<u>Note</u>:- It is best suited for <u>Constant temp</u>. Load application.

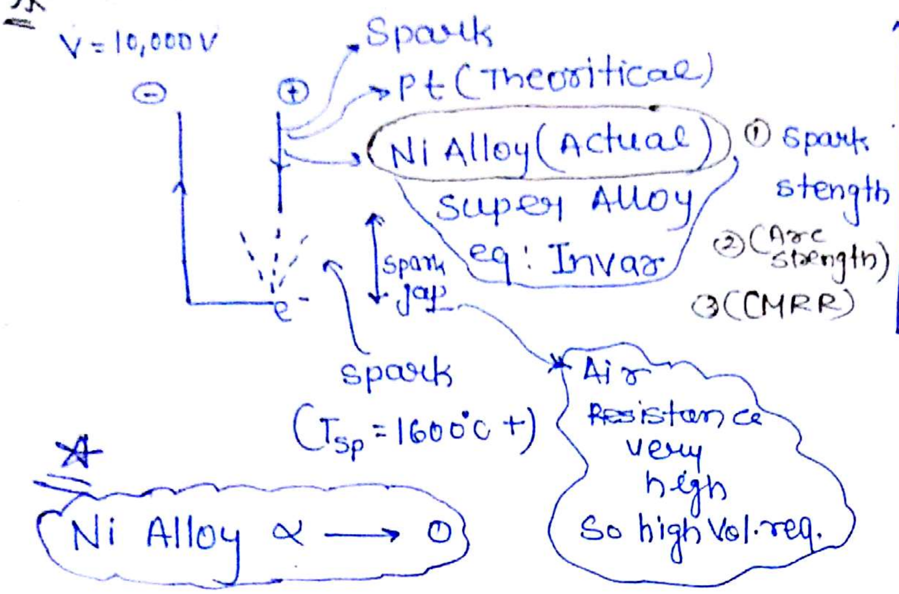
P.C.M. :- The material use for heat storage at constant temp. when a material undergoes the phase change.

Imp.

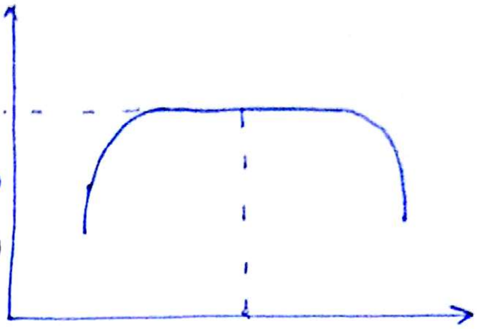
<u>Properties</u>:- *(i) Melting point should be in the temp. range of application.

(ii) High value of latent heat of fusion

(iii) $\alpha \rightarrow$ low



Graph in Varies Application



① Spark Gap
② (welding - Arc gap)
③ (NTD)

(iii) Very low value of coefficient of thermal expansion

Example's of PCM :-

Hydrated salt like Sodium Sulphate has very Volumetric storage capacity which overcome the problem of unpredictable nature of solar energy availability.

Solar Collecter

$$Na_2SO_4 \cdot 10H_2O \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftharpoons}} Na_2SO_4 + 10H_2O$$

load.

$$Q_{Storage} = 35\ MJ/m^3$$

Type-3 (Thermochemical storage)

→ In thermo chemical storage system, solar energy which is to be ~~use~~ stored in induced Endothermic chemical reaction and the product stored in storage tank.

→ Wheneve energy is required (Load), reverse Exothermic reaction is made and it release huge amount of energy.

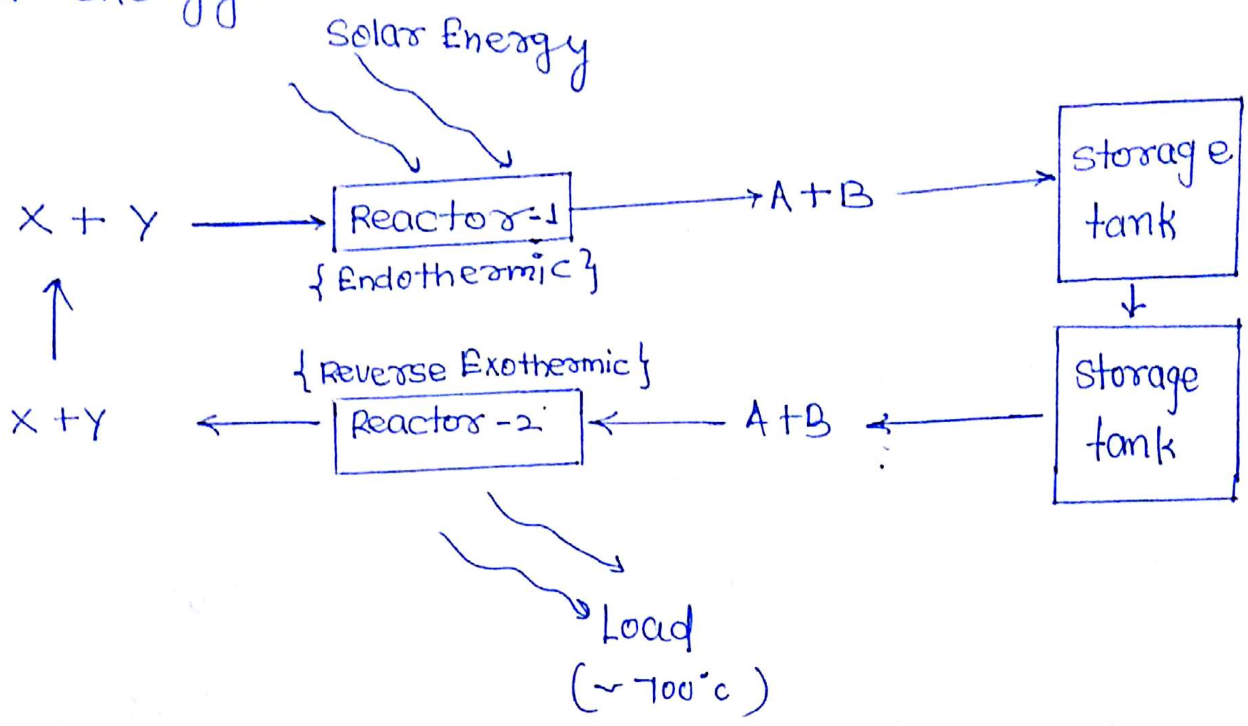


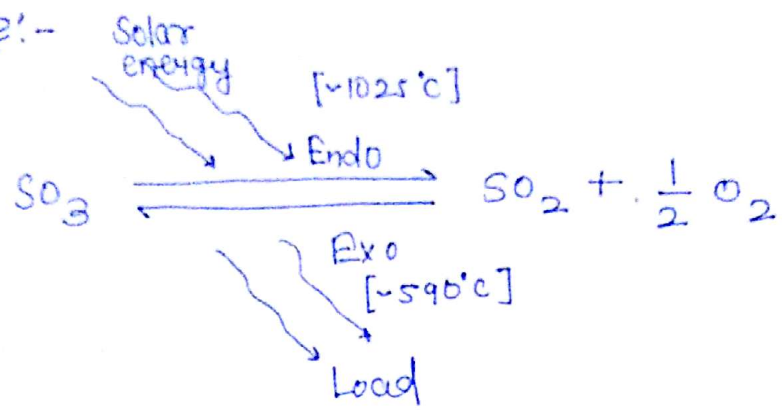
Fig:- Basic thermo chemical storage system

Note: (i) It is applieable for high temp. applications

(ii) The Forward endothermic reaction (Solar collector) and the reverse exothermic reaction (Load) is always occurs at different temp.

$T_{ENDO} > T_{EXO}$ Always

Example:-



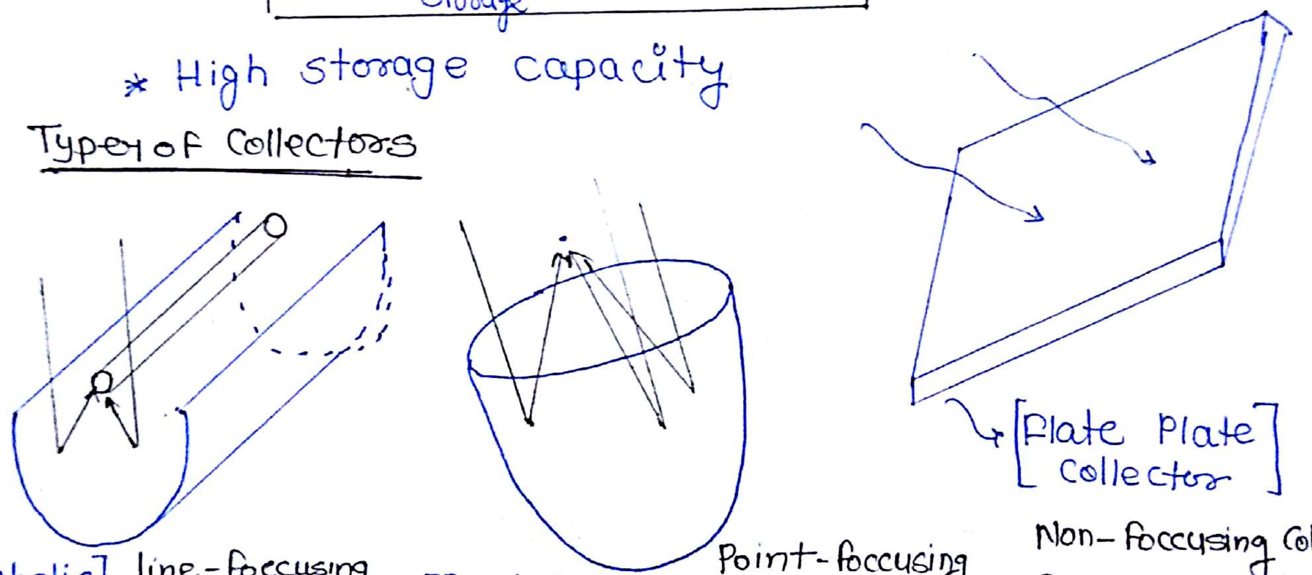
$$SO_3 \rightleftharpoons SO_2 + \frac{1}{2} O_2$$

The max. storage capacity is

$$(Q_{max})_{Storage} \simeq 2.5 \ GJ/m^3$$

* High storage capacity

* Types of Collectors



[Flate Plate Collector]

[Parabolic Collecter] line-Foccusing (Medium temp.)

[Paraboliod Collecter] Point-Foccusing (High temp.)

Non-Foccusing Collector (Low temp.)

Note:- For the high temp. application Solar Collector is should be Focusing or concentrating type

Declination Angle:-(δ)

It is the angle made by the line joining the centre of sun and earth with the projection on equitorial plane and it relation Given by Cooper's Relation

Cooper's Relation:-

$$\delta = 23.45^\circ \sin\left\{\frac{360}{365}(284+n)\right\}$$

$\delta \simeq +23.45^\circ \rightarrow$ Jun'21 $\Rightarrow n = 172$ (longest day)

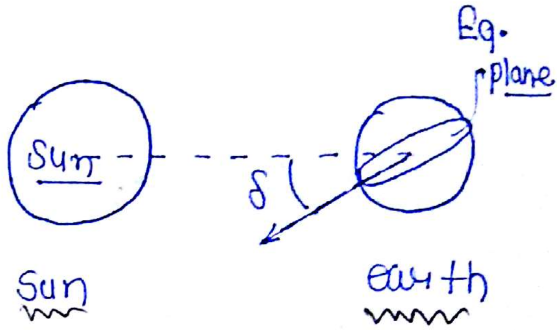
$\delta \simeq -23.45^\circ \rightarrow$ Dec'21 $\Rightarrow n = 355$ (shortest day)

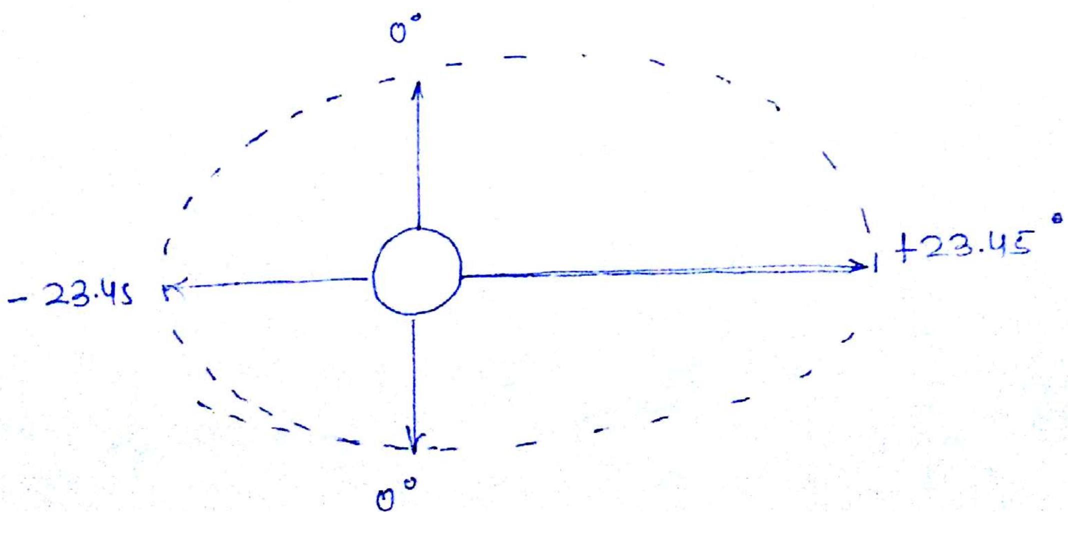
$\delta \simeq 0^\circ \rightarrow$ Sept'21 $\Rightarrow n = 265$ } equinon

$\delta \simeq 0^\circ \rightarrow$ Mar'21 $\Rightarrow n = 80$

$\delta \in [+23.45^\circ, -23.45^\circ]$

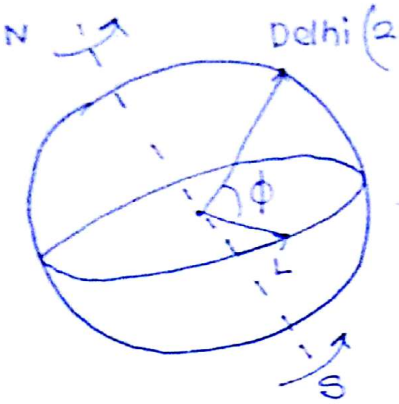
↑ Northern hemisphare   ↑ Southern hemisphare





~~Hour Angle (ω)~~ :-

Question:- On 21st Aug for the flat plate collector lying in Delhi (25°35' North, 77°22' East) what is the solar time at watch time 12:30



$$L = 77 + \frac{12}{60} = 77.2°$$

$$ST = WT - 4(T_{s_o} - T_{l_o})$$

$$ST = 1230 - 4(82.5 - 77.2)$$

$$= 1230 - 21.2 \rightarrow \text{Min}$$

$$= 12:08:48$$

$\Rightarrow$ 30 − 22 = 08

$(1-0.2)\times 60$

$\Rightarrow 0.8 \times 60$

$\Rightarrow 48$

21st Aug $n = 233$

$$\delta = 23.45 \sin\left\{\frac{360°}{365}(284+233)\right\}$$

$$\delta = 11.75°$$

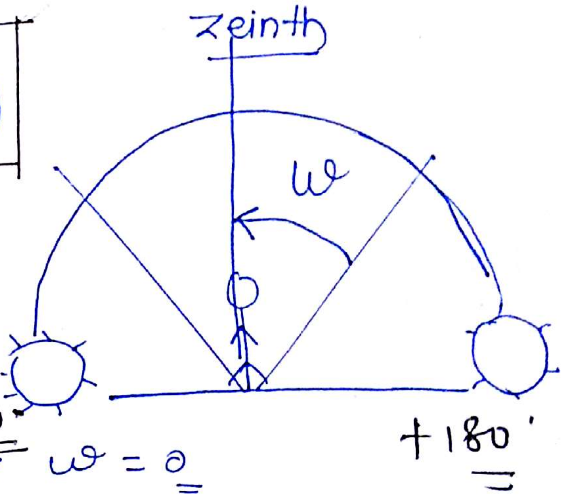
Hour Angle (ω)

The earth revolves about it's axis and complate revolution in 24 hrs it means

$$\frac{360}{24} = 15^\circ/hr$$

Hence hour angle (ω) for any location is the angle through which earth is rotated since Solar Noon.

$$\boxed{\omega = \frac{360^\circ}{24}(ST - 1200)}$$



$\Rightarrow$ ω : → -ve (Morning)
→ +ve (evening)

* Hour angle at Solar time = Solar noon $\Rightarrow \omega = 0$

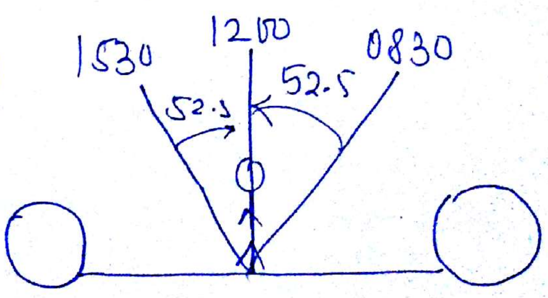
Question :- In order to design a sun tracking m an engineer wants to calculate hour angle from 08:30 to 15:30 Local apraint time (LAT) or solar time. Find out the range of hour angle to help the engineer. 3.hr 30min = 3.5 hr

Sol^n

$ST_1 = 0830$ $\quad \omega_1 = 15(0830 - 1200) = -52.5^\circ$

$ST_2 = 1530$ $\quad \omega_2 = 15(1530 - 1200) = +52.5^\circ$

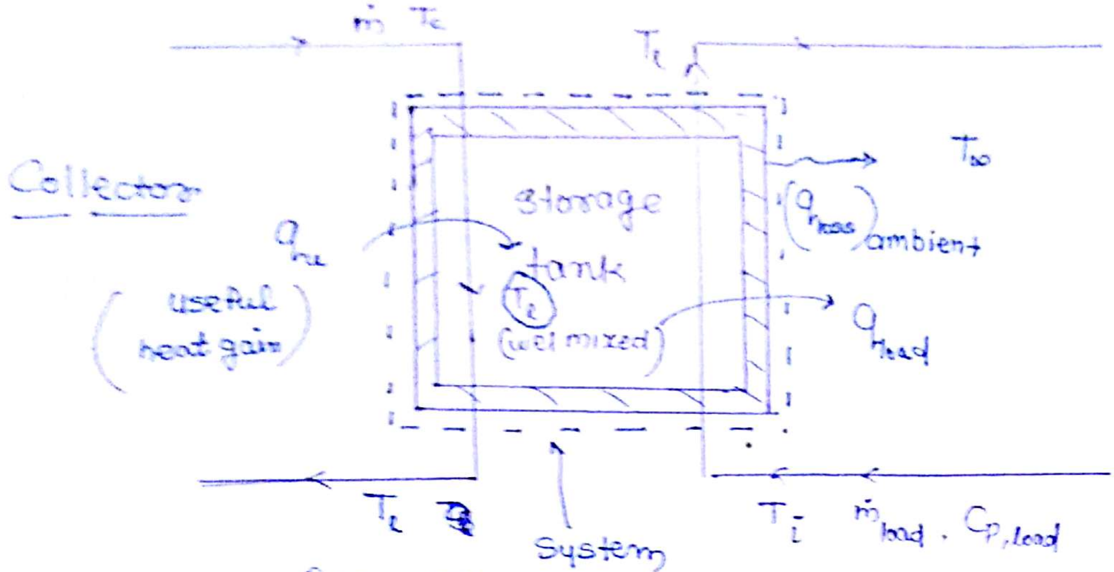
$$\omega \in [-52.5^\circ, 52.5^\circ]$$



$3hr\,30min = 210 \text{ min}$
$= 210/60 = 3.5 \text{ hr}$

Analysis of liquid storage tank:-

Assumption:- well mixed condition



For whole tank / For system

$$m_s \cdot C_{p,s} = m_l \cdot C_{p,l} + m_t \cdot C_{p,t}$$

m_l - mass of liquid tank

$C_{p,l}$ - Sp. heat of liquid

m_t - mass of the Storage tank

$C_{p,t}$ - Sp. heat of the storage tank

$$m_s C_{p,s} \frac{dT}{dt} = \dot{q}_u - \dot{q}_{load} - q_{loss} \quad -(1)$$

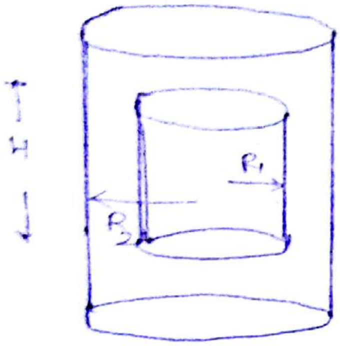
$$\dot{q}_u = \dot{m} C_p (T_c - T_l)$$

$$\dot{q}_{load} = m_{load} \cdot C_{p\,load} (T_l - T_i)$$

$$\dot{q}_{loss} = (UA)_l (T_l - T_\infty)$$

$$R_{th} = \frac{L}{kA} = \frac{r_2 - r_1}{4\pi r_1 r_2} = \frac{\ln(r_2/r_1)}{2\pi k L}$$

Top & bottom



Top & bottom

$$A = \pi R_1^2$$

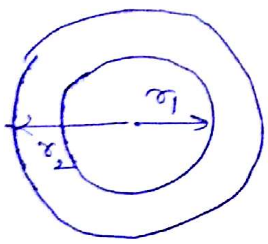
$$R_{th} = \frac{t}{k.A}$$

$$(UA)_{top} = \frac{k.A}{t}$$

$$\frac{\Delta T}{R_{th}} = (UA)\,\Delta T$$

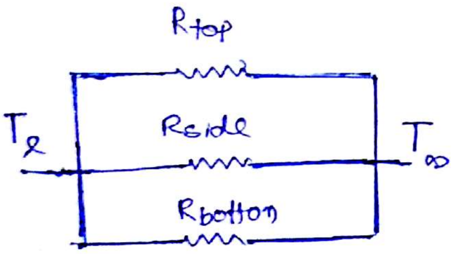
$$\frac{1}{R_{th}} = (UA)$$

Side surface



$$R_{th} = \frac{\ln(r_2/r_1)}{2\pi K L}$$

$$(UA)_{side} = \frac{2\pi K L}{\ln(r_2/r_1)}$$



$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

From eqn ①

$$\int_{T_l}^{T_l^+} dT = \frac{\dot{q}_u - \dot{q}_{load} - \dot{q}_{loss}}{\dot{m}_s C_{p,s}} \int_{T_1}^{T_2} dt$$

$$T_l^+ = T_l + \frac{\left[\dot{m} C_p (T_c - T_l) - \dot{m}_{load} C_{p,load} (T_l - T_i) - (UA)_i (T_l - T_\infty)\right]}{\dot{m}_s, C_{p,s}} \times \Delta t$$

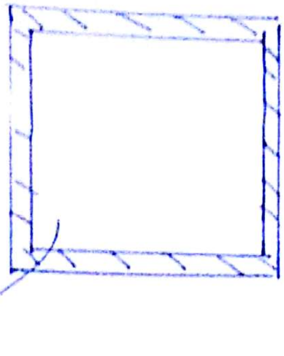
Problem:- A cylindrical hot water liquid storage tank, 1.7 m in daimeter and 2.1 m high is made from steel plate of density $\rho = 7800\ kg/m^3$ and the specific heat of $0.46\ kJ/kg\text{-}K$ plate thickness is 6 mm. A part from the mass of the steel require for making the surface an additional 2000 kg of steel is required for the strengthning of take. The initial temp. of water in the tank is (T_e) is $50°C$ (water density $1000\ kg/m^3$ and specific heat of water $4.18\ kJ/kg\text{-}k$).

For a perticular day the variation in useful heat transfer is upto 0900 hrs is given below

Time	7-8	8-9
$\dot{q}$ (kJ/h)	18660	37496
T_∞	17.8	21.9

The load requirement for the agriculture purpose is at the constant rate of $q_{Load} = 27,000\ kJ/h$. Assuming the water in tank is well mixed and the overall heat transfer Coefficient for loss of heat from tank & ambient $(UA)_e = 3.407\ W/K$

Sol^n



$(T_l) = 50°C$ at 0700 hrs

$H = 2.1\ m$

$D = 1.7\ m$

$t = \frac{6}{1000}\ m$

$\rho_t = 7800\ kg/m^3$

~~mass of tank~~ Volume $= (\pi D H) \times t + \frac{\pi}{4} \times D^2 \times t \times 2$

$$V = (\pi \times 1.7 \times 2.1) \times \frac{6}{1000} + \frac{\pi}{4}(1.7)^2 \times \frac{6}{1000} \times 2$$

$$V = 0.0945\ m^3$$

mass of tank $= (\rho V) + m_{additional}$

$$m_t = (7800)(0.0945) + 200$$

$$m_t = 937.33\ kg$$

$$C_{p,t} = 0.46\ kJ/kg$$

$$m_t C_{p,t} = 431.1718\ kJ/K$$

for liquid

$$m_l = \rho_l \times \frac{\pi}{4} D^2 H = 4766.5\ kg$$

$$C_{p,l} = 4.187\ kJ/kg\text{-}K$$

$$m_l C_{pl} = 19957.33\ kg/K$$

$$m_s C_{ps} = m_t C_{pt} + m_l C_{p,l}$$

$$= 19957.33 + 431.1718$$

$$m_s C_{ps} = 20388.50\ kg/K.$$

$$(UA)_l = 3.407 \ W/K = 3.407 \times \frac{3600}{1000}$$

$$(UA)_l = 12.272 \ kJ/hr$$

$$q_{load} = 27{,}000 \ kJ/h$$

$$\int_{T_l}^{T_l^+} dT = \frac{\dot{q}_{le} - \dot{q}_{load} - \dot{q}_{loss}}{m_s C_{ps}} \int_{t_1}^{t_2} dt$$

$$T_l^+ - T_l = \frac{\dot{q}_{le} - q_{load} - (UA)_l (T_l - T_\infty)}{m_s C_{ps}} \times \Delta T$$

$$T_l^+ = 50 + \frac{(18660 - 27{,}000 - 12.272(50 - 17.8))}{20388.84}$$

1st iteration $T_l^+ = 49.54°C$

2nd iteral $T_l = 49.54°C$

$$T_l^+ = 49.54 + \frac{(37496 - 27000 - 12.272(49.54 - 21.9))}{20388.84}$$

$$T_l^+ = 50.068°C$$