Dry Bulb Temp: The dry bulb ~~air~~ temp. refers basically to the ambient air temperature. It is indicated by a thermometer not affected by the moisture of the air.

Wet Bulb Temp: The wet temperature is the temperature of adiabatic saturation. This is the temperature indicated by a moistened thermometer bulb exposed to the air flow.

Dew Point Temp: It is the temperature at which first dew is formed and the temp. at which air becomes saturated

★ At D. Point temp:

$$\boxed{\bar{P}_A = \bar{P}_{A\,sat.} \ \& \ \text{Rel. Humid} = 1}$$

For any saturated air:
DBT > WBT > Dew. Pt. Temp.

Absolute Humidity/Mass Humidity/Humidity: It is the ratio of Mass of Water Vapour per mass of ~~dry~~ Moist air.

$$\boxed{H_A = \frac{M_V}{M_a}} \qquad \boxed{H_A = \frac{\bar{P}_A}{P_T - \bar{P}_A} \times \frac{18}{29}}$$

P_A: → Partial Pressure of water-vapour in air-gas mixture

Molal Humidity:

$$\boxed{H_M = \frac{\bar{P}_A}{P_T - \bar{P}_A}} \qquad \boxed{H_A = \frac{18}{29} \times H_M}$$

Saturation Humidity:

$$\boxed{H_S = \frac{P_A^{Sat.}}{P_T - P_A^{Sat.}} \times \frac{18}{29}}$$

Relative Humidity

$$\boxed{R_H = \frac{\bar{P}_A}{\bar{P}_{A\,sat.}}}$$

% Saturation

$$\boxed{\%S = \frac{H_A}{H_S} \times 100\%}$$

★ For unsaturated air ($P_A^{Sat.} > \bar{P}_A$)

$$\boxed{\%R.H > \%S}$$

★ For saturated air ($\bar{P}_A = P_{A\,sat.}$)

$\%S = \%RH = 100\%$

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Humid Heat: Amount of heat energy required to ~~raise~~ raise the temperature of dry air accompanying vapour mixture by 1°C.

$$\boxed{C_H = \{\underbrace{1.005}_{\text{dry air}}\} + \{\underbrace{1.88Y'}_{\text{vap. mix.}}\}}$$

unit → KJ/Kg dry air·K

For Air-Water System

$$\boxed{\ln P_A^v = 11.96481 - \frac{3984.923}{T - 39.724}}$$

~~DBT~~ # Psychometric Chart

DBT = 50°
WBT = 32.4°

Find: Abs. Humid., Molar Humid., Percentage Humid., Rel. Humid., Dew Point, Humid Vol., Humid Heat, Enthalpy.

① Absol. Humid.: WBT → 100% Humidity → Adiabetic Saturation cutting ~~at~~ DBT → Horizontal line to y-axis.

$\boxed{Y' = 0.024}$

② Molar Humid. Y ⇒ $Y' = Y \times \frac{18}{29} \Rightarrow Y = Y' \times \frac{29}{18} = 0.024 \times \frac{29}{18} \Rightarrow \boxed{Y = 0.03866}$

③ % Humidity Extend ~~the~~ the DBT and AS curve parallel to the Humid.% curves.

$\boxed{P.H. = 28\%}$

④ Rel Humid. $= \frac{P_A}{P_A^{Sat.}} \times 100\%$ ⇒ $Y = \frac{P_A}{P - P_A}$ → 0.03960 ⇒ $P_A = 0.0377$

$P_A^{Sat.}$ by Antoine eq.

$\boxed{\text{Rel. Humid} = 30.86\%}$

⑤ DPT: Extend the Molar Humid line to 100% Humidity and drop it to x-axis.

$\boxed{= 27.5°C}$

$\boxed{\text{Sat. Humid} = \frac{P_A^{Sat.}}{P_T - P_A^{Sat}} \times \frac{18}{29} = 0.0851}$

⑥ Humid Vol. ⇒ Extend ~~at~~ DBT to Sp. Vol. Dry air curve and then join horizontal to humid volume → 0.91

→ Extend DBT to Sat. Humid Vol. curve → 1.045

Y'	v_H
0	0.91
0.024	x
0.0851	1.045

$$\frac{0.0851 - 0}{0.0851 - 0.024} = \frac{1.045 - 0.91}{1.045 - x}$$

$$\boxed{x = v_H = 0.948\ m^3/\text{Kg-dry air}}$$

⑦ Humid Heat: $C_H = \{1.005\} + \{1.88 \times 0.024\}$

$$\boxed{C_H = 1.05\ \frac{KJ}{\text{Kg dry air}\cdot K}}$$

⑧ Enthalpy

Y'	H
0	50
0.024	x
0.0851	275

$$\frac{0.0851 - 0}{0.0851 - 0.024} = \frac{275 - 50}{275 - x}$$

$$\boxed{x = H' = 112.5\ \frac{KJ}{\text{Kg dry air}}}$$

COOLING TOWER

→ Special type of heat exchanger in which the warm water & the air ~~being~~ are brought in direct contact for "Evaporative cooling".

→ Provides a very good contact of air and water while keeping air pressure drop low.

→ Enthalpy of air is lower than enthalpy of water.

→ Sensible heat and latent heat transfer take place from water drop to surrounding air.

Factors that govern the operation of cooling tower:

→ Dry bulb & wet bulb temperatures of air

→ Temperature of warm water.

→ Efficiency of contact between air & water in terms of volumetric mass transfer coefficient.

→ Contact time between air & water.

→ Air Pressure Drop

→ Desired temp. of cooled water.

Atmospheric Towers

→ It is a big rectangular chamber with two ~~of~~ opposite 'louvered' walls.

→ Tower is packed with a suitable 'tower fill'.

→ Atmospheric air enters the tower through louvers driven by its own velocity.

→ Direction and velocity of wind greatly influence its performance.

Natural Draft Towers

→ Large reinforced concrete shell of hyperbolic shape.

→ Natural flow of air occurs through the tower.

→ Factors responsible for creating natural draft:

1) Rise in temp. & humidity of air in the column reduces its density

2) Wind velocity at the tower bottom.

Why hyperbolic shape

→ More packing materials can be placed at the bottom

→ The entering air gets smoothly directed towards the centre

→ Greater structural strength and stability

Mechanical Draft Towers

1) **Forced Draft Towers:** Has one or more fans located at the tower bottom to push air into tower.

Advantages:

i) It makes energy efficient than induced draft.

ii) Less susceptible to vibrations as fans are installed near the ground.

Disadvantages:

i) Air flow through the packing may not be uniform.

ii) Recirculation of warm and humid air back.

iii) It is not popular except for small quantities.

2) **Induced Draft Towers:** One or more fans are installed at the top of the tower.
- Cross flow
- Counter flow.

Advantages:

i) Relatively dry air contacts the coldest water at the bottom of the cooling tower.

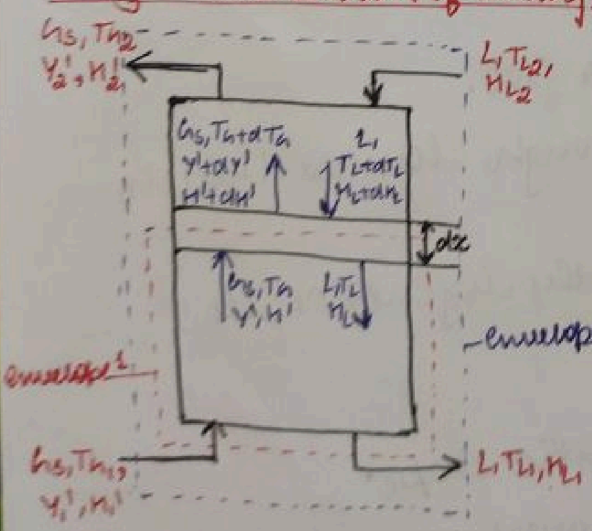
ii) Humid air is in contact with the warm water and hence maximum D.F. for both HT & MT.

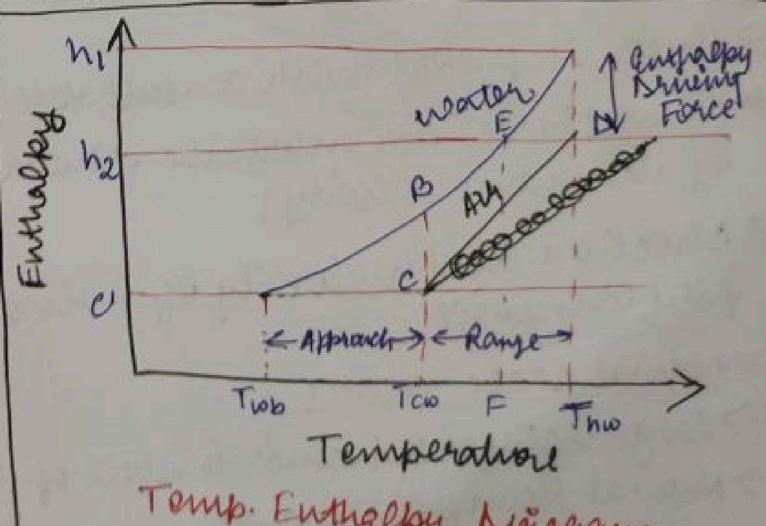
Disadvantages:

i) It consumes more horsepower.

*** Cross-flow induced draft cooling tower requires less motor HP than countercurrent induced draft cooling towers.

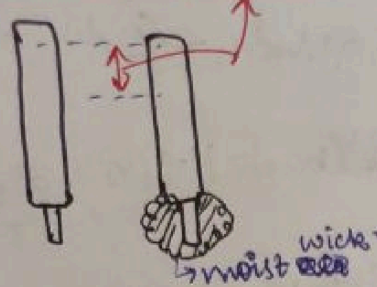
Design Calculation of Cooling Tower

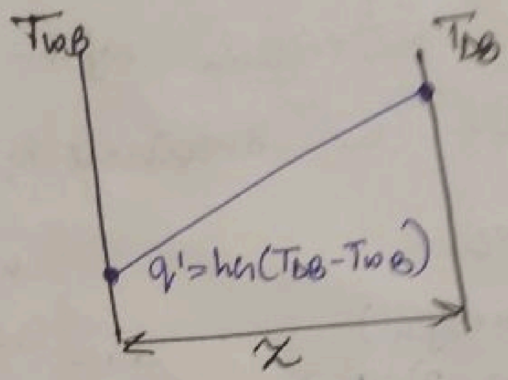




Temp. Enthalpy Diagram of Air-Water System.

Wet-Bulb Depression





Enthalpy [H']

$$\boxed{H' = \underbrace{\lambda_w Y'}_{\text{Latent Heat}} + \underbrace{C_H [T_{DB} - T_0]}_{\text{Sensible Heat}}}$$

$T_0 \rightarrow$ reference temp.

Humid volume (V_H)

$$\boxed{v_H = \left(\frac{1}{28.97} + \frac{Y'}{18.02}\right) \times 22.4 \times \left(\frac{T_a + 273}{273}\right)}$$ $\frac{m^3}{\text{dry-air}}$

$$\boxed{\text{Heat flux, } q = h_a(T_a - T_w)}$$

$$\boxed{q = h_a(T_a - T_w) = \lambda_w K_Y (Y_w' - Y')}$$

COOLING ~~[illegible]~~ TOWER CONTINUES

Enthalpy balance over envelope 1.

$$\boxed{L C_{wL}(T_L - T_{L1}) = G_s(H' - H_1')}$$

Enthalpy balance over envelope 2.

$$\boxed{L C_{wL}(T_{L2} - T_{L1}) = G_s(H_2' - H_1')}$$

Q2) $T_{L2} = 45°C$, $T_{L1} = 30°C$, $DBT = 31°C$, $WBT = \cancel{25°C}$ 22°C, $L = \cancel{5500\ Kg/m^2h}$ 6000 Kg/m² H

$G_S = 1.4 \times G_{S\,min}$ $K_y' \bar{a} = 6000\ Kg/m^2\text{-}h\ (\Delta Y')$.

$h_L \bar{a} = 0.059\, L^{0.51} G_S$. Antoine eq^n: $\ln P_A^v(bar) = 11.9648\,1 - \frac{3984.923}{(T-39.724)}$

$T_{G1} = T_{DBT} = 31°C$

$T_{WBT} = 22°C$

$Y_1' = 0.012$ (From Psych.)

$H_1' = (1.005 + 1.88 \times 0.012)(31-0) + 2500 Y_1'^{\,0.012} = 64.3\ KJ/Kg$ dry air

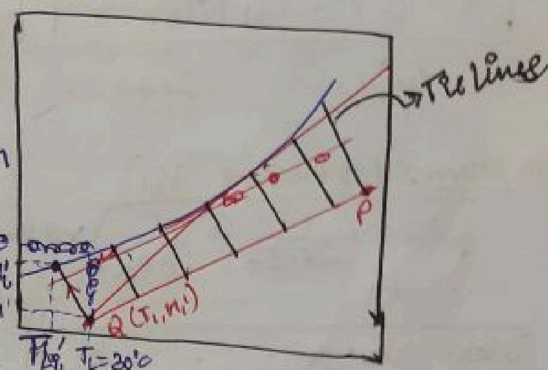
Change in enthalpy of water $= L \cdot C_{WL} \cdot dT$

Change in enthalpy of Air $= G_S \cdot dH'$

$\boxed{\text{slope of the tangent} = 10.76 = \frac{L C_{WL}}{G_{S,min}}}$

$G_S = 1.4 G_{S,min}$ $G_{S\,min} = 2335\ Kg/m^2 h$

$G_S = 3270\ Kg/m^2.h$



$L C_{WL}(T_{L2} - T_{L1}) = G(H_2' - H_1')$

$\Rightarrow (6000)(4.187)(45-30) = 3270(H_2' - 64.3)$

$H_2' = 179.6\ KJ/Kg$.

* Locate the point $P(T_{L2}, H_2') = (45°C, 179.6\ KJ/Kg)$

$\boxed{\text{* Slope of Tie-Lines} = -\frac{h_L \bar{a}}{K_y \bar{a}}} = \frac{-68{,}250\ KJ/h.m^3}{6000} = -11.4$

T_L
H'
T_{Li}
H_i'
$\frac{1}{H_i' - H'}$

$\boxed{H_{tG} = \frac{G_S}{K_y \cdot \bar{a}} = 0.545}$

Area under the curve $= (H_2' - H_1') \times$ Avg. $\left(\frac{1}{H_i' - H'}\right) \simeq 6 = N_{tG}$

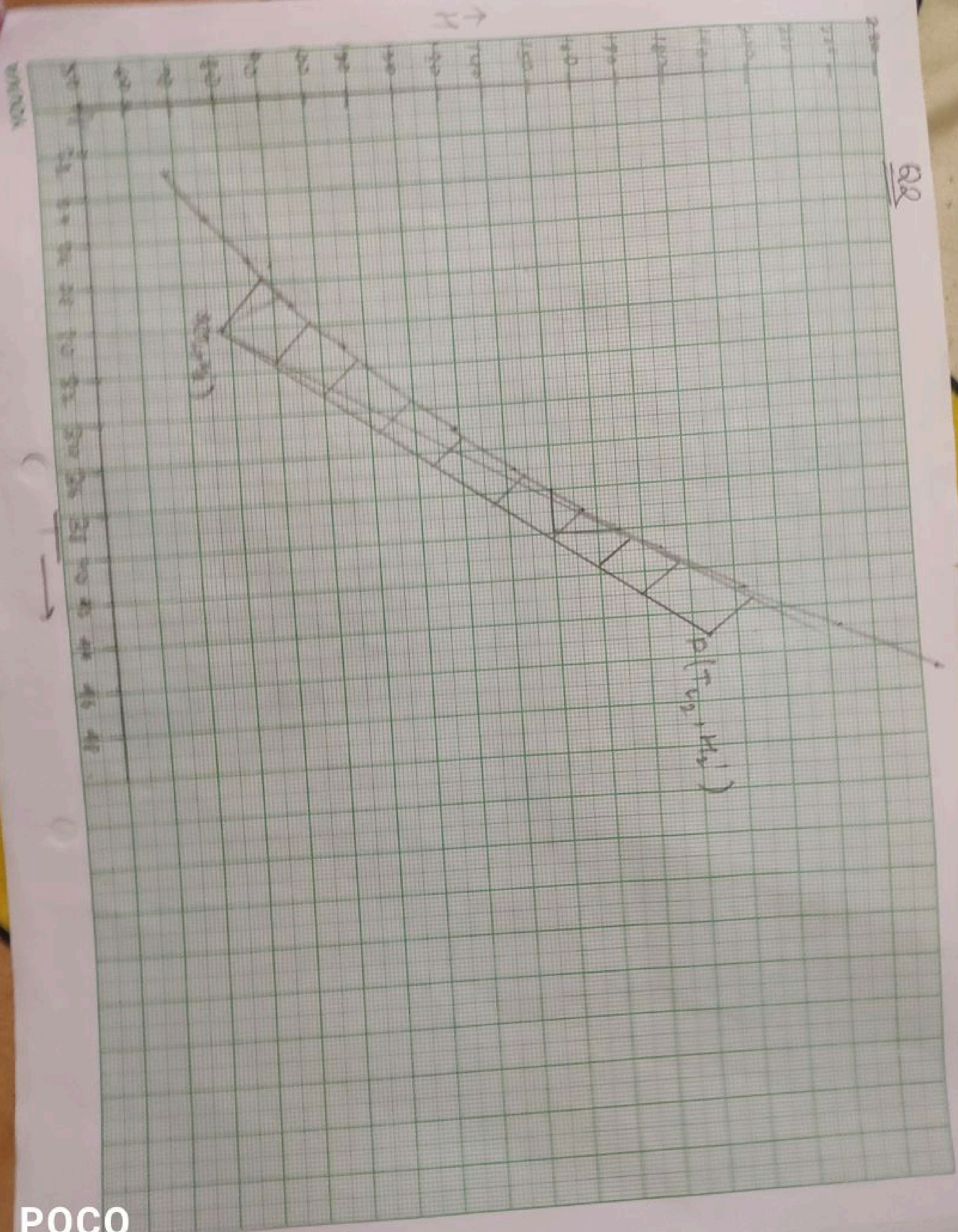
$H_{tG} = 0.545$

$Z = H_{tG} \times N_{tG} = 3.68m$

b) WB depression = Air Temp. (At bottom) − WBT

$= 31 - 22$

$= 9°C$.


Q2

Given: $T_{L2} = 45°C$, $T_{L1} = 30°C$, $T_{DB} = 30°C$, $T_{WB} = 26°C$ (4)

$L = 5500\ kg/m^2 \cdot h$, $G_s = 1.25\, G_{s\,min}$, $K_y\bar{a} = 5743.5\ kg/m^3 h\,(\Delta Y')$

$h_L\bar{a} = 0.059\, L^{0.51} G_s$

$Y_1' = 0.019$, $H_1' = [(1.005 + 1.88 \times 0.019) \times (30-0) + 2500 \times 0.019]$

$H_1' = 78.7\ KJ/Kg$

By graph slope $= 8.78$

$\text{Slope} = \frac{L \times C_{WL}}{G_{s\,min}} \Rightarrow G_{s\,min} = \frac{5500 \times 4.2}{8.78} = 2680$

$G_s = 1.25 \times 2680 = 3280\ kg/m^2\text{-}h$

$L C_{WL} (T_{L2} - T_{L1}) = G_s (H_2' - H_1')$

$H_2' = 184\ KJ/Kg$

Slope of Tie line $\Rightarrow -\frac{h_L\bar{a}}{K_y'\bar{a}}$

$h_L\bar{a} = 0.059\, L^{0.51} G_s$

$\Rightarrow 15687.9\ Kcal/m^3 hK$

$= 15687.9 \times 4.18$

$= 65475\ KJ/m^3 hK$

$\Rightarrow -\frac{65475}{5743.5} \Rightarrow \underline{\underline{-11.4}}$

$$\boxed{H_{tG} = \frac{G_s}{K_y'\bar{a}} = \frac{3280}{5743.5} = 0.57}$$

From the graph we can get T_L, H', T_{Li}, H_i' and $\frac{1}{(H_i' - H')}$

$$\boxed{N_{tG} = (H_2' - H_1') \times \left[\text{avg. of } \frac{1}{(H_i' - H')}\right]}$$

$N_{tG} = 9.26$

$Z = N_{tG} \times H_{tG} = 9.26 \times 0.57$

$\underline{\underline{Z = 5.28\,m}}$ Ans

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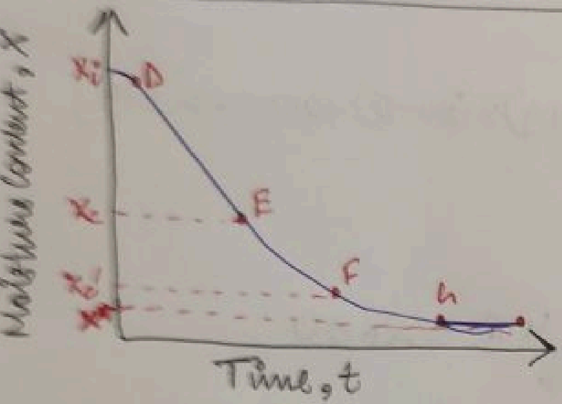
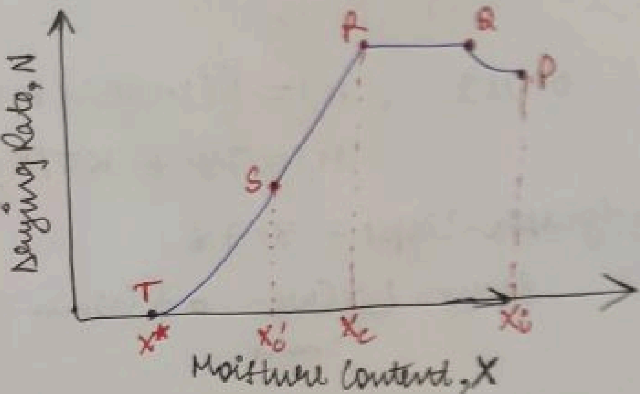
DRYING (MIDSEMS)

$$\boxed{t = t_c + t_f = \frac{W_s}{aN_c}(X_i - X_c) + \frac{W_s(X_c - X^*)}{aN_c} \ln\left(\frac{X_c - X^*}{X_f - X^*}\right)}$$





$X_i \rightarrow D$: Heating of solids & releasing of moisture

$D \rightarrow E$: Constant rate Period
$N = \frac{dX}{dt}$ = Const.

$E \rightarrow F$ & $F \rightarrow G$: Falling rate periods $N \neq$ Const, Non-linear drop of moisture content.

G : The eq. moisture content (X^*) is reached at G, No further loss of moisture.

*** Read more from the book.
*** Practice Questions.

$P \rightarrow Q$: Solid gradually gets heated and the rate of drying increases

$Q \rightarrow R$: Constant rate Period
N = Const

R : where the constant rate period terminates is called the critical moisture content, X_c.

$R \rightarrow S$ & $S \rightarrow T$: First & Second Falling rate periods respectively.