Example 9.3-2 1/2
Adiabatic Saturation of Air

An air stream at 87.8 ºC having a humidity H = 0.030 kg H_2O/kg dry air is contacted in an adiabatic saturator with water. It is cooled and humidified to 90 % saturation.

(a) What are the final values of H and T ?

(b) For 100 % saturation, what would be the values of H and T ?

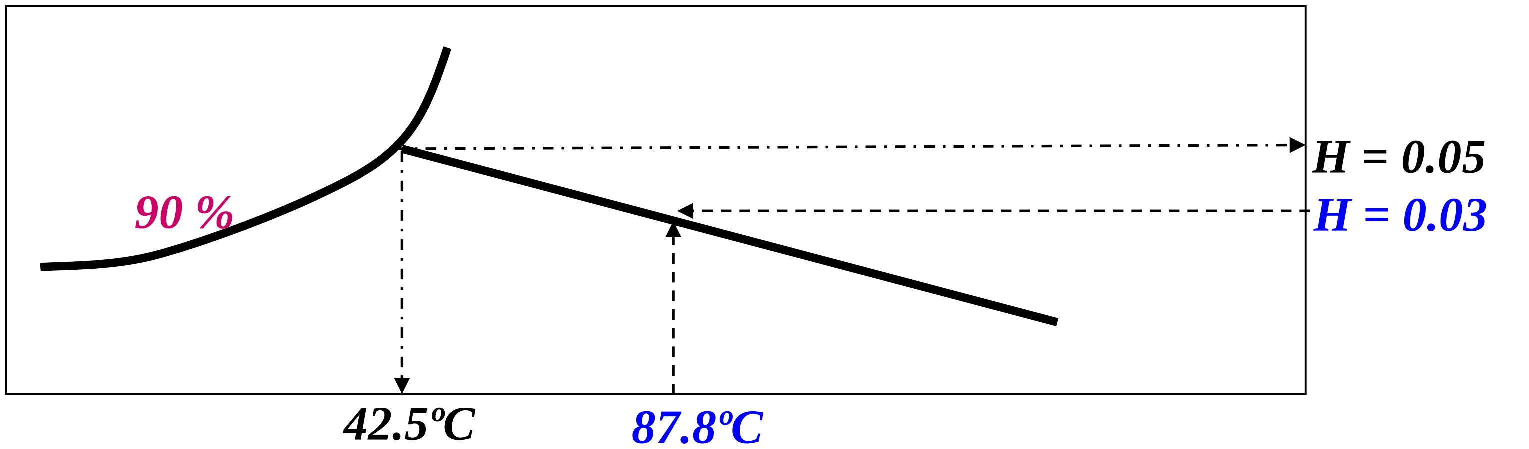
Solution,

(a) The adiabatic saturation curve through this point is followed upward to the left until it intersects the 90 % line at 42.5 ºC and H = 0.0500 kg H_2O/kg dry air.

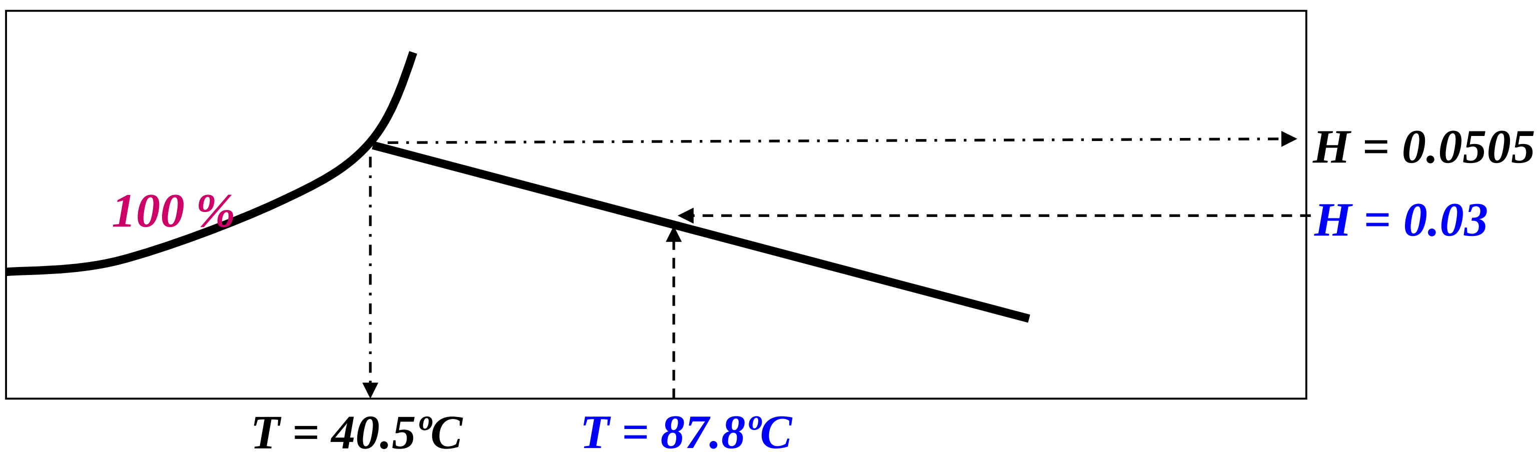
(b) The same line is followed to 100 % saturation, where T = 40.5 ºC and H = 0.0505 kg H_2O/kg dry air.

Example 9.3-2 2/2

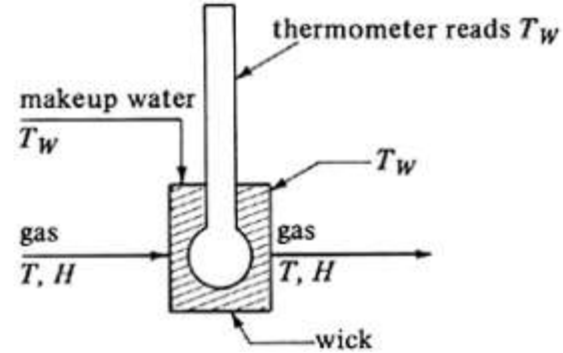
(a)



(b)



Wet bulb temperature T_W



- Steady-state non-equilibrium temperature reached when a small amount of water is contacted under adiabatic conditions by a continuous stream of gas.

- Steady state temp. attained by a wet-bulb thermometer under standardized condition.

- The temperature and humidity of the gas are not changed.

- At $T_W = T_S$, the convective heat transfer and wet bulb lines.

$$q = M_B k_y \lambda_W (H_W - H) A$$

M_B is the molecular weight of air

λ_W is the latent heat of vaporization at T_W

k_y is the mass-transfer coefficient

Tw: wet bulb temperature

or,

$$\frac{H - H_W}{T - T_W} = -\frac{h/M_B k_y}{\lambda_W}$$

$$q = h(T - T_W)A$$

The operating line

$$G(H_y - H_{y1}) = Lc_L\,(T_L - T_{L1})$$

where,

G = dry air flow, kg/s.m^2.

L = water flow, kg water/s.m^2

c_L = heat capacity of water, assumed constant at 4187 kJ/kg.K.

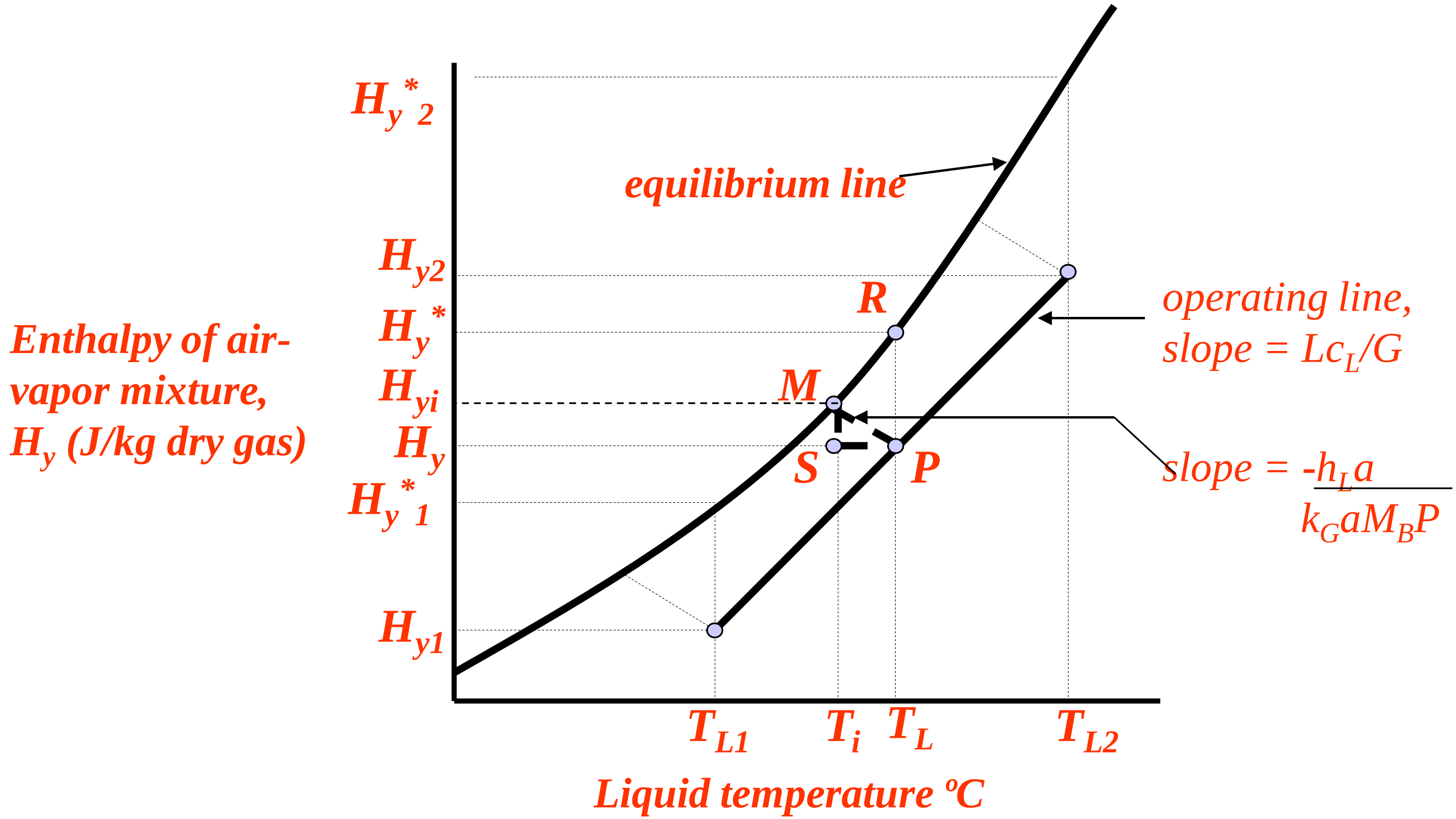
T_L = temperature of water, °C or K.

H_y = enthalpy of air-water vapor mixture, J/kg air.

= $c_s\,(T-T_0) + H\lambda_0 = (1.005 + 1.88H)10^3\,(T-0) + 2.501\text{x}10^6 H$

H = humidity of air, kg water/kg dry air.

Figure 10.5-3: Temperature enthalpy diagram and operating line for water-cooling.



Design of Water-Cooling Tower Using Film Mass-Transfer Coef.

- **Please follow the steps mentioned in section 10.5C in book**

- To calculate the tower height

$$\int_0^z dz = z = \frac{G}{M_B k_G a P} \int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_{yi} - H_y}$$

where,

z = tower height

P = atm pressure.

M_B = molecular weight of air

$k_G a$ = volumetric mass transfer coeff. in gas, kg mol/s.m^3.Pa

Design Using Overall Mass-Transfer Coefficients.

$$\int_0^z dz = z = \frac{G}{M_B K_G a P} \int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_y^* - H_y}$$

where,

$K_G a$ = overall mass transfer coefficient.

- If experimental cooling data in an actual run in a cooling tower with known height z are available, then the value of $K_G a$ can be obtained.

Table 10.5-1

Table 10.5-1. Enthalpies of Saturated Air–Water Vapor Mixtures (0°C Base Temperature)							
		H_y				H_y	
T_L		btu	J	T_L		btu	J
°F	°C	lb_m dry air	kg dry air	°F	°C	lb_m dry air	kg dry air
60	15.6	18.78	43.68×10^3	100	37.8	63.7	148.2×10^3
80	26.7	36.1	84.0×10^3	105	40.6	74.0	172.1×10^3
85	29.4	41.8	97.2×10^3	110	43.3	84.8	197.2×10^3
90	32.2	48.2	112.1×10^3	115	46.1	96.5	224.5×10^3
95	35.0	55.4	128.9×10^3	140	60.0	198.4	461.5×10^3

Example 10.5-1 1/7

Design of Water-Cooling Tower Using Film Coefficients.

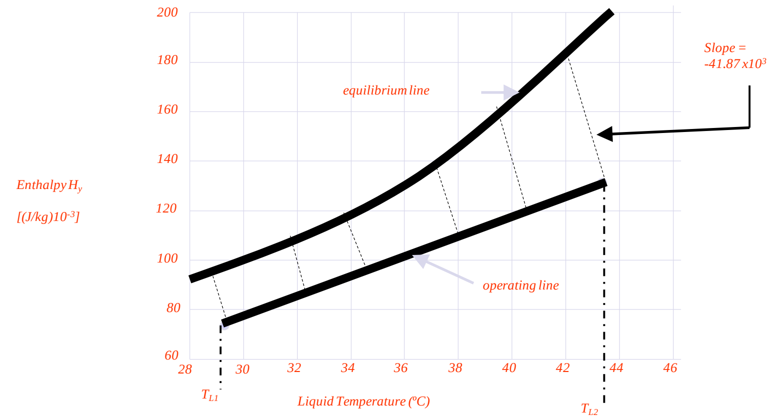
A packed countercurrent water-cooling tower using a gas flow rate of $G = 1.356$ kg dry air/s. m^2 and a water flow rate of $L = 1.356$ kg water/s. m^2 to cool the water from $T_{L2} = 43.3$ ºC to $T_{L1} = 29.4$ ºC.

The entering air at 29.4 ºC has a wet bulb temperature of 23.9 ºC . The mass-transfer coefficient $k_G a$ is estimated as 1.207×10^{-7} kg mol/s.m^3.Pa and $h_L a / k_G a M_B P$ as 4.187×10^4 J/kg.K. .

Calculate the height of packed tower **z**. The tower operates at a pressure of 1.013×10^5 Pa.

Example 10.5-1 2/7

Solution



Following the step outlined

Data preparation to be used in equation (9.3.8)

1. The enthalpies from the saturated air-water vapor mixtures from Table 10.5-1 are plotted in Fig. 10.5-4.
2. The inlet air at T_{G1} = 29.4 °C has a wet bulb temperature of 23.9 °C.
3. The humidity from the humidity chart is H_1 = 0.0165 kg H_2O/kg dry air.
4. Substituting into Eq.(9.3-8),

$$H_{y1} = c_s (T-T_0) + H\lambda_0 = (1.005 + 1.88H)\, \mathbf{10^3}\, (T-T_0) + H\lambda_0$$
$$H_{y1} = (1.005 + 1.88 \times 0.0165)10^3 (29.4-0) + 2.501 \times 10^6(0.0165).$$
$$= \mathbf{71.7 \times 10^3\ J/kg.}$$

The point **H_{y1} = 71.7 x 10^3 and T_{L1} = 29.4 °C is plotted**. Then substituting into Eq. (10.5-2) and solving,

Example 10.5-1 3/7

$$G(H_{y2} - H_{y1}) = Lc_L\,(T_{L2} - T_{L1})$$

$$1.356\,(H_{y2} - 71.7 \times 10^3) = 1.356\,(4.187 \times 10^3)\,(43.3 - 29.4).$$

$$H_{y2} = 129.9 \times 10^3 \text{ J/kg dry air.}$$

Now both H_{y1} and H_{y2} are calculated

Then

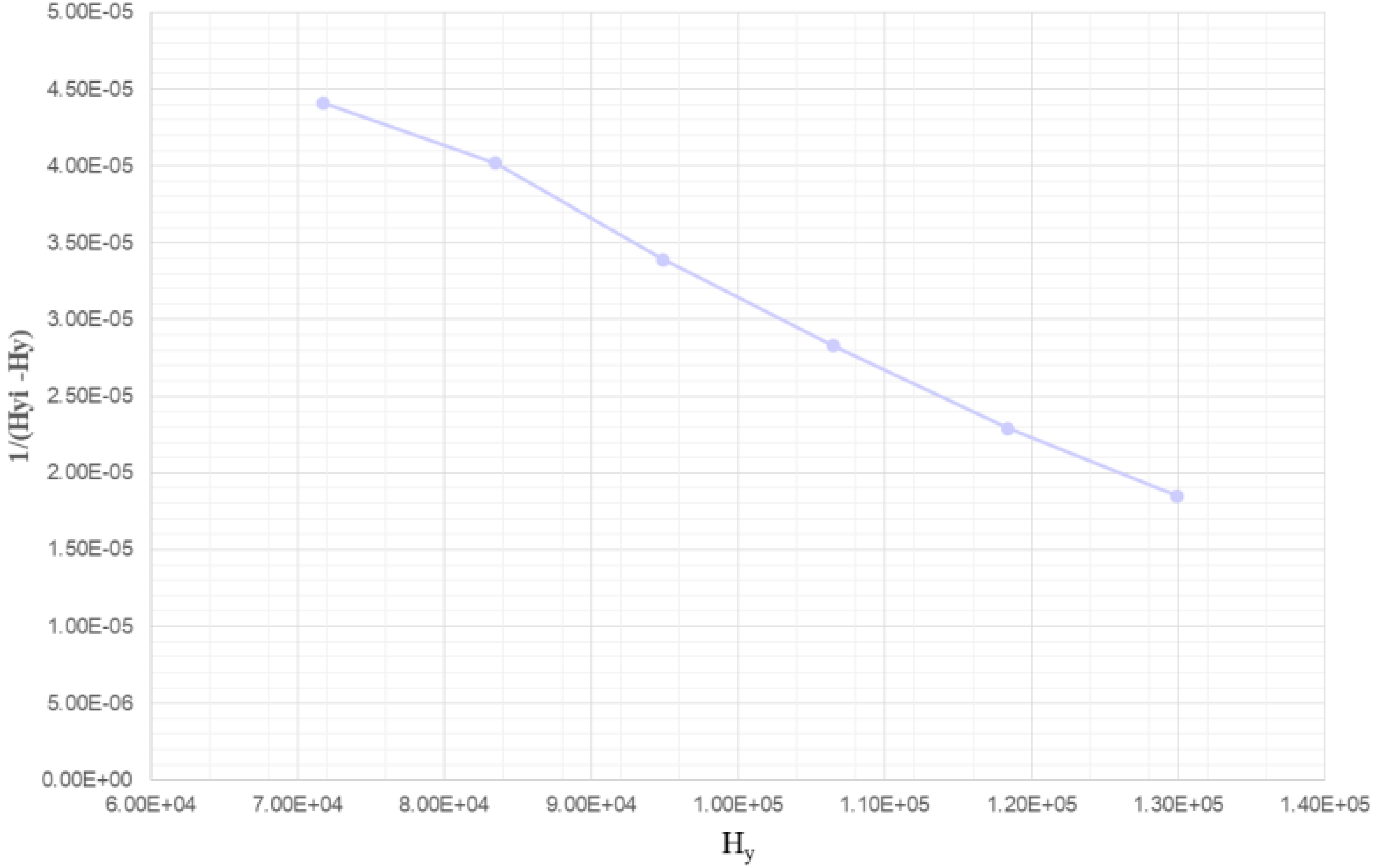
(1) The point $H_{y2} = 129.9 \times 10^3$ and $T_{L2} = 43.3$ ºC is plotted, giving the operating line.

(2) Lines with slope **$- h_L\, a / k_G\, aM_BP = -41.87 \times 10^3$ J/kg.K** are plotted giving H_{yi} and H_y values, which are tabulated in Table 10.5-2 along with derived values as shown.

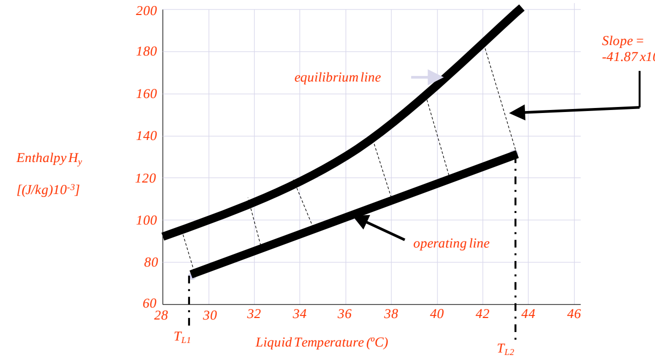
(3) Values of $1/(H_{yi} - H_y)$ are plotted versus H_y and the area under the curve from $H_{y1} = 71.7 \times 10^3$ to $H_{y2} = 129.9 \times 10^3$ is

$$\int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_{yi} - H_y} = 1.82$$

Example 10.5-1 4/7



Example 10.5-1 5/7



$$\int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_{yi} - H_y} = 1.82$$

Substituting into Eq. (10.5-13),

$$z = \frac{G}{M_B k_G a P} \int \frac{dH_y}{H_{yi} - H_y} = \frac{1.356}{29(1.207 \times 10^{-7})(1.013 \times 10^5)} (1.82)$$

$$\therefore z = 6.98m$$

Example 10.5-1 6/7

H_{yi}	H_y	$H_{yi} - H_y$	$1/(H_{yi} - H_y)$
94.4×10^3	71.7×10^3	22.7×10^3	4.41×10^{-5}
108.4×10^3	83.5×10^3	24.9×10^3	4.02×10^{-5}
124.4×10^3	94.9×10^3	29.5×10^3	3.39×10^{-5}
141.8×10^3	106.5×10^3	35.3×10^3	2.83×10^{-5}
162.1×10^3	118.4×10^3	43.7×10^3	2.29×10^{-5}
184.7×10^3	129.9×10^3	54.8×10^3	1.85×10^{-5}

Table 10.5-2: Enthalpy Values for Solution to Example 10.5-1 (enthalpy in J/kg dry air).

Example 10.5-1 7/7

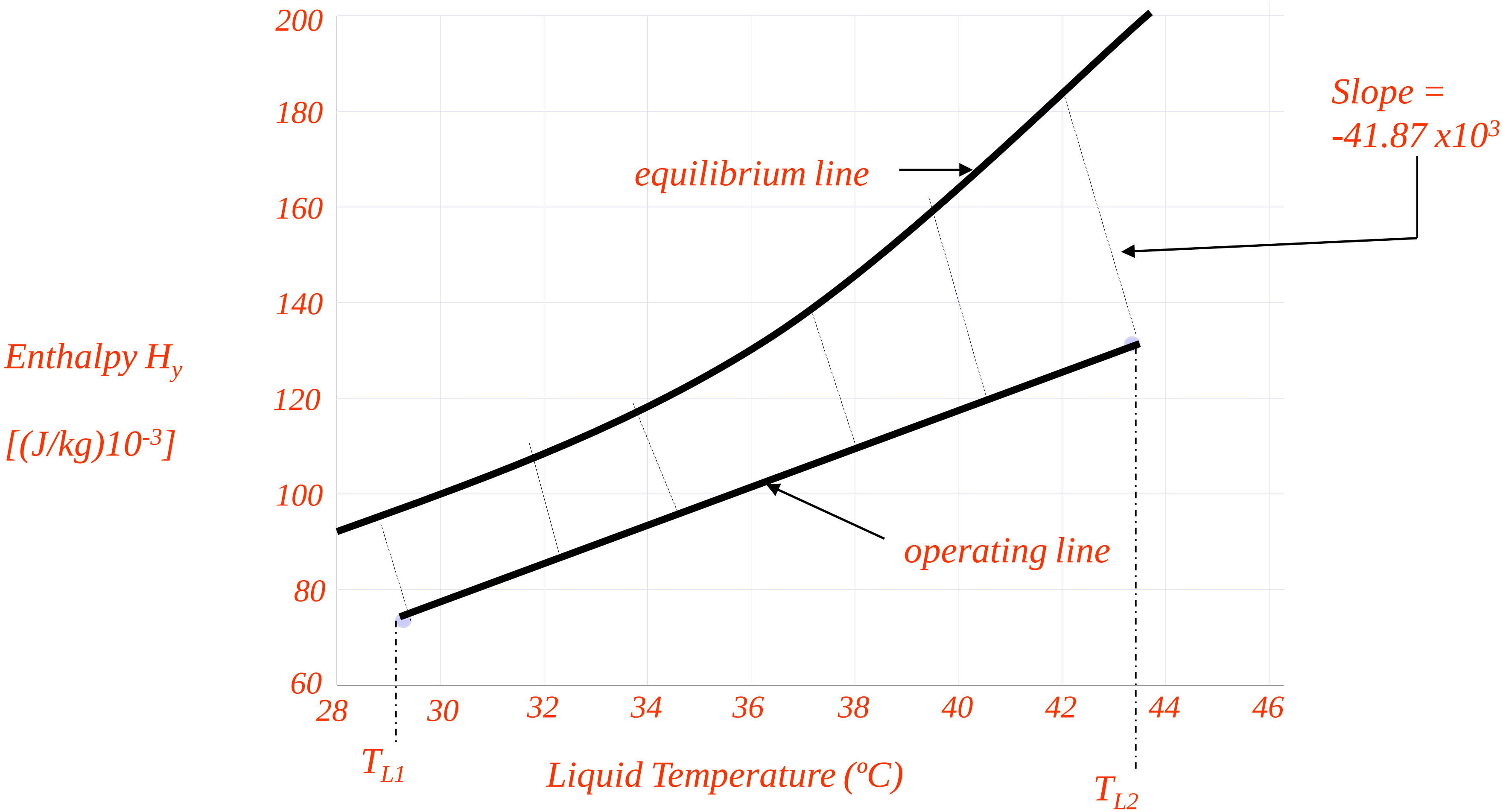
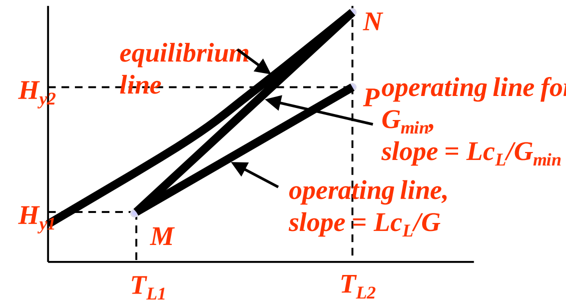


Figure 10.5-4: Graphical solution of Example 10.5-1

Minimum Value of Air Flow 1/2



- The air flow **G** is not fixed but must be set for the design of the cooling tower.
- For a minimum value of **G**, the operating line **MN** is drawn through the point $\mathbf{H_{y1}}$ and $\mathbf{T_{L1}}$ with a slope that touches the equilibrium line at $\mathbf{T_{L2}}$, **point N.**
- If the equilibrium line is quite curved, line **MN** could become tangent to the equilibrium line at a point farther down the equilibrium line than point **N.**
- For the actual tower, a value of **G** greater than $\mathbf{G_{min}}$ must be used. Often, a value of ***G equal to 1.3 to 1.5 times*** G_{min} is used.

Minimum Value of Air Flow 2/2

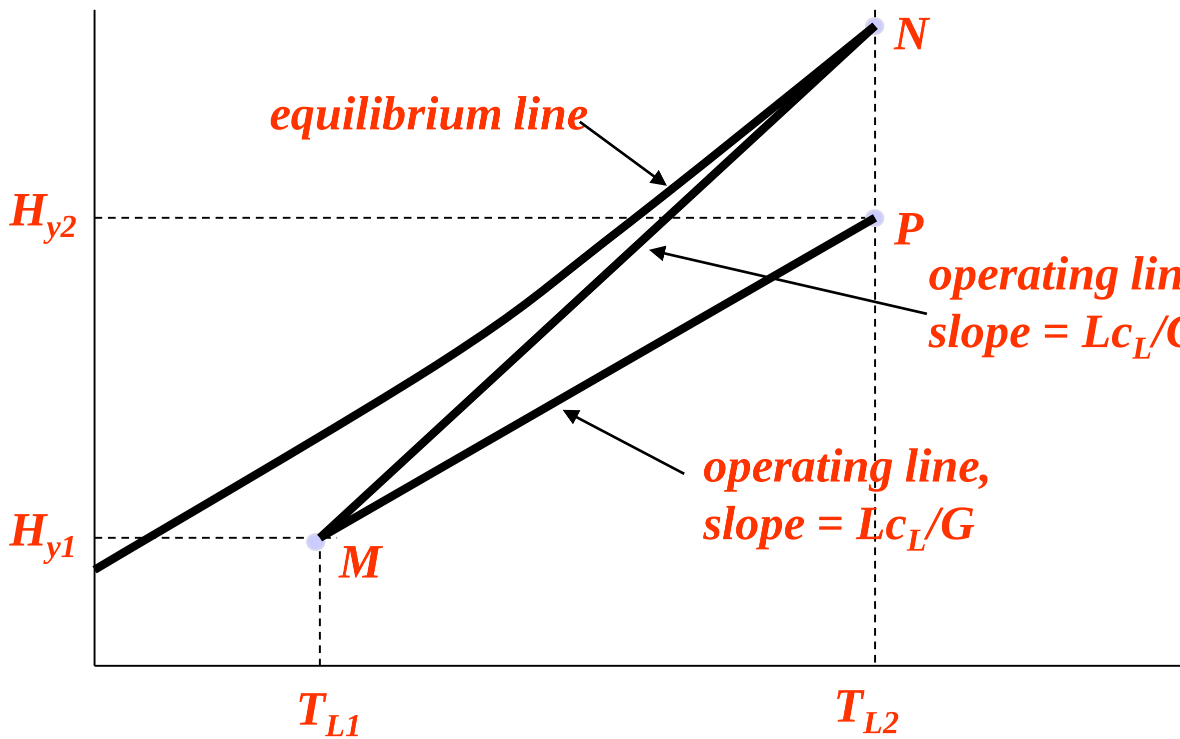


Figure 10.5-5: Operating-line construction for minimum gas flow.