UNIT OPERATION (I)

Department of Chemical and Petroleum Industries Engineering
Fourth Year
AL-Mustaqbal University Collage

Lecture **(5)**

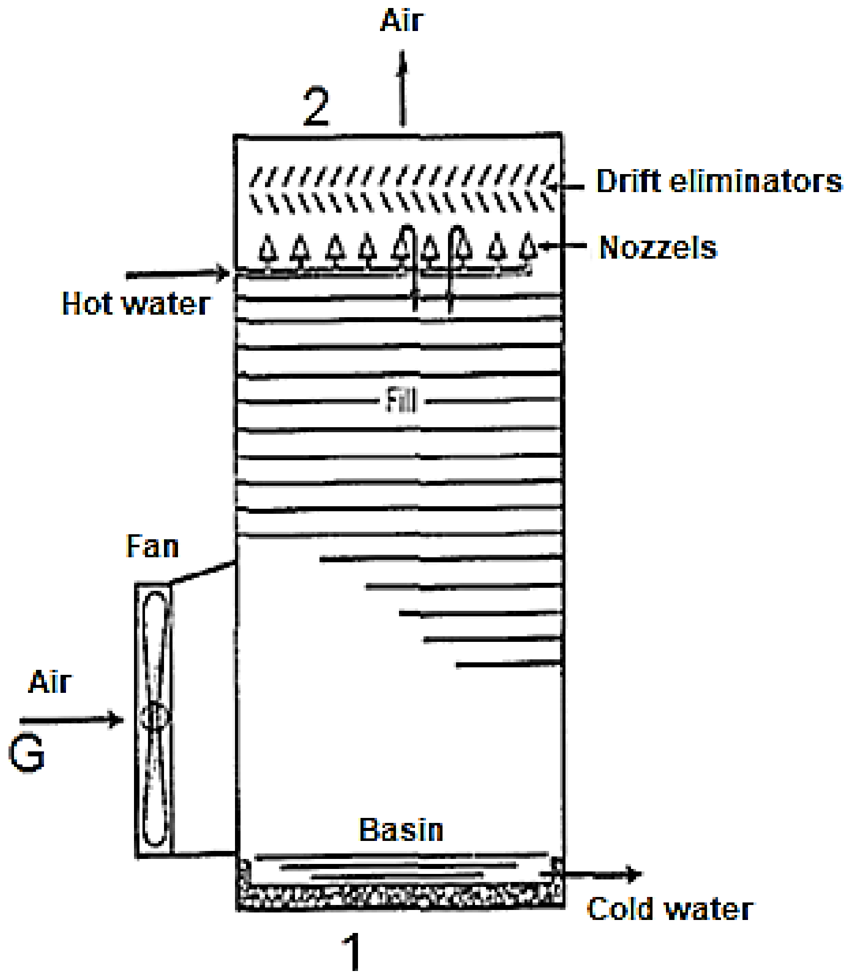
Cooling Towers (1)

EQUIPMENT FOR HUMIDIFICATION OPERATION

COOLING TOWER

When warm liquid is brought into contact with unsaturated gas, part of liquid is vaporized and the liquid temperature drops and humidity of the air is rise . This cooling of the liquid is purpose behind many gas- liquid contact operations, especially air-water contact.

Water is cooled in large quantities in tall towers through which air passes by natural draft or by the action of fan. A cooling tower is a special kind of packed tower. A typical forced draft-cooling tower is shown in the figure.



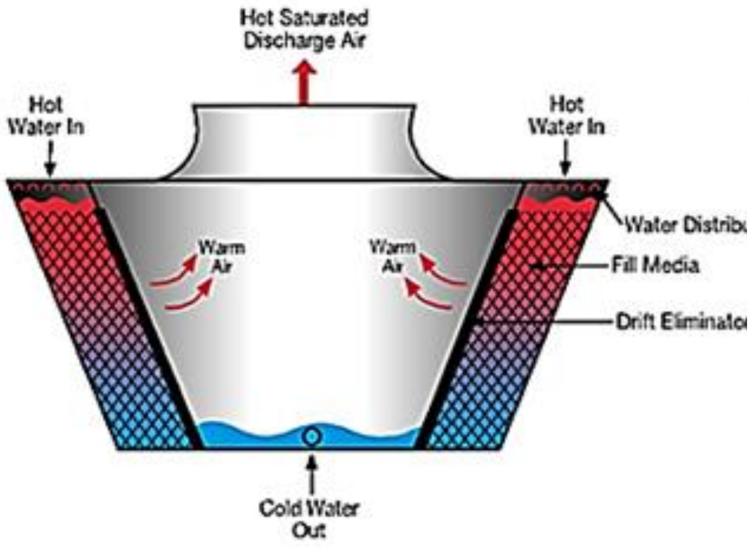
PRINCIPLES OF COOLING TOWER OPERATION

Different models of the cooling tower use various components to achieve the best results. Tower Components offers a wide variety of cooling tower products. Each component has a principle of operation specifically suited to operating conditions

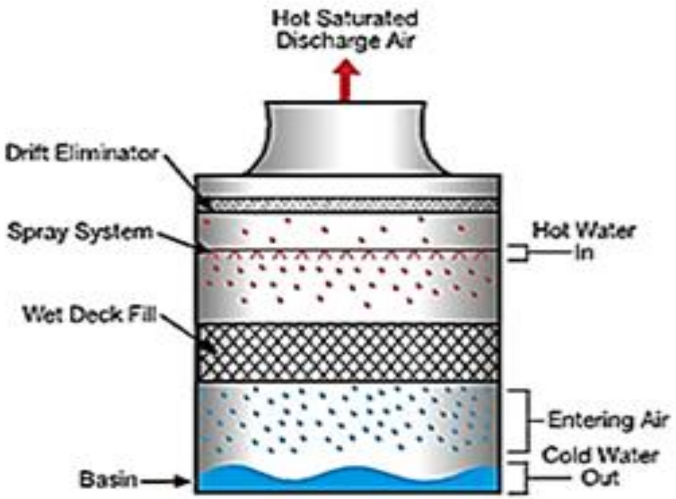
In cross flow cooling towers, air travels horizontally across the direction of the falling water.

In counter flow towers, air travels in the opposite direction (counter) to the direction of the falling water.

The type of application usually dictates whether a crossflow or counter flow cooling tower would be better suited for the process.



Crossflow Tower



Counterflow Tower

CLASSIFYING COOLING TOWERS

Cooling towers come in many different shapes and sizes. They range from small two-ton factory models to large towers capable of rejecting thousands of heat BTUs. Although the shapes and sizes can vary, the principle of operation remains the same. The cooling tower industry has several ways to classify.

Field-erected (FEP) cooling tower – induced-draft counterflow cooling tower

MANUFACTURE TYPE

The broadest way to classify a cooling tower is by ***the way it is manufactured***. The two primary types are field-erected products **(FEP)** and factory-assembled products **(FAP)**. Field-erected cooling towers typically serve the power and heavy industrial market where the heat rejection required and water volume are very large.

Factory-assembled cooling towers are primarily assembled at the manufacturing plant, then shipped and installed at the site of use.

Factory-assembled (FAP) cooling tower – induced-draft crossflow cooling tower

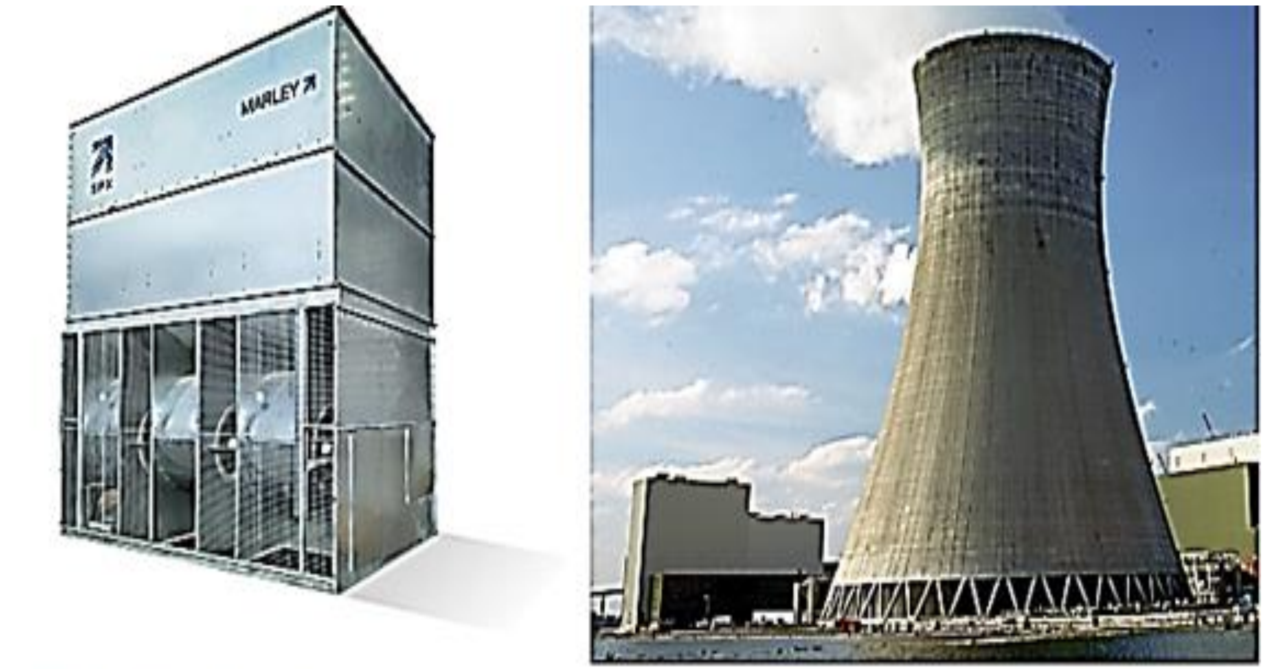
Once a manufacture type is determined, a **sub classification exists:**

By the method in which air is introduced into the cooling tower. **Draft Type**

There are three ways to bring air into the tower — natural draft (FEP only), induced draft, and forced draft. Fig.(1)

By the method by which the air and the process water make contact. **Air Movement**

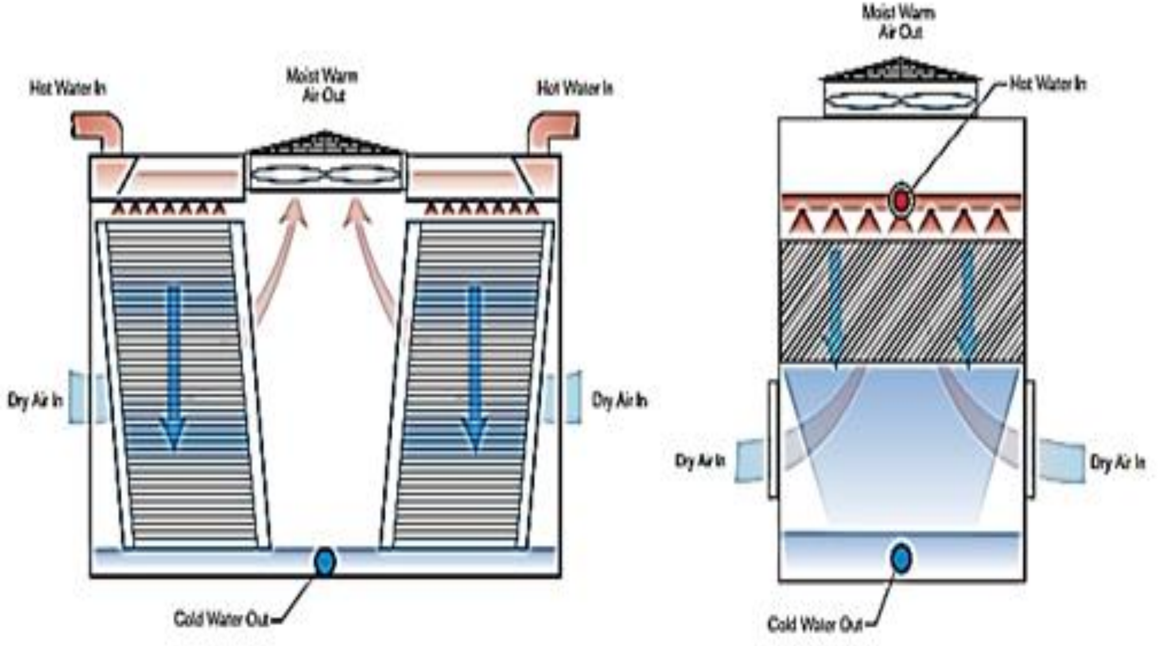
The two classifications are crossflow and counter flow, both of which are used in FEP and FAP cooling towers. Fig.(2)



Forced-draft cooling tower – factory-assembled (FAP) counterflow cooling tower

Natural-draft cooling tower – field-erected (FEP) counterflow cooling tower

Fig.(1)



Crossflow cooling tower schematic

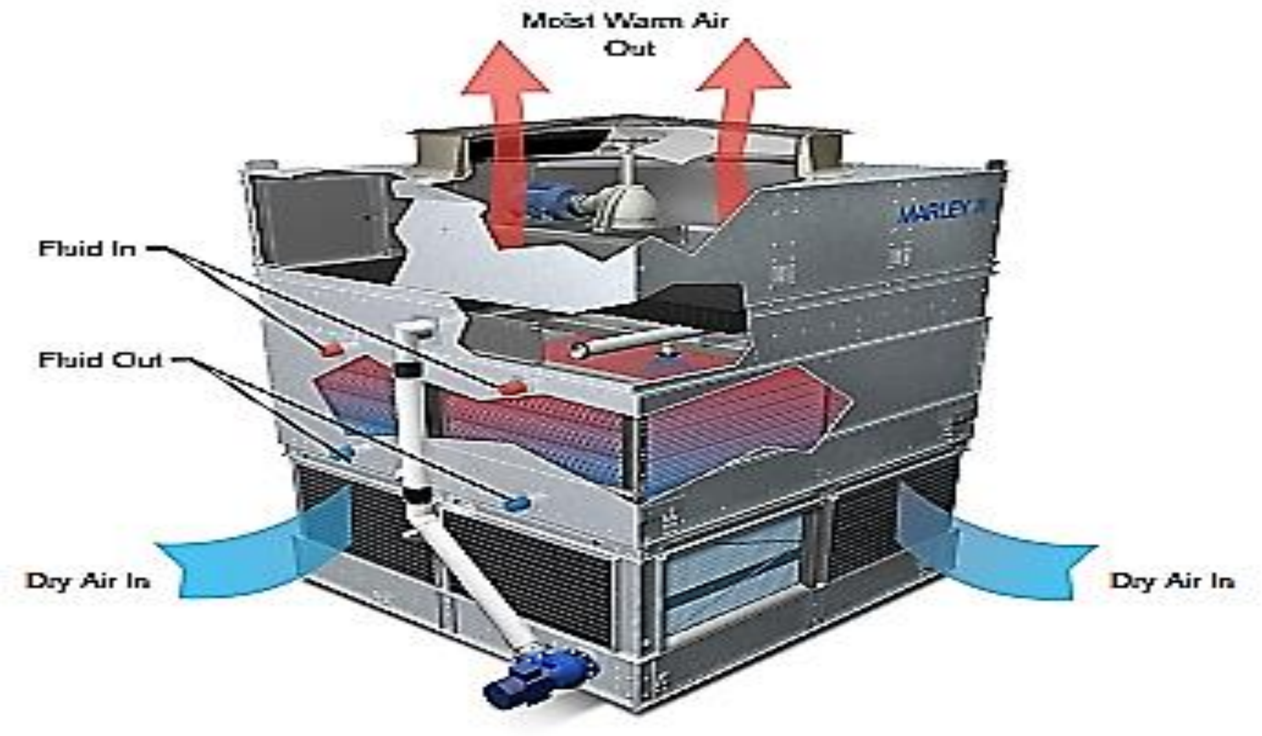
Counterflow cooling tower schematic

Fig.(2)

Within the FAP, cooling towers are also classified ***By air/ water contact type*** based on ***open-loop or closed-loop design***.

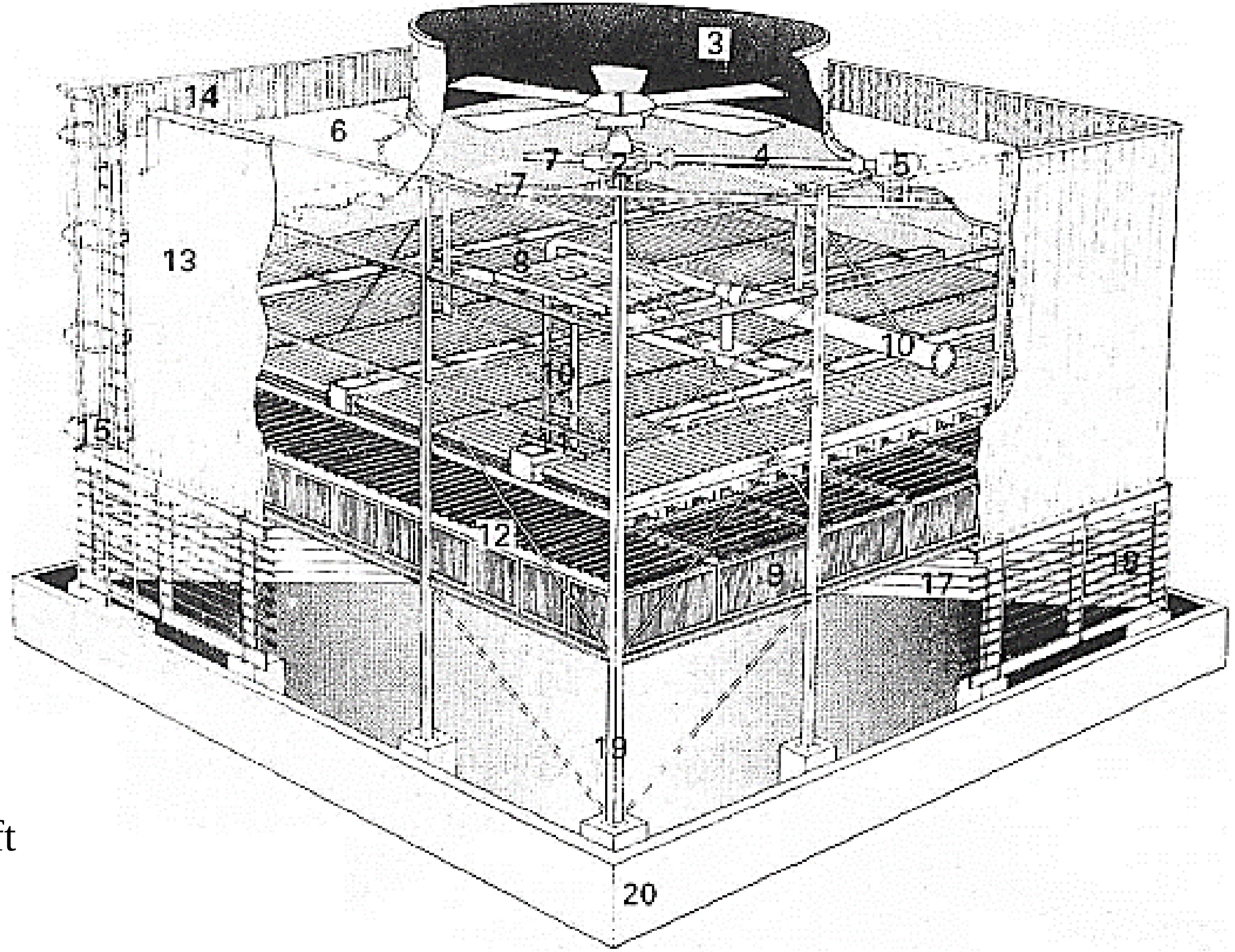
Closed-loop cooling towers (fluid coolers) have a smaller single-cell capacity relative to an open tower, but have several advantages.

Closed-loop cooling towers keep the process fluids separated and clean. Because the process fluid is in a closed loop, fluids other than water and fluids at much higher temperatures can be cooled



Induced-draft closed-loop cooling tower (fluid cooler) cutaway

1. Fan assembly
2. Gearbox
3. Fan stack
4. Drive shaft assembly
5. Motor
6. Fan deck
7. Mechanical equipment supports
8. Drift eliminators (PVC or Timber - Timber shown)
9. Cooling tower packing (plastic plate or wooden lath)
10. Inlet water distribution pipe
11. Open type distribution system
12. Timber laths for even water distribution
13. Cladding
14. Cladding extended to form handrail
15. Access ladder
16. Internal access ladder to distribution system and drift eliminators
17. Diagonal wind baffles
18. Air inlet louvres
19. Steel structures with horizontal and diagonal ties
20. Cold water sump



mechanical draught, water cooling tower

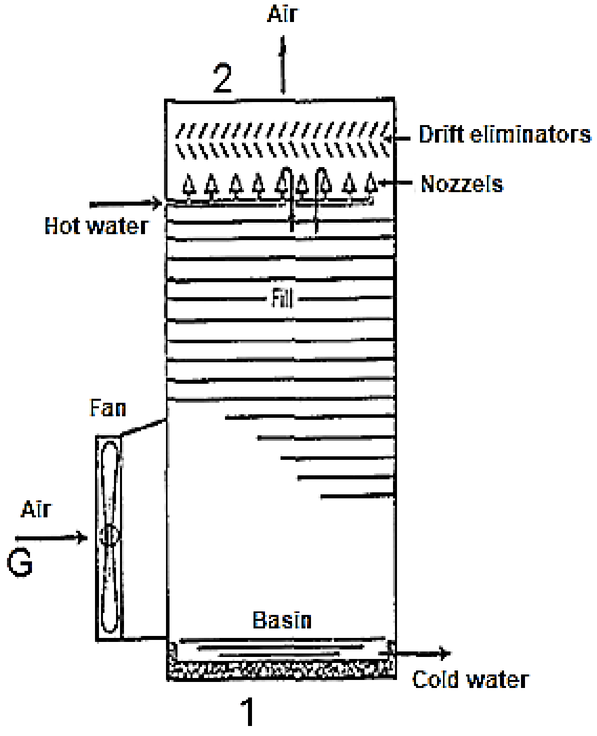
COOLING TOWER:

Is an evaporative heat-exchanger in which two fluids (air & water) are brought into direct contact to effect transfer of heat from water to the air. Heat is rejected primarily through evaporation of a small percentage of the circulating water (about 1%) of the circulating flow rate for every 5^{o} C of temperature drop.

In a cooling tower, water is distributed over a packing of height ***Z*** m, through which air passes upwards causing evaporation and hence cooling of the water stream. Referring to the figure ***G*** kg/m^{2}s is the mass flow of dry air and ***L*** kg/m^{2}s the mass flow of water (usually assumed constant as the evaporation is small).

The height of the column, ***Z***, can be calculated by the following Eq.:

$$Z = \frac{G}{h_D a \rho_A} \int_1^2 \frac{dH_G}{(H_f - H_G)}$$



Where:

h_D : is mass transfer coefficient, m/s

ρ_A : is density of air, kg/m^3

a : is interfacial area/ unit volume of packing, m^2/m^3

H_f : is enthalpy of gas (air) at the interface, k$_J$/kg

H_G : is the enthalpy of gas (air), k$_J$/kg

H_G can be calculated by the equation:

$$H_G = c_A(\theta_G - \theta_o) + \mathscr{H}\lambda_o$$

Or from Fig. 13.5

Where:

c_A : is the specific heat of gas (air), kJ/kg K

θ_G : is gas (air) temperature

θ_o : is the reference temperature e.g. 273 K

λ_o : is latent heat of vaporization at reference temp

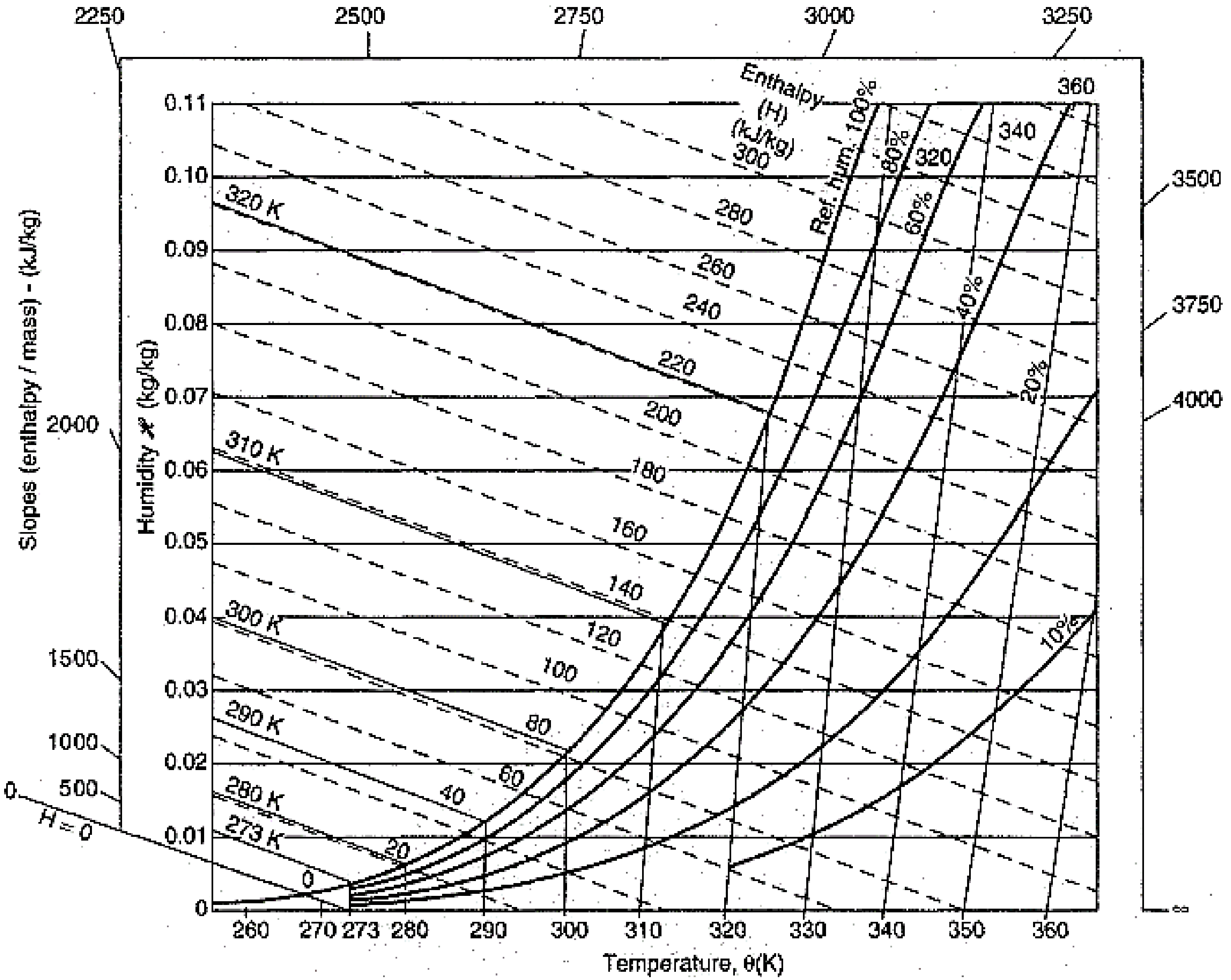


Fig. 13.5

Procedure for determining the height of water-cooling tower

The slope of tie-lines $A'C'$ ...etc. is $$\frac{(H_G - H_f)}{(\theta_L - \theta_f)} = -\frac{h_L}{h_D \rho}$$

Where:

h_L = *heat transfer Coef. For liq. Phase*

h_D = *mass transfer Coeff,*

ρ = *Mean density of gas and vapor,*

θ_f = *temp at interface*

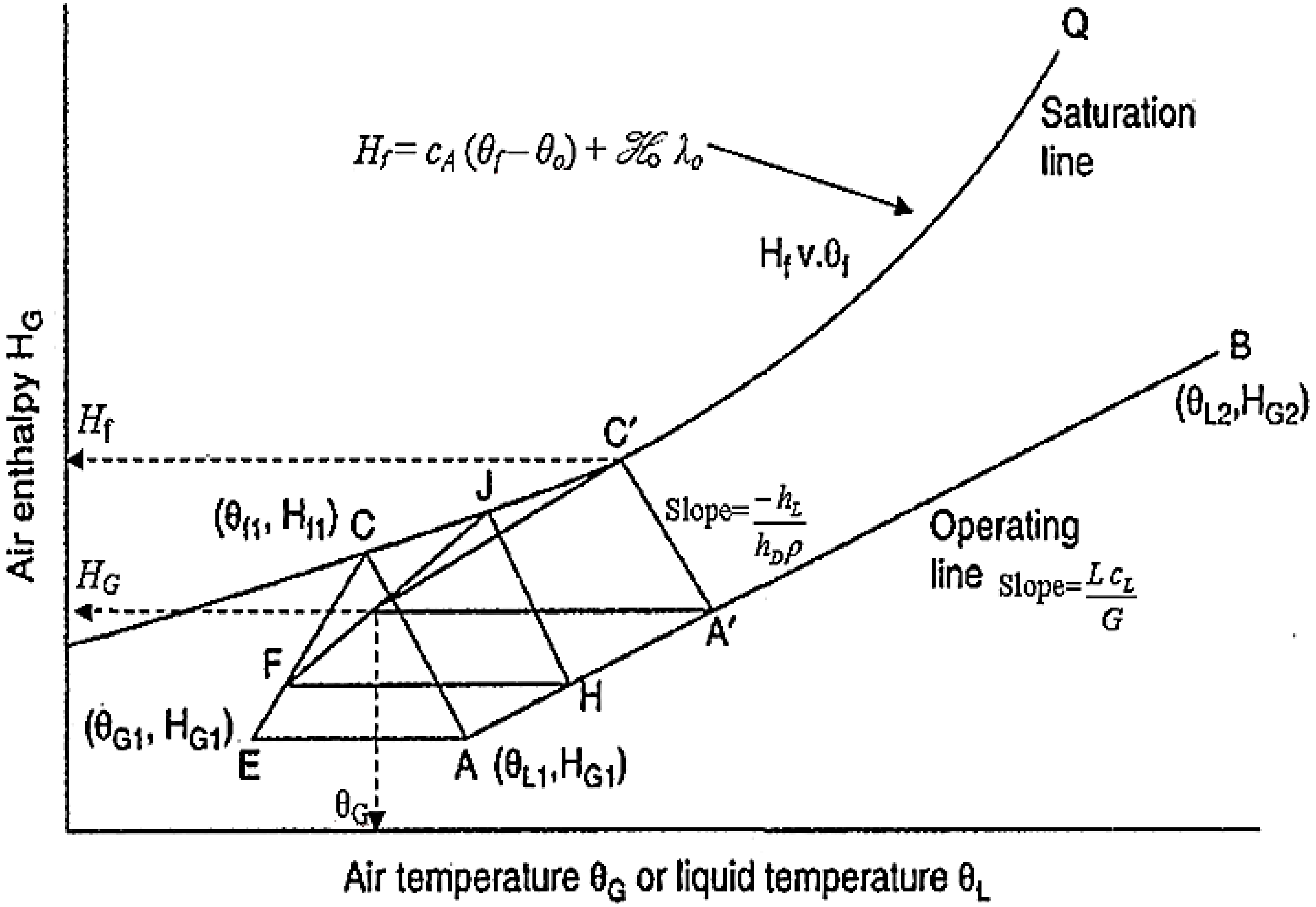
If the slope is not given, another statement is given such as the whole resistance to heat and mass transfer lie in the gas side. i.e. the slope is vertical.

L = mass flow rate of liquid,

G = mass flow rate of gas (kg/m^2.s) ,

c_L = specific heat of liquid

From Figures 13.4 and 13.5 the curve representing the enthalpy of ***saturated*** air as a function of temperature is obtained and drawn in.



Ex:

Water is to be cooled from 328 to 293 K by means of a countercurrent air stream entering at 293 K with a relative humidity of 20%. The flow of air is 0.68 m^3/m^2s and the water throughput is 0.26 kg/m^2s. The whole of the resistance to heat and mass transfer may be assumed to be in the gas phase and the product, $h_D\, a$, may be taken as 0.2 (m/s)(m^2/m^3), that is 0.2 s^{-1}. What is the required height of packing and the condition of the exit air stream?

Solution:

$$Z = \frac{G}{h_D a \rho_A} \int_1^2 \frac{dH_G}{(H_f - H_G)} \qquad H_G = c_A(\theta_G - \theta_o) + \mathscr{H}\lambda_o$$

The latent heat of water at 273 K = 2495 kJ/kg

Specific heat of air = 1.003 kJ/kg K,

and specific heat of water vapor = 2.006 kJ/kg K

From Figure 13.4: at θ_G = 293 K and RH = 20% $\rightarrow$ $\mathscr{H}$ = 0.003 kg/kg dry air

$\rightarrow$ H_{G1} = 1.003(293 – 273) + 0.003×2495 = 27.67 kJ/kg [or using figure 13.5]

In the inlet air, water vapor = 0.003 kg/kg dry air [figure 13.4]

$$\rightarrow \frac{(0.003/18)}{(1/29)} = 0.005 \text{ kmol water/kmol dry air}$$

Thus flow of dry air = (1 – 0.005) ×0.68 = 0.677 m ^{3}/m^{2}s [*mole fraction = volume fraction in gases*]

Density of air is estimated by $PV = nRT$

$$\rightarrow \rho = \frac{P \cdot M_W}{RT} = 101.3\times29/8.314\times293 \quad = 1.206 \text{ kg/m}^3$$

→ mass flow of air is 0.677×1.206 = 0.817 kg/m^{2}s

Slope of operating line: $\frac{L\,c_L}{G} = \frac{(0.26 \times 4.18)}{0.817} = 1.33$ kJ/kg K [c_L is the specific heat of water]

The coordinates of the bottom of the operating line are: θ_{L1} = 293 K, H_{G1} = 27.67 kJ/kg and using the slope (1.33) the top point of the operating line is given by θ_{L2} = 328 K, and H_{G2} is found to be 76.5 kJ/kg as in the figure below

From Figures 13.4 and 13.5 the curve representing the enthalpy of ***saturated*** air as a function of temperature is obtained and drawn in.

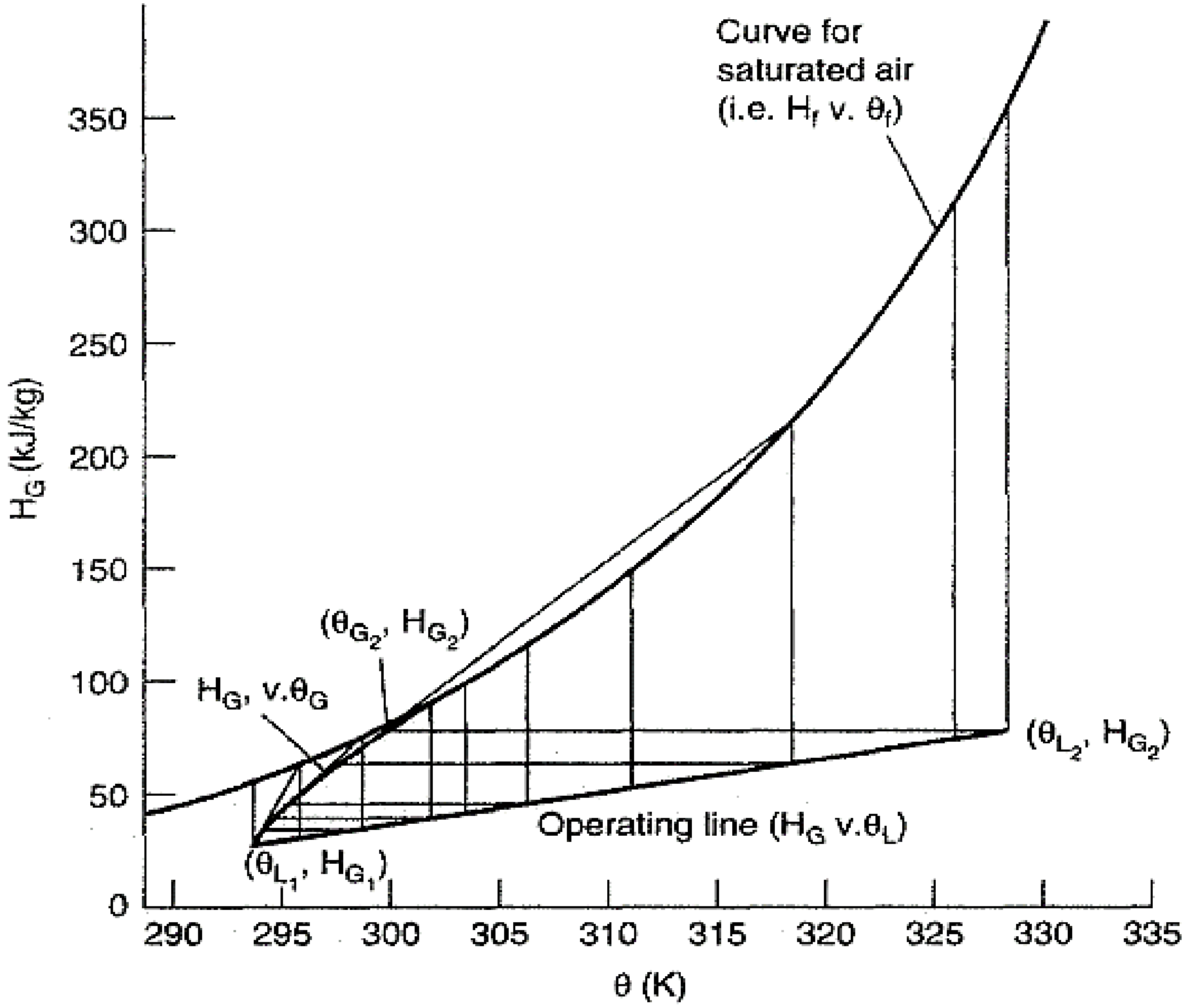


Figure (A)

It now remains to evaluate the integral

$$\int_1^2 \frac{dH_G}{(H_f - H_G)}$$ between the limits, $H_{G\,1}$ = 27.7 kJ/kg and $H_{G\,2}$ = 76.5 kJ/kg.

At the bottom of the column:

$H_{G\,1}$ = 27.7 kJ/kg, H_{f1} = 57.7 kJ/kg → ΔH_1 = 30 kJ/kg

At the top of the column:

$H_{G\,2}$ = 76.5 kJ/kg, H_{f2} = 355 kJ/kg → ΔH_2 = 279 kJ/kg

At the mean water temp of (328 + 293)/2 = 310.5 K

→ Fig. (A) H_{Gm} = 52 kJ/kg, H_f = 145 kJ/kg

and ΔH_m =145 – 52 = 93 kJ/kg

$$\frac{\Delta H_m}{\Delta H_1} = 3.10, \quad \frac{\Delta H_m}{\Delta H_2} = 0.333$$

And from figure (13.17):
the correction factor, f = 0.79

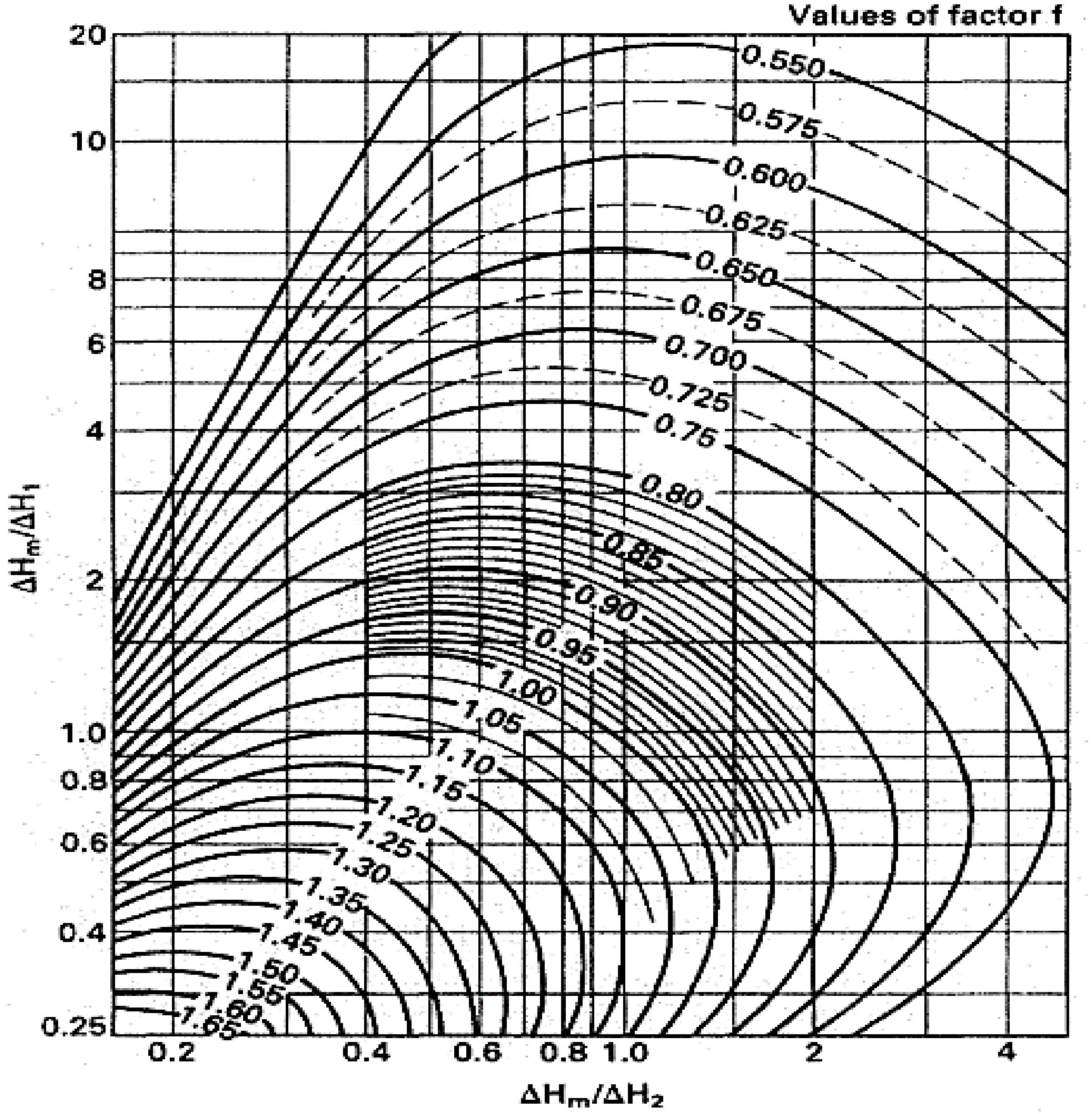


Figure 13.17

$$\rightarrow \frac{(H_{G2} - H_{G1})}{f\,\Delta H_m} = \frac{(76.5 - 27.7)}{(0.79 \times 93)} = 0.66 \quad = \quad \int_{H_{G1}}^{H_{G2}} \frac{dH_G}{(H_f - H_G)}$$

$$Z = \frac{G}{h_D a \rho_A} \int_1^2 \frac{dH_G}{(H_f - H_G)}$$

$$\rightarrow Z = \frac{0.817 * 0.66}{0.2 * 1.206} = 2.2 \text{ m}$$

From figure (A) above the value of θ_{G2} corresponding to H_{G2} = 76.5 kJ/kg is 300 K.

From Figure 13.5, under these conditions, the exit air has a humidity of 0.019 kg/kg which from figure 13.4 corresponds to a relative humidity of 83 %.