UNIT OPERATION (I)

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

Lecture **(2)**

TIME OF DRYING:

a- ***constant rate period***:

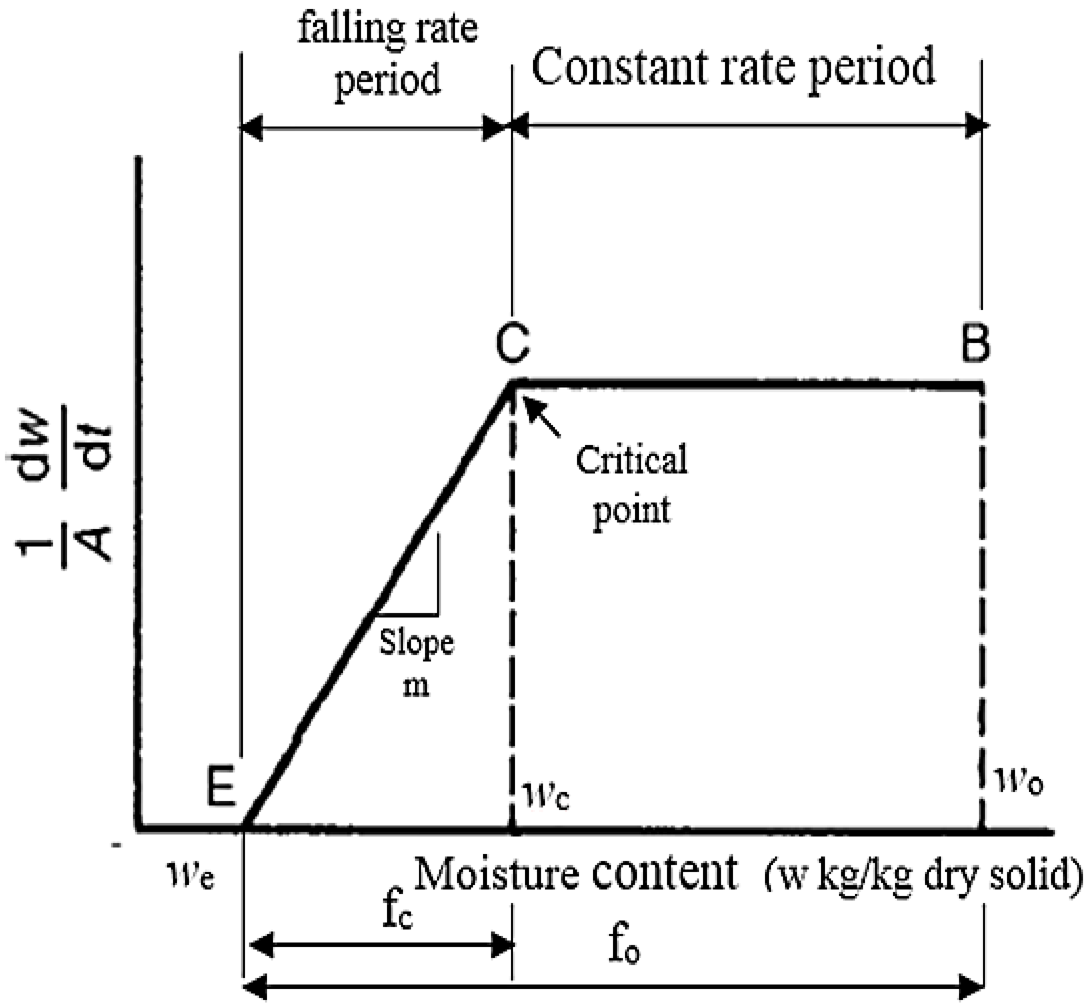
In the drying from w_o to w_c the surface is wet and the drying rate, R_C (kg(solute)/m^{2}s) is constant and the time to dry from w_o to w_c is

$$t_c = (w_o - w)/R_C A \qquad \text{s/kg solid}$$

w may be = w_C or more

$$R_C = \frac{h_C(T - T_i)}{\lambda_i} \qquad \text{kg/m}^2\text{s}$$

w_o = initial moisture content (kg water/kg dry solid)
w_c = critical moisture content (kg water/kg dry solid)
w_e = equilibrium moisture content (kg water/kg dry solid)
T = Temp of gas (air)
T_i = interfacial temperature



b- ***falling rate period***:

The time required to dry between w_c and w_e or more is

$$t_f = \frac{1}{mA} \ln \frac{w_c - w_e}{w - w_e} = \frac{1}{mA} \ln \frac{f_c}{f} \qquad \text{(s)}$$

Where:

$$f_c = w_c - w_e$$

$$f = w - w_e$$

$$R_C = m f_c$$

where: m = slope = R_C/f_c (kg solid/m^2s)

w = final moisture content

c- ***total time*** *for drying* $(t_c + t_f)$

$$\mathbf{(t_c + t_f) = t_T}$$

$$= \frac{1}{mA}\left[\frac{(f_o - f_c)}{f_c} + \ln \frac{f_c}{f} \right] \quad , \qquad f_o = w_o - w_e$$

Ex: A wet solid is dried from 25 to 10% moisture under constant drying conditions in 15 ks (4.17 h). If the critical and the equilibrium moisture contents are 15 and 5 per cent respectively, how long will it take to dry the solid from 30 to 8% moisture under the same conditions? All on a *dry basis*.

Solution:

For the first drying operation :

$w_o = 0.25$ kg/kg dry solid

$w = 0.1$ kg/kg dry solid

$w_e = 0.05$ kg/kg dry solid

$w_c = 0.15$ kg/kg dry solid

The total time for drying is $t_T = \frac{1}{mA}\left[\frac{(f_o - f_c)}{f_c} + \ln\frac{f_c}{f}\right]$

$f_o = w_o - w_e = 0.25 - 0.05 = 0.2$ kg/kg dry solid

$f_c = w_c - w_e = 0.15 - 0.05 = 0.1$ kg/kg dry solid

$f = w - w_e = 0.1 - 0.05 = 0.05$ kg/kg dry solid

Substitute in above Eq.

$$15000 = \frac{1}{mA}\left[\frac{(0.2-0.1)}{0.1} + \ln\frac{0.1}{0.05}\right] \quad \rightarrow \quad mA = 0.113\times10^{-3} \text{ kg solid/s}$$

For the second drying operation:

$w_o = 0.3$ kg/kg dry solid

$\rightarrow \quad f_o = w_o - w_e$

$= 0.3 - 0.05 = 0.25$ kg/kg dry solid

$w = 0.08$ kg/kg dry solid

$\rightarrow \quad f = w - w_e$

$= 0.08 - 0.05 = 0.03$ kg/kg dry solid

$w_e = 0.05$ kg/kg dry solid

$w_c = 0.15$ kg/kg dry solid

$\rightarrow \quad f_c = w_c - w_e$

$= 0.15 - 0.05 = 0.1$ kg/kg dry solid

The total time for drying is

$$t = \frac{1}{0.113 \times 10^{-3}} \left[\frac{(0.25 - 0.1)}{0.1} + \ln \frac{0.1}{0.03} \right] = 23.9 \text{ ks } (6.65 \text{ h})/\text{kg solid}$$

Ex: A filter cake 610 mm square and 51 mm thick, supported on a screen, is dried from both sides with air at a wet-bulb temperature of 26.7°C and a dry-bulb temperature of 49°C. The air flows parallel with the faces of the cake at a velocity 1.07 m/s. The dry density of the cake is 1922 kg/m^3. The equilibrium-moisture content is negligible. Under the conditions of drying the critical moisture is 9 percent, *dry basis*.

(a) What is the drying rate during the constant-rate period?

(b) How long would it take to dry this material from an initial moisture content of 20 percent (dry basis) to a final moisture content of 10 percent? Equivalent diameter *De* is equal to 0.61 m.

Solution

$$\text{(a) } R_C = \frac{h_C(T - T_i)}{\lambda_i}$$

For parallel flow: $h_C = 8.8G^{0.8}/D_e^{0.2}$

Mass velocity of air G, is: $G = u\rho$

$$\rho = P.Mw/RT = \frac{101.3(29)}{8.314(322)} = 1.1 \text{ kg/m}^3$$

$$\rightarrow G = 1.07(1.1) = 1.177 \text{ kg/m}^2\text{s}$$

$$\rightarrow h_C = 8.8(1.177)^{0.8}/0.61^2 = 11.07 \text{ W/m}^2\ ^{o}\text{C}$$

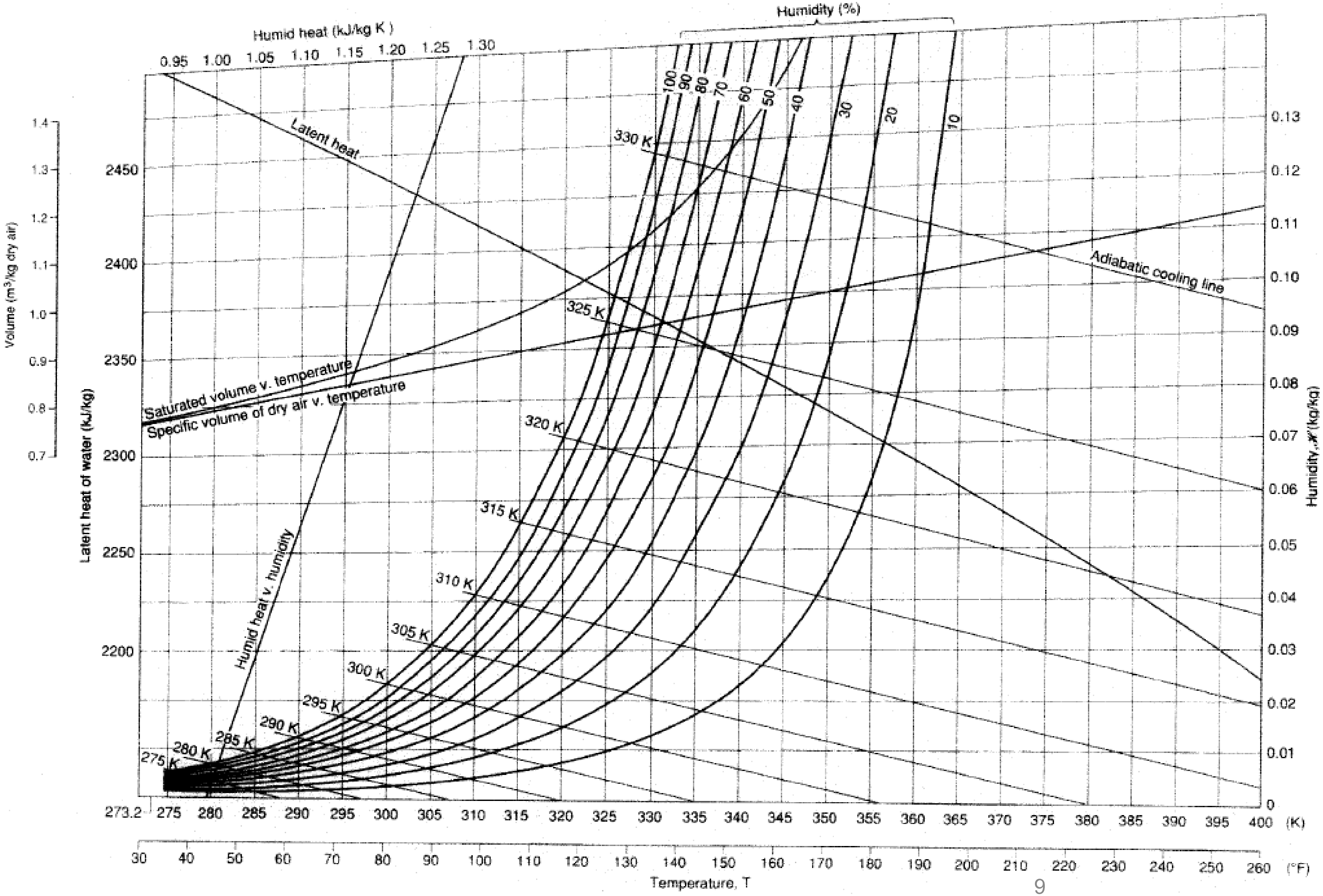
At $T_i = 26.7^{o}C$ (wet bulb temp)

$\rightarrow \lambda_i = 2440$ kJ/kg (from steam table or Fig. 13.4 at T = 26.7^{o}C)

$$\rightarrow R_C = \frac{h_C(T - T_i)}{\lambda_i}$$

$$= \frac{11.07(49 - 26.7)}{2440}$$

$$= 0.1011 \times 10^{-3} \text{ kg/m}^2\text{s} = 0.362 \text{ kg/m}^2\text{h}$$



Humidity (%)
Humid heat (kJ/kg K)
0.95 1.00 1.05 1.10 1.15 1.20 1.25 1.30
100 90 80 70 60 50 40 30 20 10
Latent heat
Humid heat v. humidity
Saturated volume v. temperature
Specific volume of dry air v. temperature
Adiabatic cooling line
330 K
325 K
320 K
315 K
310 K
305 K
300 K
295 K
290 K
285 K
280 K
275 K
Volume (m³/kg dry air)
1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7
Latent heat of water (kJ/kg)
2450 2400 2350 2300 2250 2200
Humidity, ℋ (kg/kg)
0.13 0.12 0.11 0.10 0.09 0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 0
273.2 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 (K)
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 (°F)
Temperature, T

(b) For constant rate: $t_c = (w_o - w)/R_C A$

Since drying is from both faces, $A = 2\times(0.61)^2 = 0.744\ \text{m}^2$

$\rightarrow t_c = (0.2 - 0.1)/(0.362*0.744) = 0.3713$ h/kg solid

The volume of cake is : $(0.61)^2\times0.051 = 0.019\ \text{m}^3$

Mass of solid: $1922\times0.019 = 36.52$ kg

$\rightarrow t_c = 0.3713\times36.52 = 13.6$ h

Ex: A 100 kg batch of granular solids containing 30% moisture is to be dried in a tray drier to15.5% of moisture by passing a current of air at 350 K tangentially across its surface at a velocity of 1.8 m/s. If the constant rate of drying under these conditions is 0.0007 kg/s.m^2 and the critical moisture content is 15%, calculate the approximate drying time. Assume the drying surface to be 0.03 m^2/kg dry mass. [all on *wet basis*].

Solution: $t_c = (w_o - w)/R_C A$

In 100 kg feed, mass of water = 0.3×100 = 30 kg

And mass of dry solids = (100 − 30) = 70 kg

Thus: initial moisture content, w_o = (30/70) = 0.429 kg/kg dry solids

final moisture content, $w = \frac{15.5}{84.5} = 0.183$

The surface area available for drying = (0.03 × 70) = 2.1 m^2

$\rightarrow t_c = (0.429 - 0.183)/(0.0007\times 2.1)$

$= 167.35$ s/kg solid $= 167.35\times 70 = 11714$ s

OR t_C = *water removed/rate of drying*

After drying the water in the dried solid (assume = b)

$$\rightarrow \frac{b}{b+70} = 0.155 \rightarrow b = 12.8 \text{ kg}$$

and water to be removed = (30 − 12.8) = 17.2 kg

t = 17.2/(0.0007×2.1) = 11700 s

Ex: 100 kg/hr of dried neomycin (*drug most commonly used in combination-drug preparations to treat skin, eye, and ear infections*) containing 4% moisture are produced in a counter current flow spray dryer. The feed solution containing 45% solids by weight is pumped to the atomizer at 15°C. Atmospheric air at 15°C and 50% relative humidity is heated with indirect steam at 150°C before entering the dryer. The air stream leaves the dryer at a temperature of 95°C. The product leaves the dryer at 70°C. Assume that the heat capacity of the dry solids is 1.675 kJ/kg °C. The reference temperature will be 0°C. Calculate the air flow and its exit humidity.

Solution: Enthalpy in = Enthalpy out

Solid M.B.: $0.45F = 0.96\times100$ $\rightarrow$ $F = 213.33$ kg/hr

$\rightarrow$ Water evaporated = 113.33 kg/hr

$\mathscr{H}_1 = 0.005$ kg water/kg dry air (from fig.13.4 at T = 15°C & RH = 50%)

Water M.B. on the air: $G(\mathscr{H}_2 - 0.005) = 113.33$ ……(1)

Enthalpy Balance (Heat Balance): Air Enthalpy: $H_G = c_A(\theta_G - \theta_o) + \mathscr{H}\lambda_o$

For inter air $H_{G1} = 1(150\text{-}0) + (0.005)\,2500 = 162.5$ kJ/kg (don't use fig.13.5)

For exit air $H_{G2} = 1(95\text{-}0) + \mathscr{H}_2 \times 2500$

Enthalpy of the feed = $(m\,C_P\Delta T)_{solid} + (m\,C_P\Delta T)_{water}$

$$= 96\times1.675(15) + 117.33\times4.18(15)$$
$$= 9768.6 \text{ kJ}$$

Enthalpy of product leaving the dryer = $96\times1.675\times70 + 4\times4.18\times70$

$$= 18612.6 \text{ kJ}$$

Enthalpy in = Enthalpy out

$\rightarrow 162.5G + 9768.6 = G\,(95 + \mathscr{H}_2\times2500) + 18612.6$ …(2)

From Eqns (1) and (2):

$$G = 6838 \text{ kg dry air/hr}$$

and $\mathscr{H}_2 = 0.0166$ kg water/kg dry air