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SEPARATION PROCESS

DRYING
Part 3

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Experimental Determination Rate Of Drying Curves

- solid placed on a tray
- only top surface exposed to air stream
- tray suspended from a balance
- record loss in weight during drying
- conditions closely resemble actual large-scale operations
  - ratio of drying to nondrying surface, bed depth, velocity, humidity, temperature, & direction of air.
- Free moisture content, X

$$\text{Moisture Content, } X_t = \frac{W - W_S}{W_S}$$

$$\text{Free Moisture Content, } X = X_t - X^*$$

Where W = weight of wet solid at given time, Ws= weight of dry solid

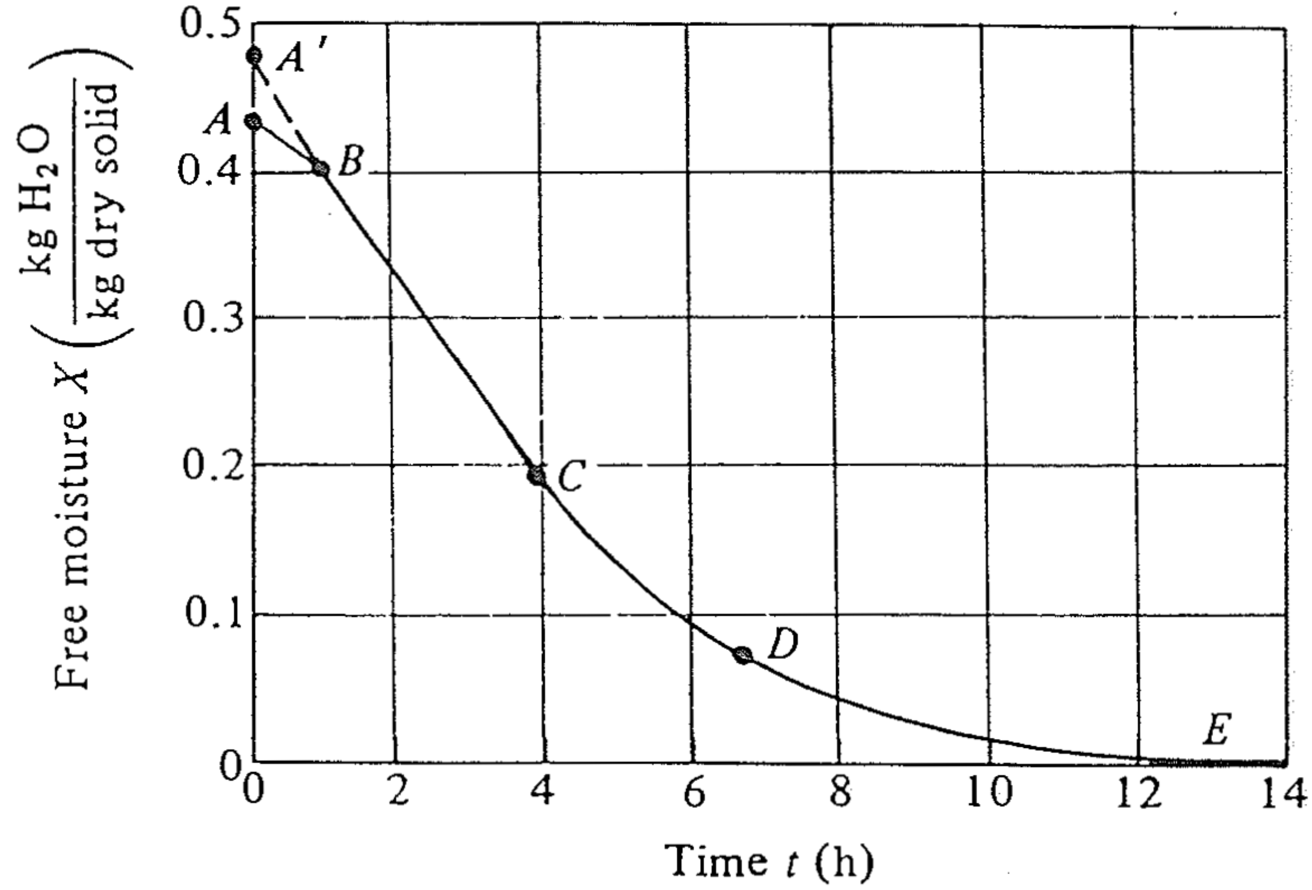
- To obtain rate of drying R: get slopes of tangents (dX/dt) at different values of t.

$$R = -\frac{L_S}{A}\frac{dX}{dt}$$

Where, Ls = kg of dry solid used; A = exposed surface area for drying.

Drying Rate Curve

Free Moisture Content vs Time



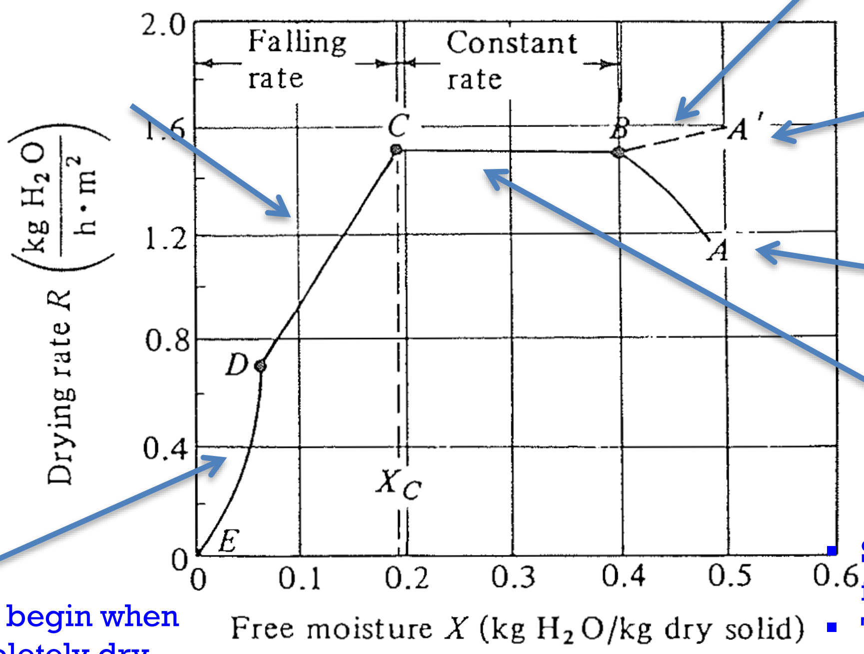
Drying Rate Curve

Rate vs Free Moisture Content

- Xc - critical free moisture content
- Insufficient water on surface for continuous film of water.
- Entire surface no longer wetted and the area continually decrease until the surface is completely dry
- Linear rate

Line A-B: unsteady-state adjustment period; short and often ignored

Point A' - initial free moisture content if solid if hot than the ultimate temp.



Point A - initial free moisture content if solid if cold than the ultimate temp.

- Second falling rate begin when the surface is completely dry
- Evaporation from interior of solid
- Sometimes, this rate is completely missing or may constitute with first falling rate period

- Solid surface very wet initially and continuous film of water exist on drying surface.
- This water is entirely unbound water
- Rate of evaporation independent of the solid and same as rate of a free liquid surface.
- However, roughness of solid surface □, rate □.
- For porous surface, water continuously replaced by liquid from interior.

Calculation Methods For Constant-Rate Drying Period

Using Experimental Drying Curve

- For free moisture vs time plot
  - read off the time for specific initial and final moisture content
- Using rate of drying curve equation
  - Integrate over the time interval for drying from $X_{initial}$ to X_{final}

$$R = -\frac{L_S}{A}\frac{dX}{dt}$$

rearrange

$$t = \int_{t_1}^{t_2} dt = \frac{L_S}{A}\int_{X_2}^{X_1}\frac{dX}{R}$$

$$t = \frac{L_S}{AR_C}\left(X_1 - X_2\right)$$

Calculation Methods For Constant-Rate Drying Period

Using Predicted Transfer Coefficients

- Drying occur by mass transfer of water vapor from saturated surface through an air film to the bulk gas phase
- The rate of moisture movement within the solid is sufficient to keep the surface saturated
- The rate of water vapor removal is controlled by the rate of heat transfer to the evaporating surface, which furnished the latent heat of vaporization
- At steady state, rate of mass transfer = rate of heat transfer.
- Assumptions:
  - Only convective heat transfer to solid surface from hot gas to surface.
  - Mass transfer is from surface to hot gas.

$$R_C = \frac{q}{A\lambda_W} = \frac{h(T - T_W)}{\lambda_W} = k_y M_B (H_W - H)$$

$$t = \frac{L_S \lambda_W (X_1 - X_2)}{Ah(T - T_W)} = \frac{L_S (X_1 - X_2)}{A k_y M_B (H_W - H)}$$

A = exposed drying area (m^2)
T, T_w = temperature of gas & surface of solid, respectively (°C).
λ_w = latent heat at T_w (J/kg)
M_A, M_B = molecular weight of water & air, respectively.
h = heat-transfer coefficient (W/m^2.K)
Ky = mass transfer coefficient (kmol/s.m^2)
H, Hw = humidity

Calculation Methods For Constant-Rate Drying Period

Using Predicted Transfer Coefficients

- It is found to be more reliable to use heat transfer coefficient, h than mass transfer coefficient since an error in determine the interface temperature Tw affects the driving force (T-Tw) is less than it affects (Hw-H)

Case 1: Air flowing parallel to the drying surface

$$h = 0.0204G^{0.8} \text{ (SI)}$$

- Condition: T = 45 – 150 ºC, G = 2450 – 29,300 kg/h.m^2 (G, mass velocity = v⍰) v = 0.61 – 7.6 m/s

Case 2: Air flowing perpendicular to the surface

$$h = 1.17G^{0.37} \text{ (SI)}$$

- Condition: G = 3900 – 19,500 kg/h.m2; v = 0.9 – 4.6 m/s

Combined Convection, Radiation and Conduction Heat Transfer in Constant Rate Period

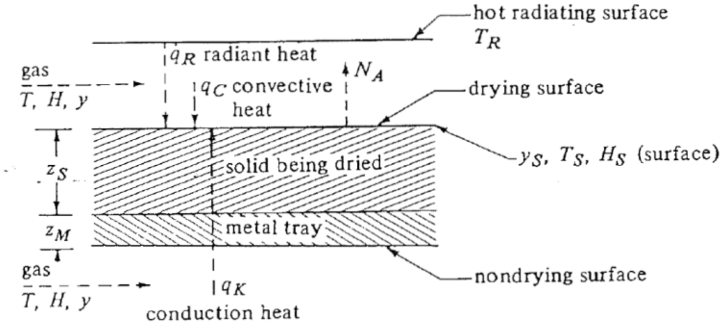
- Total rate of heat transfer to the drying surface is

$q = q_c + q_R + q_K$

q_C – convective heat transfer from gas T to the solid surface T_s

q_R – radiant heat transfer from the surface at T_R to T_s

q_K – conduction heat transfer from the bottom



$$q_C = h_C(T - T_s)A$$

$$q_R = h_R(T_R - T_s)A$$

$$h_R = \varepsilon(5.676)\frac{\left(\frac{T(K)_R}{100}\right)^4 - \left(\frac{T(K)_S}{100}\right)^4}{T_R - T_s}$$

$$R_C = \frac{q}{A\lambda_S} = \frac{(h_c + U_K)(T - T_s) + h_R(T_R - T_s)}{\lambda_S} = k_y M_B (H_S - H)$$

$$q_K = U_K(T - T_s)A$$

$$U_K = \frac{1}{1/h_c + z_M/k_M + z_S/k_s}$$

$$\frac{(H_S - H)\lambda_S}{h_c/k_y M_B} = (1 + U_K/h_c)(T - T_s) + (h_R/h_c)(T_R - T_s)$$

$$h_c/k_y M_B = cs = (1.005 + 1.88H)103$$

zM – metal thickness in m, kM – metal thermal conductivity in W/m.K, zS – solid thickness in m, kS – solid thermal conductivity, hc assumed to be same as convective heat transfer coefficient

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Azilah Ajit
Hayder Bari, Prof
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