...Question 3 continued

Useful equation:

$$\Delta T_i = \frac{\frac{1}{U_i}}{\frac{1}{U_1} + \frac{1}{U_2}} (T_s - T_2)$$

QUESTION 4 DRYING

Green tea extract is spray dried to produce instant tea. The tea extract is sprayed as a fine mist into the top of the spray dryer together with hot air at 90°C dry bulb temperature and 32°C wet bulb temperature. Assume all drying is by convection only.

The flow rate of tea extract into the dryer is 500 kg h^{-1} and enters the dryer with a moisture content of 70% water. The instant tea powder exiting has a moisture content of 3.7% water, dry solid density of 650 kg m^{-3} and mean particle size of 300 µm. The critical moisture content for dried green tea extract is 1.5 kg water/kg dry solids.

(a) Determine the time required to dry green tea extract to a moisture content of 1.5 kg water/kg dry solids. The mass transfer coefficient k_H', during the constant rate drying period, is 9.25 kg m^{-2} s^{-1}.

[6 marks]

(b) Estimate the time required in the spray dryer to dry the green tea extract to a final m, moisture content of 3.7% water if capillary drying dominates in the falling rate period. The equilibrium moisture content for the dried green tea extract powder is 0.002 kg water/kg dry solids.
[Note: If you did not find R_C in part (a) use 0.2 kg $m^{-2}s^{-1}$.]

[4 marks]

Question 4 continued over...

… Question 4 continued

(c) Calculate the flow rate of air required in the dryer to dry 500 kg h^{-1} green tea extract solution to the final moisture content of 3.7% water if the exit air has a humidity of 0.015 kg kg^{-1}.

[4 marks]

(d) Based on a flow rate of 500 kg h^{-1}, how much water is evaporated in the dryer (kg s^{-1})?

[1 mark]

(e) What is the exit temperature of the air leaving the dryer?

[1 mark]

(f) If the dryer air is recycled back into the dryer, what impact will this have on the overall drying process?
[Note: No calculations required]

[2 marks]

(g) Recommend operating conditions or procedures to ensure the required drying rate is maintained with recycling of dryer air.

[2 marks]

[Total: 20 marks]

A high temperature psychrometric chart is provided on page14, if used, please attach it to your exam script.

Question 4 continued over…

Drying 2014

$\theta_{air} = 90°C$
$\theta_{WB} = 32°C$
$M_i = 500 kg h^{-1} = 0.139 kg/s$

moisture content$_i$ = 70% ∴ $X_i = \frac{70}{30} = 2.3$ kg/kg.

moisture content out = 3.7% ∴ $X_o = \frac{3.7}{96.3} = 0.038$ kg/kg.

$X_c = 1.2$ kg/kg.
$\rho_s = 650 kg m^{-3}$
diameter = 300 μm.

(a) $R_c = \frac{k_H A (H_s - H_{air})}{A}$ $k_H = 9.25 kg m^{-2} s^{-1}$

$H_s = 0.030$
$H_{air} = 0.0075$

$R_c = 9.25(0.03 - 0.0075) = 0.208 kg m^{-2} s^{-1}$

t_d to 1.5 kg/kg. constant rate

$$t_d = \frac{r \rho_s}{3R_c}(X_1 - X_2)$$

$$= \frac{150 \times 10^{-6} \times 650}{3 \times 0.208}(2.3 - 1.5) = 0.125 s$$

(f) air recycled back into dryer
- humidity of air ↑
- rate of drying ↓
- drying time will increase to achieve same final moisture content
- air temperature after recycling back ↓

(g) pass recycle air over heater to increase temperature
purge some of the recycled moist air
introduce make up air of low humidity to keep humidity ↓

(h) constant rate + falling rate drying

$$t_d = \frac{r \rho_s (X_1 - X_c)}{3 R_c} + \frac{r \rho_s (X_c - X^*)}{3 R_c} \ln \left[\frac{X_c - X^*}{X_2 - X^*} \right]$$

$$= \frac{150 \times 10^{-6} \, 650 \, (2.3 - 1.5)}{3 \times 0.208}$$

$$+ \frac{150 \times 10^{-6} \, 650 \, (1.5 - 0.002)}{3 \times 0.208} \ln \left[\frac{1.5 - 0.002}{0.038 - 0.002} \right]$$

$$= 0.125 + \cancel{0.00268} \ \cancel{1.34} \ \cancel{0.873} \ 0.8726$$

$$= \cancel{0.125} \ \cancel{\ldots} \ 0.997 s = 1 s.$$

(e) $M_i \frac{1}{1+X_i} = M_o \frac{1}{1+X_o}$

$$0.139 \times \frac{1}{1+2.3} = M_o \frac{1}{1+0.038}$$

$$M_o = 0.044 \text{ kg/s.} \quad 158.4 \text{ kg/hr}$$

$H_i = H_{FR} = 0.0075$

$H_o = 0.015 \text{ kg/kg.}$

$$M_i \frac{X_i}{1+X_i} + (F_{\cdots}) H_{\cdots} = M_o \frac{X_o}{1+X_o} + (F_{\cdots}) H_o$$

$$M_i \frac{X_i}{1+X_i} - M_o \frac{X_o}{1+X_o} = (F_{\cdots}) (H_o - H_{Ec}^{i})$$

$$\left[0.139\ \frac{2.3}{1+2.3} - 0.044\ \frac{0.038}{1+0.038}\right] = (F)(0.015 - 0.0075)$$

$$0.0953 = F\ (0.0075)$$

$$F = 12.69\ kg/s.$$

$$12.7\ kg/s.$$

$$45,720\ kg/hr.$$

(d) mass H_2O evaporated = 0.0953 kg/s.

343 kg/hr.

(e) exit air temperature = 70°C

PSYCHROMETRIC CHART HIGH TEMPERATURES 1013.25 MILLIBARS