國立高雄應用科技大學

104學年度研究所碩士班招生考試

化學工程與材料工程系碩士班

單元操作及輸送現象

標準答案

(本答案卷格式謹作參考，打字後印出或書寫工整)

1. 回答以下問題。(50%)
   (1) Explain the meaning of the Net Positive Suction Head (NPSH). (4%)
   避免發生孔蝕效應(cavitation)，幫浦吸入端之速度揚程(高差 or head)及壓力揚程(head)之和，必須大於液體之蒸氣壓，此差異稱為淨正吸引揚程(NPSH)**。**
   (2) Explain the meaning of "terminal velocity". (3%)
   粒子沈降時，受到浮力與拖曳阻力的影響，下降加速度為 0 時的沈降速度稱為終端速度(terminal velocity)。
   (3) 說明 fully developed flow 的意義？(3%)
   流體流動時，當速度分布與流動距離無關時的狀態，稱為全展開流動(fully developed flow)。
   (4) 常見的過濾操作模式有 dead end flow 與 cross flow，兩者差異為何？(4%)
   Dead end flow: 過濾流體流動方向與過濾膜互為垂直
   cross flow: 過濾流體流動方向與過濾膜互為平行
   (5) 列舉歸類於物理-機械分離程序(physical-mechanical separation process)的單元操作類型？(5%)
   Filtration, Settling, Centrifugation, Screening, Classification
   (6) 說明乾燥(drying)與蒸發(evaporation)的差異？(5%)
   蒸發：**將揮發性液體自固態物質中移除，產物含水量仍高。**
   乾燥：**將揮發性溶劑自非揮發性溶質中移除，產物含水量極低。**
   (7) 說明牛頓流體(Newtonian fluid)與非牛頓流體(non-Newtonian fluid)的差異？(4%)
   牛頓流體的黏度不隨剪應速率而改變，非牛頓流體的黏度隨剪應力速率而改變。
   (8) 液體黏度與溫度之關係，隨溫度提高而增加？或是降低？請說明原因。(3%)
   液體的黏度隨溫度遞增而遞減。
   原因為溫度上升導致分子接近，增加分子摩擦的機率。
   (9) 熱輻射的熱傳機制不同於熱傳導與熱對流，主要差異為何？(3%)
   熱輻射不需要熱傳介質。

(10) 說明增加精餾程序回流比(reflux ratio)之缺點。(5%)

增加回流比將導致精餾塔內溫度下降。

精餾塔內溫度下降，塔頂產物產量下降。

精餾塔內溫度下降，液體量增加，再沸器之水蒸氣消耗量增加(熱負荷增加)。

(11) 許多植物富含油溶性物質「類胡蘿蔔素」，欲從植物組織純化類胡蘿蔔素，需要利用那些單元操作？(5%)

Filtration, Extraction, Adsorption, Chromatography

(12) 說明如何以類比法，由 Fanning friction factor (范寧摩擦因子)估計圓管內流體的對流質傳係數？(6%)

1. 計算 Reynold number (Re)，判斷流體流動的模式屬於層流或是亂流。(2%)

2. 根據 Re，計算 Fanning friction factor (f_f)。(2%)

3. 計算 Schmidt number (Sc)，根據層流或亂流狀態，帶入相對應類比公式。(2%)

4. 若為層流常用 Chilton-Colburn analogies

$$j_D = j_H = \frac{C_f}{2} \quad \left(\frac{h}{\rho v_\infty c_p} \mathrm{Pr}^{2/3} = \frac{k_c}{v_\infty} \mathrm{Sc}^{2/3} = \frac{C_f}{2} \right)$$

5. **若為層流常用 Prandtl analogies**

$$\mathrm{Sh} = \frac{(C_f/2)\,\mathrm{Re}\,\mathrm{Sc}}{1+5\sqrt{C_f/2}(\mathrm{Sc}-1)}$$ **或是 von Kármán analogy**

$$\mathrm{Sh} = \frac{(C_f/2)\,\mathrm{Re}\,\mathrm{Sc}}{1+5\sqrt{C_f/2}\{\mathrm{Sc}-1+\ln[(1+5\mathrm{Sc})/6]\}}$$

2. An oil with a kinematic viscosity of 0.8×10^{-5} m^2/s and a density of 1050 kg/m^3 flows through a horizontal circular conduit 2.0 cm in inner diameter at the rate of 0.72 m^3/hr. The length of the conduit is 30 m. Answer the following questions.

(a) What is the Reynolds number? (5%)

(b) Calculate the Fanning friction factor. (2%)

(c) What is the head loss? (3%)

$$v = \frac{Q}{A} = \frac{\left(0.72\,\mathrm{m^3/h}\right)\left(\frac{1\,\mathrm{h}}{3600\,\mathrm{s}}\right)}{\frac{\pi}{4}\left(0.02\right)^2} = 0.637\ \mathrm{m/s}\,;\ \mathrm{Re} = \frac{vAD}{A\nu} = \frac{(0.72)(\frac{1}{3600})(0.02)}{\frac{\pi}{4}\left(0.02\right)^2(0.8\times10^{-5})} = 1591.5$$

$$\mathrm{Re} = \frac{\rho v D}{\mu} = \frac{vD}{\nu} = \frac{(0.637)(0.02)}{0.8\times10^{-5}} = 1592 < 2300\,;\quad f_f = \frac{16}{1592} = 0.0100$$

$$h_L = 2 f_f \frac{L}{D}\frac{v^2}{g} = 2\frac{16}{1592}\frac{30}{0.02}\frac{(0.637)^2}{9.8} = 1.25\ \mathrm{m}$$

3. A well-stirred storage vessel contains 1500 kg of sucrose solution containing 10% sucrose by mass. A constant flow rate of 10 kg/h of sucrose solution consisting of 30% sucrose is suddenly introduced into the tank and a constant withdrawal rate of 20 kg/h is also started. Answer the following questions.
   (a) Draw a diagram to describe the layout of this question. (3%)
   (b) Determine the total mass of sucrose solution at the time of 15 h. (5%)
   (c) Calculate the mass fraction of sucrose in the tank at the time of 15 h. (6%)
   (d) Determine the mass of sucrose at the time of 15 h. (6%)

Initial mass of sucrose solution in the tank =1500 kg

The total mass balance:

$$\dot{m}_2 - \dot{m}_1 + \frac{dM}{dt} = 0 \Rightarrow 20 - 10 + \frac{dM}{dt} = 0$$

$$\frac{dM}{dt} = -10 \Rightarrow \int_{1500}^{M} dM = -10\int_0^t dt \Rightarrow M - 1500 = -10t \Rightarrow M = -10t + 1500$$

At 15 h, the mass of sucrose solution in the tank: $M = -10(15) + 1500 = 1350$ kg

Method 1: The sucrose mass balance

$$\dot{m}_{A2} - \dot{m}_{A1} + \frac{dM_A}{dt} = 0 \Rightarrow 20\omega_A - 10(0.30) + M\frac{d\omega_A}{dt} + \omega_A\frac{dM}{dt} = 0$$

$$20\omega_A - 3 + (-10t + 1500)\frac{d\omega_A}{dt} - 10\omega_A = 0 \Rightarrow 10\omega_A - 3 + (-10t + 1500)\frac{d\omega_A}{dt} = 0$$

$$(1500 - 10t)\frac{d\omega_A}{dt} = 3 - 10\omega_A \Rightarrow \int_{0.1}^{\omega_A} \frac{d\omega_A}{3 - 10\omega_A} = \int_0^t \frac{dt}{(1500 - 10t)}$$

$$-\frac{1}{10}\ln\left(\frac{3 - 10\omega_A}{3 - 10(0.1)}\right) = -\frac{1}{10}\ln\left(\frac{1500 - 10t}{1500}\right)$$

$$\frac{3 - 10\omega_A}{2} = \frac{150 - t}{150} \Rightarrow \omega_A = \frac{3}{10} - \frac{2}{10}\left(\frac{150 - t}{150}\right) = 0.3 - 0.2\left(\frac{150 - t}{150}\right)$$

At 15 h, the mass fraction of sucrose in the tank is 12%.

At 15 h, the mass of sucrose in the tank:

$$M_A = M\omega_A = (-10t + 1500)\left[0.3 - 0.2\left(\frac{150 - t}{150}\right)\right] = 162 \text{ kg sucrouse}$$

Method 2: The sucrose mass balance

$$\dot{m}_{A2} - \dot{m}_{A1} + \frac{dS}{dt} = 0 \Rightarrow 20\frac{S}{M} - 10(0.30) + \frac{dS}{dt} = 0 \Rightarrow 20\frac{S}{-10t + 1500} - 10(0.30) + \frac{dS}{dt} = 0$$

$$\frac{dS}{dt} - \frac{20S}{10t - 1500} = 3 \Rightarrow S = e^{-\int -\frac{20}{10t - 1500}dt}\left[\int e^{\int -\frac{20}{10t - 1500}dt}(3)dt + c\right]$$

$$S = e^{\frac{20}{10}\ln(t-150)}\left[\int e^{-\frac{20}{10}\ln(t-150)}(3)dt + c\right] = e^{\ln(t-150)^2}\left[\int e^{\ln(t-150)^{-2}}(3)dt + c\right]$$

$$S = (t-150)^2\left[3\int (t-150)^{-2}dt + c\right] = (t-150)^2\left[-\frac{3}{t-150} + c\right]$$

$$S = -3(t-150) + c(t-150)^2 \ \ (S = 150 \text{ at } t = 0)$$

$$150 = -3(-150) + c(-150)^2 \Rightarrow c = \frac{-300}{(150)^2} = -\frac{1}{75}$$

$$\Rightarrow S = -3(t-150) - \frac{1}{75}(t-150)^2$$

At 15 h, the mass of sucrose is $\Rightarrow S = -3(15-150) - \frac{1}{75}(15-150)^2 = 162 \text{ kg}$

At 15 h, the mass fraction of sucrose in the tank is 162/1350 = 12%.

4. 欲使用一根內徑 2.5 cm、外徑 4.2 cm 的電熱管，將質量流率為 0.165 kg/s 的去離子水從 25°C 加熱至 85°C。電熱管的外壁為完全絕熱，內壁溫度為 99°C。
   (a) 根據題意與能量平衡，推導水的入口溫度、出口溫度與管長之關係式。(6%)
   (b) 已知電熱管內流體的熱傳係數為 2200 W/m^2·K，水的密度與定壓熱含量分別為 980 kg/m^3 以及 4180 J/kg·K，估計電熱管的長度。(4%)

Heat balance: $q_1 + q_2 = q_3$

$$\dot{m}c_p\left(T\big|_x - T_{datum}\right) + hA(T_s - T) = \dot{m}c_p\left(T\big|_{x+\Delta x} - T_{datum}\right)$$

$$\rho v_x \frac{\pi}{4}D^2 c_p\left(T\big|_x - T_{datum}\right) + h(\pi D\Delta x)(T_s - T) = \rho v_x \frac{\pi}{4}D^2 c_p\left(T\big|_{x+\Delta x} - T_{datum}\right)$$

$$\rho v_x \frac{\pi}{4}D^2 c_p\left(T\big|_{x+\Delta x} - T\big|_x\right) - h(\pi D\Delta x)(T_s - T) = 0$$

$$\frac{D}{4}\frac{\left(T\big|_{x+\Delta x} - T\big|_x\right)}{\Delta x} + \frac{h}{\rho v_x c_p}(T - T_s) = 0 \ \Rightarrow \ \frac{dT}{dx} + \frac{h}{\rho v_x c_p}\frac{4}{D}(T - T_s) = 0$$

$$\frac{dT}{T - T_s} + \frac{h}{\rho v_x c_p}\frac{4}{D}dx = 0 \ \Rightarrow \ \int_{T_0}^{T_L}\frac{dT}{T - T_s} + \frac{h}{\rho v_x c_p}\frac{4}{D}\int_0^L dx = 0$$

$$\ln\frac{T_L - T_s}{T_0 - T_s} + \frac{h}{\rho v_x c_p}\frac{4L}{D} = 0 \Rightarrow \frac{T_L - T_s}{T_0 - T_s} = e^{-\frac{h}{\rho v_x c_p}\frac{4L}{D}}$$

ρvA = 0.165 kg/s ⇨ v = 0.343 m/s

$$\ln\frac{T_L - T_s}{T_0 - T_s} + 4\frac{L}{D}\frac{h}{\rho v c_p} = 0 \Rightarrow \ln\frac{T_L - T_s}{T_0 - T_s} + 4\frac{L}{D}\frac{hA}{\dot{m} c_p} = 0$$

$$\Rightarrow \ln\frac{85-99}{25-99} + 4\frac{L}{0.025}\frac{2200[\frac{\pi}{4}(0.025)^2]}{(0.165)(4180)} = 0 \Rightarrow L = 6.65 \text{ m}$$

5. 根據 Fick's first law，一維方向(z 方向)雙成分擴散系統之通量方程式可表示為

$$N_{Az} = -cD_{AB}\frac{dy_A}{dz} + y_A(N_{Az} + N_{Bz})$$

N_{Az}: A 成分在 z 方向之通量

N_{Bz}: B 成分在 z 方向之通量

y_A: A 成分莫耳分率

c: 總濃度

D_{AB}: 擴散係數

(a) 在什麼物理條件下，

$N_{Az} = -cD_{AB}\frac{dy_A}{dz} + y_A(N_{Az} + N_{Bz})$ 可簡化為： $N_{Az} = -cD_{AB}\frac{dy_A}{dz}$? (6%)

(b) 在什麼物理條件下，

$N_{Az} = -cD_{AB}\frac{dy_A}{dz} + y_A(N_{Az} + N_{Bz})$ 可簡化為： $(1 - y_A)N_{Az} = -cD_{AB}\frac{dy_A}{dz}$? (4%)

(a) 等莫耳逆向擴散(equimolar counterdiffusion)

A 成分濃度很低，$y_A \cong 0$

(b) 單一成分(A 成分)擴散，B 成分為靜滯成分。