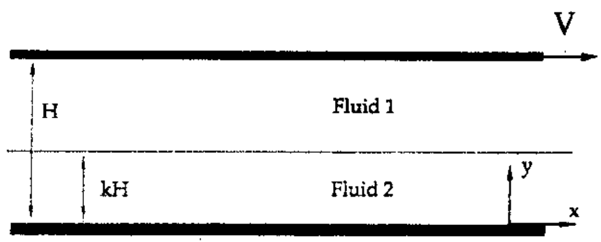
編號：E 105　系所：化學工程學系甲組　科目：單元操作與輸送現象

本試題是否可以使用計算機：☑可使用　，　☐不可使用　（請命題老師勾選）

1. (8%) 一顆直徑為 D_1、密度為 ρ_s 的圓球在密度為 ρ_1、黏度為 μ_1 的流體中沉降，其終端速度(terminal velocity)為 v_{∞_1}。另有一顆材質相同，但直徑為 D_2 ($D_2 = 2D_1$)的圓球在相同密度($\rho_2 = \rho_1$)、但黏度為 μ_2 ($\mu_2 = 3\mu_1$)的流體中沉降，請問這顆球的終端速度為多少？假設兩者流場皆為 creeping flow，其 drag coefficient $C_D = 24/Re$。請詳細寫出計算過程。

2. (12%) 如下圖所示，下層板固定，兩不互溶的牛頓流體在平行平板間的流動是由於上層板以 V 的恒定速度往右拉動所造成的。假設流體的密度與黏度都為常數，分別為 ρ_1、ρ_2 與 μ_1、μ_2，steady state，不考慮 end effects，$v_y = v_z = 0$, $v_x = v_x(y)$ only。假設 $\mu_1 = 3\mu_2$，$k = 1/3$，求流體的速度分佈。



The Navier-Stokes equations for constant ρ and μ in Cartesian coordinates are:

x direction

$$\rho\left(\frac{\partial v_x}{\partial t} + v_x\frac{\partial v_x}{\partial x} + v_y\frac{\partial v_x}{\partial y} + v_z\frac{\partial v_x}{\partial z}\right) = -\frac{\partial P}{\partial x} + \rho g_x + \mu\left(\frac{\partial^2 v_x}{\partial x^2} + \frac{\partial^2 v_x}{\partial y^2} + \frac{\partial^2 v_x}{\partial z^2}\right)$$

y direction

$$\rho\left(\frac{\partial v_y}{\partial t} + v_x\frac{\partial v_y}{\partial x} + v_y\frac{\partial v_y}{\partial y} + v_z\frac{\partial v_y}{\partial z}\right) = -\frac{\partial P}{\partial y} + \rho g_y + \mu\left(\frac{\partial^2 v_y}{\partial x^2} + \frac{\partial^2 v_y}{\partial y^2} + \frac{\partial^2 v_y}{\partial z^2}\right)$$

3.

Energy exchange between Fluid A and B in a cocurrent flow, single-pass, double-pipe heat exchanger:

Fluid A: mass flow rate=1.0 kg/s, specific heat=1500 J/kg.K, T_{in}=375 K

Fluid B: mass flow rate=0.3 kg/s, specific heat=2500 J/kg.K, T_{in}= 280 K

Overall heat transfer coefficient=225 W/m^2.K and heat transfer area=5 m^2

a. What is the number of heat transfer unit (NTU)? (2%)

b. If using the same heat exchanger but with energy exchange between Fluid A and B in a COUNTERCURRENT flow fashion (same T_{in} as the above), will the NTU(countercurrent) > or = or < NTU(cocurrent)? Explain your answer. (1%)

c. Derive the expression of heat-exchanger effectiveness, ε, for the cocurrent flow, single-pass, double-pipe heat exchanger. (5%) What is the value of ε for this case? (2%) Evaluate the heat transfer rate, the T_{out} for Fluid A and B, and the logarithmic-mean temperature difference. (4%).

d. Will the effectiveness, ε(cocurrent) > or = or < ε(countercurrent)? Explain your answer. (2%)

e. For the shell-and-tube heat exchanger, what does it mean by "2-4"? (1%) If we use the shell-and-tube heat exchanger (at the same conditions as described), will the effectiveness, ε(shell and tube) > or = or < ε(countercurrent)? Explain your answer. (3%)

(背面仍有題目,請繼續作答)

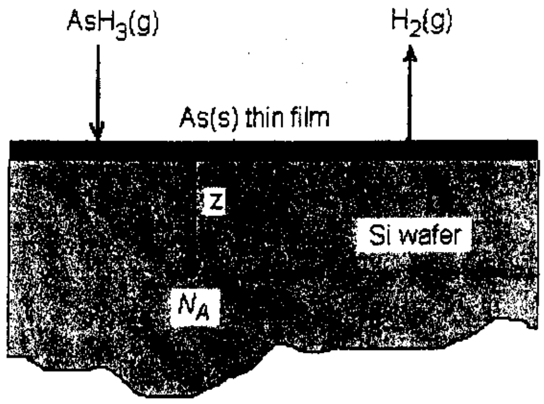
本試題是否可以使用計算機： ☑可使用 ， □不可使用 （請命題老師勾選）

4.

In the manufacture of semiconducting thin films, a thin film of solid arsenic (As) is laid down onto the surface of a silicon wafer by the chemical vapor deposition of arsine, AsH_3

$$2AsH_3(g) \rightarrow 2As(s) + 3H_2(g)$$

The arsenic atoms then diffuse into the solid silicon to dope the wafer, as shown in the figure below.



(a) Write down the simplified governing equation and the appropriate initial and boundary conditions for this problem. (4%)

(b) Show that the solution can be expressed as

$$\frac{c_{As} - c_A}{c_{As} - c_{A0}} = \operatorname{erf}\left(\frac{z}{2\sqrt{D_{AB}t}}\right)$$

where c_{A0} is the initial concentration of arsenic in the silicon wafer, c_{As} is the surface concentration of arsenic in silicon, and D_{AB} is the diffusivity. (4%) From this result, deduce a relation between the characteristic length of diffusion and $D_{AB}t$. (2%)

(c) What is the flux of arsenic atoms into the silicon wafer after 30 minutes, in units of atoms/cm^2·s? (6%) What is the arsenic concentration one micron into the silicon wafer after one hour, in units of atoms/cm^3? (4%) The initial concentration of residual arsenic in the silicon wafer is 10^{12} atoms/cm^3. The process temperature is 1050°C. The average diffusivity of arsenic in silicon is 5×10^{-13} cm^2/s at this temperature, and the maximum solubility of arsenic in silicon is 2×10^{21} atoms/cm^3. The error function can be approximated by

$$\operatorname{erf}(\phi) = 1 - \frac{1}{\sqrt{\pi}} e^{-\phi^2} \quad \text{if } \phi \geq 1 \quad ; \quad \operatorname{erf}(\phi) = \frac{2}{\sqrt{\pi}}\left(\phi - \frac{\phi^3}{3}\right) \quad \text{if } \phi \leq 0.5$$

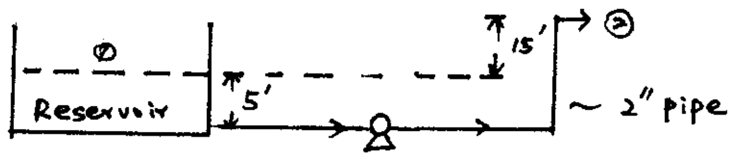
5. 60 gal/min of a liquid (sp. gr. = 0.85, vapor pressure = 4.2 lbf/in^2) is pumped from an open reservoir to a height of 15 feet, as shown in the figure. The frictional pressure losses in the inlet and outlet pipes of the pump are 0.8 lbf/in^2 and 7.5 lbf/in^2, respectively. The liquid pressure at point 2 is 45 lbf/in^2 gauge.

本試題是否可以使用計算機： ☑可使用 ， □不可使用 （請命題老師勾選）

If the pump efficiency is 0.65, determine

(1) the head developed by the pump (expressed as lb_f/in^2) (15%)

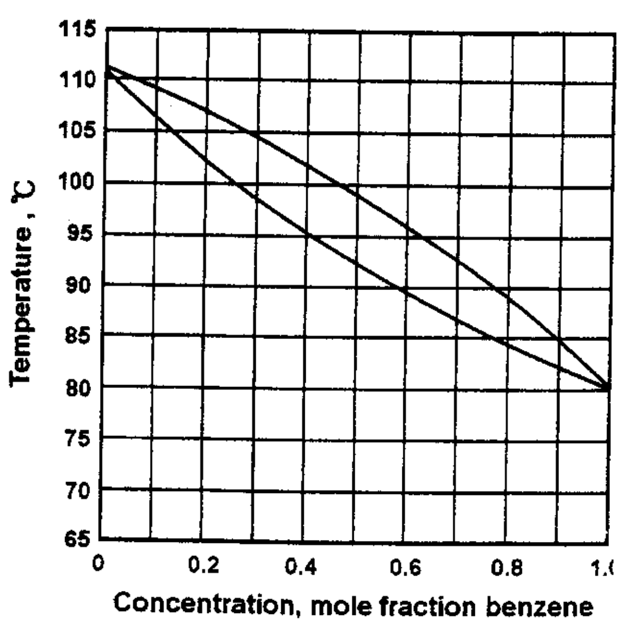
(2) NPSH = ? (expressed as ft) (ρ_{H_2O} = 62.4 lb_m/ft^3) (5%)

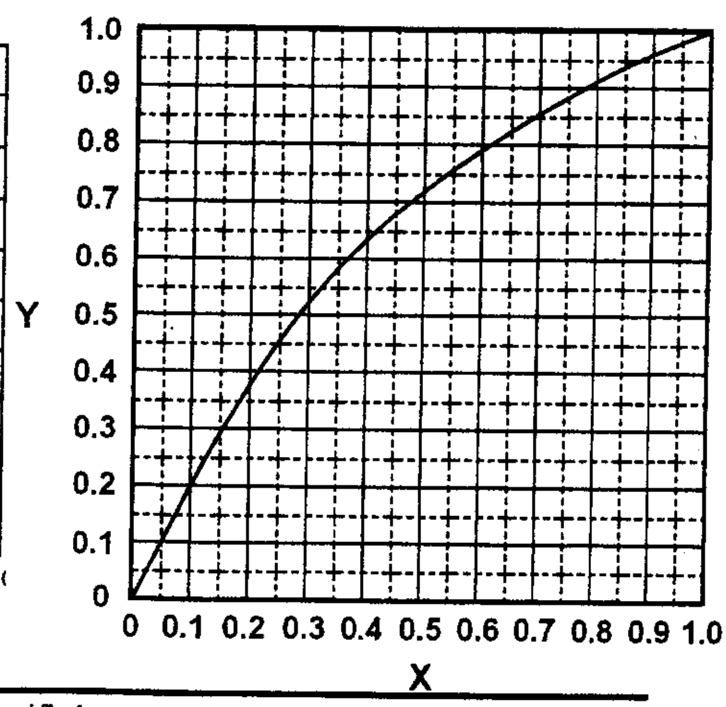


($1 ft^3$ = 7.481 gal)

6.

利用一急驟蒸餾塔(flash distillation)分離含 40 mole% benzene in 60 mole% toluene 的混合液體，混合液先於高壓下加熱至 T_0，而後噴入一壓力為 1atm 的分離塔中。請利用所附的平衡關係圖回答下列問題：(1)利用此一裝置，氣相中 Benzene 可被濃縮的最大值(y_{max})，及液相中 Benzene 殘餘濃度的最低值(x_{min})為何？(請說明你的作法)(5%)；(2)若進料溶液經分離後，40% 成為氣相。請求出此一操作條件下分離塔的溫度(T_f)， Benzene 在氣相中的濃度(y)，及在液相中的濃度(x)。(7%)；(3)若要達到上一小題的分離結果，進料液體的預熱溫度(T_0)為何？(8%)(可利用所附方格紙做圖求解，但***必須***在答案卷中繪一簡圖說明求解方法)





component	Enthalpy of vaporization, cal/g mol.	Specific heat at constant pressure, cal/g mol.℃		Boiling point, ℃
		liquid	Vapor	
Benzene	7360	33	23	80.1
Toluene	7960	40	33	110.6