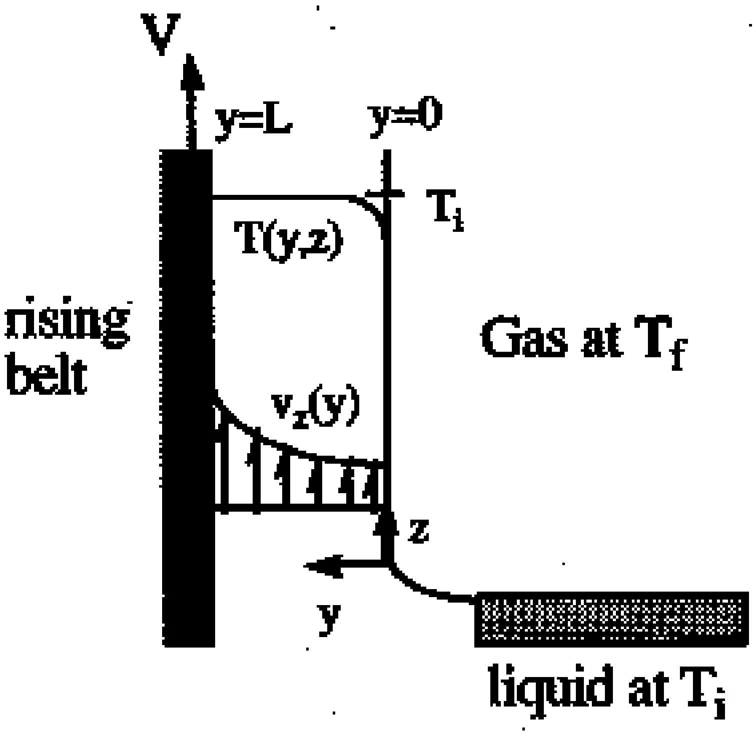
八十九學年度 化學工程學 系（所） 組碩士班研究生招生考試
科目 輸送現象及單元操作 科號 2401 共 3 頁第 1 頁 *請在試卷【答案卷】內作答

Problem 1 (20%)

As described in the following figure, a liquid film of thickness L forms on a continuous belt that moves upward at a constant velocity V passing through a liquid bath at temperature T_i. As the liquid film rises, it is exposed briefly to a gas at temperature T_f and the liquid near the free surface is cooled. Find the steady-state temperature distribution in the film. Assume constant thermal properties and neglect end effect.



Problem 2 (20%)

A common procedure for surface micromachining involves etching of surface layers. In one procedure, phosphosilicate glass is etched by hydrofluoric acid, with an overall reaction of

$$6HF + SiO_2 \rightarrow H_2SiF_6 + 2H_2O$$

When etching depth is large, the diffusion of the acid through the solution becomes rate limiting. Assuming a one-dimensional model, obtain an expression of etching depth as a function of time. The reaction is first-order in HF, with rate constant $k = 2*10^{-6}$ m/s, diffusivity of HF, $D = 2*10^{-9}$ m^2/s. The bulk concentration of HF in the aqueous solution is $7.0\,\mathrm{kmol/m^3}$. No numerical calculation is required.

Problem 3 (20%)

The friction factor, f, of flow in tubes may be defined as

$$f = \frac{1}{4}\frac{D}{L}\frac{P_0 - P_L}{\frac{1}{2}\rho < v >^2}$$

Here, $P_0 - P_L$ is the modified pressure drop $(P = p + \rho g h)$ between point 0 and point L further down stream, D is the tube diameter, L is the considered tube length, ρ is the fluid density, and $< v >$ is the cross section averaged fluid velocity. To derive the Blasius formula, let us consider the simplest turbulent (time averaged) velocity distribution, the 1/7-power law,

$$\frac{v}{v_*} = C_1\left(\frac{s v_* \rho}{\mu}\right)^{1/7},$$

where μ is the fluid viscosity, $v_* = \sqrt{(P_0 - P_L)D/4L\rho}$, $s = R - r$,R is the tube radius, C_1 is a numerical constant, and r is the radial coordinate measured from the centerline of the tube.

(a) Show that

$$< v >= C_2\left(\frac{R v_* \rho}{\mu}\right)^{1/7} v_*,$$

with C_2 as a numerical constant. Note: you do not have to give the numerical value of C_2.

(5%)

(b) Derive the Blasius formula

$$f = \frac{C_3}{\mathrm{Re}^{1/4}}\ ,\ \mathrm{Re} = \frac{D < \bar{v} > \rho}{\mu}.$$

Here, C_3 is a numerical constant. Note: you do not have to give the numerical value of C_3.

(5%)

(c) Assume that the Blasius formula holds. By what factor does the modified pressure drop increase if the volume flow rate is doubled at a fixed D? (5 %)

(d) What should the diameter of a new tube be to obtain the original modified pressure drop at the doubled volume flow rate? (5 %)

Problem 4 (20%)

Humidity and temperature control are important subjects in chemical plants. Both heat and mass transfer are involved in such operations. The following questions are simple tests of your knowledge on this subject. (air - water system)

(a) Humidity H = mass of water vapor/mass dry air; please express H in terms of water vapor pressure P_w and total pressure P. (3 points)

(b) If unsaturated air is flowing over the surface of water, its temperature falls below that of air due to evaporations, with the heat supplied by air. At equilibrium, the temperature attained by the water is wet bulb temperature T_w. When the gas rate is high, there will be no significant change in temperature and humidity of air. Derive an equation for T_w in terms of heat transfer coefficient h, mass transfer coefficient k, temperature of air T, humidity of air H, saturated humidity H_{sw} at T_w;

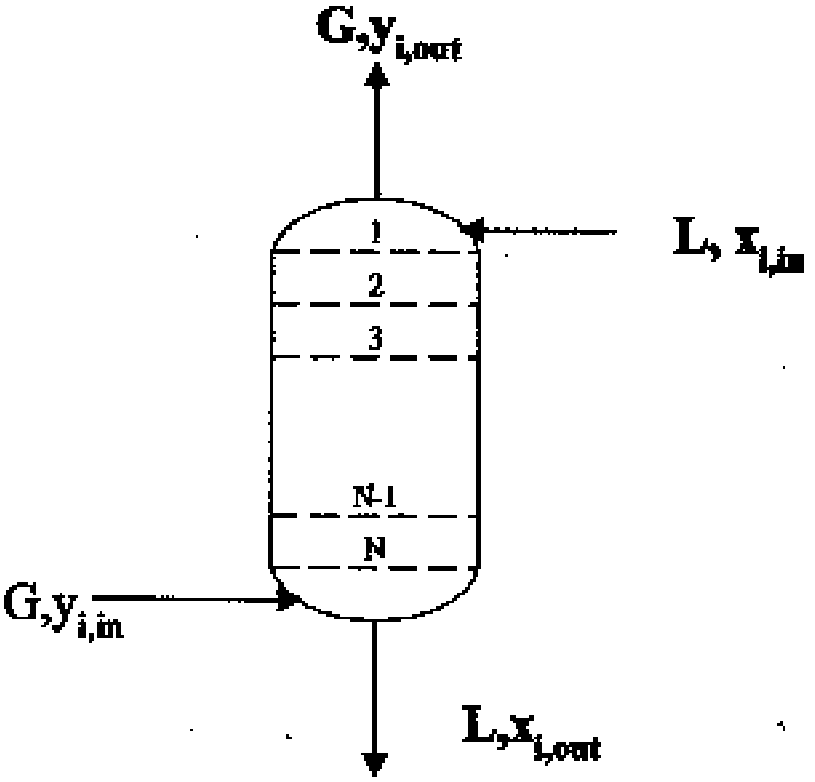
(8 points)

(c) On the other hand, when the contact between air and water is long enough, such as in a very tall column, the air will be saturated and both the temperatures of water and air will be the same. This is the adiabatic saturation temperature Ts. Derive an expression for Ts in terms of appropriate parameters. (Be sure to define every symbol you used) (5 points)

(d) Explain sensible heat and latent heat. (4 points)

Problem 5 (20%)

A gas absorber can be represented by the following diagram:



The feed gas stream at the bottom has a flow rate G gmol/hr and contains a waste gas species i. The rest can be considered as insoluble gases. Mole fraction waste gas species i in the inlet stream is $y_{i,in}$. It is so small that $1-y_i \sim 1$ throughout the absorption column.

(a) 8% L gmol/hr of pure solvent ($x_{i,in} \sim 0$) is used to remove the soluble gas i. The mole fraction of i in the cleaned gas is $y_{i,out}$. Express the concentration of outlet solution $x_{i,out}$ in terms of G, L, $y_{i,in}$ and $y_{i,out}$. You can assume that amount of water vaporized is negligible.

(b) 12% If the number of stages can be estimated by the following expression

$$N = \frac{\ln\frac{\left(Hx_{i,out} - y_{i,in}\right)}{\left(Hx_{i,in} - y_{i,out}\right)}}{\ln\left(A\right)}$$

A is known as the absorption factor:

$$A = \frac{HL}{G'}$$

and H is the Henry's Law constant of the gaseous solute in a solvent:

$$y_i = Hx_i$$

Express the minimum amount of water L_m required to achieve the desired outlet gas concentration