ME6203 MASS TRANSPORT

Department of Mechanical Engineering, NUS

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Practice Problems on Diffusive Mass Transfer

Please attempt solution to these problems. Solutions will be discussed after the class has worked out and handed in solutions to the problems.

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Question 1

Vapor degreasers are widely used for cleaning metal parts. A suitable liquid solvent rests at the bottom of the degreaser tank. A heating coil immersed in the solvent vaporizes a small portion of the solvent and maintains a constant temperature, so that the solvent exerts a constant vapor pressure. The cold parts to be cleaned are suspended in the solvent vapor zone where the concentration of solvent vapors is highest. The solvent condenses on the part, dissolves the grease, and then drips back down into the tank, thereby cleaning the part. Vapor degreasers are often left open to the atmosphere for ease of dipping and removing parts and because covering them might release an explosive mixture. When the degreaser is not in use, molecular diffusion of the solvent vapor through the stagnant air inside the headspace can result in significant solvent emissions, because the surrounding atmosphere serves as an infinite sink for the mass-transfer process.

A cylindrical degreaser tank with a diameter of 2 m and total height of 5 m is in operation and the solvent level height is kept constant at 0.2 m. The temperature of the solvent and headspace of the degreaser are both constant at 35ºC. The solvent used for vapor degreasing is trichloroethylene (TCE). Current regulations require that the degreaser cannot emit more than 1.0 kg TCE per day. Does the estimated emissions rate of the degreaser exceed this limit? TCE has molecular weight of 131.4 g/mole and a vapor pressure of 115.5 mm Hg at 35ºC. The binary-diffusion coefficient TCE in air is 0.088 cm^2/s at 35ºC, as determined by the Fuller-Schettler-Giddings correlation.

How would you estimate the heater rating for such a degreaser?

State all assumptions you make in arriving at your solution.

Comment on effects of all pertinent parameters e.g. temperature, height of solvent layer, geometry of the tank, height of the freeboard zone etc.

Question 2

It is desired to reduce the TCE emissions associated with the vapor degreaser described in question 1. At the current conditions of operation, the vapor degreaser emits 0.432 kg of TCE vapor per day. TCE emissions can be reduced by installing a condenser at the top of the vapor zone, or by increasing the length of the freeboard, which is the portion of the degreaser tank that extends above the condenser. Modify the degreaser to decrease TCE vapor emissions by at least 30%. The solvent in the bottom of the tank must b maintained at 35ºC, the "vapor zone" of the degreaser tank must extend at least 2 meters from the bottom of the tank and the total height of the tank, including vapor zone and freeboard, is fixed at 5 meters. The vapor pressure of TCE can be estimated by an Antoine equation of the form

$$\ln(P_A) = 16.1827 - \frac{3028.13}{T - 43.15}$$

where temperature T must be in units of K and P_A must be in units of mm H_g. Provide a sketch of your proposed process along with all the necessary assumptions and calculations to support your design.

Question 3 – Mass Transfer in Free/ Natural Convection

Natural convection currents will develop if there exists any variation in density within a liquid or gas phase. The density variation may be due to temperature differences or to relatively large concentration differences.

In the case of natural convection involving mass transfer from a vertical plane wall to an adjacent fluid, the variables will differ from those used in the forced-convection analysis. The important variables, their symbols, and dimensional representations are listed below.

Variable	Symbol	Dimensions
Characteristic length	L	L
Fluid diffusivity	D_{AB}	L^2/t
Fluid density	ρ	M/L^3
Fluid viscosity	μ	M/LT
Buoyant force	$g\Delta \rho_A$	M/L^2t^2
Mass-transfer coefficient	k_c	L/t

Question 4 Vaporization rate from a spill of acetone

A container of acetone was accidentally spilled, covering the top, smooth surface of a laboratory bench located in a semiconductor-fabrication building. The exhaust fan for the fabrication building produced a 6 m/s air flow parallel to the 1-m wide, bench surface. The air was maintained at 298 K and 1.013×10^5 Pa. The vapor pressure of acetone at 298 K is 3.066×10^4 Pa.

Determine the mass-transfer coefficient at a location 0.5 m downstream from the leading edge of the laboratory bench.

Also determine the amount of acetone evaporating from one square meter surface area each second. State any assumptions you may make in this estimation. What will be the increase in vaporization rate if the ambient temperature rises by 5 degrees? (Refer to appropriate handbooks for needed data). Compare the vaporization rate if the liquid spilled is ethanol.

Question 5 Estimation of evaporation from a spherical drop

Estimate the distance a spherical drop of liquid water, originally 1 mm in diameter, must fall in quiet, dry air at 323 K in order to reduce its volume by 50%. Assume that the velocity of the drop is its terminal velocity evaluated at its mean diameter and that the water temperature remains at 293 K. Evaluate all gas properties at the average gas film temperature of 308 K.

The physical system requires a combined analysis of momentum and mass transport. The liquid water droplet is the source for mass transfer, the surrounding air serves as an infinite sink, and water vapor (species A) is the transferring species. The rate of evaporation is sufficiently small so that the water droplet is considered isothermal at 293 K; otherwise, a combined analysis of momentum, mass, and heat transport would be required! By considering a force balance on a spherical particle falling in a fluid medium, we can show that the terminal velocity of the particle is

$$\upsilon_o = \sqrt{\frac{4d_p(\rho_w - P_{air})g}{3C_D\rho_{air}}}$$

where d_p is the diameter of the particle, ρ_w is the density of the water droplet, ρ_{air} is the density of the surrounding fluid (air), g is the acceleration due to gravity, and C_D is the drag coefficient.
Discuss effects of temperature and initial drop size on the distance. Also, what if the droplet was ethanol? Can this model calculation be applied if the droplet was one of a suspension? Discuss your response briefly.