Example 1

For the purification of hydrogen gas by diffusion through a palladiumsheet.Compute the number of kilograms of hydrogen that pass per hour through a 5 mm thick sheet of palladium having an area of 0.20 m^2 at 500°C. Assume a diffusion coefficient of $1.0x10^{-8}$ m/s^2, that the concentrations at the high and low pressure sides of the plate a re 2.4 and 0.6 kg of hydrogen per cubic meter of palladium, and that steady state conditions have been attained.

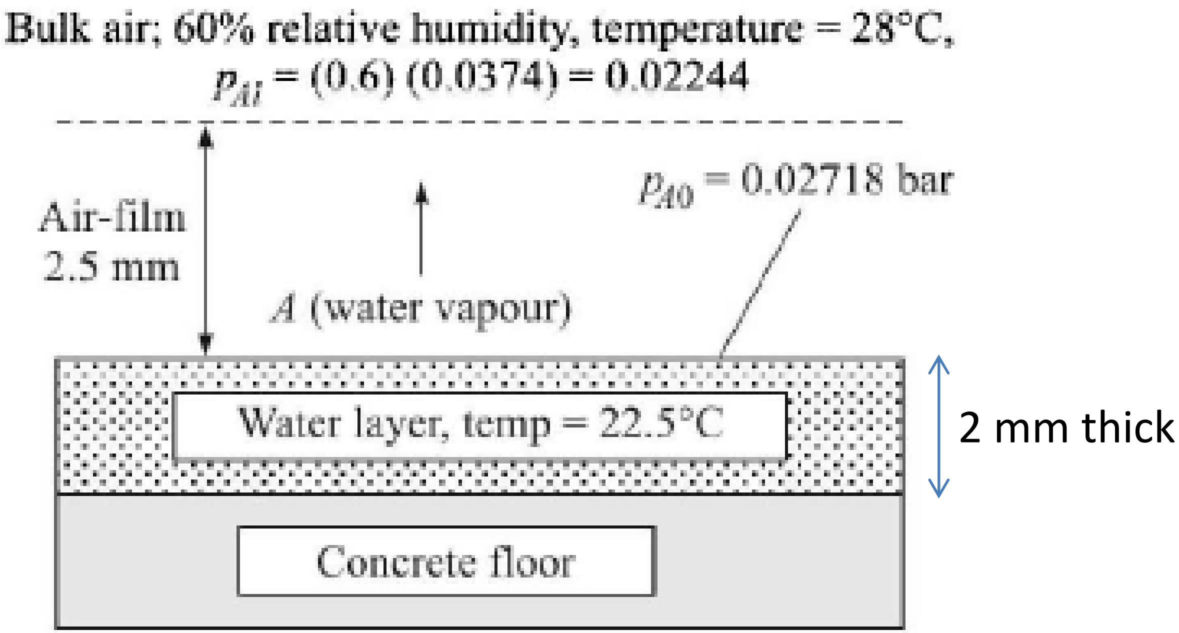
Example 2

5.7 A sheet of steel 1.5 mm thick has nitrogen atmospheres on both sides at 1200°C and is permitted to achieve a steady-state diffusion condition. The diffusion coefficient for nitrogen in steel at this temperature is 6×10^{-11} m^2/s, and the diffusion flux is found to be 1.2×10^{-7} kg/m^2-s. Also, it is known that the concentration of nitrogen in the steel at the high-pressure surface is 4 kg/m^3. How far into the sheet from this high-pressure side will the concentration be 2.0 kg/m^3? Assume a linear concentration profile.

Example 3

(Diffusion of A through non-diffusing B) There is a 2 mm thick layer of water on the floor of a room. The water vaporizes and diffuses through a stagnant film of air of estimated thickness of 2.5 mm on the water surface. Under the condition of evaporation, the water temperature is essentially equal to its wet-bulb temperature. If the ambient temperature is 28°C, calculate the time required for the water layer to disappear completely if the ambient air has a relative humidity of 60%;

The diffusivity of water vapour in air is 0.853 ft^2/h at 1 atm and 0°C.



Example 4

(*Diffusion with changing bulk*† *concentration*) A reagent bottle containing 3 kg of *iso*-propanol is accidentally dropped on the floor of an empty room adjacent to a laboratory causing a spill of the entire liquid. The liquid quickly spreads on the floor of the room (3 m × 4 m, 3 m high), and starts vaporizing. Although the temperature of the vaporizing liquid will be lower than that of the ambient air, for simplicity it may be assumed that both are at the same temperature, 27°C. The pressure is atmospheric.

(a) Two exhaust fans are switched on immediately after the spill to ventilate the room. It takes 5 minutes for the liquid to vaporize completely. If it is assumed that the concentration of *iso*-propanol in the air of the room remains *small* (because of efficient ventilation), and the alcohol vapour diffuses out from the liquid surface through a stagnant film of air, calculate the thickness of the air-film.

(b) If the exhaust fans do not work and the vapour continues to accumulate in the air in the room, how long will it take for the evaporation of the liquid? The thickness of the air-film is the same as that calculated in part (a) and the concentration of the organic vapour in the room remains fairly uniform at any time.

Given: vapour pressure of *iso*-proponal at 27°C = 0.065 bar and its diffusivity in air = 0.0995 cm^2/s.

Example 8

6.2-5. ***Mass Transfer from a Naphthalene Sphere to Air.*** Mass transfer is occurring from a sphere of naphthalene having a radius of 10 mm. The sphere is in a large volume of still air at 52.6°C and 1 atm abs pressure. The vapor pressure of naphthalene at 52.6°C is 1.0 mm Hg. The diffusivity of naphthalene in air at 0°C is 5.16×10^{-6} m^2/s. Calculate the rate of evaporation of naphthalene from the surface in kg mol/s · m^2. [*Note:* The diffusivity can be corrected for temperature using the temperature-correction factor of the Fuller et al. Eq. (6.2-45).]

$$r = \infty$$

Example 9: Diffusion in solids following Fick's Law

6.5-4. *Loss from a Tube of Neoprene.* Hydrogen gas at 2.0 atm and 27°C is flowing in a neoprene tube 3.0 mm inside diameter and 11 mm outside diameter. Calculate the leakage of H_2 through a tube 1.0 m long in kg mol H_2/s at steady state.

7.3-3. *Mass-Transfer Coefficient for Various Geometries.* It is desired to estimate the mass-transfer coefficient k_G in kg mol/s · m² · Pa for water vapor in air at 338.6 K and 101.32 kPa flowing in a large duct past different geometry solids. The velocity in the duct is 3.66 m/s. The water vapor concentration in the air is small, so the physical properties of air can be used. Water vapor is being transferred to the solids. Do this for the following geometries.

(a) A single 25.4-mm-diameter sphere.

(b) A packed bed of 25.4-mm spheres with $\varepsilon = 0.35$.

Ans. (a) $k_G = 1.98 \times 10^{-8}$ kg mol/s · m² · Pa (1.48 lb mol/h · ft² · atm)

7.3-5. *Mass Transfer to Packed Bed and Driving Force.* Pure water at 26.1°C is flowing at a rate of 0.0701 ft³/h through a packed bed of 0.251-in. benzoic acid spheres having a total surface area of 0.129 ft². The solubility of benzoic acid in water is 0.00184 lb mol benzoic acid/ft³ solution. The outlet concentration c_{A2} is 1.80×10^{-4} lb mol/ft³. Calculate the mass-transfer coefficient k_c.

Exercise

6.2-8. *Evaporation Losses of Water in Irrigation Ditch.* Water at 25°C is flowing in a covered irrigation ditch below ground. Every 100 ft there is a vent line 1.0 in. inside diameter and 1.0 ft long to the outside atmosphere at 25°C. There are 10 vents in the 1000-ft ditch. The outside air can be assumed to be dry. Calculate the total evaporation loss of water in lb_m/d. Assume that the partial pressure of water vapor at the surface of the water is the vapor pressure, 23.76 mm Hg at 25°C. Use the diffusivity from Table 6.2-1.

7.2-3. *Absorption of H_2S by Water.* In a wetted-wall tower an air-H_2S mixture is flowing by a film of water which is flowing as a thin film down a vertical plate. The H_2S is being absorbed from the air to the water at a total pressure of 1.50 atm abs and 30°C. The value of k_c' of 9.567×10^{-4} m/s has been predicted for the gas-phase mass-transfer coefficient. At a given point the mole fraction of H_2S in the liquid at the liquid–gas interface is $2.0(10^{-5})$ and p_A of H_2S in the gas is 0.05 atm. The Henry's law equilibrium relation is p_A (atm) $= 609x_A$ (mole fraction in liquid). Calculate the rate of absorption of H_2S. (*Hint*: Call point 1 the interface and point 2 the gas phase. Then calculate p_{A1} from Henry's law and the given x_A. The value of p_{A2} is 0.05 atm.)

Ans. $N_A = -1.485 \times 10^{-6}$ kg mol/s · m^2

7.3-1. *Mass Transfer from a Flat Plate to a Liquid.* Using the data and physical properties of Example 7.3-2 calculate the flux for a water velocity of 0.152 m/s and a plate length of $L = 0.137$ m. Do not assume that $x_{BM} = 1.0$, but actually calculate its value.

Exercise

6.5-6. ***Diffusion of CO_2 in a Packed Bed of Sand.*** It is desired to calculate the rate of diffusion of CO_2 gas in air at steady state through a loosely packed bed of sand at 276 K and a total pressure of 1.013×10^5 Pa. The bed depth is 1.25 m and the void fraction ε is 0.30. The partial pressure of CO_2 at the top of the bed is 2.026×10^3 Pa and 0 Pa at the bottom. Use a τ of 1.87.

Ans. $N_A = 1.609 \times 10^{-9}$ kg mol $CO_2/s \cdot m^2$

6.2-9. ***Time to Completely Evaporate a Sphere.*** A drop of liquid toluene is kept at a uniform temperature of 25.9°C and is suspended in air by a fine wire. The initial radius $r_1 = 2.00$ mm. The vapor pressure of toluence at 25.9°C is $P_{A1} = 3.84$ kPa and the density of liquid toluene is 866 kg/m³.

(a) Derive Eq. (6.2-34) to predict the time t_F for the drop to evaporate completely in a large volume of still air. Show all steps.

(b) Calculate the time in seconds for complete evaporation.

Ans. (b) $t_F = 1388$ s

6.2-4. *Diffusion of Methane Through Nondiffusing Helium.* Methane gas is diffusing in a straight tube 0.1 m long containing helium at 298 K and a total pressure of 1.01325×10^5 Pa. The partial pressure of CH_4 at one end is 1.400×10^4 Pa and 1.333×10^3 Pa at the other end. Helium is insoluble in one boundary, and hence is nondiffusing or stagnant. The diffusivity is given in Table 6.2-1. Calculate the flux of methane in kg mol/s · m² at steady state.

6.2-5. *Mass Transfer from a Naphthalene Sphere to Air.* Mass transfer is occurring from a sphere of naphthalene having a radius of 10 mm. The sphere is in a large volume of still air at 52.6°C and 1 atm abs pressure. The vapor pressure of naphthalene at 52.6°C is 1.0 mm Hg. The diffusivity of naphthalene in air at 0°C is 5.16×10^{-6} m²/s. Calculate the rate of evaporation of naphthalene from the surface in kg mol/s · m². [*Note:* The diffusivity can be corrected for temperature using the temperature-correction factor of the Fuller et al. Eq. (6.2-45).]

6.2-6. *Estimation of Diffusivity of a Binary Gas.* For a mixture of ethanol (CH_3CH_2OH) vapor and methane (CH_4), predict the diffusivity using the method of Fuller et al.

(a) At 1.0132×10^5 Pa and 298 and 373 K.
(b) At 2.0265×10^5 Pa and 298 K.

Ans. (a) $D_{AB} = 1.43 \times 10^{-5}$ m²/s (298 K)

6.2-7. *Diffusion Flux and Effect of Temperature and Pressure.* Equimolar counterdiffusion is occurring at steady state in a tube 0.11 m long containing N_2 and CO gases at a total pressure of 1.0 atm abs. The partial pressure of N_2 is 80 mm Hg at one end and 10 mm at the other end. Predict the D_{AB} by the method of Fuller et al.

(a) Calculate the flux in kg mol/s · m² at 298 K for N_2.
(b) Repeat at 473 K. Does the flux increase?
(c) Repeat at 298 K but for a total pressure of 3.0 atm abs. The partial pressure of N_2 remains at 80 and 10 mm Hg, as in part (a). Does the flux change?

Ans. (a) $D_{AB} = 2.05 \times 10^{-5}$ m²/s, $N_A = 7.02 \times 10^{-7}$ kg mol/s · m²;
(b) $N_A = 9.92 \times 10^{-7}$ kg mol/s · m²;
(c) $N_A = 2.34 \times 10^{-7}$ kg mol/s · m²