Problems

12.1 An oil with a kinematic viscosity of $\nu = \mu/\rho = 10^{-4}$ m^2/s and a density of $\rho = 800$ kg/m^3 flows through a horizontal pipe of $D = 0.1$ m diameter at a volumetric flow rate of $Q = 0.5$ l/s. Calculate the pressure loss in 10 m of length. (Hint: check whether the flow is laminar or turbulent).

12.2 The pressure loss in a pipe is to be determined through experiments with water ($\nu = 10^{-6}$ m^2/s, $\rho = 10^3$ kg/m^3). If the pressure loss is 130 000 Pa for a water flow rate of 15 kg/s, what is the pressure loss for 20 kg/s of liquid oxygen ($\rho = 1121$ kg/m^3)? It will be assumed that the friction factor is the same for both cases.

12.3 A 280 km oil pipeline connects two pumping stations. It is desired to pump 0.56 m^3/s through a 0.62 m diameter pipe to the exit station which is 250 m below the inlet station. The gage pressure at the exit station must be maintained at $p_e = 300\,000$ Pa. Calculate the power required to pump the oil, which has a kinematic viscosity of 4.5×10^{-6} m^2/s and a density of 810 kg/m^3. The friction factor can be taken equal to $\lambda = 0.015$. The inlet pressure can be assumed atmospheric.

12.4 A long 20 mm diameter cylinder of naphthalene, used in mothballs to repel insects, is exposed to an air stream that has a mean mass transport coefficient of $\bar{K}_m = 0.05$ m/s. The vapor concentration of naphthalene at the cylinder surface is 6.4×10^{-4} kg/m^3. How much naphthalene sublimates per unit length of the cylinder?

12.5 The chips of an electronic circuit are cooled down by an air stream of $T_\infty = 25$ °C and $V = 10$ m/s. One of the chips is a square of 4 mm$\times$4 mm and is placed at 120 mm of the leading edge of the electronic board. Experiments have shown that the Nusselt number based on the distance to the leading edge x can be correlated as

$$\mathrm{Nu}_x = 0.04\ \mathrm{Re}_x^{0.85}\ \mathrm{Pr}^{1/3}$$

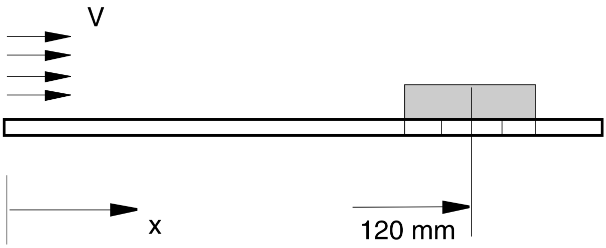
$$\mathrm{Nu}_x = \frac{h_x x}{\kappa} \qquad \mathrm{Re}_x = \frac{\rho U x}{\mu}$$

Estimate the temperature of the surface of the chip if it dissipates 30 mW. *Data for air:* $\mu = 1.8 \times 10^{-5}$ kg/(m s), $\rho = 1.2$ kg/m^3, $\kappa = 0.026$ W/(m K), $\mathrm{Pr} = 0.7$.

12.6 A series of experiments about heat transfer on a flat plate with a very rough surface show that Nu_x could be correlated as

$$\mathrm{Nu}_x = 0.04\ \mathrm{Re}_x^{0.9}\ \mathrm{Pr}^{1/3}$$

Obtain an expression for the ratio between the global $\bar{h}_L$ and local h_x heat transfer coefficients ($\bar{h}_L/h_x$).



Problem 12.5. Cooling of an electronic chip by forced convection.

12.7 The water evaporation rate of a lake can be calculated by measuring the decrease of the free surface level. Consider a summer day, where the water and ambient air are at 305 K, and the air relative humidity is 40%. If the lake water level decreases at a rate of 0.1 mm/h, how much water is evaporating per unit time and surface? What is the mass transfer coefficient?
Saturation pressure at 305 K: $P_s = 3\,531$ Pa.

12.8 Photosynthesis, which takes place at the leaves and green areas of the plants, produces a transport of carbon dioxide (CO_2) from the atmosphere to the chloroplasts of the leaves. Therefore, the speed of photosynthesis can be quantified as a function of the assimilation rate of CO_2 by a leaf, which is strongly influenced by the concentration boundary layer about the leaf. If the density of CO_2 in the air and at the leaf surface is, respectively, 6×10^{-4} kg/m^3 and 5×10^{-4} kg/m^3, and the mass transfer coefficient around a leaf is 10^{-2} m/s, calculate the rate of assimilation of CO_2 per unit time and surface of the leaf.

12.9 Chemical species A evaporates from a plane surface to the species B. The concentration profile of A in the boundary layer can be approximated by $C_A(y) = Dy^2 + Ey + F$ with D, E and F constants for any position x. The coordinate y is normal to the surface. Calculate the mass transfer coefficient K_m as a function of the above constants, the concentration of A in fluid B $C_{A\infty}$, and the mass diffusion coefficient D_{AB}.

12.10 In the boundary layer over a solid surface, the fluid velocity and temperature profiles can be approximated by

$$u(y) = Ay + By^2 - Cy^3 \qquad T(y) = D + Ey + Fy^2 - Gy^3$$

where y is the axis orthogonal to the surface and the rest of the coefficients are constants. Obtain an expression for the friction coefficient f and the heat transport coefficient h as a function of the above constants, U_∞, T_∞ and the fluid properties.

12.11 A way to keep a liquid cool at high ambient temperatures consists of covering its container with a damp cloth, like felt. This principle is applied, for example, to water bottles. Assume that the container is exposed

at an atmosphere of dry air at 40 °C. The cloth surrounding the container is moistened with a liquid of 200 kg/kmol molar mass and 100 kJ/kg latent heat of vaporization. The saturation pressure at those conditions is $P_s = 5\,000$ Pa and the diffusion coefficient of the vapor in air, $D = 0.2 \times 10^{-4}$ m^2/s. What is the container temperature and that of the liquid that it contains?
Data for air: $\mu = 1.8 \times 10^{-5}$ kg/(m s), $c_p = 1\,007$ J/(kg K), $\kappa = 0.026$ W/(m K), $\rho = 1.2$ kg/m^3.

12.12 On a cold day in April a jogger losses 2 000 W due to convective heat transfer between the jogger's skin, which is maintained dry at a temperature of 30 °C, and the environment, also dry, at a temperature of 10 °C. Three months later, the jogger moves at the same pace but the day is warm and humid, with a temperature of $T_\infty = 30$ °C and a relative humidity of $\Phi = 60\%$. The skin of the jogger is sweating and at a temperature of 35 °C. In both cases, the properties of air can be considered constant and equal to: $\nu = 1.6 \times 10^{-5}$ m^2/s, $\kappa = 0.026$ W/(m K), $\mathrm{Pr} = 0.7$, $D = 2.3 \times 10^{-5}$ m^2/s (for water vapor in air), $L = 2257$ kJ/kg (latent heat of vaporization), $P_s = 6221$ Pa.

(a) What is the rate of water evaporation on a summer day?
(b) What is the total heat loss per unit time during the summer day?

12.13 Cooling and heating involved in boiling and condensation processes depend on the fluid properties (ρ, μ, κ, c_p), a characteristic length L, a characteristic temperature difference ΔT, on the characteristic buoyance force between the liquid and gas phases $(\rho_{\mathrm{liq}} - \rho_{\mathrm{vap}})g$, the latent heat of vaporization h_{lv} and the surface tension σ. Determine the dimensionless parameters that govern the behavior of the dimensionless heat transport coefficient Nu.

12.14 Check the dimensionless expression (12.60) for the natural convection mass transport coefficient.

12.15 Check the derivation of expression (12.54).