Exercise 1.1

Consider the common case of a room, with internal air temperature T, having a glass window through which solar radiation can enter. Windows can have a single pane structure or a double pane construction in which adjoining panes are separated by an air space.

a) For each case draw a sketch of the window system and identify the relevant heat transfer processes leading to heat transfer across the window.

b) Consider a single pane glass window with $W = 1m$, $H = 2m$ and a thickness $L = 5mm$. The glass thermal conductivity is $k_g = 1.4W/mK$. In a winter day the inner and outer surface temperatures of the glass are $15°C$ and $-20°C$ respectively. What is the rate of heat loss through the glass?

c) Now consider a double pane glass window with the same W,H as in the previous part. In this case the two adjoining glass panes, each of thickness $t = 5mm$, are separated by an air space of thickness $t_{air} = 10mm$ ($k_{air} = 0.024K/mK$). Under the assumption that the air in the gap space is at rest and radiation effects are negligible, if the glass surfaces in contact with the air space have a temperature of $10°C$ and $-15°C$ respectively, what is the rate of heat loss?

d) Could doubling the thickness of the single glass pane make the performance of the single pane window acceptable compared to a double pane window?

Exercise 1.2

A hot-wire anemometer is a common instrument to measure the velocity of an air stream. It consists of a heated wire which is placed into the air flow with the axis oriented perpendicular to the flow direction. The electrical energy dissipated in the wire is transferred to the air by air convection and it is assumed that no other heat transfer mechanism plays a role. Thus, for a given electrical power, the temperature of the wire depends on the convection coefficient, which in turn depends on the velocity of the air flow. Let's thus consider a wire with $L = 20mm$ and a diameter $D = 0.5mm$. This has been calibrated to have:

$$v = 6.25 \cdot 10^{-5} h^2$$

where h is the convection coefficient.

a) Make a sketch of the system, identify the boundaries, the heat transfer mechanisms and the energy source terms. List the most important assumptions.

b) Write the energy balance for the system you identified in part a)

c) If the air temperature is $T_{air} = 25°C$ and the surface temperature of the anemometer is $T_s = 75°C$ when a voltage of $5V$ is applied to the wire and a current of $0.1A$ is flowing through it, what is the velocity of the air stream?

Note: remember that the power dissipated due to Joule heating is $P_{Joule} = VI$

Exercise 1.3

A hair dryer can be modelled as a circular duct through which a small fan draws ambient air and within which the air is heated as it flows over a coiled electrical resistance.

a) Make a sketch of the air drier, identify the control volume, the heat transfer mechanisms and heat sources.

b) An hair drier is designed to operate with an electric power consumption of $P_{el} = 500W$ when heating air from $T_i = 20°C$ to $T_o = 45°C$. Heat loss from the casing to the ambient air and the surroundings can be neglected. The duct diameter is $D = 70mm$, the density and specific heat of the air are $\rho = 1.1kg/m^3$ and $c_p = 1007J/kgK$. What is the volumetric flow rate $V[m^3/s]$ of air in the drier? What is the discharge velocity v_o?

c) Consider a dryer duct length $L = 150mm$ and a surface emissivity $\epsilon = 0.8$. If the heat transfer coefficient for natural convection from the casing to the ambient air is $h = 4W/m^2K$ and the temperature of the surrounding air is $T_{air} = 20°C$, confirm that the heat loss from the casing is negligible. Use $T_s = 40°C$ as the average casing temperature.

Exercise 1.4 FOR REVISION

A square isothermal electronic chip has a width w=5mm and it is mounted on a substrate. Its side and back surfaces are well insulated while the front surface is exposed to the flow of a coolant at $T_{cool} = 15°C$. During operation, for reliability reasons, the chip temperature must not exceed $T_{max} = 85°C$.

a) Make a sketch of the system, identify the boundaries, heat transfer mechanisms and heat sources.

b) If the coolant is air and the convection coefficient is $h_1 = 200W/m^2K$, what is the maximum allowable chip power?

c) If the coolant is a dielectric liquid for which $h_2 = 3000W/m^2K$, what is the maximum allowable chip power?

d) Now consider case b) and include the heat transfer by radiation from the chip surface to the surroundings at $15°C$. If the chip has an emissivity of $\epsilon = 0.9$, what is the maximum allowable chip power?

Exercise 1.5 FOR REVISION

A pan is used to boil water by placing it on the stove, from which heat is transferred at a fixed rate Q_0. The boiling happens in two stages. In stage 1, the water is taken from its initial room temperature T_i to the boiling point, as heat is transferred from the pan by natural convection. During this stage, a constant value of the convection coefficient h may be assumed while the temperature of the bulk water increases with time as $T_\infty = T_\infty(t)$. In stage 2 the water temperature remains at a fixed value, T_B as heating continues. The pan bottom has a thickness L and a diameter D with a coordinate system corresponding to $x = 0$ and $x = L$ for the surfaces in contact with the stove and water respectively.

a) Make a sketch of the system and the heat transfer mechanisms.

b) Write the form of the heat diffusion equation and the boundary/initial conditions that determine the variation of the temperature of the pan with position and time, $T(x, t)$ in the pan bottom during stage 1. Write all the equations in terms of the parameters Q_0, D, L, h and $T_\infty(t)$ as well as appropriate properties of the pan material.

c) During stage 2, the surface of the pan in contact with the water is at a fixed temperature $T(L, t) = T_L > T_B$. Write the form of the heat diffusion equation and boundary conditions that determine the temperature distribution $T(x)$ in the pan bottom. Express your results in terms of the parameters Q_0, D, L, T_L as well as appropriate properties of the pan material.

d) Consider a pan with $L = 5mm$, $D = 200mm$ made of aluminum ($k = 240W/mK$) or copper ($k = 390W/mK$). When used to boil water, the surface of the bottom exposed to the water is at $T_L = 110°C$. If the heat transferred from the stove to the pan is $Q_0 = 600W$, what is the temperature of the surface in contact with the stove for each of the two materials?