Section III

# Convection exercises

**Exercise III.1** (Walking man ⋆):

A man has a body surface area of $A$ and a skin temperature of $T_{\mathrm{s}}$, with an average surface temperature of the clothed person of $T_{\mathrm{c}}$. The convection heat transfer coefficient $\alpha$ for a clothed man walking in the air with temperature $T_{\mathrm{A}}$ is expressed as:

$$\alpha = C \cdot \sqrt{V},$$

for $0.5 < V < 5$ m/s, and where $C = 8.2\ \frac{\mathrm{J}}{\mathrm{m}^{2.5}\mathrm{s}^{0.5}\mathrm{K}}$, and $V$ is the relative velocity of the man with respect to the air.

**Given parameters:**

- Surface area of the body: $A = 1.8\ \mathrm{m}^2$
- Thermal conductivity of the skin: $\lambda_{\mathrm{s}} = 0.25\ \mathrm{W/mK}$
- Thermal conductivity of clothes: $\lambda_{\mathrm{s}} = 0.03\ \mathrm{W/mK}$
- Thermal conductivity of the air: $\lambda_{\mathrm{a}} = 0.026\ \mathrm{W/mK}$
- Skin temperature of the man: $T_{\mathrm{s}} = 33\ ^{\circ}\mathrm{C}$
- Surface temperature of the clothed man: $T_{\mathrm{c}} = 30\ ^{\circ}\mathrm{C}$
- Air temperature: $T_{\mathrm{A}} = 15\ ^{\circ}\mathrm{C}$

**Hints:**

- Assume steady-state operating conditions.
- Assume the heat transfer coefficient to be constant over the entire surface.

**Tasks:**

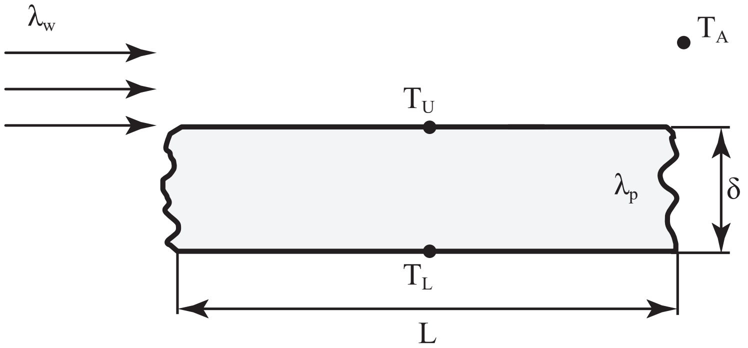
a) Determine the rate of heat loss from the man by convection while walking in still air at a speed of 1 m/s.

b) Determine the rate of heat loss from the man walking in the air when walking in the same direction of the wind with a velocity of 1.5 m/s, while the wind is blowing at a velocity of 2 m/s.

c) Determine the rate of heat loss and the relative velocity from the man while walking in still air with a Nusselt number of Nu = 510, and a characteristic length of $L = 1$ m.

**Exercise III.2** (Thick solid plate ⋆):

The top surface of a thick solid plate is cooled by water flowing. The upper and lower surfaces of the solid plate are maintained at constant temperatures $T_\mathrm{U}$ and $T_\mathrm{L}$ respectively.




**Given parameters:**

- Thickness of the plate: $\delta$
- Length of the plate: $L$
- Thermal conductivity of the plate: $\lambda_\mathrm{p}$
- Thermal conductivity of the water: $\lambda_\mathrm{w}$
- Upper surface temperature of the plate: $T_\mathrm{U}$
- Lower surface temperature of the plate: $T_\mathrm{L}$
- Ambient temperature: $T_\mathrm{A}$

**Hints:**

- Assume steady-state operating conditions.
- Assume the heat transfer coefficient to be constant over the entire surface.
- $T_\mathrm{L} > T_\mathrm{U}$

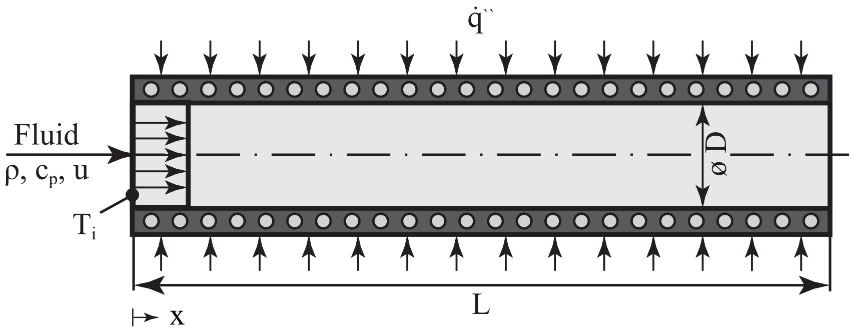
**Tasks:**

a) Determine the Nusselt number in terms of the given variables, using the length $L$ of the plat as the characteristic length.

b) Determine the temperature gradient inside the water at the interface in terms of the given variables.

**Exercise III.3** (Pipe flow ⋆⋆)**:**

A fluid flows through a long cylindrical tube. A constant heat flux density $\dot{q}''$ is imposed on the fluid.




**Given parameters:**

- Diameter of the pipe: $D$
- Length of the plate: $L$
- Heat flux density: $\dot{q}''$
- Density of the fluid: $\rho$
- Specific heat capacity of the fluid: $c_\mathrm{p}$
- Average velocity of the fluid: $u$
- Fluid inlet temperature: $T_\mathrm{i}$

**Hints:**

- Assume one-dimensional heat transfer in the axial direction.
- Assume steady-state operating conditions.
- Conduction in the fluid is negligible.

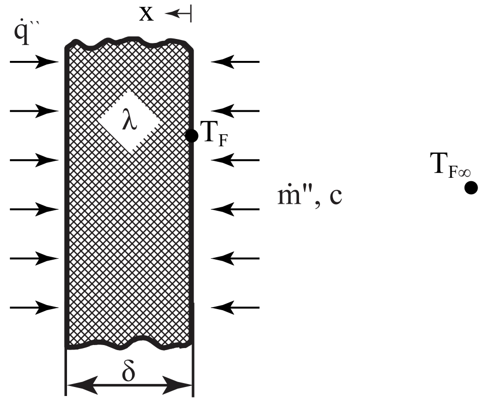
**Tasks:**

a) Determine the temperature profile of the fluid.

b) Determine the temperature of the fluid at 75% of the pipe length.

**Exercise III.4** (Porous wall ⋆⋆⋆)**:**

The surface of a porous wall, impermeable to radiation, absorbs a radiative heat flux. For cooling purposes, a coolant is circulated through the wall with an inlet temperature is $T_\mathrm{F}$.




**Given parameters:**

- Imposed radiative heat flux: $\dot{q}'' = 150 \cdot 10^3$ W/m$^2$
- Wall thickness: $\delta = 50$ mm
- Wall Thermal conductivity: $\lambda = 8$ W/mK
- Coolant specific heat capacity: $c = 1000$ J/kgK
- Coolant inlet temperature: $T_\mathrm{F} = -15$ °C
- Coolant area specific mass flux: $\dot{m}'' = 0.6$ kg/m$^2 \cdot$ s

**Hints:**

- Within the wall, conduction of the imposed radiative heat flux is negligible.
- The local fluid and wall temperatures can be assumed to be identical.

**Tasks:**

a) Determine the temperature profile $T(x)$ for the porous wall.

b) Determine the maximum temperature $T_\mathrm{max}$ reached within the wall.

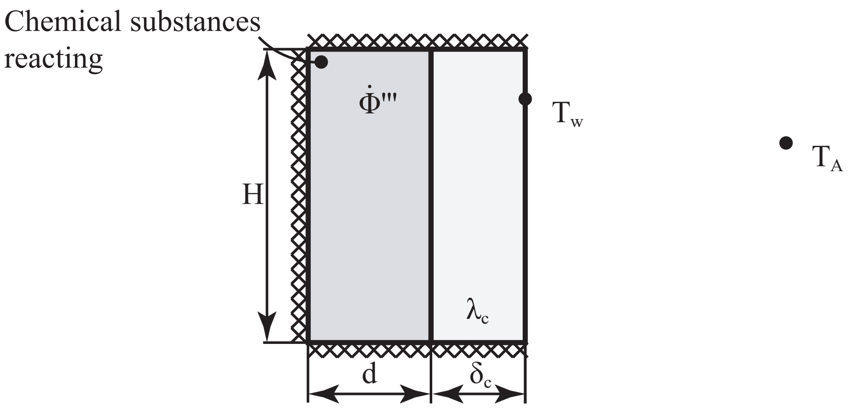
c) Determine the heat flux $\dot{q}''_\mathrm{F}$ per unit area, which is transmitted into the fluid at $x = 0$.

d) Which temperature $T_{\mathrm{F},\infty}$ does the fluid reach far away from the wall?

e) Sketch the temperature profiles for two different mass fluxes and mark each curve.

**Exercise III.5** (Substance container ⋆):

Imagine you are involved in the design of a chemical substance container. These containers house substances that generate heat during chemical reactions. The top and back are adiabatically insulated. During this reaction heat is dissipated to the surrounding air.




**Given parameters:**

- Height of the container: $H = 80$ cm
- Depth of the container: $d = 50$ cm
- Wall thickness of the container: $\delta_c = 10$ cm
- Thermal conductivity of the wall: $\lambda_c = 0.3$ W/mK
- Thermal conductivity of the air: $\lambda = 0.025$ W/mK
- Prandtl number of the air: $\mathrm{Pr} = 0.72$
- Kinematic viscosity of the air: $\nu = 1.5 \cdot 10^{-5}$ m$^2$/s
- Outside temperature of the wall: $T_w = 30$ °C
- Temperature of the ambient air: $T_A = 20$ °C

**Hints:**

- Assume one-dimensional heat transfer.
- Assume steady-state operating conditions.

**Tasks:**

a) Determine the interface temperature between the chemical substances and their container.

b) Determine the heat generated by the substances per unit volume $\dot{\Phi}'''$.