SECTION III

Convection exercises

> **Exercise III.1:** (Walking man ★)
>
> A man has a body surface area of A and a skin temperature of T_s, with an average surface temperature of the clothed person of T_c. The convection heat transfer coefficient α for a clothed man walking in the air with temperature T_A is expressed as:
>
> $$\alpha = C \cdot \sqrt{V},$$
>
> for $0.5 < V < 5$ m/s, and where $C = 8.2 \; \frac{\text{J}}{\text{m}^{2.5}\text{s}^{0.5}\text{K}}$, and V is the relative velocity of the man with respect to the air.
>
> **Given parameters:**
>
> - Surface area of the body: $\qquad\qquad$ $A = 1.8$ m^2
> - Thermal conductivity of the skin: $\qquad$ $\lambda_s = 0.25$ W/mK
> - Thermal conductivity of clothes: $\qquad$ $\lambda_s = 0.03$ W/mK
> - Thermal conductivity of the air: $\qquad$ $\lambda_a = 0.026$ W/mK
> - Skin temperature of the man: $\qquad$ $T_s = 33$ °C
> - Surface temperature of the clothed man: $\qquad$ $T_c = 30$ °C
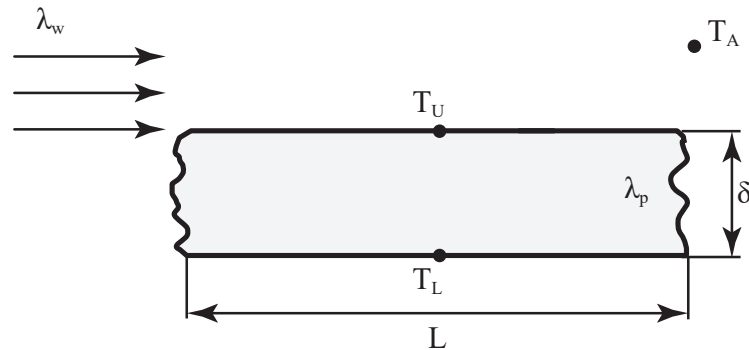> - Air temperature: $\qquad$ $T_A = 15$ °C
>
> **Hints:**
>
> - Assume steady-state operating conditions.
> - Assume the heat transfer coefficient to be constant over the entire surface.
>
> **Tasks:**
>
> a) Determine the rate of heat loss from the man by convection while walking in still air at a 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_U and T_L respectively.

Given parameters:

- Thickness of the plate: δ
- Length of the plate: L
- Thermal conductivity of the plate: λ_p
- Thermal conductivity of the water: λ_w
- Upper surface temperature of the plate: T_U
- Lower surface temperature of the plate: T_L
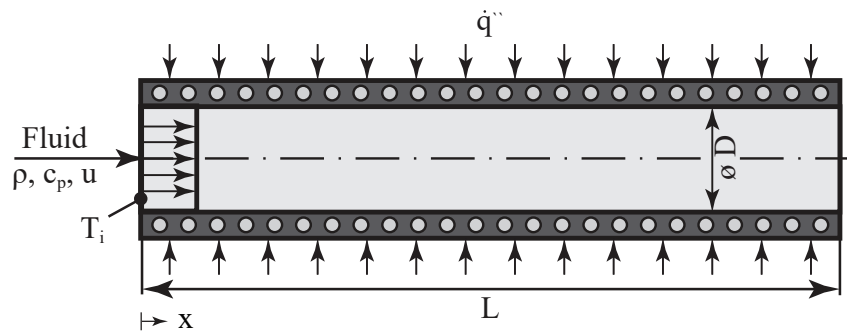- Ambient temperature: T_A

Hints:

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

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: $\qquad\qquad\qquad\qquad\qquad\qquad$ D

- Length of the plate: $\qquad\qquad\qquad\qquad\qquad\qquad$ L

- Heat flux density: $\qquad\qquad\qquad\qquad\qquad\qquad$ $\dot{q}''$

- Density of the fluid: $\qquad\qquad\qquad\qquad\qquad\qquad$ ρ

- Specific heat capacity of the fluid: $\qquad\qquad\qquad$ c_{p}

- Average velocity of the fluid: $\qquad\qquad\qquad\qquad$ u

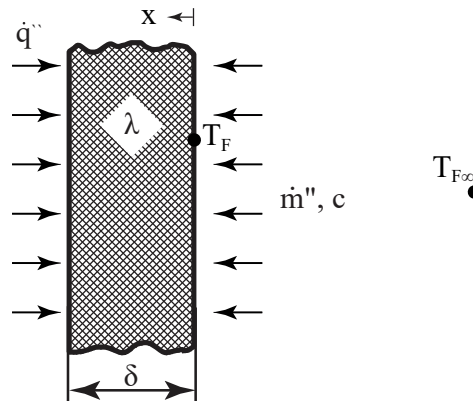- Fluid inlet temperature: $\qquad\qquad\qquad\qquad\qquad$ T_{i}

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_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: $T_F = -15$ °C

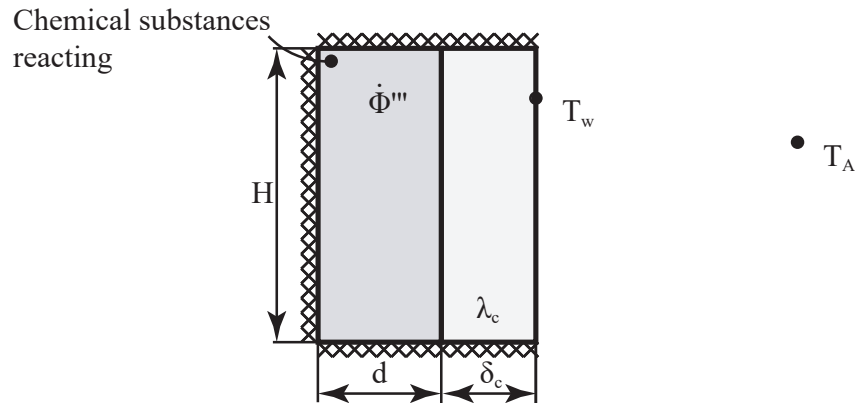- Coolant area specific mass flux: $\dot{m}'' = 0.6$ kg/m$^2 \cdot$s

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 $T_{\max}$ reached within the wall.

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

d) Which temperature $T_{F,\infty}$ 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: $T_\mathrm{w} = 30$ °C

- Temperature of the ambient air: $T_\mathrm{A} = 20$ °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 $\dot{\Phi}'''$.