Underwater duct

Air enters duct at 50 °C and 1 bar that is cooled by the water outside.

a) Determine the exit temperature.

b) Determine rate of heat transfer, e.g. the total heat flux.

c) Determine the appropriate driving potential for convection along the duct.

Given parameters:

- Pipe diameter: $D = 13$ cm
- Pipe length: $L = 20$ m
- Mean velocity: $V = 9$ m/s
- Average heat transfer coefficient: $\overline{\alpha} = 75$ W/m^{2}K
- Tube temperature: $T_{\text{water}} = 10$ °C

Hints:

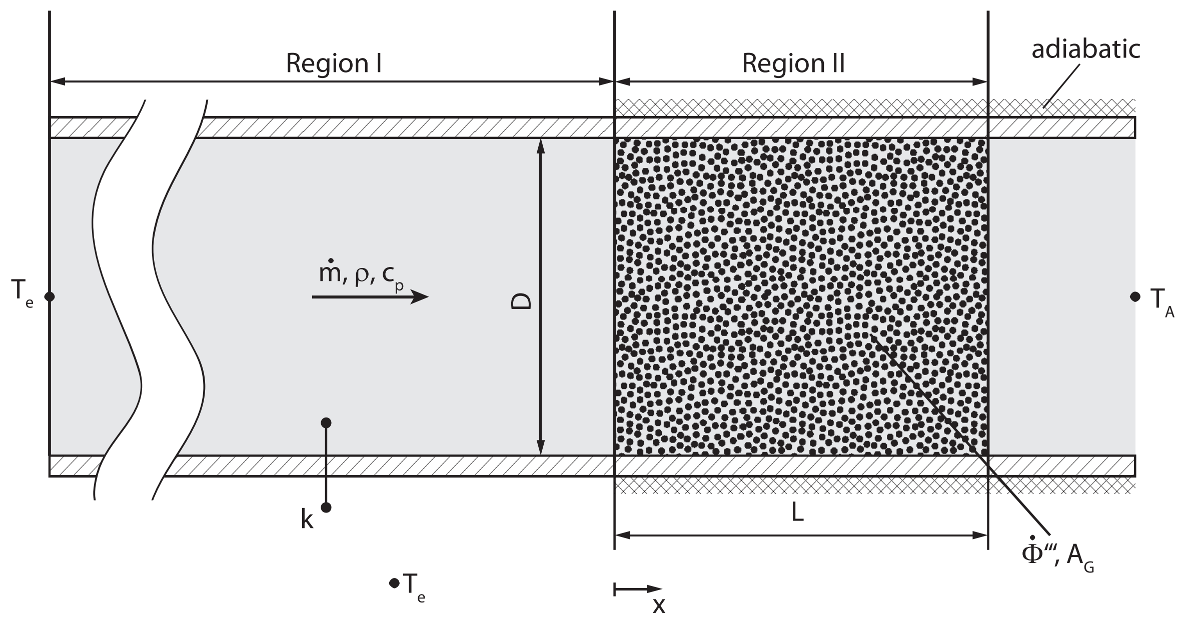
- Evaluate the air properties at a bulk mean temperature of 30 °C.
- The tube temperature is nearly equal to the water temperature.

T [°C]	ρ [kg/m^3]	c [J/kg · K]	λ [$\cdot 10^{-3}$W/mK]	ν [$\cdot 10^{-6}$ m^2/s]	a [$\cdot 10^{-6}$ m^2/s]	Pr
0	1.264	1007	24.22	13.44	18.70	0.717
10	1.226	1007	24.955	14.395	20.085	0.716
20	1.188	1007	25.69	15.35	21.47	0.715
30	1.15	1007	26.425	16.305	22.855	0.714
40	1.112	1007	27.16	17.26	24.24	0.712
50	1.08	1008	27.873	18.283	25.715	0.711

Table 1.1: Properties of air at 1 bar

Flow through a grid

Water flows through a long tube which has adiabatic walls from a certain location $x = 0$. The area upstream of $x = 0$ is named region I. Between the point $x = 0$, and $x = L$ (region II) a very fine-meshed, electrically heated grid is located in the flow. Well ahead of the grid, the flow has the ambient temperature T_e and downstream of the grid, the temperature T_A.



a) Determine the volumetric heat release $\dot{\Phi}'''$ created by the electrically heated grid.

b) Derive the differential equation for the temperature profile of the water in the pipe in region I. Also write the differential equation for the temperature profile in region II, and provide all the coupling or boundary conditions required for the solution of the problem (regions I and II).

c) Sketch the temperature profiles of the water in the pipe with and without consideration of the diffusive heat transport.

Hints:

- The problem is steady and one-dimensional.
- The electrically heated mesh is so fine that a homogeneous heat flux is introduced.
- The volume of the fine-meshed grid can be neglected.

Given parameters:

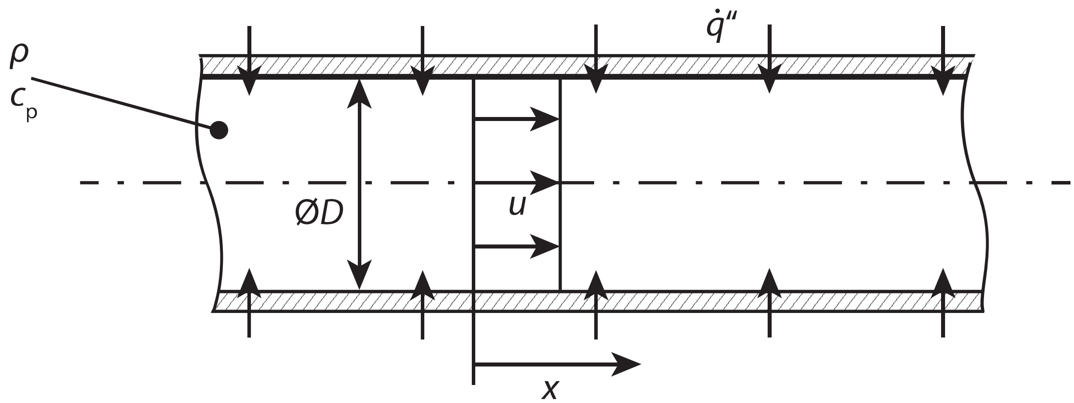
- **Temperatures:**
  - Water temperature before the grid: T_{e}
  - Environment temperature: T_{e}
  - Water temperature after the grid: T_{A}
- **Water:**
  - Mass flow rate: $\dot{m}$
  - Thermal conductivity: λ
  - Specific heat capacity: c_{p}
- **Pipe and grid:**
  - Diameter of the pipe/grid: D
  - Length of the grid: L
  - Average heat flux on the surface of the grid: $\dot{q}''$
  - Heat transfer area of the grid: A_{G}
- **Overall heat transfer coefficient:**
  - Overall heat transfer coefficient (inverse of total resistance) between water and environment, based on the inner pipe wall area k

Pipe flow - constant heat flux

A fluid flows through a long cylindrical tube. A constant heat flux density $\dot{q}''$ is imposed on the fluid.
Derive the transient differential energy balance for the averaged temperature in the fluid, using a stationary coordinate system in the x–direction. Axial heat conduction is negligible in this case.

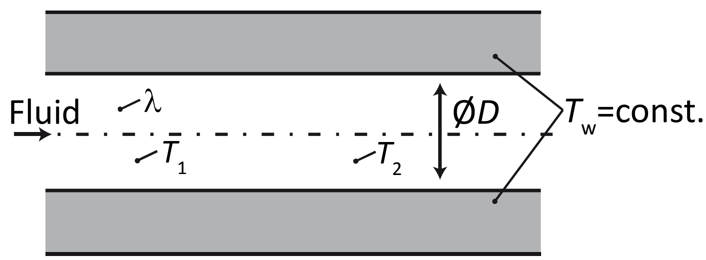
Given parameters:

- Average axial velocity: u
- Heat flux density: $\dot{q}''$
- Fluid density: ρ
- Fluid thermal capacity: c_p
- Inner pipe diameter: D



Pipe flow - constant wall temperature

A fluid is flowing laminar through a long cylindric pipe. The flow is fully developed, both thermal and hydrodynamic. The pipe wall is kept on a constant temperature T_{W}. Temperatures T_1 and T_2 are measured in the liquid. Derive an equation for the calculation of the mean heat flux $\dot{q}''_m$ using the given variables.



Given parameters:

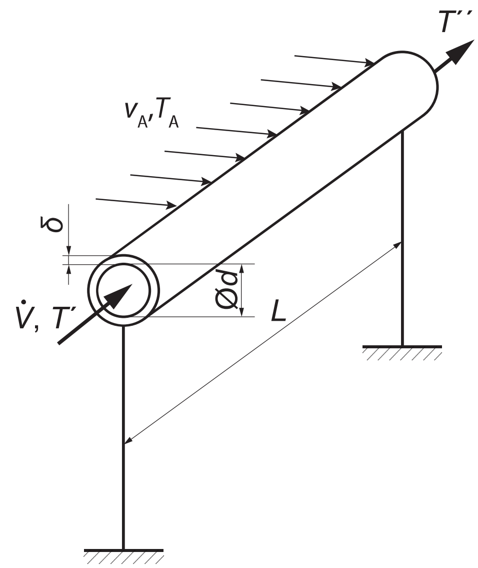
- Pipe diameter: D
- Pipe length: L
- Temperature at location x: T_1
- Temperature at location $x + L$: T_2
- Thermal conductivity of the fluid: λ

Hint:

- Axial thermal conduction is to be neglected

Hot water pipe

A 10 m long hot water pipe runs freely (supported by stands) through open air. In addition to the length L and the inner diameter d, the wall thickness δ of the pipe is known. Water is flowing through the pipe at $0.05 \times 10^{-3}\,\mathrm{m^3\,s^{-1}}$ ($= 0.05\,\mathrm{L\,s^{-1}}$) with an inlet temperature of $T' = 65\,^\circ\mathrm{C}$. The pipe stands against strong cross winds (air velocity v_A, air temperature T_A).



a) Determine all individual thermal resistances and the respective total thermal resistance necessary to calculate the heat flow rate between the water and the air. Specify all necessary material properties, as well as the required characteristic numbers.

   Hint: If you cannot solve subproblem a), use 0,025 K/W as numerical value for the total thermal resistance.

b) Determine the temperature T'' of the water at the end of the pipe, as well as the heat loss by calculating the heat flow rate $\dot{Q}_\mathrm{L}$. Write down the required energy balance to obtain these two parameters.

c) The volume flow $\dot{V}$ of the water is increased. Which of the individual thermals resistances change and how does the outlet temperature T'' change? Justify your answers making reference to the values and relationships expressed in subproblems a) and b).

Hints:

- Obtain the physical properties of the water using the given reference temperature $T_{\mathrm{ref,W}}$.
- Assume all viscosities of the involved materials to be constant in the respective temperature ranges.

Given parameters:

- **Pipe:**
  - Pipe length: $L = 10$ m
  - Pipe internal diameter: $d = 15$ mm
  - Pipe wall thickness: $\delta = 5$ mm
  - Thermal conductivity of steel: $\lambda_{\mathrm{B}} = 45$ W/mK
- **Air:**
  - Wind velocity: $v_{\mathrm{A}} = 10$ m/s
  - Air temperature: $T_{\mathrm{A}} = 20$ °C
- **Water:**
  - Volume flow: $\dot{V} = 0.05 \cdot 10^{-3}$ m^3/s
  - Inlet temperature: $T' = 65$ °C
  - Water reference temperature: $T_{\mathrm{ref,W}} = 60$ °C