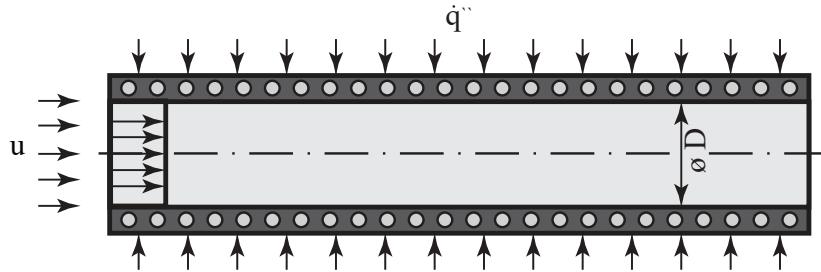


**Exercise III.9:** (Pipe flow with a constant heat flux  $\star\star$ )

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



**Given parameters:**

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

**Hint:**

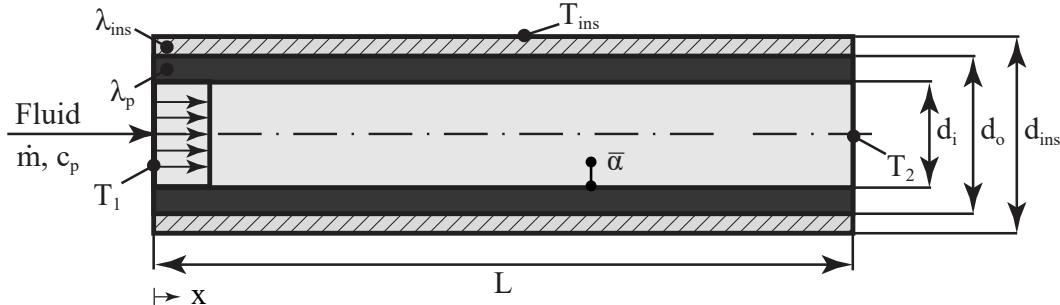
- Axial heat diffusion cannot be neglected.

**Tasks:**

- a) Derive the transient differential energy equation for the mean fluid temperature along the axial direction.

**Exercise III.10: (Insulated pipe ★★)**

A pipe is being heated by a stationary flow. The outer surface of the pipe has an insulation layer with its external side kept at a constant temperature  $T_{\text{ins}}$ .



**Given parameters:**

- Temperature of the fluid at the inlet:  $T_1$
- Temperature of outer surface area of the pipe:  $T_{\text{ins}}$
- Convective heat transfer coefficient:  $\bar{\alpha}$
- Mass flow of the fluid:  $\dot{m}$
- Specific heat capacity of the fluid:  $c_p$
- Inner diameter of the pipe:  $d_i$
- Outer diameter of the pipe excluding insulation:  $d_o$
- Outer diameter of the pipe including insulation:  $d_{\text{ins}}$
- Length of the pipe:  $L$
- Thermal conductivity of the pipe wall:  $\lambda_p$
- Thermal conductivity of the insulation layer:  $\lambda_{\text{ins}}$

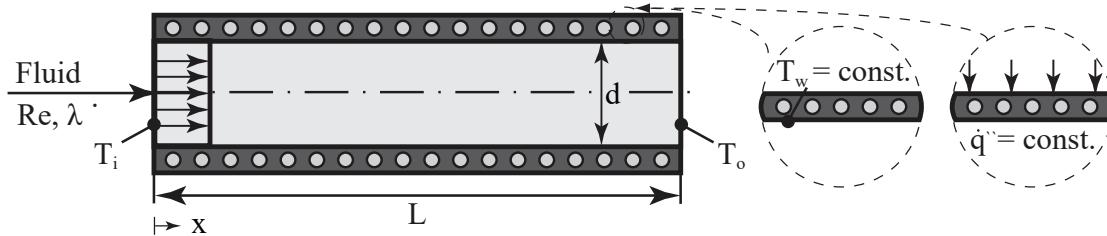
**Tasks:**

- a) Find an expression for the exit temperature  $T_2$  in terms of given parameters.

**Exercise III.11:** (Heating of a pipe ★★)

A fluid is flowing through a pipe. The flow is thermally and hydrodynamically developed. A heat flow that is transferred from the wall by convection is heating the fluid from  $T_i$  to  $T_o$ . For this purpose

- in case 1: a constant, homogeneous **wall temperature**  $T_w$  is impressed,
- in case 2: a constant, homogeneous **heat flux**  $\dot{q}''$  is impressed.



**Given parameters:**

- |   |             |
|---|-------------|
| • Temperature of the fluid at the inlet:  | $T_i$       |
| • Temperature of the fluid at the outlet: | $T_o$       |
| • Wall temperature (case 1):              | $T_w$       |
| • Heat flux (case 2):                     | $\dot{q}''$ |
| • Length of the pipe:                     | $L$         |
| • Inner diameter of the pipe:             | $d$         |
| • Reynolds number of the flow:            | $Re < 2300$ |
| • Density of the fluid:                   | $\lambda$   |
| • Dynamic viscosity of the fluid:         | $\eta$      |
| • Conductivity of the fluid:              | $\lambda$   |

**Hints:**

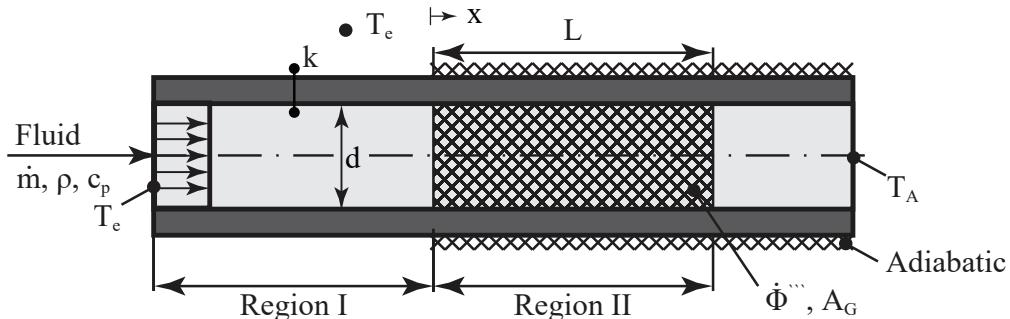
- Heat conduction in the direction of the fluid flow is negligible.
- Difference in fluid properties in the radial direction is negligible.

**Tasks:**

- a) Write out the global energy balance in terms of given parameters, determine the mean heat transfer coefficient  $\bar{\alpha}$  and provide the respective mean temperature difference  $\Delta T_m$  between the inner wall of the tube and the fluid for both cases.
- b) Draw qualitatively for both cases the profile of the wall temperature  $T_w$  and the mean fluid temperature  $T_{fl}$ .

**Exercise III.12:** (Flow through a grid ★★★)

Water flows through a long tube that 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  $T_A$ .

**Given parameters:**

- Water temperature before the grid:  $T_e$
- Environment temperature:  $T_e$
- Water temperature after the grid:  $T_A$
- Mass flow rate:  $\dot{m}$
- Thermal conductivity:  $\lambda$
- Specific heat capacity:  $c_p$
- 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 between water and environment, based on the inner pipe wall area  $k$

**Hint:**

- 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.

**Tasks:**

- a) Determine the volumetric heat release  $\dot{\Phi}'''$  created by the electrically heated grid.
- b) Derive the differential equations for the temperature profile of the water in the pipe in regions I and II. It is unknown whether heat diffusion is negligible, and thus should be included in the equation.
- c) Provide all the coupling or boundary conditions required for the solution of the problem (regions I and II).
- d) Sketch the temperature profiles of the water in the pipe with and without consideration of the diffusive heat transport.