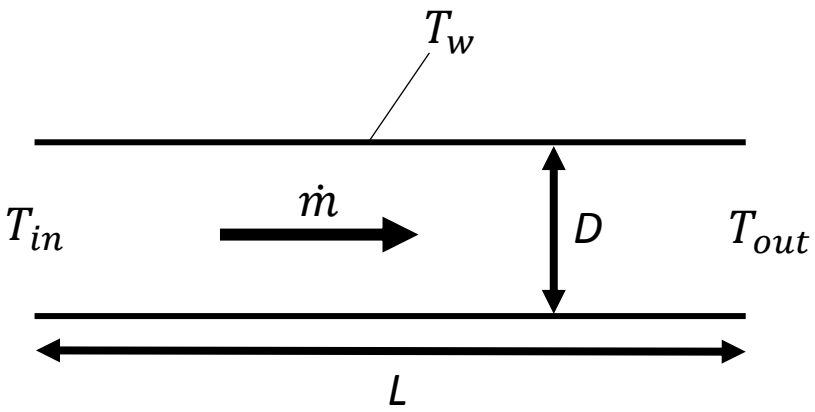
KEB-45250 Numerical techniques for process modeling – Exercise 2

In this exercise, we will make a Python program to calculate the outlet temperature of a fluid flowing inside pipe with constant wall temperature. The problem is shown schematically in the following figure:



The equations required for calculating the temperature change between the pipe inlet and outlet are as follows:

$$\frac{T_w - T_{out}}{T_w - T_{in}} = e^{-\frac{hA}{\dot{m}c_p}}$$

$$Nu_D = \frac{\frac{f}{8}(Re_D - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}(Pr^{\frac{2}{3}} - 1)}; \;\; 3000 < Re_D < 5 \cdot 10^6; \;\; 0.5 < Pr < 2000$$

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\epsilon}{3.7D} + \frac{2.51}{Re_D\sqrt{f}}\right); \;\; Re_D > 4000$$

$$Re_D = \frac{VD}{\nu}$$

$$Nu_D = \frac{hD}{k}$$

$$\Delta P = f\frac{L}{D}0.5\rho V^2$$

In our problem, we want to design a copper coil for domestic water heater, such that we achieve a specified outlet temperature for the water. The material properties for water are presented in the following table:

Table 1: Water properties at 40°C

Specific heat capacity (J/kgK)	4180
Thermal conductivity (W/mK)	0.634
Prandtl number (-)	4.16
Kinematic viscosity (m^2/s)	$6.58 \cdot 10^{-7}$
Density (kg/m^3)	992

Other constants specific to our problem are shown in next table.

Table 2: Specified values for our problem

Inlet temperature (°C)	30
Desired outlet temperature (°C)	45
Volumetric flow rate of water in system (L/min)	6.65

Finally, the goal of the calculation is to determine the optimal pipe diameter for the copper coil in the heater in order to achieve the desired outlet temperature. The details of the copper coil are presented in the following table:

Table 3: Details about the copper coil

Roughness of the copper pipe (mm)	0.0013
Pipe length (m)	6.3
Available pipe inner diameters (mm)	12, 13, 14, 16, 20, 23, 26, 33

Calculate the outlet temperature and pressure drop for all pipe diameters and determine the best diameter for the coil to achieve the desired outlet temperature.

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*This exercise contains many approximations compared to real heater and is somewhat unrealistic. A more realistic calculation would require determination of the heat transfer coefficient at the outer surface of the copper coil, as well as taking into consideration the curvature of the copper pipe in the coil. The main goal in the exercise is to learn programming and equation solving.