# Heat Transfer Assignment 8 — Pipe & Duct Flow

### Instructions

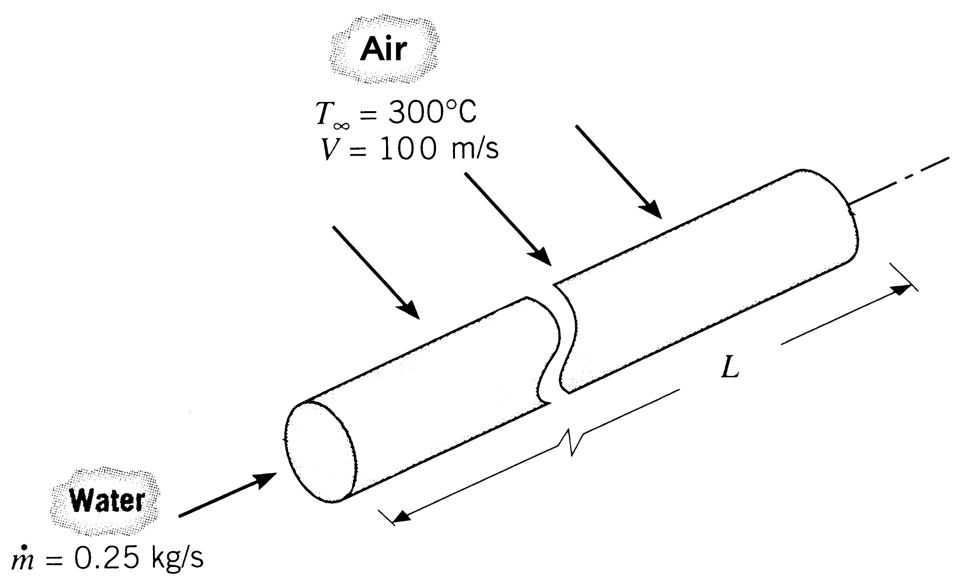
$\xi$ is a parameter related to your student ID, with $\xi_1$ corresponding to the last digit, $\xi_2$ to the last two digits, $\xi_3$ to the last three digits, etc. For instance, if your ID is 199225962, then $\xi_1 = 2$, $\xi_2 = 62$, $\xi_3 = 962$, $\xi_4 = 5962$, etc. Keep a copy of the assignment — the assignment will not be handed back to you. You must be capable of remembering the solutions you hand in.

### Question #1

Water at 43° C enters at a rate of 6 kg/s a 5-cm-internal-diameter pipe having a relative roughness $e/D$ of 0.002. If the pipe is 2 m long and the pipe walls are maintained at 71° C, calculate the exit bulk temperature of the water and the total heat transfer.

### Question #2

Water at 30° C enters at a rate of 0.25 kg/s a 4-cm-diameter smooth pipe.




Over its entire length of $L = 6$ m, the pipe is heated on its outside surface by a cross flow of air at a pressure of 1 atm, a temperature of 300° C, and a speed of 100 m/s. For a pipe of negligible wall thickness (resulting in essentially equal internal and external pipe diameters), calculate the bulk water temperature at the pipe exit.

## Question #3

Consider a pipeline used to transport oil over a distance of 100 kilometers. The pipeline is buried 3 m in the earth and is composed of a tube of internal diameter of 1.2 m surrounded by a 15-cm-thick isolator which has a thermal conductivity of 0.05 W/m·°C. Oil with a density of 900 $kg/m^3$, a viscosity of 0.765 kg/ms, a heat capacity of 2000 J/kg·°C and a Prandtl number of $10^4$ enters the pipeline with a mass flow rate of 500 kg/s and a bulk temperature of 120°C. What is the bulk temperature of the oil after it has travelled 100 kilometers if the surface temperature of the earth is −40°C and its thermal conductivity 0.5 W/m·°C?

## Question #4

The first design project given to you after you join a water distribution company is to prevent water flowing in an underground pipe from freezing. Consider a long 100 m pipe with a 0.15 m radius buried 2 m under ground (the center of the pipe is 2 m below the earth surface). Water flows in the pipe with the following properties:

$$\rho = 1000 \text{ kg/m}^3, \quad c_p = 4000 \text{ J/kgK}, \quad k = 0.6 \text{ W/m°C}, \quad \mu = 10^{-3} \text{ kg/ms}$$

On a cold winter day, the surface of the ground is measured to be −10°C. Water enters the pipe at a bulk temperature of 20°C. To prevent freezing (with a safety margin), the water temperature should not drop below 3.3°C at any location. The ground conductivity can be taken as 1.5 W/m°C, and the pipe walls can be assumed smooth and to oppose negligible resistance to heat flow. Do the following:

(a) Determine the minimum water mass flow rate through the pipe that prevents the water temperature to fall below 3.3°C *anywhere* within the pipe; make your design safe by taking into consideration that the ground surface temperature varies by as much as ±2.4°C and that the ground conductivity varies by as much as ±0.5 W/m°C.

(b) Determine the wall temperature of the pipe for the mass flow rate found in (a)

(c) Determine the bulk temperature of the water exiting the pipe for the mass flow rate found in (a)

## Question #5

Consider a 30 m long pipe with a diameter of 1 cm and with a smooth interior wall surface. The pipe wall temperature is kept constant at 60°C.

(a) Some liquid enters the pipe with a temperature of 20°C and exits the pipe with a mixing cup (bulk) temperature of 57°C. Knowing that the mass flow rate of the liquid is of 0.015 kg/s, that the liquid density is of 1000 $kg/m^3$, that the friction force exerted on the pipe due to the motion of fluid is equal to 0.144 N, determine the viscosity and the Prandtl number of the liquid.

(b) Using the Prandtl number and viscosity found in part (a), estimate the bulk temperature at the exit of the pipe for the same inflow temperature as in (a) but with the mass flow rate increased to 0.15 kg/s.

*Hint:* When the flow in a pipe is fully-developed, the friction factor is equal to:

$$f = \frac{(-\mathrm{d}P/\mathrm{d}x)D}{\rho u_{\mathrm{b}}^2/2}$$

## Answers

1. 49°C, 149 kW.
2. 71.4°C.
3. 111.9°C.
4. 0.12 kg/s, 3.3° C, 7° C.
5. 0.001 kg/ms, 8.88, 60°C.

**Due on Wednesday June 5th at 9:00. Do Questions #1, #4, and #5 only.**