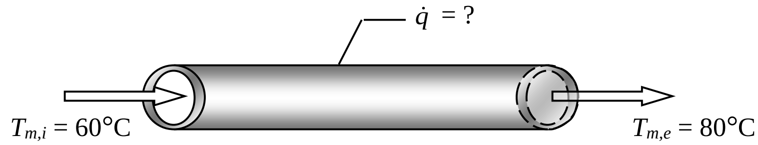
Example

Water flows through a section of 2.54-cm diameter tube 3.0 m long. The water enters the section at 60°C with a velocity of 2 cm/s. Assuming that the flow is **fully developed** (buzza buzza buzz) by the time it enters the region of interest and that the wall is subject to constant wall heat flux,

(a) ~~calculate the wall heat flux (in W/m²) needed to heat the water to 80°C.~~ **DONE!**
(b) ~~Calculate the wall temperatures at the inlet and the exit.~~ **DONE!**
(c) ~~Repeat part (a) and (b) if the velocity of the water is increased to 2 m/s.~~ **DONE!**
(d) Find the pressure drops and the pumping powers required for the two velocities above.

NEW!



(d) Already have Re from previous example(s)

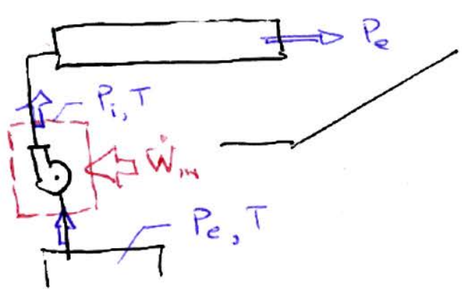
(d)(a) $Re = 1229$ (Laminar)

- Laminar
- Fully developed
- Round duct

$$f = \frac{64}{Re} = \frac{64}{1229} = 0.0521$$

$$P_i - P_e = f \rho \frac{L}{D} \frac{V^2}{2} = (0.0521)(997 \frac{kg}{m^3})\left(\frac{3\cancel{m}}{0.0254\cancel{m}}\right)\left(\frac{0.02^2 \cancel{m^2}}{\cancel{s^2}}\right)\left\langle\frac{N \cdot \cancel{s^2}}{\cancel{kg \cdot m}}\right\rangle$$

$$= 1.203 \frac{N}{m^2} = 1.203 \text{ Pa}$$



CoE $\cancel{\frac{d}{dt}(E_{sys})}_{0} = \cancel{\dot{Q}}_{0} + \dot{W}_{IN} + \dot{m}(h_e + \ldots) - \dot{m}(h_i + \ldots)$

$$\dot{W}_{IN} = \dot{m}(h_i - h_e) = \dot{m}\left[\cancel{c(T - T)}_{0} + \frac{P_i - P_e}{\rho}\right]$$

$$\dot{W}_{IN} = \frac{\dot{m}}{\rho}\left[P_i - P_e\right]$$

What is $\frac{\dot{m}}{\rho} = ?$ $\ldots = \dot{\forall}$!!!

$$\boxed{\dot{W}_{IN} = \dot{\forall}(P_i - P_e)}$$

$$\dot{W}_{IN} = \left(\frac{9.406\times10^{-3}\ \frac{kg}{s}}{997\ \frac{kg}{m^3}}\right)(1.203\ \cancel{Pa})\left\langle\frac{W\cdot s}{\cancel{Pa}\cdot m^3}\right\rangle$$ ($\dot{m}$ from previous example)

$$= 12.2\times10^{-6}\ W = \boxed{12.2\ \mu W}$$

(d)(b) Same method, different numbers. Here are highlights

$Re = 122,900 \longrightarrow$ TURBULENT

$\left.\begin{array}{l}\bullet\ \text{TURBULENT}\\ \bullet\ \text{Fully developed}\\ \bullet\ \text{Round duct}\end{array}\right\}$ Use Moody diagram, Assume $\varepsilon/D \approx 0$ $\longrightarrow f = 0.017$

$$P_i - P_e = f\frac{L}{D}\frac{V^2}{2} = \ldots = 3925\ Pa$$

$$\dot{W}_{IN} = \frac{\dot{m}}{\rho}(P_i - P_e) = \ldots = \boxed{3.98\ W}$$

We see the trade-off between <u>higher</u> <u>h</u> & <u>higher</u> <u>$\dot{W}_{PUMP}$</u>.

We got $\approx 100\times$ the $\dot{Q}$ with the larger flow, but the pumping power is $10,000\times$ the laminar value!