Solutions
Name

Grade: ____/20

Problem 1 (4 pts)

(a) [2 pt] The log mean temperature difference (check all that apply)

- ☑ is used for internal flow situations where surface temperature is constant.
- ☐ is used for external flow situations where surface temperature is constant.
- ☑ is the correct value of the surface-to-fluid temperature difference to be used with average heat transfer coefficient.
- ☐ is the correct value of the surface-to-fluid temperature difference to be used with local heat transfer coefficient.

(b) [1 pt] How does T_m change in the flow direction for a constant T_s boundary condition for fully-developed flow?

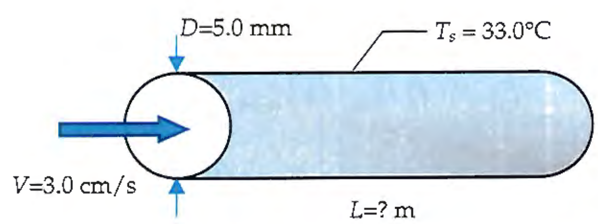
- o Linearly
- (o) Exponentially
- o It doesn't

(c) [1 pt] How does h change in the flow direction for a constant T_s boundary condition for fully-developed flow?

- o Linearly
- o Exponentially
- (o) It doesn't

Problem 2 (16 pts)

10W engine oil at a velocity V=3.0 cm/s flows through a round duct with diameter D=5.0 mm and unknown length L. The oil enters at $T_{m,i}$=20.0°C and exits at $T_{m,e}$=30.0°C. The wall of the duct is maintained at a constant temperature of T_s=33.0°C. Take the properties of engine oil to be k=0.143 W/m·°C, ρ=876 kg/m³, μ=0.056 kg/m·s, c=1901 J/kg·°C, and Pr=771.



Perform each of the four parts in **the order listed.**

(a) [2 pts] Find the mass flow rate of oil.

$$\dot{m} = \rho A V = \rho \frac{\pi D^2}{4} V = 876 \frac{kg}{m^3} \cdot \pi \frac{0.005^2}{4} m^2 \cdot 0.03 \frac{m}{s}$$

$$= 5.16 \times 10^{-3} \frac{kg}{s}$$ ← ANS

(b) [3 pts] Find the rate of heat transfer, $\dot{Q}$, to the flowing fluid. Ignore pressure loss in the duct.

CoE $\cancel{0} = \dot{Q}_{in} - \; + \dot{m}(h_{in} + ..) - \dot{m}(h_{out} + ..)$

$$\dot{Q} = \dot{m}(h_{out} - h_{in}) = \dot{m}\left(c(T_{out} - T_{in}) + \cancel{\frac{P_{out} - P_{in}}{\rho}}^{0}\right)$$

$$\dot{Q} = \left(5.16 \times 10^{-3} \frac{kg}{s}\right)\left(1901 \frac{J}{kg\,°C}\right)(30 - 20)°C \left\langle \frac{W}{J/s} \right\rangle$$

$$= 98.1 \text{ W}$$ ← ANS

(c) [6 pt] Estimate the convective heat transfer coefficient, h, between the duct wall and the flowing fluid. Assume the flow is both hydrodynamically and thermally fully-developed for the entire length of the duct.

$$Re = \frac{\rho V D}{\mu} = \frac{(876 \frac{kg}{m^3})(0.03 \frac{m}{s})(0.005\ m)}{0.056 \frac{kg}{m \cdot s}} \approx 2.35$$

- Laminar
- T_s = CONST
- Fully developed
- Round

$Nu = 3.66 = \frac{hD}{k}$

$$h = \frac{Nu \cdot k}{D} = \frac{(3.66)(0.143 \frac{W}{m \cdot °C})}{0.005\ m} = 105 \frac{W}{m^2 \cdot °C}$$ ANS

(d) [5 pts] Assume the answers to (a) and (b) are 10 W and 106 $W/m^2 \cdot °C$ respectively. Find the required length of the duct at the exit, L, to achieve this heat transfer.

$$\dot{Q} = hA_s \Delta T_{LM} = h \pi D L \Delta T_{LM}$$

$$L = \frac{\dot{Q}}{h \pi D \Delta T_{LM}} = \frac{10\ W}{106 \frac{W}{m^2 °C} \cdot \pi \cdot 0.005 m \cdot \frac{(33-30)-(33-20)}{\ln\left(\frac{33-30}{33-20}\right)} °C}$$

$= 0.881\ m$ ANS

Bonus [+1 pt]

If the flow in Problem 2 were not thermally fully developed, would you expect the required length to be smaller, the same, or larger than the value you calculated? Briefly explain.