TEMPLE UNIVERSITY

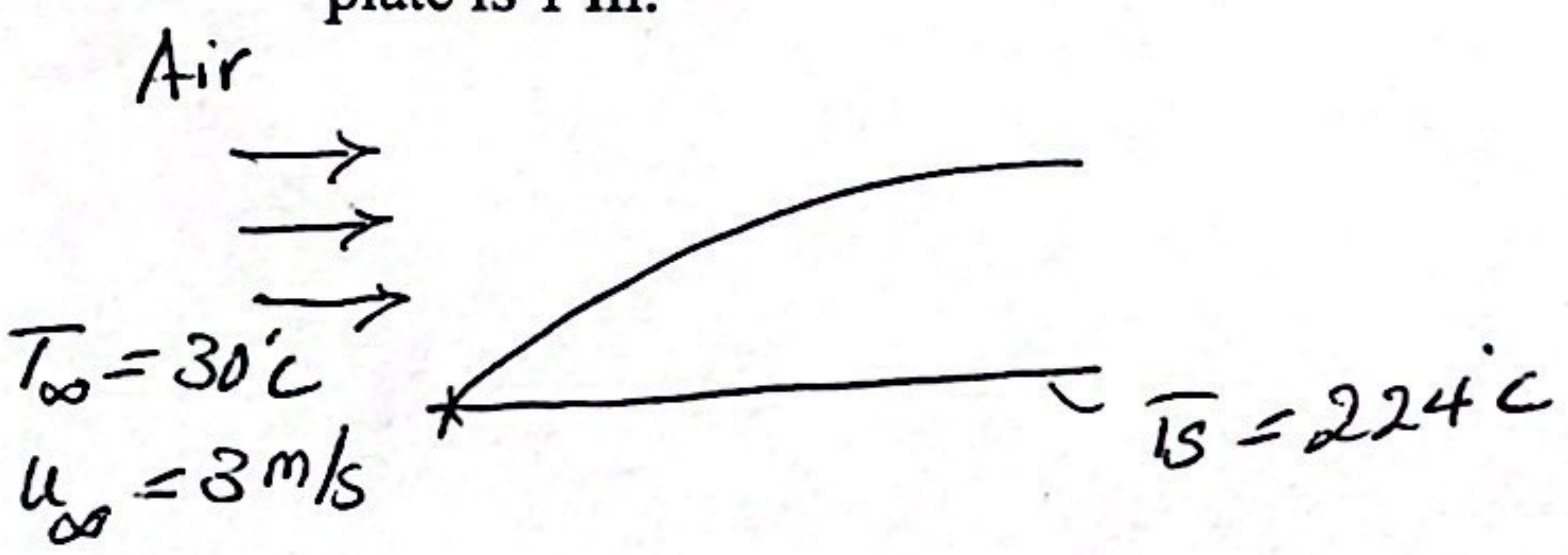
Mechanical Engineering Department

MEE 4572 Heat and Mass Transfer

Quiz 6

Full Name:

1- Air at 30 ˚C flows over a flat plate of 30 cm length at a velocity of 3 m/s. The plate is heated, and its temperature is maintained at 224 ˚C. Use Reynolds analogy, compute the drag force exerted on the plate. The average heat transfer coefficient is 8.7 W/m^2.K. Assume width of the plate is 1 m.



$$T_f = \frac{T_s + T_\infty}{2} = \frac{224 + 30}{2} = 127^\circ C \; (400K)$$

From table A.4

$$\rho = 0.8711 \text{ kg/m}^3 \;, \mu = 230.1 \times 10^{-7} \text{ Pa.S}$$

$$P_r = 0.69 \;, \; K = 33.8 \times 10^{-3} \text{ W/m.K}$$

Reynolds Analogy:

$$① \quad \frac{\bar{C_f}}{2} = St \times P_r^{2/3} \qquad P_r \geq 0.6$$

$$St = \frac{Nu}{Re \, P_r} \qquad Re_L = \frac{\rho u_\infty L}{\mu} = \frac{0.8711 \times 3 \times 0.3}{230.1 \times 10^{-7}} = 34078.00$$

$$\bar{Nu}_L = \frac{\bar{h} L}{K} = \frac{8.7 \times 0.3}{33.8 \times 10^{-3}} = 77.22$$

$$① \rightarrow \bar{C_f} = 2\left(\frac{Nu}{Re \, P_r}\right) \times P_r^{2/3} = 2\left(\frac{77.22}{34078 \times 0.69}\right)(0.69)^{2/3} = 0.00512$$

$$\bar{\tau_s} = \bar{C_f} \times \frac{1}{2} \rho u_\infty^2 \Rightarrow F_D = \bar{C_f} \times \frac{1}{2} \rho u_\infty^2 (L \times W)$$

$$= 0.00512 \times \frac{1}{2} \times 0.8711 \times 3^2 (0.3 \times 1)$$

$$= 0.006 \text{ N}$$

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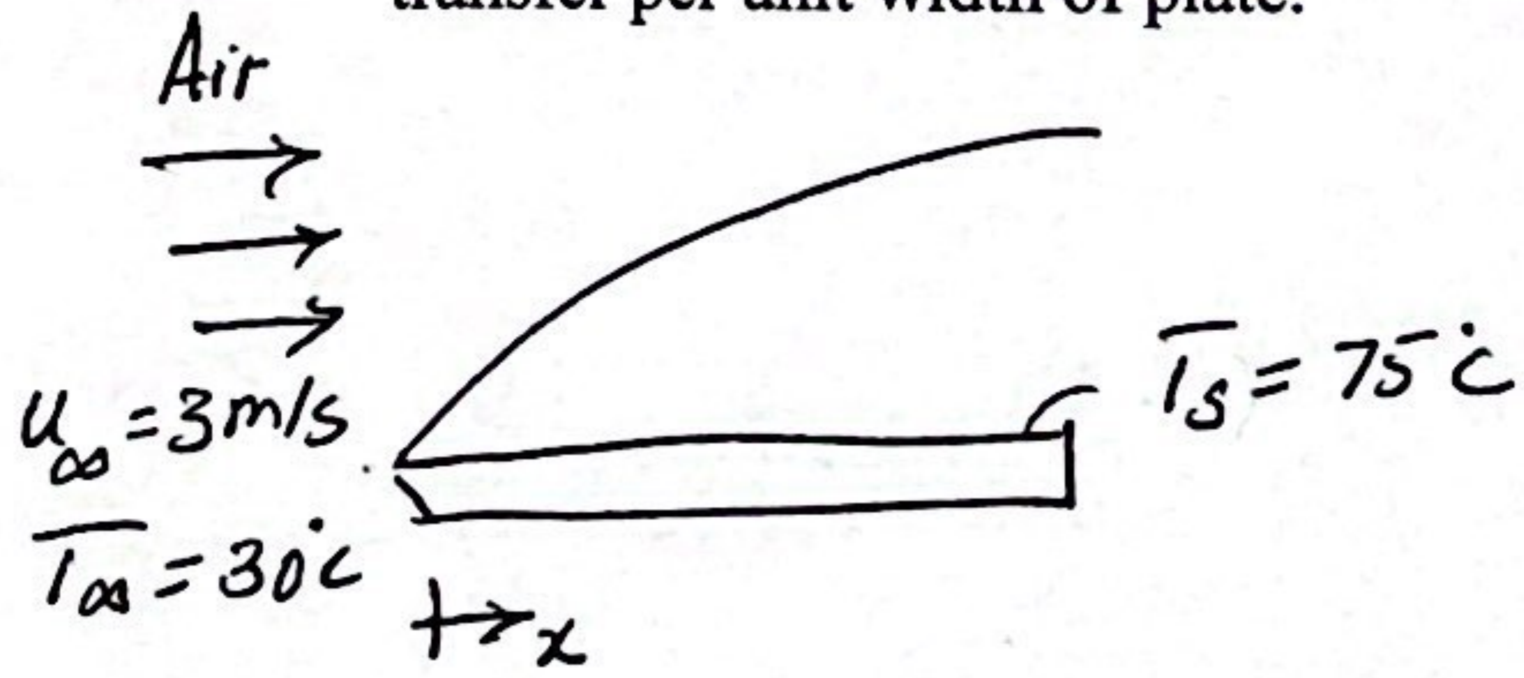
Quiz 7

Full Name:

1- Atmospheric air flows over a 1 m long flat plate with velocity of 3 m/s and temperature of 30 ˚C. The surface temperature is maintained at 75 ˚C. Compute a) boundary layer thickness, b) heat transfer per unit width of plate.



$$T_f = \frac{T_\infty + T_s}{2} = \frac{30+75}{2} = 52.5°C\ (325.5K)$$

From table A.4 for air:

$\rho = 1.0782\ kg/m^3$, $\nu = 18.405 \times 10^{-6}\ m^2/s$

$k = 28.15 \times 10^{-3}\ W/m.k$ $\quad P_r = 0.7035$

$$Re_L = \frac{u_\infty L}{\nu} = \frac{3 \times 1}{18.405 \times 10^{-6}} = 1.6 \times 10^5 < 5 \times 10^5 = Re_{cr}$$ Therefore Laminar flow

$$\delta = \frac{5x}{Re_L^{1/2}} = \frac{5 \times 1}{(1.6 \times 10^5)^{1/2}} = 0.0125 m\ (12.5 mm)$$

$$\overline{Nu}_L = 0.664\, Re_L^{1/2}\, P_r^{1/3} = 0.664\,(1.6 \times 10^5)^{1/2}\,(0.7035)^{1/3} = 236.22$$

$$\overline{Nu}_L = \frac{\bar{h} L}{k} \Rightarrow \bar{h} = \frac{k}{L} \times \overline{Nu}_L = \frac{28.15 \times 10^{-3}}{1} \times 236.22 = 6.65\ W/m^2.k$$

$$q = \bar{h} A (T_s - T_\infty) = \bar{h} (L \times W) \times (T_s - T_\infty)$$

$$q/W = \bar{h} \times L (T_s - T_\infty) = 6.65 \times 1\,(75 - 30) = 299.25\ W/m$$

for both sides $\quad q/W = 299.25 \times 2 = 598.5\ W/m$

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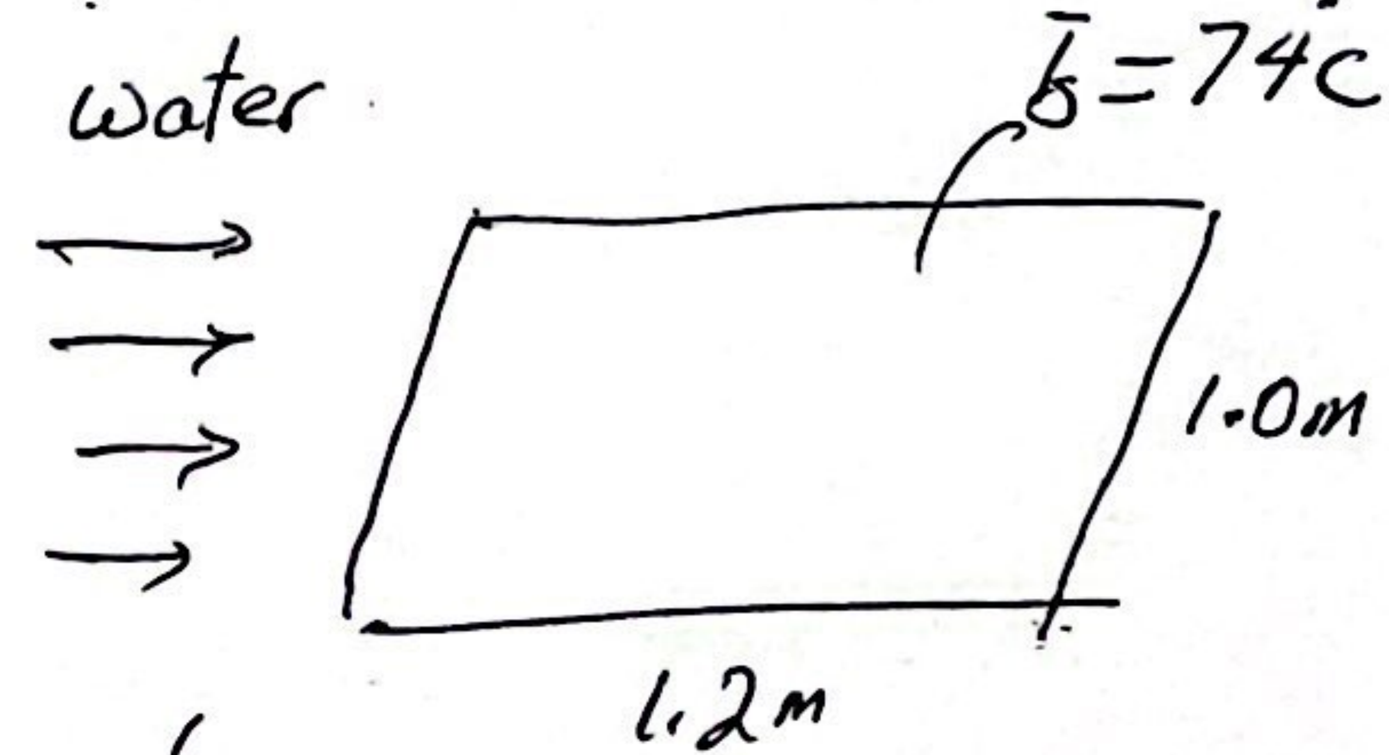
Water at 10 ˚C flows at a velocity of 3 m/s across a plate maintained at temperature of 74 ˚C. If the length and width of the plate are 1.2 m and 1 m respectively, determine the convective heat transfer from the plate.

$$T_f = \frac{T_s + T_\infty}{2} = \frac{74+10}{2} = 42^\circ C \quad (315K)$$

$T_\infty = 10^\circ C$

$u_\infty = 3 m/s$



From table A.6 (water)

$v_f = 1.009 \times 10^{-3}\ m^3/kg$, $\mu_f = 631 \times 10^{-6}\ kg/m.s$

$P_r = 4.16$ $\quad k = 634 \times 10^{-3}\ W/m.K$

$$e = \frac{1}{v_f} = 991.08\ kg/m^3$$

$$Re_{cr} = \frac{e u_\infty x_{cr}}{\mu}$$

$$x_{cr} = \frac{5 \times 10^5 \times 631 \times 10^{-6}}{991.08 \times 3} = 0.1 m$$

$$Re_L = \frac{e u_\infty L}{\mu} = \frac{991.08 \times 3 \times 1.2}{631 \times 10^{-6}} = 5.65 \times 10^6 > Re_{cr} = 5 \times 10^5$$

Turbulent at the end of the plate

Therefore mixed flow

$$A = 0.037 Re_{cr}^{0.8} - 0.664 Re_{cr}^{1/2} = 871$$

eq: 7.38

$$\overline{Nu}_L = \left[0.037 Re_L^{0.8} - \underbrace{A}_{871}\right] Pr^{1/3}$$

$$= \left[0.037(5.65 \times 10^6)^{0.8} - 871\right](4.16)^{1/3} = 13682.7$$

$$\bar{h} = \frac{k}{L} \overline{Nu}_L = \frac{634 \times 10^{-3}}{1.2} \times (13682.7) = 7229.0\ W/m^2.K$$

$$q = \bar{h} A_s (T_s - T_\infty)$$

$$= 7229 \times (1.2 \times 1)(74-10) = 555189.2 W$$

$$= 555.2 KW$$

Atmospheric air at 17°C flows inside a metallic tube with a mean velocity of 5m/s. The inner diameter of the tube is 5cm, and its walls are maintained at 97°C. Assume that the flow and temperature distribution inside the tube are fully-developed. Determine the flow regime in the tube and calculate:

i. The air-tube heat transfer coefficient.

ii. The length of the tube, if the mean temperature of the air stream at the outlet is required to be 87°C.

$\bar{T}_m = \frac{T_{m,i} + T_{m,o}}{2} = \frac{17+87}{2} = 52°c \; (325K)$

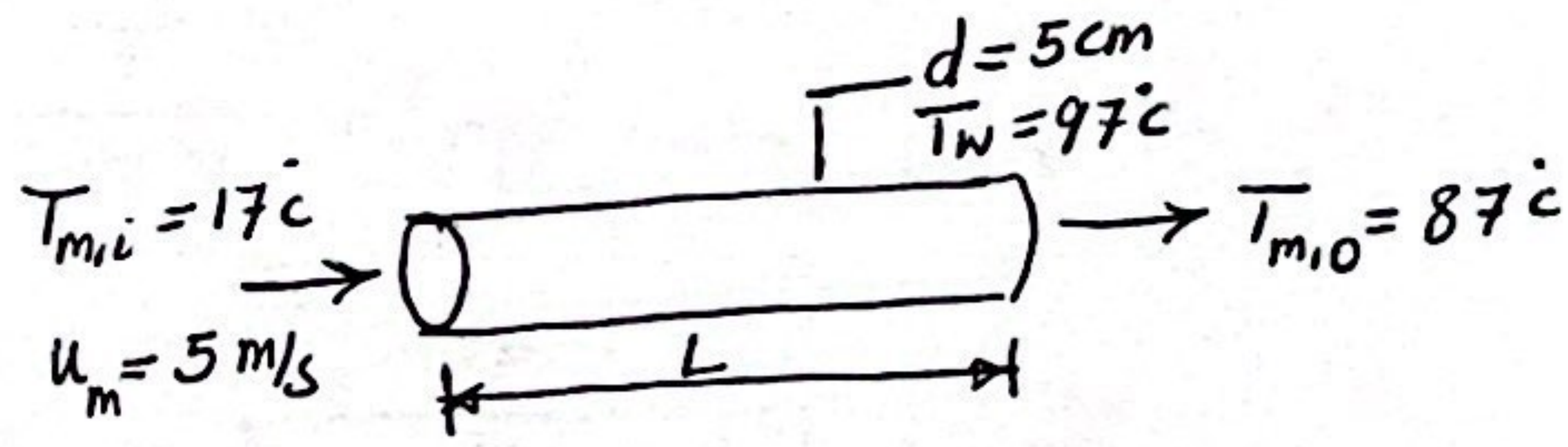


Table A.4 (Air)

$\rho = 1.078 \; kg/m^3 \; , \; \nu = 18.41 \times 10^{-6} \; m^2/s$

$K = 0.028 \; W/mK \; , \; P_r = 0.704 \; , \; c_p = 1.008 \; \frac{kJ}{kgK}$

Flow regime : $Re_D = \frac{u_m d}{\nu} = \frac{5 \times 0.05}{18.41 \times 10^{-6}} = 13580 > 10^4 \; \therefore$ turbulent flow

Eq : 8.60

$\bar{Nu}_D = 0.023 \; Re_D^{0.8} \; P_r^{n} \qquad n = 0.4$ heating

$= 0.023 \, (13580)^{0.8} \, (0.704)^{0.4} = 40.46$

$\bar{h} = \frac{K}{d} \bar{Nu}_D = \frac{0.028}{0.05} \times 40.46 = 22.7 \; W/m^2K$

$q = \dot{m} \, c_p (T_{m,o} - T_{m,i}) = 0.0106 \times 1008 (87-17) = 746.75 \; W$

where $\dot{m} = \rho A_c u_m = 1.078 \times 0.00196 \times 5 = 0.0106 \; kg/s$

$q_{conv} = \bar{h} A_s (\Delta T_{lm})$ where $\Delta T_{lm} = \frac{\Delta T_o - \Delta T_i}{\ln \frac{\Delta T_o}{\Delta T_i}} = \frac{(97-87) - (97-17)}{\ln \frac{10}{80}}$

$= \bar{h} \pi d L \, \Delta T_{lm} \qquad = 33.7 \, K$

Therefore

$L = \frac{q}{\bar{h} \pi d \, \Delta T_{lm}} = \frac{746.75}{22.7 \times \pi \times 0.05 \times 33.7} = \underline{\underline{6.2 \, m}}$

Problem :- Consider the flow of oil at 10 °C in a 40 cm diameter pipeline at an average velocity of 0.5 m/s. A 1500 m long section of the pipeline passes through icy waters of a lake at 0 °C. Measurements indicate that the surface temperature of the pipe is very nearly 0 °C. Disregarding the thermal resistance of the pipe material, determine a) the temperature of the oil when the pipe leaves the lake, b) the rate of heat transfer from the oil, and c) the pumping power required to overcome the pressure losses and maintain the flow of oil in the pipe.

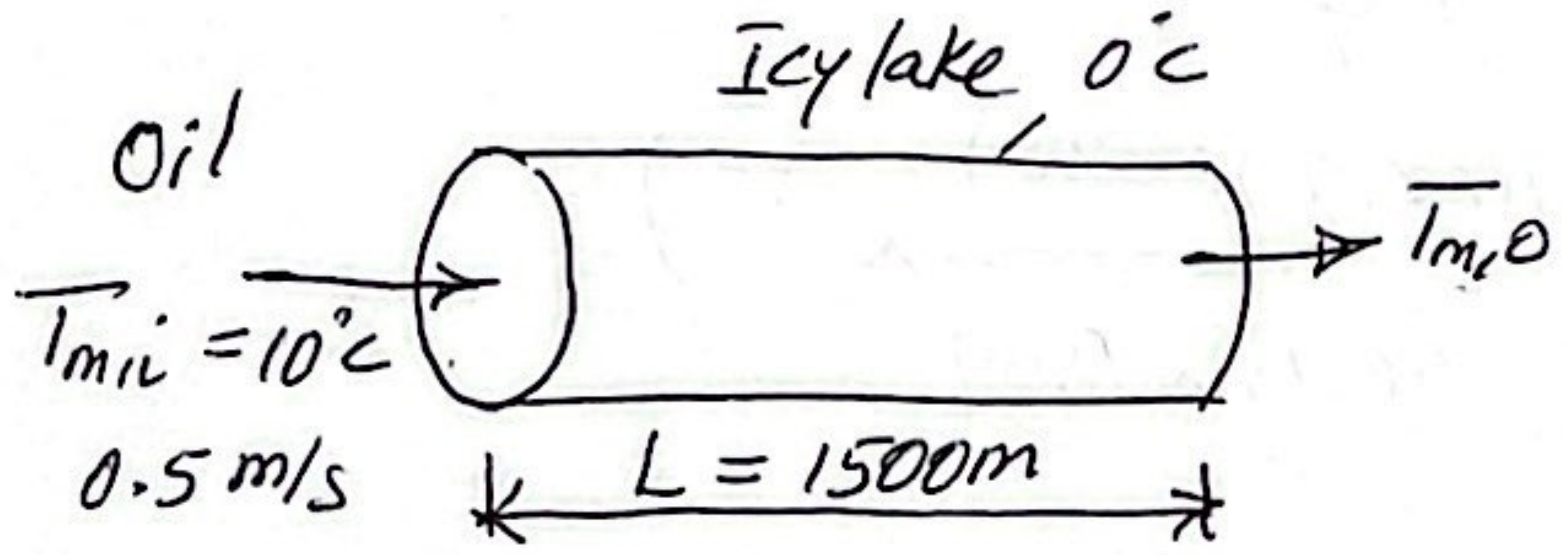


Table-A.5 :

$\rho = 893.6\ kg/m^3$

$k = 0.146\ W/mK$

$\mu = 2.326\ Pa.s$

$c_p = 1839\ J/kg.K$

$\nu = 2.592 \times 10^{-3}\ m^2/s$

$P_r = 28750$

$$Re_D = \frac{\rho V D}{\mu} = \frac{893.6 \times 0.5 \times 0.4}{2.326}$$

$$= 76.84 < 2300$$

laminar flow

$$x_{fd,h} = 0.05 \times Re_D D = 0.05 \times 76.84 \times 0.4 = 1.54\ m$$

$$x_{fd,t} = 0.05 \times Re_D D P_r = 1.54 \times 28750 = 44160\ m \gg 1500\ m$$

eq 8.57 Kays Correlation:

$$\overline{Nu}_D = 3.66 + \frac{0.0668\, Gz_D}{1 + 0.04\, Gz_D^{2/3}}$$

$$= 13.82$$

$$Gz_D = \left(\frac{D}{x}\right) Re_D P_r = \frac{0.4}{1500} \times 76.84 \times (28750) = 589.1$$

$$\bar{h} = \frac{k}{D} \overline{Nu}_D = \frac{0.146}{0.4} \times 13.82$$

$$= 5.0\ W/m^2K$$

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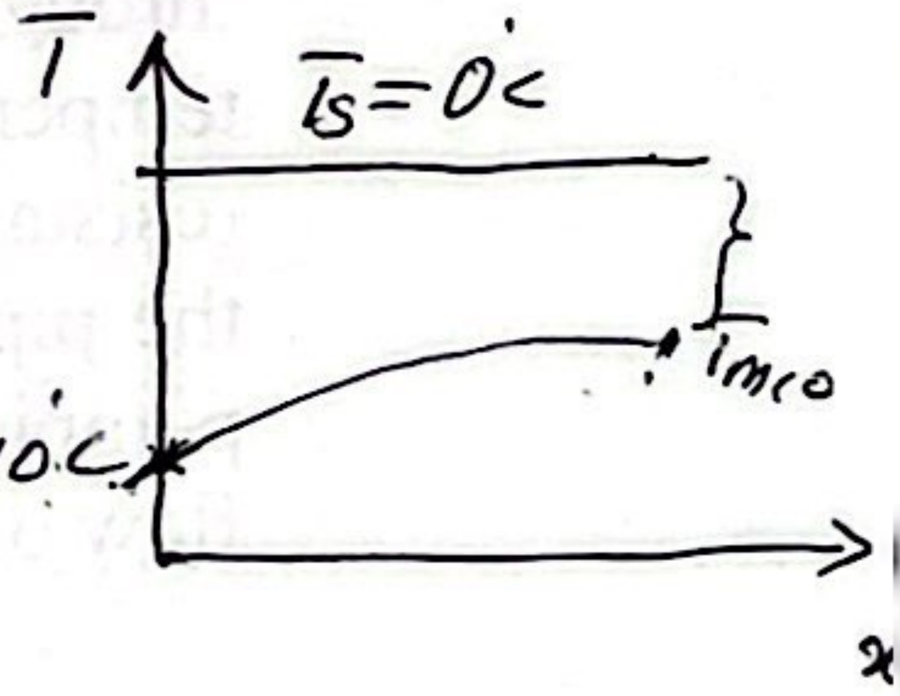
$$A_s = \pi D L = \pi(0.4)(1500) = 1885\ m^2$$

$$\dot{m} = \rho A V = 893.6 \times \frac{\pi (0.4)^2}{4} \times 0.5 = 56.15\ kg/s$$



(eq 8.41 b) $\Rightarrow$ $$\frac{\Delta T_o}{\Delta T_i} = \frac{\bar{T}_s - T_{m,o}}{\bar{T}_s - T_{m,i}} = \exp\left(-\frac{PL}{\dot{m} c_p}\bar{h}\right)$$

$$T_{m,o} = \bar{T}_s - (\bar{T}_s - T_{m,i}) \exp\left(-\frac{\pi D L}{\dot{m} c_p} h\right)$$

$$= 0 - (0 - 10) \exp\left(-\frac{\pi(0.4)(1500)}{56.15 \times 1839} \times 5\right)$$

$$= \underline{\underline{9.13°c}}$$

$$q = \dot{m} c_p (T_{m,i} - T_{m,o}) = 56.15 \times 1839 (-9.13 + 10) = \underline{89836.0\ W}$$

$$q = \bar{h} A_s \Delta T_{lm} = 5 \times \pi \times 0.4 \times 1500 \times 9.56$$
$$= \underline{90055\ W}$$

$$\Delta T_{lm} = \frac{\Delta T_o - \Delta T_i}{\ln \frac{\Delta T_o}{\Delta T_i}} = 9.56°c$$

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

$$f = \frac{64}{Re_D} = \frac{64}{78.84} = 0.833$$

$$= 0.833 \times \frac{1500}{0.4} \times 893.6 \left(\frac{0.5^2}{2}\right)$$
$$= 348923\ Pa = 348.9\ kPa$$

$$\dot{W}_p = \dot{\forall} \Delta P = A V \Delta P$$
$$= \frac{\pi D^2}{4} \times V \times \Delta P$$
$$= \frac{\pi (0.4)^2}{4} \times 0.5 \times 348.9$$
$$= \underline{\underline{21.9\ kW}}$$