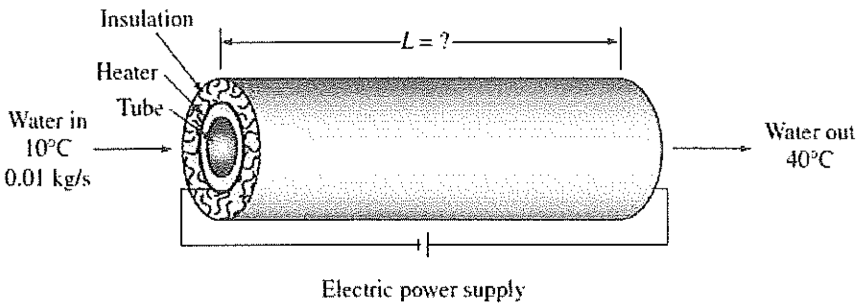
CANKAYA UNIVERSITY
FACULTY OF ENGINEERING
MECHANICAL ENGINEERING DEPARTMENT
ME 313 HEAT TRANSFER

Fall 2016

HW 8

Solutions

1) Water entering at 10°C is to be heated to 40°C in a tube of 0.02-m-ID at a mass flow rate of 0.01 kg/s. The outside of the tube is wrapped with an insulated electric-heating element (see Figure) that produces a uniform flux of 15,000 W/m^2 over the surface. Neglecting any entrance effects, determine



Schematic diagram of water flowing through electrically heated tube

(a) the Reynolds number
(b) the heat transfer coefficient
(c) the length of pipe needed for a 30°C increase in average temperature
(d) the inner tube surface temperature at the outlet

$\rho = 997$ kg/m^3
$c_p = 4180$ J/kgK
$k = 0.608$ W/mK
$\mu = 910 \times 10^{-6}$ N.s/m^2

e) friction factor
f) pressure drop
g) power required if pump efficiency is 50 %

a) $Re_D = \frac{\rho V D}{\mu} = 699 < 2300$ Laminar flow

b) $\overline{Nu}_D = \frac{\bar{h} D}{K} = 4.36$ ← uniform heat flux B.C.

$\therefore \bar{h} = 132 \ W/m^2 K$

c) $q''_w (\pi D L) = \dot{m} C_p (T_{mo} - T_{mi})$

$L = \frac{\dot{m} C_p \Delta T}{\pi D q''_w} = 1.33 \ m$ $\Delta T = T_{mo} - T_{mi}$

d) $q''_w = \frac{q}{A} = \bar{h}(T_w - T_m)$

$T_w = \frac{q}{A \bar{h}} + T_m = \frac{15000 \ W/m^2}{132 \ \frac{W}{m^2 \ ^\circ C}} + 40 = 154 \ ^\circ C$

e) $f = \frac{64}{Re_D} = 0.0915$

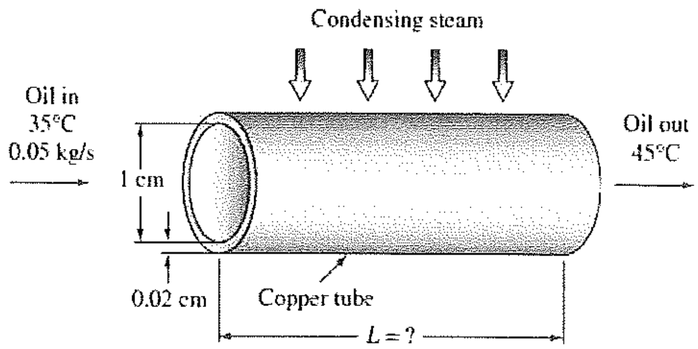
f) $\Delta P = P_1 - P_2 = f \frac{L}{D} \frac{\rho V^2}{2}$

$V = \frac{4\dot{m}}{\rho \pi D^2} = 0.032 \ m/s$

$\Delta P = (0.0915)\underbrace{(66.5)}_{\left(\frac{1.33}{0.02}\right)} \left(\frac{(997 \frac{kg}{m^3})(0.032 \ m/s)^2}{2 \left[\frac{kg \cdot m}{N \ s^2} \right]} \right) = 3.1 \ \frac{N}{m^2}$

f) $\dot{W} = \dot{m} \frac{\Delta P}{\rho \eta} = 6.2 \times 10^{-5} \ W$

2) Used engine oil can be recycled by a patented reprocessing system. Suppose that such a system includes a process during which engine oil flows through a 1-cm-ID, 0.02-cm-wall copper tube at the rate of 0.05 kg/s. The oil enters at 35°C and is to be heated to 45°C by atmospheric-pressure steam condensing on the outside, as shown in Figure. Calculate the length of the tube required.



Schematic diagram for problem 2

$c_p = 1964$ J/kg K

$\rho = 876$ kg/m3

$k = 0.144$ W/mK

$\mu = 0.210$ N.s/m^2

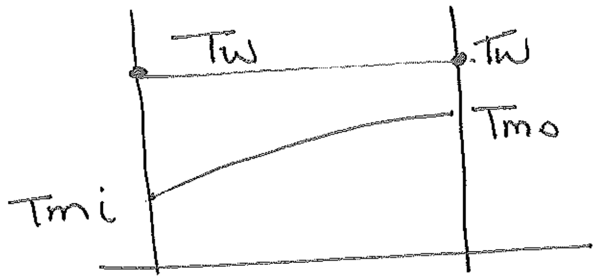
$Pr = 2870$

$$Re_D = \frac{\rho V D}{\mu} = \frac{4\dot{m}}{\mu \pi D} = 30.3$$

$$\overline{Nu}_D = \frac{\bar{h} D}{k} = 3.66 \quad \text{constant wall temperature BC}$$

$\bar{h} = 52.7$ W/mK

$q = \dot{m} c_p (T_{mo} - T_{mi}) = 982$ W



$T_w = 100\,°C$

$T_{mi} = 35\,°C$

$T_{mo} = 45\,°C$

$$\Delta T_{LMTD} = \frac{\Delta T_{out} - \Delta T_{in}}{\ln\left(\frac{\Delta T_{out}}{\Delta T_{in}}\right)} =$$

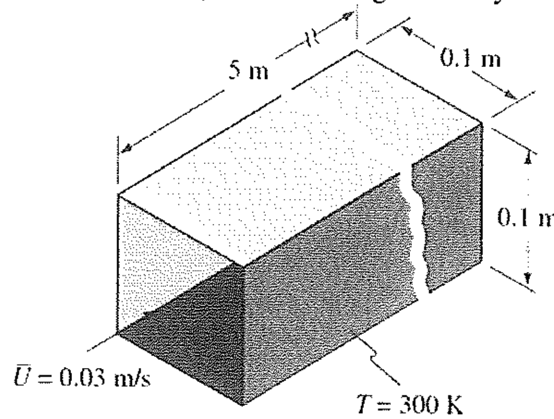
$$\Delta T_{out} = T_w - T_{mo}$$
$$= 100 - 45 = 55\,°C$$

$$\Delta T_{in} = T_w - T_{mi} = 100 - 35 = 65\,°C$$

$$\Delta T_{LMTD} = \frac{55 - 65}{\ln(55/65)} = 59.9\,K$$

$$L = \frac{q}{\pi D \bar{h}\, \Delta T_{LMTD}} = 9.91\,m$$

3) Calculate the average heat transfer coefficient and the friction factor for flow of *n*-butyl alcohol at a bulk temperature of 293 K through a 0.1-m × 0.1-m-square duct, 5 m long, with walls at 300 K, and an average velocity of 0.03 m/s (see Figure).



$$D_H = \frac{4(0.1)(0.1)}{(4)(0.1)} = 0.1\,m$$

At 293 K

$\rho = 810$ kg/m³

$C_p = 2366$ J/kg K

$\mu = 29.5 \times 10^{-4}$ N.S/m²

$\nu = 3.64 \times 10^{-6}$ m²/s

$k = 0.167$ W/m K

$Pr = 50.8$

$$Re_D = \frac{\rho V D_H}{\mu} = 824$$

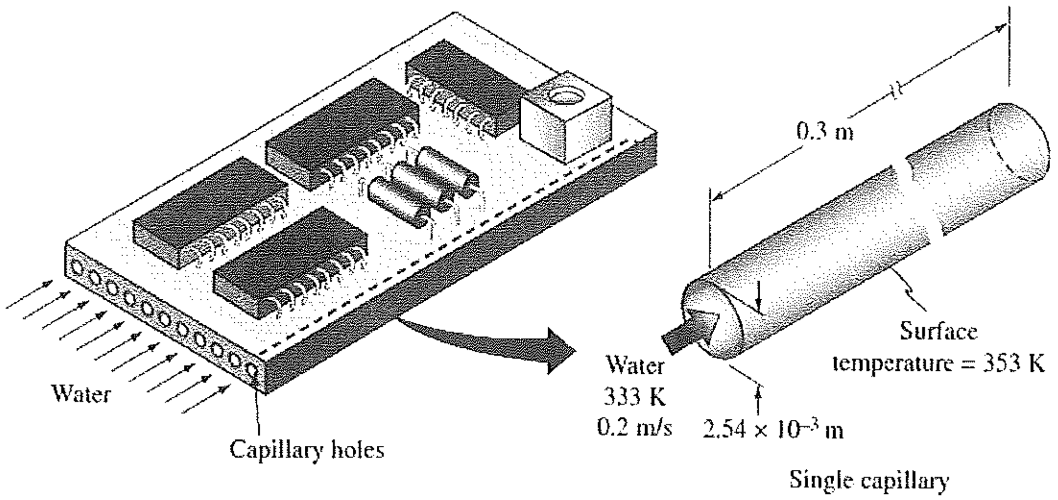
for uniform wall temperature, from Table

$$\overline{Nu} = \frac{\bar{h} D_H}{K} = 2.98, \quad f = 56.91$$

$$\bar{h} = 4.98\ W/m^2K$$

$$f = \frac{56.91}{824} = 0.0691$$

4) An electronic device is cooled by water flowing through capillary holes drilled in the casing as shown in Figure. The temperature of the device casing is constant at 353 K. The capillary holes are 0.3 m long and 2.54×10^{-3} m in diameter. If water enters at a temperature of 333 K and flows at a velocity of 0.2 m/s, calculate the outlet temperature of the water.



Schematic diagram for problem 4

At 333K

$\rho = 983K$

$c_p = 4181 \ J/kgK$

$\mu = 4.72 \times 10^{-4} \ N.s/m^2$

$k = 0.658 \ W/mK$

$Pr = 3$

$Re_D = \frac{\rho V D}{\mu} = 1058 < 2300$ laminar flow

we will use empirical correlation

$$\overline{Nu_D} = 1.86 \left[\frac{Re_D \, Pr \, D}{L}\right]^{0.33} \left(\frac{\mu_m}{\mu_w}\right)^{0.14}$$

since $Re_D Pr \frac{D}{L} = 26.9 > 10$

$$q = \bar{h} \pi D L \left[T_w - \frac{T_{mi} + T_{mo}}{2}\right] = \dot{m} c_p (T_{mo} - T_{mi})$$

At $T_W = 353\,K$ $\quad \mu_w = 3.52 \times 10^{-4}\ Ns/m^2$

now $\overline{Nu_D} = 5.74$

$\bar{h} = \frac{k}{D}\overline{Nu_D} = 1487\ W/m^2K$

$\dot{m} = \rho\left(\frac{\pi D^2}{4}\right)V = 0.996 \times 10^{-3}\ kg/s$

$T_{mi} = 333\,K$

$T_W = 353\,K$

get $T_{mo} = 345\,K$

next evaluate fluid properties at

$\overline{T_m} = \frac{T_{mi} + T_{mo}}{2} = \frac{345 + 333}{2} = 339\,K$

get new fluid properties

$\rho = 980\ kg/m^3$

$c_p = 4185\ J/kg\,K$

$\mu = 4.36 \times 10^{-4}\ N.s/m^2$

$k = 0.662\ W/m\,K$

$Pr = 2.78$

$Re_D = 1142$

$Re_D Pr \frac{D}{L} = 26.9$

$\overline{Nu_D} = 5.67$

$\bar{h} = 1479\ W/m^2K$

then we get $T_{mo} = 345\,K$

No iteration is necessary

Brtish Unit system: Engineering is not only based on SI unit System

5) Determine the Nusselt number for water flowing at an average velocity of 10 ft/s in an annulus formed between a 1-in.-OD tube and a 1.5-in.-ID tube as shown in Figure. The water is at 180°F and is being cooled. The temperature of the inner wall is 100°F, and the outer wall of the annulus is insulated. Neglect entrance effects and compare the results obtained from all four equations

(a) Dittus-Boelter
(b) Sieder-Tate
(c) Petukov
(d) Sleicher-Rouse

The properties of water are given below in engineering units.

T (°F)	m (lb_m/h ft)	k (Btu/h ft °F)	r (lb_m/ft^3)	c (Btu/lb_m °F)
100	1.67	0.36	62.0	1.0
140	1.14	0.38	61.3	1.0
180	0.75	0.39	60.8	1.0

$D_H = 0.5$ for annulus $D_H = D_o - D_i$

$Re_{DH} = \frac{\rho V D_H}{\mu} = 125\,000$

$Pr = \frac{\mu c_p}{k} = 1.92$

Dittus Boelter: $\overline{Nu_{D_H}} = 0.023\, Re_{DH}^{0.8}\, Pr^{0.3}$

$Nu_{DH} = 334$ $\quad \bar{h} = \frac{k}{D}\overline{Nu_{DH}} =$

Sieder Tate: $\overline{Nu_{DH}} = 0.027\, Re_{DH}^{0.8}\, Pr^{0.3}\left(\frac{\mu_w}{\mu_b}\right)^{0.14}$

$\overline{Nu_{DH}} = 358$

Petukov: $f = \frac{1}{[1.82\log_{10} Re_{DH} - 1.64]^2}$

$= 0.01715$

$$\overline{Nu_{DH}} = \frac{\left(\frac{f}{8}\right) Re_{DH}\, Pr}{K_1 + K_2\sqrt{f/8}\,(Pr^{2/3} - 1)}$$

$K_1 = 1 + 3.4 f$

$K_2 = 11.7 + \frac{1.8}{Pr^{1/3}}$

$K_1 = 1.0583$

$K_2 = 13.15$

$\overline{Nu_{D_H}} = 370$

Sleicher Rose

$\overline{Nu_{D_H}} = 5 + 0.015\, Re_D^{\,a}\, Pr^{b}$

$a = 0.88 - \frac{0.24}{4.4 + Pr_w}$

$b = \frac{1}{3} + 0.5 \exp(-0.6\, Pr_w)$

evaluate Prandtl number at T_w

$a = 0.852$

$b = 0.364$

$Re_{DH} = 82237$

$\overline{Nu_{D_H}} = 409$

6) The engine oil flows at the rate of 3000 lb_m/hr through a 3-in –ID pipe. The vpipe is maintained at 210 ^{0}F and oil at 320 ^{0}F .If the pipe is 50 ft long , compute the film coefficient predicted by
(a) Hasen formula
(b) Sider and Tate formula

At 320°F

$\rho = 50.3$ lbm/ft^3

$\mu = 10.9$ lbm/ft-hr

$k = 0.076$ BTU/hr ft °F

$\nu = 0.216$ ft^2/hr

$Pr = 84$

at $T_w = 210$°F

$\mu_w = 413 \dfrac{lbm}{ft\,hr}$

$V = 1215$ ft/hr $\leftarrow \dot{m} = \rho V A \quad A = \dfrac{\pi D^2}{4}$

$Re_D = \dfrac{\rho V D}{\mu} = \dfrac{VD}{\nu} = 1406 < 2300$ laminar flow

$$\overline{Nu_D} = 3.66 + \frac{0.0668\left(\frac{D}{L}\right)Re_D Pr}{1 + 0.04\left[\frac{D}{L} Re\, Pr\right]^{2/3}}$$

$= 13.96$

$\bar{h} = 4.25$ BTU/hr ft^2 °F

If we use Sieder Tate

$$\overline{Nu_D} = 1.86\left[Re\, Pr\right]^{1/3}\left(\frac{D}{L}\right)^{1/3}\left(\frac{\mu_m}{\mu_w}\right)^{0.14} = 13$$

$\bar{h} = 3.95$ BTU/hr ft^2 °F