FINAL – MEN310 (Heat Transfer)

February 02, 2001

1. Hot air at 2 atm and 127°C with a mass flow-rate of 1 kg/s flows across a finned tube bank of configuration shown in fig.P1 and exits at 27°C. Water at 15°C and a mass flow-rate of 4 kg/s flows inside the tubes. The overall dimensions and geometrical characteristics of the heat exchanger are as shown in the figure. The material used for both tubes and fins is copper. Determine:
   a) the total heat transfer rate and the outlet temperatures of water;
   b) the overall heat transfer coefficient as well as the heat transfer coefficients air and water sides.

2. Oil (assume engine oil) at 20°C enters a pipeline made of stainless steel and flows at an average velocity of 1 m/s. The pipeline is 200-m-long and is submerged in a lake of icy water at 0°C. It has a 30-cm inner diameter and 32-cm outer diameter. Determine the temperature of the oil when the pipe leaves the lake and the heat lost to the icy waters.

3. A vertical exhaust pipe (12-cm ID and 12.2-cm OD) carrying combustion gases at 900°C (16% CO_2, 8% H_2O and 76% N_2) and located in a large conditioned space maintained at 22°C is to be insulated for radiation. To do so, the pipe is inserted into a cylindrical radiation shield (24-cm ID and 24.4-cm OD) of unknown surface condition. The pipe is made of turned cast iron and assumed to have negligible resistance to heat transfer by conduction. The surrounding walls are made of rough red bricks with no gross irregularities and are assumed to be at 25°C.

   Determine the emissivity of the shield in order to reduce the radiation heat transfer between the exhaust pipe and the surrounding walls to one tenth of that without the shield. Find the net radiative heat transfer rate per unit length of pipe and calculate the equilibrium temperature of the shield. Neglect conduction and free convection effects.

Points: 1 (50%), 2 (30%), and 3 (20%).

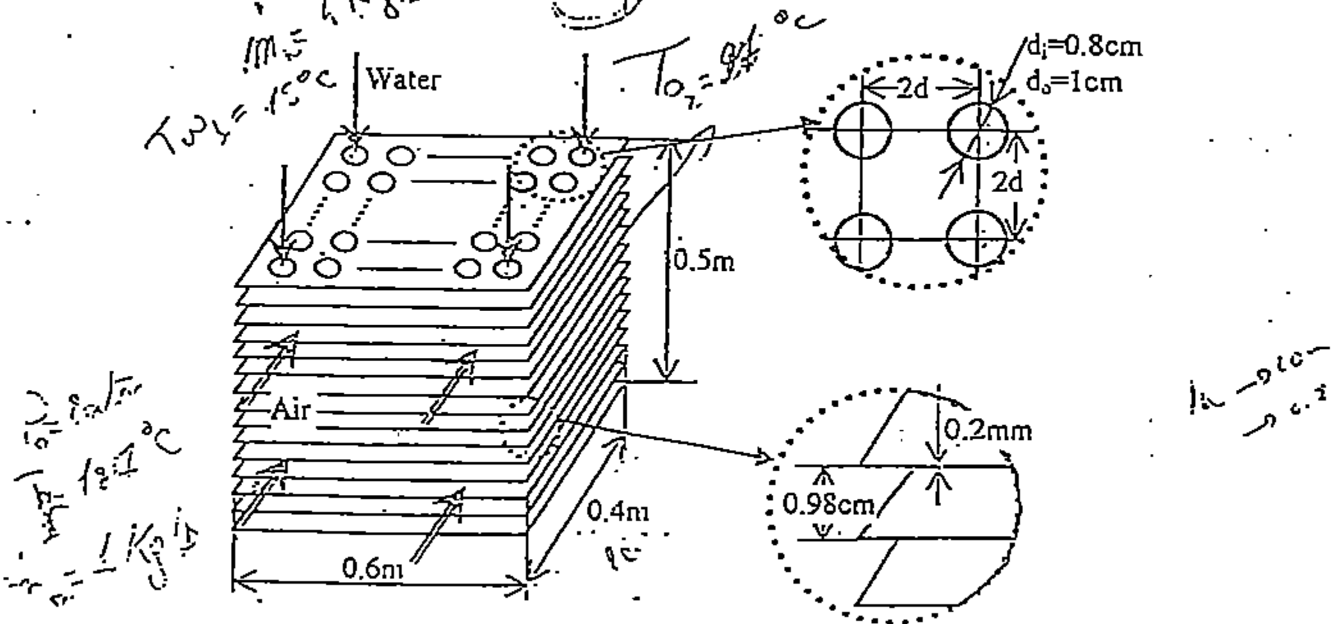

Fig.P1 Cross flow heat exchanger.

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#1/ Hot air $P = 2atm$ cold water $T = 15°C$

$T = 127°C$ $\dot{m} = 4 Kg/sec$

$m = 1 Kg/sec$

$T = 27°C$.

a) • $q = mc\Delta T$ (for air)

$= 1 \times 1006 \times 100 = 100600$ Watts.

• $q = q \longrightarrow 100600 = 4 \times 4180 \times (\Delta T) \rightarrow \Delta T = 6.016$

$\Delta T_m = 43.143$ $\longrightarrow T_{w_2} = 21.01674°C$.

b) $U = ?$

$mc|_{air} = 1 \times 1006 = 1006 \longrightarrow C_{min}$

$mc|_{water} = 4 \times 4180 = 16720 \longrightarrow C_{max}$

$\longrightarrow \epsilon = \dfrac{\Delta T_{air}}{\Delta T_{max}} = 0.8928$ & $\dfrac{C_{min}}{C_{max}} = C = 0.06$

$2.6 = NTU_{max} = \dfrac{AU}{C_{min}} \longrightarrow AU = 2615.6$

Using Fig. 10-11 $\rightarrow P = 0.051$; $R = -16.62$

$\hookrightarrow F = 1$

$q = UAF\Delta T_m$

$\rightarrow q = UA\Delta T_m \longrightarrow UA = \dfrac{q}{\Delta T_m} =$ **$2331.78 = UA$** , $A = n\pi d \ell$

~~[illegible]~~

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- for other water:

$T_b = \frac{21.016 + 15}{2} = 18°C.$

$\dot{m}_{whole} = \rho u A \rightarrow \rho u = \frac{\dot{m}}{A}$

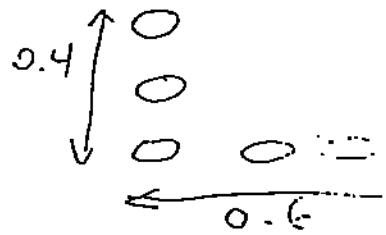
$A = N \times \pi R^2.$

$Re = \frac{u_\infty \cdot d}{\nu} = \frac{\rho u d}{\mu} = \frac{\dot{m} d}{\mu A} = \frac{4.8 \times 0.8 \times 10^{-2}}{(1.058\times10^{-3}) \times \pi (0.4 \times 0.01)^2 \times (23 \times 34)}$

$Re = \frac{601720.0117}{23 \times 34} = 769.462 \rightarrow$ laminar; $k = 0.598$

$Pr = 7.396.$

$\rightarrow$



$Nu_d = 3.66 + \frac{0.0668 (d/L) Re_d Pr}{1 + 0.04 [d/L \, Re \, Pr]^{2/3}}$

$Nu_d = 7.02$

$\hookrightarrow$ $h = 524.838 \; W/m^2 °C$

2d = 2 × 0.9 cm = 1.8.

$\frac{60}{1.8} = 33.33 \rightarrow$

$\frac{40}{1.8} = 22.22 \Rightarrow$

$\rightarrow$ we know

$\frac{\Delta T}{\frac{1}{hA} + \frac{\ln(r_o/r_i)}{2\pi k L}} = q.$

$T_b)_{avg}$ $\xleftarrow{q}$ T_{w_o}

$\frac{1}{hA}$ $\frac{\ln(r_o/r_i)}{2\pi k L}$

where q for a single pipe is $\frac{q}{23 \times 34}$

$\rightarrow$ $\Delta T = \frac{q}{23 \times 34}\left[\frac{1}{hA} + \frac{\ln(r_o/r_i)}{2\pi k L}\right]$

k: copper 386.

$\Delta T = 19.529.$

$\rightarrow T_{w_o} - T_{avg} = \Delta T \rightarrow T_{w_o} = T_{avg} + \Delta T = 37.529 °C$

free convection:

$T_w = 37.529 °C$ $T_\infty = \frac{147 + 27}{2} =$

$\rightarrow$ h forced in line arrangement

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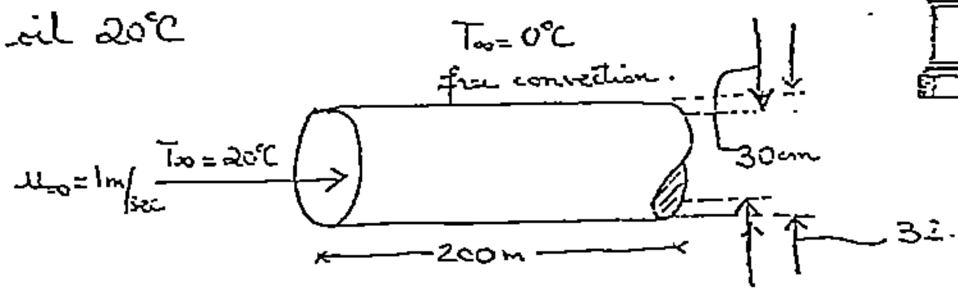
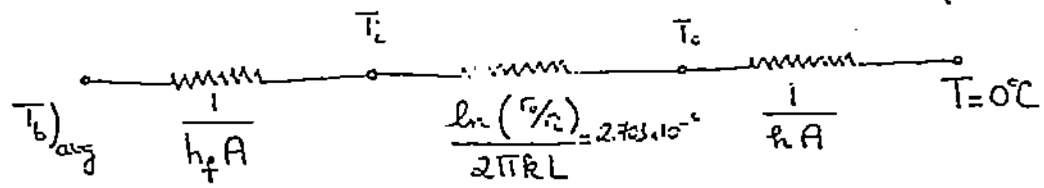
engine oil 20°C

2) steel = 19 W/m°C = k





Assuming a $T_{b_2} = 10°C \longrightarrow T_b)_{avg} = \frac{20+10}{2} = 15°C$.

↳ $\nu = 0.001745$ m²/sec ; $\rho = 890.9525$; $c_p = 1.859 \times 10^3$; k = 0.1455

$Pr = 19575$

$Re_d = \frac{1 \times 0.3}{\nu} = 171.919 < 2300 \rightarrow$ laminar

$q = \dot{m} c_p (T_{b_2} - T_{b_1}) = \rho . u . \frac{\pi d^2}{4} . c_p . (\Delta T_b) = 1170755.836$ Watts.

↳ eq. 6.9 → $Nu_d = 30.0644145$ → $h = 14.5812$ W/m²°C

↳ $q = \frac{T_{b_{avg}} - T_i}{\frac{1}{h_f A}} \rightarrow T_i = -410$ impossible.

Assuming $T_{b_2} = 19°C \longrightarrow T_b)_{avg} = 19.5°C$.

↳ $\rho = 888.50225$; $c_p = 1.8779 \times 1000$; $\nu = 9.845 \times 10^{-4}$; k = 0.14505 ; Pr = 1

↳ $Re_d = 304.7232 \rightarrow Nu_d = 30.3145 \rightarrow$ $h = 14.657$ W/m²°C

$q = \dot{m} c_p (T_{b_2} - T_{b_1}) = 117940.6141$

↳ $q = \frac{(T_{b_{avg}} - T_i)}{\frac{1}{hA}} \rightarrow T_i = -23.189$ impossible

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Assuming $T_{b_2} = 19.9°C \approx 20 \rightarrow$ $\nu =$ __ , $k =$ __ , $c_p =$ __ , $\rho =$ __ from table.

$\rightarrow h \approx 14.7\ W/m^2°C$.

$\rightarrow q = mc\Delta t$

$q = 11803.63244$ watts.

↳ $\frac{q}{hA} = T_{b_{avg}} - T_i \rightarrow T_i = T_{b_{avg}} - \frac{q}{hA} =$ **$15.7°C = T_i$**

• due to conduction $\rightarrow q = \frac{T_i - T_o}{R} \rightarrow$ **$T_o = 15.67°C$**

• due to free convection:

$T_\infty = 0°C$ $T_w = 15.67°C$.

$T_f = \frac{15.67}{2} = 7.835\ °C \rightarrow 280.835 \approx 281 K$

↳ $\nu =$

$k = 0.58111$

$Pr = 10.15855$

$\frac{g\beta\rho^2 c_p}{\mu k} = 4.61673 \times 10^5$.

↳ $Gr\,Pr = 2370573405 = 2.37 \times 10^9$

$\overline{Nu}_f = C(Gr\,Pr)^m = 0.13\,(Gr\,Pr)^{1/3} = 173.338$

$\rightarrow h = 314.7714\ W/m^2°C$. Since $h \ggg \rightarrow T_w$ must be very close to T_∞

$\rightarrow \Sigma R)_{equivalent} = \frac{1}{h_f A}\Big)_{forced} + 2.703 \times 10^{-6} + \frac{1}{hA}$

$\rightarrow \Sigma R = 3.79399 \times 10^{-4}$. $\rightarrow q = mc\Delta T = \frac{T_b)_{avg} - 0}{\Sigma R} \rightarrow T_{b_2} < 0$ imp

~~$\rightarrow q = 11803.63244 = \frac{T_b)_{avg} - 0}{\Sigma R} \rightarrow T_b)_{avg} = 4.478283°C$.~~

~~$\rightarrow \frac{T_{b_1} + T_{b_2}}{2} = 4.47 \rightarrow T_{b_2} < 0$ impossible.~~

~~$q = \frac{T_b)_{avg}}{\Sigma R} = mc_p(T_2 - T_1) \rightarrow T_{b_2} =$~~

WRONG ASSUMPTION NOT PHY

(Taking $T_w = 0°C \rightarrow$ neglecting free convection $\rightarrow$ calculate again

(see solved problem in Test 3 : Jan. 23, 2001 ; # 2 part a))

↳ This solution is <u>not</u> true.

↳ The assumption of <u>any</u> temp. b/w the 2 given values should work. Pb. might be wrong.

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neglect conduction & free convection → $T_1 = 900°C$
(else we would do convection inside)

Votre Réf. Date Feb. 02, 2001

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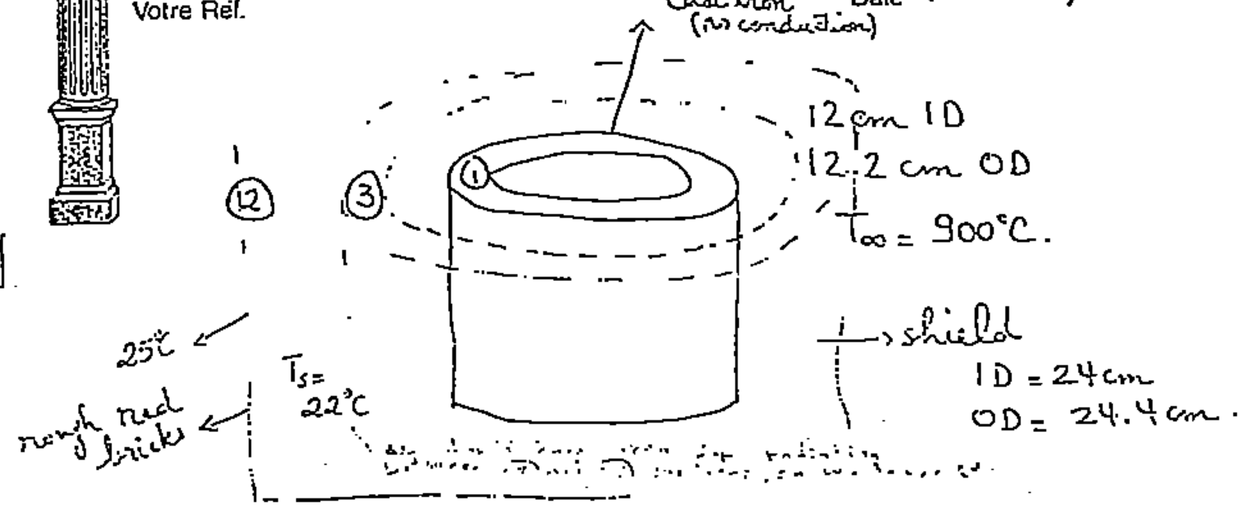

$\epsilon = ?$ $T_{shield} = ?$ $q_{net} = ?$

<u>with no shield:</u>

E_{b_1} —$\frac{1-\varepsilon_1}{A_1\varepsilon_1}$— J_1 —$\frac{1}{F_{12}A_1}$— $J_2 = E_{b_2}$ $F_{12} = 1$

$$q = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{F_{12}A_1}} = \frac{A_1\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} - 1 + 1} = \varepsilon_1 A_1 \sigma(T_1^4 - T_2^4)$$

<u>with shield:</u>

E_{b_1} —$\frac{1-\varepsilon_1}{\varepsilon_1 A_1}$— J_1 —$\frac{1}{A_1 F_{13}}$— J_3 —$\frac{1-\varepsilon_3}{\varepsilon_3 A_3}$— E_{b_3} —$\frac{1-\varepsilon_3}{\varepsilon_3 A_3}$— J_3' —$\frac{1}{F_{32}A_3}$— $J_2 = E_{b_2}$

$$q = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{13}} + \frac{1-\varepsilon_3}{\varepsilon_3 A_3} + \frac{1-\varepsilon_3}{\varepsilon_3 A_3} + \frac{1}{F_{32}} A_1} = \frac{\sigma(T_1^4 - T_2^4)}{R}$$

$$q_w = \frac{1}{10} q_{no\,shield} \rightarrow \frac{\sigma(T_1^4 - T_2^4)}{R} = \frac{1}{10}\varepsilon_1 A_1 \sigma(T_1^4 - T_2^4)$$

$$\rightarrow \frac{1}{R} = \frac{\varepsilon_1 A_1}{10} \rightarrow R = \frac{10}{\varepsilon_1 A_1} \rightarrow \frac{1-\varepsilon_1}{\varepsilon_1(\pi \times 0.122)} + \frac{1}{\pi \times 0.122} + \frac{1-\varepsilon_3}{\varepsilon_3(\pi \cdot 0.24)} + \frac{1-\varepsilon_3}{\varepsilon_3(\pi\ldots} + \frac{1}{\pi(0.244)} = \frac{10}{\varepsilon_1(\pi \times 0.1\ldots}$$

where $\epsilon_1 = 0.6$ (Table A-10)

$\rightarrow \epsilon_3 = \underline{121} = 0.06502$

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$$q = \frac{\varepsilon_1 A_1 \sigma (T_1^4 - T_2^4)}{10} = 2457.800355 \text{ Watts.}$$

$$q = \frac{\sigma (T_1^4 - T_3^4)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1 F_{13}} + \frac{1-\varepsilon_3}{\varepsilon_3 A_3}} \longrightarrow T_3 = 967.937\,K$$

$\longrightarrow$ $\boxed{T_3 = 694.937\,°C}$