Notre Dame University Faculty of Engineering Mechanical Engineering Dep.

Sp01

FINAL – MEN310 (Heat Transfer)

June 25, 2001

1. An incandescent light bulb is an inexpensive but highly inefficient device that converts electrical energy into light. It converts about 10% of the electrical energy it consumes into light while converting the remaining 90% into heat. The glass bulb of a lamp heats up very quickly as a result of absorbing all that heat and dissipating it to the surroundings by convection and radiation. Consider a 60-W light bulb of 8-cm diameter (approximated by a sphere) in a room at 25°C. Determine the equilibrium temperature of the glass bulb. Assume the interior surface of the room to be at room temperature. The emissivity of the glass is 0.9.

2. A 2-m-inner-diameter double-walled stainless-steel spherical tank (fig.P2) is used to store iced water at 0°C. Each wall is 0.5-cm-thick, and the 1.5-cm-thick air space between the two walls of the tank is evacuated in order to minimize heat transfer. The surfaces surrounding the evacuated space are polished so that each surface has an emissivity of 0.15. The tank is placed in an ambient at 25°C. Assuming that the heat transfer coefficient on the iced water side is very large so that the inner wall temperature is at 0°C, determine the rate of heat transfer to the iced water in the tank. By how much did the evacuation of the air space improve the insulation of the tank?

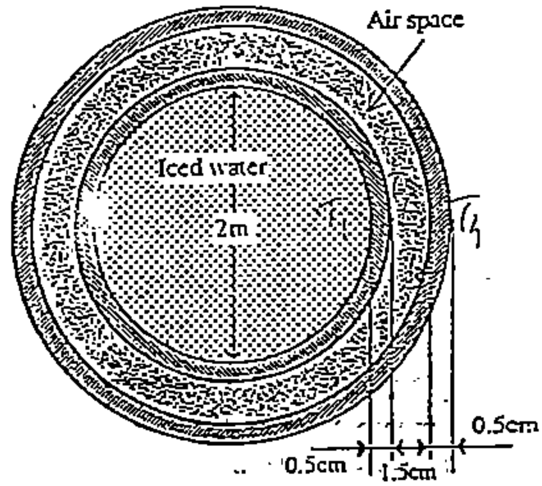

Fig. P2 Spherical Tank.

3. A cross-flow heat exchanger consists of 40 thin walled copper tubes of 1-cm diameter located, as a single row across the flow, in a duct of 1m×1m cross-section. There are no fins attached to the tubes. Cold water enters the tubes at 18°C with an average velocity of 1 m/s, while hot air enters the channel at 130°C and an average velocity of 1 m/s. If the overall heat transfer coefficient is 80 W/m^2°C, determine the exit temperatures of both fluids and the rate of heat transfer. What can be said about such a design of heat exchanger and how may the things be improved?

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

PS. Free convection in a spherical annulus can be described by

$$Nu_\delta = 0.228 Ra_\delta^{0.226} \qquad \text{for} \quad 10^2 < Ra_\delta < 10^9$$

where δ is the annulus thickness.

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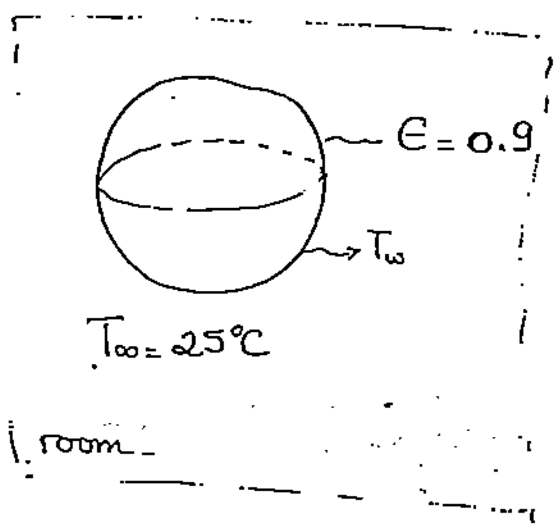
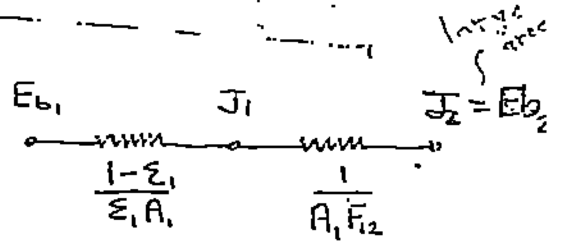
1) $q = 60$ Watt

$d = 8$ cm diameter.

$T_\infty = 25°C$



$q_{radiation} = A_1 \epsilon_1 \sigma (T_w^4 - T_\infty^4)$



$q_{convection} = h A (T_w - T_\infty)$

$q \times 0.9 = q_{rad} + q_{convection}$

$F_{12} = 1$

for convection $\rightarrow$ Assuming $T_w = 75°C$ $\rightarrow T_f = \frac{75+25}{2} = 50°C \rightarrow 323K$

$\rightarrow \quad Gr_f = \frac{g\beta (T_w - T_\infty) d^3}{\nu^2}$

$\hookrightarrow \beta = \frac{1}{323}$

$\nu = 18.0222 \times 10^{-6}$ m²/sec

$Gr\,Pr = 1680994.01$

$Pr = 0.70294$

$\hookrightarrow \quad Nu_f = 2 + 0.5 (Gr\,Pr)^{1/4}$

$k = 0.0279834$ W/m°C

$\hookrightarrow \quad h = \frac{k}{d} \left[2 + 0.5 (Gr\,Pr)^{1/4} \right] = 6.99714$ W/m²°C.

$\therefore \quad 60 \times 0.9 = 4\pi (0.08)^2 \times 0.9 \times 5.669 \times 10^{-8} (T_w^4 - 25^4) + 6.99714 \times 4\pi (0.08)^2 (T_w -$

$\rightarrow T_w = 119.47°C.$

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Repeating the problem :

$$T_f = \frac{119.47 + 25}{2} = 72.235° = 345.235\ K$$
$$\approx 345\ K.$$

$\rightarrow \beta = \frac{1}{345}$

$\rightarrow \nu = 20.253 \times 10^{-6}$

$\rightarrow Pr = 0.6981$

$\rightarrow k = 0.029651$

$Gr\,Pr = 2338351.365$

$\hookrightarrow \quad Nu_f = 2 + 0.5\,(Gr\,Pr)^{1/4}$

$\rightarrow h = 7.8841\ W/m^2\,°C$

$\rightarrow 60 \times 0.9 = 4\pi(0.08)^2 + \cdots\cdots$ change h

$\rightarrow \boxed{T_w = 109.24\ °C}$

We could iterate more -----

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Votre Réf.

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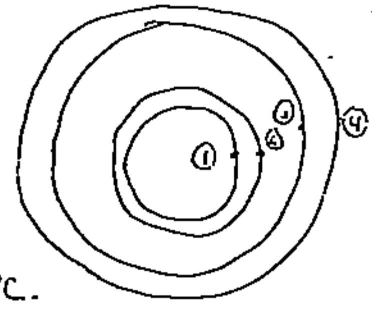
spherical tanks

$\varepsilon = 0.15$



⑤ $T_\infty = 25°C$

$r_1 = 1\,m.$

$r_2 = 1.005\,m$

$r_3 = 1.02\,m$

$r_4 = 1.025\,m$

2/ $T_1 = 0°C.$

$k_{steel} = 19\,W/m°C.$

evacuation:

$T_1 = 0°C$ — T_2 — $R_{radiation}$ — T_3 — T_4 — $T_5 = 25°C$

$$\frac{\frac{1}{r_1}-\frac{1}{r_2}}{4\pi K} = 2.08373 \times 10^{-5} \qquad R_{radiation} \qquad \frac{\frac{1}{r_3}-\frac{1}{r_4}}{4\pi K} = 2.003 \times 10^{-5} \qquad \frac{1}{hA}$$

where

$$q_{2\text{-}3} = \frac{\sigma A_2 (T_2^4 - T_3^4)}{1/\varepsilon_2 + \left(\frac{1}{\varepsilon_3}-1\right)\left(\frac{r_2}{r_3}\right)^2} = \frac{\sigma A_2 (T_2 - T_3)(T_2+T_3)(T_2^2+T_3^2)}{\frac{1}{\varepsilon_2} + \left(\frac{1}{\varepsilon_3}-1\right)\left(\frac{r_2}{r_3}\right)^2} = \frac{(T_2 - T_3)}{R_{rad}}$$

where

$$R_{rad} = \frac{1}{\varepsilon_2} + \left(\frac{1}{\varepsilon_3}-1\right)\left(\frac{r_2}{r_3}\right)^2 \cdot \frac{1}{\sigma A_2 (T_2+T_3)(T_2^2+T_3^2)} = \frac{7645596.61}{(T_2+T_3)(T_2^2+T_3^2)}$$

Assuming $T_4 = 15°C \longrightarrow T_f = \frac{15+25}{2} = 20°C \longrightarrow 293K.$

$\hookrightarrow \nu = 15.0768 \times 10^{-6}\,m^2/sec.$

$k = 0.0256842$

$Pr = 0.70996. \longrightarrow Gr\,Pr = 8999856228$

$$\longrightarrow Nu = 2 + \frac{0.589\,Ra_d^{1/4}}{\left[1 + (0.469/Pr)^{9/16}\right]^{4/9}} \longrightarrow h = 1.77891229\,W/m^2°C$$

$$\longrightarrow q = \frac{T_5 - T_4}{R_{45}} \longrightarrow q = \frac{10}{R_{45}} \longrightarrow \boxed{q = 234.861\,\text{Watts}}$$

$$\longrightarrow q = \frac{T_4 - T_3}{R_{34}} \longrightarrow \boxed{T_3 = 14.995°C} \longrightarrow T_3 = 287.995K$$

$$\longrightarrow q = \frac{T_2 - T_1}{R_{12}} \longrightarrow \boxed{T_2 = 0.00489°C} \qquad T_2 = 273.00489K$$

$\longrightarrow R_{rad} = 0.086545$

$\longrightarrow q = 173.2055$ Watts

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$q = 173.2055$

$\rightarrow \quad q = (T_5 - T_4)\, hA \rightarrow$

$\hookrightarrow T_4 \simeq 17.625°C \rightarrow T_4 = 18°C.$

2nd iteration:

$T_f = \frac{18+25}{2} = 21.5 \rightarrow 294.5\ K$

$\hookrightarrow \nu = 15.2082 \times 10^{-6}\ m^2/sec$

$k = 0.0258033\ W/m°C.$

$P_r = 0.70954.$

$G_r P_r = 6156326620$

$\hookrightarrow h = 3.25496\ W/m^2 °C.$

$\hookrightarrow q = \frac{T_5 - T_4}{R_{45}} \rightarrow q = 300.8162484$ watts

$\hookrightarrow T_3 = 17.99°C \rightarrow 290.99K$

$\hookrightarrow T_2 = 0.00628°C \rightarrow 273.00628K.$

$\hookrightarrow R_{rad} = 0.085147$

$\hookrightarrow q_{2-3} = 211.207911$

- whenever the gap is full of air

the same network resistance is encountered
but another resistance for free convection should be
added b/w 2 & 3 in parallel with R_{rad}.

2 — R_{rad} — 3
— $\frac{1}{h_{free}A}$ —

for case (a) → when $T_f = 15$ was chosen

$\rightarrow T_2 = 0.00489 \quad \& \quad T_3 = 14.995. \rightarrow T_f = \frac{14.995 + 0}{2} \approx 7.5°C = 280.5K$

$\hookrightarrow \nu = 13.9818 \times 10^{-6} \ ; \ k = 0.0246917 \ , \ P_r = 0.71346 \rightarrow G_\delta P_r = 6450.$

$Nu_\delta = \frac{h\delta}{k} = 0.228\, Ra_\delta^{0.226} \Rightarrow h = 2.725\ W/m^2 °C.$

$\rightarrow \frac{1}{h_{free}A} = R_{free} = 0.028486$

$\hookrightarrow R_{eq} = \frac{1}{\frac{1}{R} + \frac{1}{R}} = 0.0214\,3 \rightarrow q = \frac{15}{R_{eq}} = \boxed{699.894}$ W

(it has gone down from 699.894 to 173.2055)

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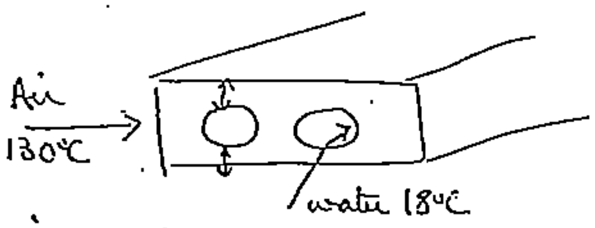

3)

$$\dot{m}_a C_a \Delta T_a = \dot{m}_w C_w \Delta T_w.$$

Assuming $T_{a_2} = 100°C$.

$\rightarrow \rho V A C_a \Delta T_a = \dot{m}_w C_w \Delta T_w = \rho_w V A_w C_w \Delta T_w$. (Using app. values)

$$\rightarrow \Delta T_w = \frac{0.8826 \times 1 \times 0.99 \times 1014 \times 30}{998 \times 1 \times 40 \times \pi \times 0.005^2 \times 4180} \rightarrow T_{w_2} = 20.028°C$$

$\dot{m}c\rfloor_{air} = C_a = 886$

$\dot{m}c\rfloor_{water} = C_w = 13105.593 \longrightarrow C_{min} = air = 886.$

$$\rightarrow \varepsilon = \frac{\Delta T)_{air}}{\Delta T_{max}} = \frac{130-100}{130-18} = 0.26785$$

using figure 10-1~~0~~ $\rightarrow$ $P = 0.018$; $R = -$; $F \approx 1 \rightarrow$ no factor.

having $\varepsilon = 0.26785$ & $C = \frac{C_{min}}{C_{max}} = 0.0676 \xrightarrow{Fig\ 10-15} N = 0.4 = NTU_{max}$

$\rightarrow NTU_{max} = \frac{AU}{C_{min}} \rightarrow A = 4.43\ m^2.$

$\rightarrow q = UA \Delta T_m = \dot{m} C_a \Delta T_a.$

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$$q = \underset{\sim}{UA}\,\Delta T_m = mc\,\Delta T_a = mc\,\Delta T_b.$$

$$\rightarrow \underset{80\times 4.43}{UA}\left[\frac{(T_{h_2}-T_{c_2})-(130-18)}{\ln\left((T_{h_2}-T_{c_2})/130-18\right)}\right] = C\,\Delta T_a = 886(130-T_{h_2})$$
$$= 13105\,(T_{c_2}-18)$$

where $\rightarrow$ $886\,(130-T_{h_2}) = 13105\,(T_{c_2}-18)$

$$\rightarrow \boxed{T_{c_2} = \frac{886\,(130-T_{h_2}) + 13105\times}{13105}}$$

Solving $\rightarrow$

where $$T_{h_2}-T_{c_2} = \frac{T_{h_2}\times 13105 - 886(130-T_{h_2}) - 13105\times 18}{13105}$$

$$= \frac{13991\,T_{h_2} - 351070}{13105}$$

$$= \boxed{1.068\,T_{h_2} - 26.789}$$

$$\rightarrow 80\times 4.43\left[\frac{1.068\,T_{h_2}-26.789-112}{\ln\left[(1.068T_{H_2}-26.789)/112\right]}\right] = 886(130-T_{h_2})$$

Solving

$\rightarrow$ $T_{h_2} = 93.53107173\,°C$

$\hookrightarrow$ $T_{c_2} = 20.465\,°C$.

$q = 32311.534$ Watts