Notre Dame University | Faculty of Engineering | Mechanical Engineering Dep.

F91

TEST – MEN310 (Heat Transfer)

November 12, 2001

1. A stainless steel pipe of 12-mm inner diameter and 16-mm outer diameter is used to carry steam over a distance of 20 m. The steam enters at 150°C with a mass flowrate of 0.5 kg/s. The flow regime is assumed to be turbulent and as a result the heat transfer coefficient can be considered very large so that the temperature of the inner surface of the pipe wall and the steam temperature are the same. The pipe is subjected to an outside environment characterized by a heat transfer coefficient of 15 $W/m^2 °C$ and a temperature of 20°C. Determine the heat lost to the surroundings and the exit temperature of steam. Find the temperature distribution across the pipe wall at 10m from the inlet.

2. The pipe of problem 1 is now considered as a part of a double-pipe condenser used to condense the steam by removing its heat content. In general, faster the heat rate exchanged between the steam and the cooling fluid, better is the performance of the condenser. To enhance the heat transfer mechanism, the pipe is surrounded by a set of circular fins as sketched in fig.P2. The fins are made of aluminum and have a diameter of 30 mm and a thickness of 2mm.The distance between fins is 3 mm. The cooling fluid flows in the annular space with a heat transfer coefficient of 50 $W/m^2 °C$ and an average temperature of 25°C. Determine the heat lost by the steam and its exit temperature.

3. Another application of piping carrying steam is district heating. The same pipe as in problem 1 is now buried in the earth at a depth of 50 cm and at a location where the conductivity of the soil is 0.9 W/m°C. The surface temperature of the earth is assumed to be constant equal to 10°C. Determine the heat lost by the steam and its exit temperature.

4. Assuming that the fins used in problem 2 are optimized so that the final shape is as shown in fig.P4. Considering the node distribution given, find the temperatures of nodes 1 and 2. Neglect heat resistance in the pipe wall.

Points: 1 (30%), 2 (30%), 3 (15%) and 4 (25%).

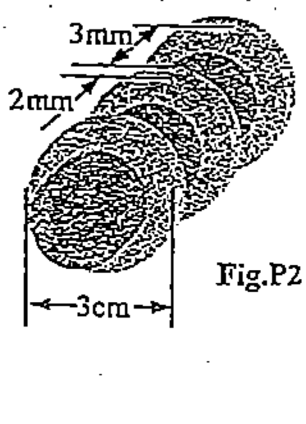

Fig.P2

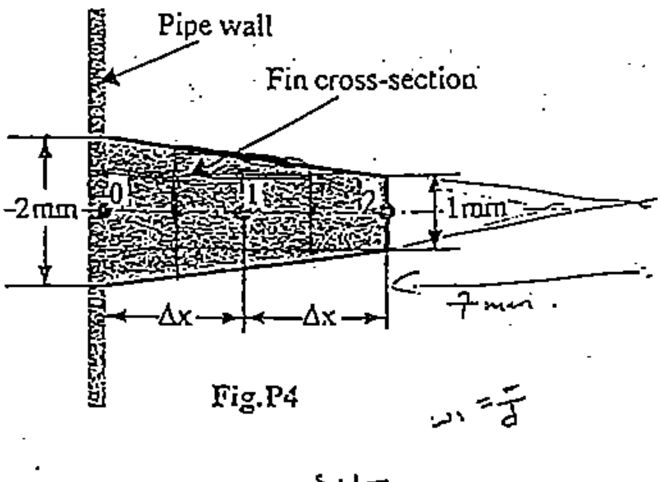

Fig.P4

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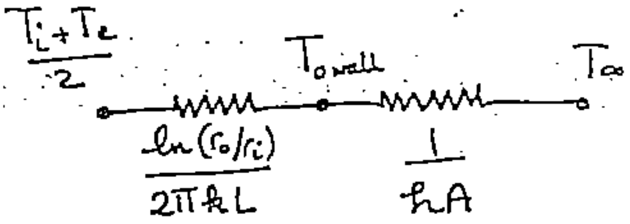
1)
ID = 12 mm
OD = 16 mm
L = 20 m

$T_i = 150°C$ $\quad \dot{m} = 0.5\ Kg/sec$
steam

$h = 15\ W/m^2\,°C$ $\quad T_\infty = 20°C$



$q = ?$ $\quad T_e = ?$

$T(r)\big|_{x=10m}$

$$q = \frac{\frac{T_i+T_e}{2} - T_\infty}{\frac{\ln(r_o/r_i)}{2\pi k L} + \frac{1}{hA}}$$

$$q = \dot{m}c\,(T_i - T_e) = q$$

where $\dot{m} = 0.5\ Kg/sec$
$c = 4.296\ KJ/Kg\,°C$
$T_i = 150°C$

$T_i = 150°C$
$T_\infty = 20$
$r_o = 8$ mm
$r_i = 6$ mm
$k = 19\ W/m°C$

$L = 20m$
$h = 15\ W/m^2\,°C$
$A = 2\pi r_o . L$

$$\rightarrow \quad 0.5 \times 4.296 \times 1000 \times (150 - T_e) = \frac{\frac{150+T_e}{2} - 20}{\frac{\ln(8/6)}{2\pi \times 19 \times 20} + \frac{1}{15 \times 2 \times \pi \times 0.008 \times 20}}$$

$\hookrightarrow$ $\boxed{T_e = 149.092154°C}$

$\hookrightarrow$ $\boxed{q = 1949.967\ \text{Watts}}$ $\longrightarrow$ $q = hA(T_{ow} - T_\infty)$ $\rightarrow$ $T_{\text{outer wall}} = 149.311°C$

$$p.\ 2.27 \longrightarrow T = \frac{-\dot{q}r^2}{4K} + C_1 \ln r + C_2 \;/\; \dot{q} = 0 \rightarrow T = C_1 \ln r + C_2.$$

$$r_i = 6mm \longrightarrow T_i\big|_{x=10} = T_{avg} = \frac{T_i+T_e}{2} = 149.546077°C$$

$$r_o = 8mm \longrightarrow T_o\big|_{x=10} = 149.311°C$$

$\rightarrow$ system of equations $\longrightarrow$ $C_1 = -0.817211$ / $C_2 = 145.365$

#2) $h = 50\ W/m^2\,^\circ C$

$T_\infty = 25^\circ C$

$t = 2\ mm$

$L = r_2 - r_o = 7\ mm$ (r_o: r_1)

for circular fins

$$L_c = L + t/2 = 7 + \frac{2}{2} = 8\ mm$$

$$r_{2c} = r_1 + L_c = 8 + 8 = 16\ mm$$

$$A_m = 2(8) = 16\ mm$$

$k_{Al} = 200\ W/m\,^\circ C$

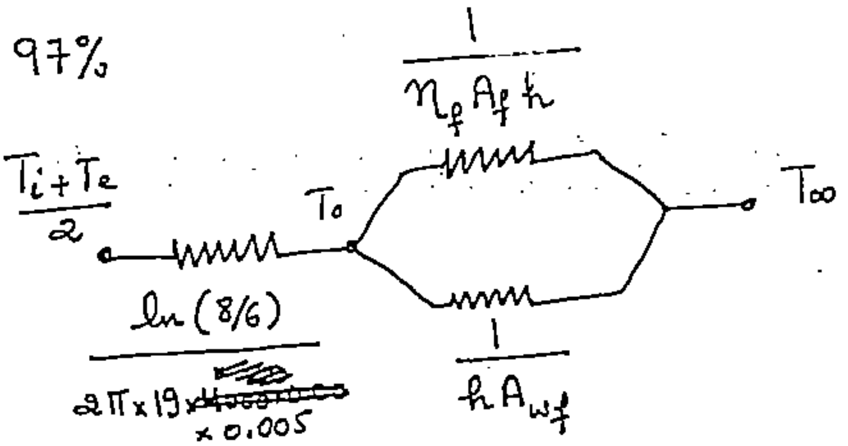
$\hookrightarrow \frac{r_{2c}}{r_1} = \frac{16}{8} = 2$

$$L_c^{3/2} \cdot \left(\frac{h}{kA_m}\right)^{\frac{1}{2}} = (0.008)^{\frac{3}{2}} \cdot \left(\frac{50}{200 \times 16 \times 10^{-6}}\right)^{\frac{1}{2}}$$

$$= 0.089$$

$\hookrightarrow \eta_f = 97\%$

20 m
$\frac{20000}{5} \hookrightarrow$ 4000 fin



where $\frac{1}{\eta_f \cdot A_f \cdot h} = \frac{1}{0.97 \times 2\pi(r_{2c}^2 - r_1^2) \times 50} = 17.09$

$\frac{1}{h A_{wf}} = \frac{1}{50 \times 2\pi \times 0.008 \times 0.003} = 132.63$

$\hookrightarrow R_{eq} = 15.62$

$\hookrightarrow \quad mc\Delta t = 4000 \times \frac{\frac{T_i + T_e}{2} - 25}{R_{eq}}$

$\hookrightarrow 0.5 \times 4.296 \times 1000 \times (150 - T_e) = \frac{4000}{15.62} \times \left(\frac{150 + T_e}{2} - 25\right)$

Solving $\rightarrow$ $\boxed{T_e = 135.935\,^\circ C}$

#3) Table 3-1

$D = 50\,cm = 0.5\,m$ $\qquad$ $k = 0.9\,W/m\,°C$

$r = 0.008\,m.$ $\qquad$ $T_c = 10°C.$

$L = 20\,m$

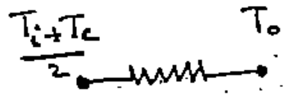
$\left.\begin{array}{l} L \gg r \\ D > 3r \end{array}\right\} \rightarrow \quad S = \dfrac{2\pi L}{\ln(D/r)}$ $\qquad$ $\Delta T =$

$$q = kS\Delta T_{overall} = k \times \frac{2\pi L}{\ln(D/r)} \times (T_{object} - 10)$$

$$mc\,\Delta T = k \times \frac{2\pi L}{\ln(D/r)} \cdot (T_{object} - 10)$$

$$1.5 \times 4.296 \times 1000 \times (150 - T_e) = \frac{0.9 \times 2\pi \times 20}{\ln(0.5/0.008)} (T_o - 10)$$

$$78.54\,(150 - T_e) = (T_o - 10)$$



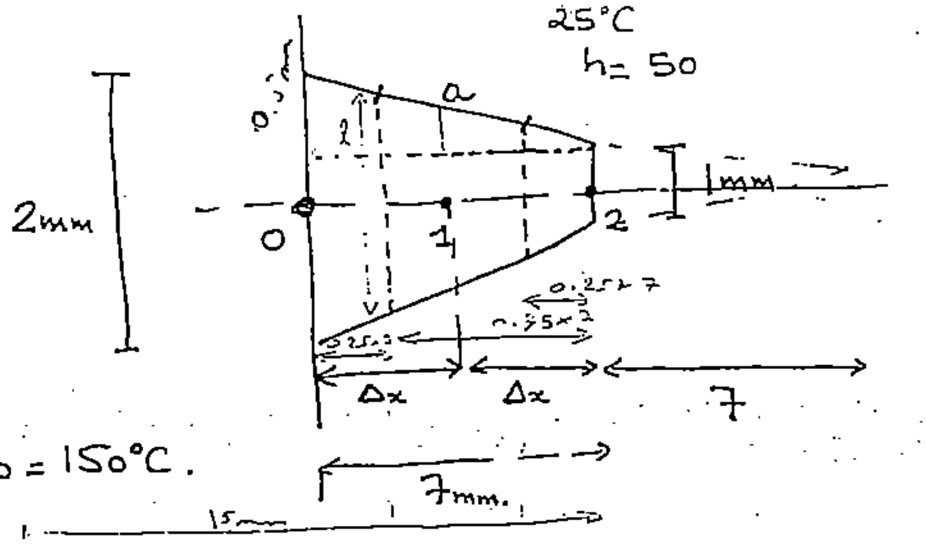
$$T_o \approx \frac{T_i + T_e}{2}.$$

$\hookrightarrow \quad 78.54\,(150 - T_e) = \left(\dfrac{150 + T_e}{2} - 10\right)$

$\hookrightarrow \quad \boxed{T_e = 148.228°C}$

$\hookrightarrow \quad \boxed{q = 3806.256 \text{ Watts}}$

#4



At 0 : $T_0 = 150°C$.

Node 1

$$\cancel{\dot{q}_1} + \frac{T_0 - T_1}{R_{01}} + \frac{T_2 - T_1}{R_{21}} + 2\,\frac{T_\infty - T_1}{R_{1\infty}} = 0$$

$$\hookrightarrow \quad \frac{150 - T_1}{R_{01}} + \frac{T_2 - T_1}{R_{21}} + 2 \cdot \frac{25 - T_1}{R_{1\infty}} = 0$$

$$R_{01} = \frac{0.0035}{200 \times 2\pi \times \underbrace{0.00975}_{r} \times \underbrace{0.00175}_{l}}$$

$$\frac{l}{2} = \frac{7 + 7\times 0.75}{14}$$

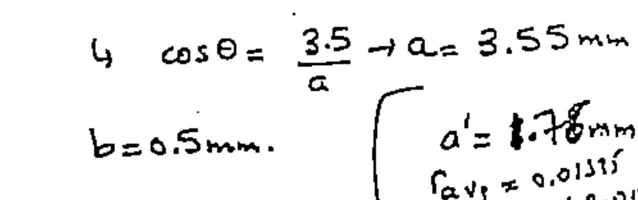
$\hookrightarrow l = 0.00175\ m$

$$\hookrightarrow \frac{1}{R_{01}} = 6.126$$

$$R_{21} = \frac{0.0035}{200 \times 2\times\pi \times 0.01325 \times 0.00125}$$

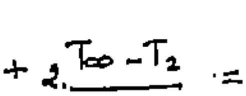
$$\frac{l}{2} = \frac{7 + 7\times 0.25}{14}$$

$$\hookrightarrow \frac{1}{R_{21}} = 5.947$$



$$R_{1\infty} = \frac{1}{hA} = \frac{1}{50 \times A_1}$$

$\hookrightarrow \theta = \tan^{-1}\frac{1}{7} \rightarrow \theta = 8.13°$.



$$A_1 = 2\pi\left(\frac{0.00975 + 0.01325}{2}\right)a$$

$\hookrightarrow \cos\theta = \frac{3.5}{a} \rightarrow a = 3.55\ mm.$

$A_1 = 2.565\times 10^{-4}\ m^2$.

$b = 0.5\ mm.$

$a' = 1.78\ mm$

$r_{avg} = 0.01375 + \frac{0.015}{2}$

Node 2:

$$\frac{T_1 - T_2}{R_{12}} + \frac{T_\infty - T_2}{\underset{(right)}{R_{2\infty}}} + 2\,\frac{T_\infty - T_2}{\underset{(up, down)}{R_{2\infty}}} = 0$$

; $A_2 = 2\pi\, r_{avg} \cdot a'$.

$A_2 = 1.562\times 10^{-4}\ m^2$.

where $R_{2\infty\,(up,down)} = \frac{1}{h\,A}$; $R_{2\infty\,(right)} = \frac{1}{\ }$; $A = 2\pi \times 0.015 \times 0.001$

The 2 equations becomes:

$$\begin{cases} 6.126(150 - T_1) + 5.947(T_2 - T_1) + 2 \times 50 \times 2.565 \times 10^{-4}(25 - T_1) = 0 \\ 5.947(T_1 - T_2) + 50 \times 2\pi \times 0.015 \times 0.001(25 - T_2) + 2 \cdot 50 \times 1.562 \times 10^{-4}(25 - T_2) \end{cases}$$

$$\begin{cases} 919.54125 - 12.09865\, T_1 + 5.947\, T_2 = 0 \\ 5.947\, T_1 - 5.967\, T_2 + 0.5083 = 0 \end{cases}$$

Solving:

$$\boxed{\begin{aligned} T_1 &= 149.0780974\,^\circ C \\ T_2 &= 148.66\,^\circ C. \end{aligned}}$$