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ENCH 501: Transport Processes Quiz #2 **September 24, 2002**

Time Allowed: 50 mins. **Name:**

Problem #1 (7 points)

A modern alternative to heating homes with forced air flow through a furnace (located in the basement) is the electric or hydronic floor heating ("radiant") system. Electric resistance elements or tubes are buried in the floor. In the hydronic system, hot water or ethylene glycol is passed through rows of horizontal parallel tubes to transfer heat, via the floor, into a room or to melt snow/ice from runways or walkways exposed to the elements. For home heating, the system is claimed to reduce heating costs by 40% compared to forced air systems and does not throw dust into the air.

You are required to design a system to maintain a walkway in your petroleum refinery ice-free. A variable-capacity heater maintains glycol at 85°C and the glycol is to be passed through the tubes at a sufficiently high rate that you can assume a negligible temperature drop along the length of each tube. Each tube has an i.d. of 1.8cm. Temperatures of ambient air at the location, when snow falls, vary between -2 and -25°C. The typical heat transfer coefficient in the area, at the ground-air interface, is given as 23.8 W/m^2K.

(a) If the tubes are buried to a depth of 9.1cm (i.e. if you are digging down to the top of the tube) in concrete, k=0.76 W/mK, and the walkway is 16m long, how far apart (wall-to-wall) should the tubes be positioned? State any assumptions. Show your calculations.

(b) If the ambient air temperature suddenly dropped to -40°C and snow is falling, what would you recommend be done to keep the walkway free of ice? Justify.

Problem #2 (3 points)

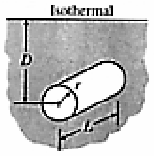
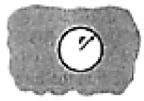
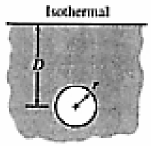
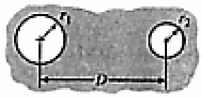
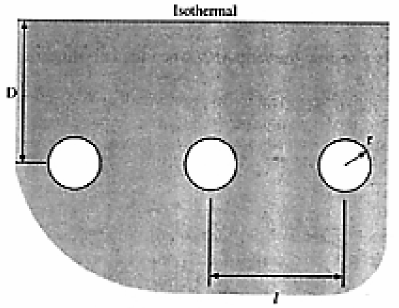
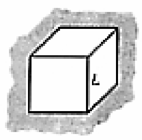
The shear stress along a flat plate may be estimated from the expression:

$$\tau_w = 0.0296\,(\nu/u_\infty x)^{0.2}\rho u_\infty^2\,, \quad \text{where } \nu = \mu/\rho$$

Estimate the value for and the error in the wall shear, given the following data -

$u_\infty = 5\pm0.3$ m/s, $x=1.2\pm0.05$ m, $\rho=980\pm12$ kg/m^3, $\mu=3.8\pm0.2$ Pa.s.

CONDUCTION SHAPE FACTORS

Physical system	Schematic	Shape factor	Restrictions
Isothermal cylinder of radius r buried in semi-infinite medium having isothermal surface		$\frac{2\pi L}{\cosh^{-1}(D/r)}$ $\frac{2\pi L}{\ln(D/r)}$	$L \gg r$ $L \gg r$ $D > 3r$
Isothermal sphere of radius r buried in infinite medium		$4\pi r$	
Isothermal sphere of radius r buried in semi-infinite medium having isothermal surface $\Delta T = T_{surf} - T_{far\ field}$		$\frac{4\pi r}{1 - r/2D}$	
Conduction between two isothermal cylinders of length L buried in infinite medium		$\frac{2\pi L}{\cosh^{-1}\left(\frac{D^2 - r_1^2 - r_2^2}{2r_1r_2}\right)}$	$L \gg r$ $L \gg D$
Row of horizontal cylinders of length L in semi-infinite medium with isothermal surface		$S = \frac{2\pi L}{\ln\left[\left(\frac{l}{\pi r}\right)\sinh(2\pi D/l)\right]}$	$D > 2r$
Buried cube in infinite medium, L on a side		$8.24L$	

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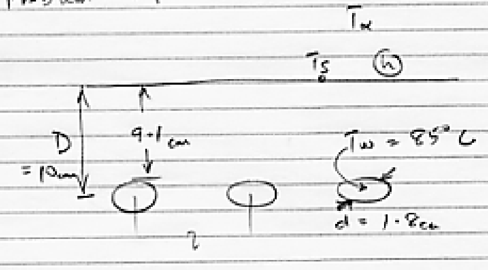
Problem #1



This is a shape-factor method problem.

Let the centre-to-centre separation of the tubes $= \ell$

The length of the tubes $L = 16$ m

The heat rate (minimum) to keep the walkway ice-free is to be calculated with the following assumptions:

- $T_\infty = -25°C$
- $T_S = 0°C$ (melting point)
- The tubes are run parallel to the length (16m) and the "repeating unit" area of walkway surface which is repeating is $\ell(16)\ m^2 = A$

(a)

Heat Rate $= Q = hA(T_S - T_\infty)$ above walkway

$= kS(T_w - T_S)$ below walkway

where $S = \dfrac{2\pi L}{\ln\left[\left(\frac{\ell}{\pi r}\right)\sinh\left(\frac{2\pi D}{\ell}\right)\right]}$; $D > 2r$ in supplied table

Substituting

$$(23.8)(\cancel{16})\ell(25) = (0.76)(85)\frac{2\pi(\cancel{16})}{\ln\left[\frac{\ell}{\pi r}\sinh\frac{2\pi(0.1)}{\ell}\right]}$$

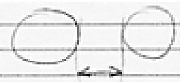
where $r = d/2 = 0.9(10^{-2})$ m

$$\therefore \quad \ell \cdot \ln\left[\frac{\ell}{\pi(0.9)(10^{-2})}\sinh\frac{2\pi(0.1)}{\ell}\right] = \frac{2\pi(0.76)(85)}{25(23.8)}$$

$$= 0.6822$$

Solve, by trial + error, $\ell = 9.8(10^{-2})$ m

∴ wall-to-wall separation of tubes



$= 9.8\text{ cm} - 1.8\text{ cm}$

$= 8\text{ cm}$ →

(b) Once the tubes are buried in the cement, spacing cannot be changed any more. The only option is to increase the feed glycol temperature of the

$$\therefore\ 23.8\,(16)(40) = (6.76)(T_w - 0)\,\frac{2\pi\,(16)}{0.6822}$$

$$T_w = 136^\circ C$$

i.e. The glycol temperature would need to be increased from 85°C to 136°C. →

Problem #2

$$\tau_w = 0.0296\left(\frac{\nu}{U_\infty x}\right)^{0.2}\rho U_\infty^2 \quad ; \quad \nu = \mu/\rho$$

Value $$\tau_w = 0.0296\left(\frac{3.8}{980}\cdot\frac{1}{5}\cdot\frac{1}{1.2}\right)^{0.2} 980\cdot(5)^2$$

$$= 166.93\ \text{Pa}$$ →

Error $$\tau_w = 0.0296\,\mu^{0.2}\rho^{0.8}U_\infty^{1.8}x^{-0.2}$$

$$\frac{\Delta\tau_w}{\tau_w} = 0.2\mu_r + 0.8\rho_r + 1.8U_{\infty r} + 0.2x_r$$

$$= 0.2\left(\frac{0.2}{3.8}\right) + 0.8\left(\frac{12}{980}\right) + 1.8\left(\frac{0.3}{5}\right) + 0.2\left(\frac{0.05}{1.2}\right)$$

$$= 0.1367$$

$$\therefore\ \Delta\tau_w = 0.1367(166.93) = \pm 22.8\ \text{Pa}$$ →