Université d'Ottawa
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University of Ottawa
Faculty of Engineering

Department of
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CHG 2314

HEAT TRANSFER OPERATIONS

MIDTERM EXAM

DATE: **Wednesday March 1, 2017, 13:00 – 14:20**

DURATION: **80 minutes**

PROFESSOR: **Dr. B. Kruczek**

1) Closed book examination

2) One single-side reference page with your own notes/information is allowed. Your reference page is to be submitted with the exam booklet; it will be returned to you with the marked exam

3) Additional useful information is provided in the Appendix.

4) Do 2 out of 3 problems; each problem is worth 25 marks.

5) Please indicate which problems should be evaluated; if no indication is provided, the first two problems appearing in the exam booklet will be evaluated.

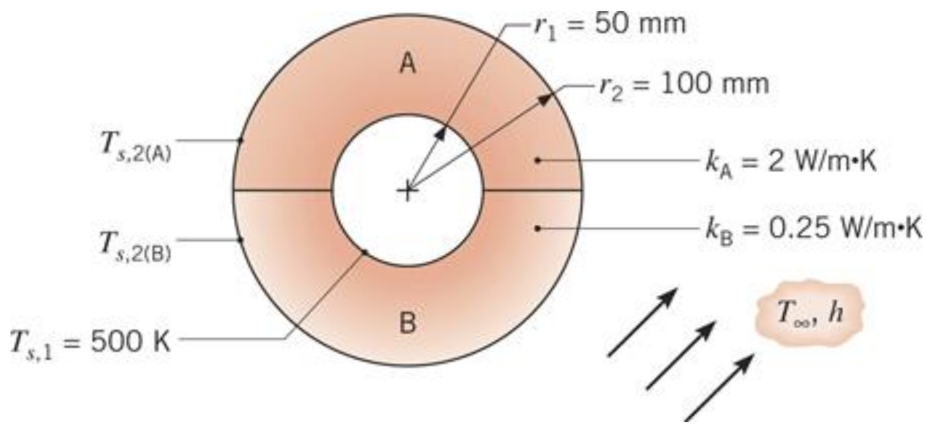
6) Calculator allowed: TI-30X or equivalent

7) Cell phones and all other electronic devices must be turned off and stored away from the desk

8) If you finish the exam before 14:10, you may leave the room. Otherwise, please wait till the end of the exam

Good luck!!!

1. Steam is flowing through a long, thin-walled pipe maintains the pipe wall at a uniform temperature of 500 K. The pipe is covered with an insulation blanket comprised of two different materials, A and B. The interface between the two materials may be assumed to have infinite contact resistance, and the entire outer surface is exposed to air for which $T_{\infty,}$ = 300 K and h = 25 W/m^2 K.

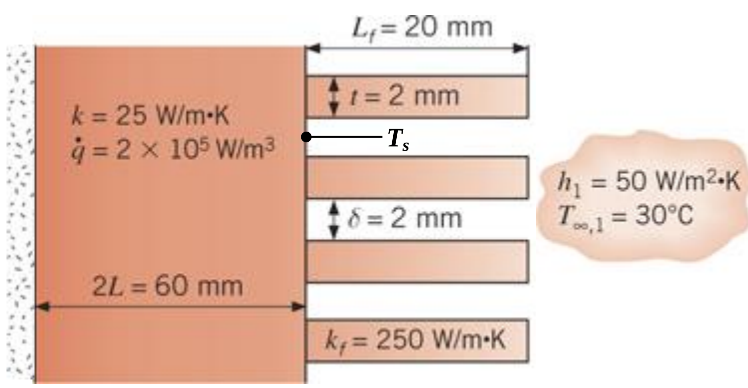


a) Sketch the thermal circuit of the system. Label (using the preceding symbols) all pertinent nodes and resistances **(10 points)**.

b) For the prescribed conditions, what is the total heat loss per unit length of the pipe **(10 points)**?

c) What are the outer surface temperature $T_{s,2(A)}$ and $T_{s,2(B)}$ **(5 points)**?

2. Heat is uniformly generated at the rate of 2 x 10^5 W/m^3 in a wall of thermal conductivity 25 W/m K and thickness 60 mm. The wall is insulated on one side and there are straight rectangular fins on the other side, with dimensions as shown and thermal conductivity of 250 W/m K. The exposed side is in contact with fluid at $T_{\infty,1}$ = 30°C with the heat transfer coefficients h_1 = 50 W/m^2 K.

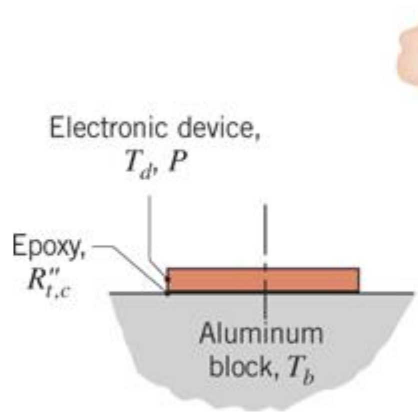


a) What is the efficiency of the finned surface **(10 points)**? ***Hint:*** as a basis, use unit surface area 1 m (high) x 1 m (wide) = 1 m^2

b) What is the temperature of the prime surface T_s **(7.5 points)**?

c) What is the maximum temperature in the wall **(7.5 points)**?

3. An electronic device, in form of a disk 20 mm in diameter and 1 mm thick, is mounted flush on a large aluminum block (k = 177 W/m K). In the off-mode the electronic device is in thermal equilibrium with the aluminum block and air, which are maintained at $T_b = T_{\infty,} = 300$ K. The density and specific heat of the device are $\rho = 2000$ kg/m^3 and c = 700 J/kg K, respectively. The mounting arrangement is such that a contact resistance of $R''_{t,c} = 1 \times 10^{-4}$ m^2 K/W exists at the interface between the device and the block. For purposes of analysis, the energized electronic device is characterized by uniform volumetric heating of 9×10^7 W/m^3. The convective heat transfer coefficient between the exposed surface of the device and air is 150 W/m^2 K.



a) Sketch the thermal circuit of the system at steady state when the electronic device is energized **(5 points)**.
b) Determine the steady state temperature of the energized electronic device (T_d) **(10 points)**.
c) Following activation, since $T_b = T_\infty$ the temperature of the device changes with time according to the following equation:

$$\frac{T - T_\infty - (b/a)}{T_i - T_\infty - (b/a)} = \exp(-at)$$

where: $T_i = T_b = T_\infty$

Derive expressions for constants a and b, and evaluate them using the data provided above **(10 points)**.

Appendix

Table 3.3 One-dimensional, steady-state solutions to the heat equation with no generation

	Plane Wall	Cylindrical Wall[a]	Spherical Wall[a]
Heat equation	$\frac{d^2T}{dx^2}=0$	$\frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right)=0$	$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)=0$
Temperature distribution	$T_{s,1}-\Delta T\frac{x}{L}$	$T_{s,2}+\Delta T\frac{\ln(r/r_2)}{\ln(r_1/r_2)}$	$T_{s,1}-\Delta T\left[\frac{1-(r_1/r)}{1-(r_1/r_2)}\right]$
Heat flux (q'')	$k\frac{\Delta T}{L}$	$\frac{k\,\Delta T}{r\ln(r_2/r_1)}$	$\frac{k\,\Delta T}{r^2[(1/r_1)-(1/r_2)]}$
Heat rate (q)	$kA\frac{\Delta T}{L}$	$\frac{2\pi Lk\,\Delta T}{\ln(r_2/r_1)}$	$\frac{4\pi k\,\Delta T}{(1/r_1)-(1/r_2)}$
Thermal resistance ($R_{t,\text{cond}}$)	$\frac{L}{kA}$	$\frac{\ln(r_2/r_1)}{2\pi Lk}$	$\frac{(1/r_1)-(1/r_2)}{4\pi k}$

[a]The critical radius of insulation is $r_{cr}=k/h$ for the cylinder and $r_{cr}=2k/h$ for the sphere.

Table 3.5 Efficiency of common fin shapes

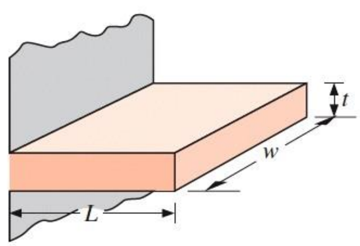
Straight Fins

Rectangular[a]

$A_f=2wL_c$

$L_c=L+(t/2)$

$A_p=tL$

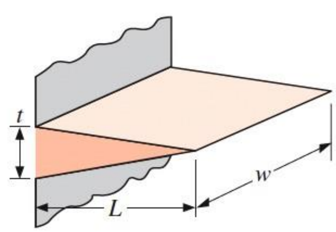


$$\eta_f=\frac{\tanh mL_c}{mL_c}$$

Triangular[a]

$A_f=2w[L^2+(t/2)^2]^{1/2}$

$A_p=(t/2)L$



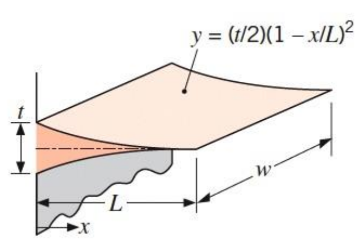
$$\eta_f=\frac{1}{mL}\frac{I_1(2mL)}{I_0(2mL)}$$

Parabolic[a]

$A_f=w[C_1L+(L^2/t)\ln(t/L+C_1)]$

$C_1=[1+(t/L)^2]^{1/2}$

$A_p=(t/3)L$



$$\eta_f=\frac{2}{[4(mL)^2+1]^{1/2}+1}$$

[a]$m=(2h/kt)^{1/2}$.

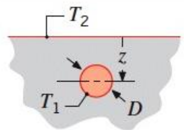
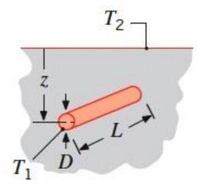
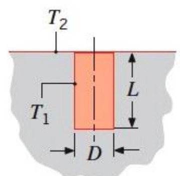
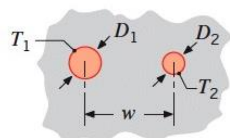
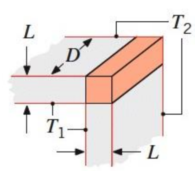
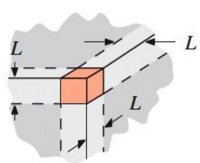
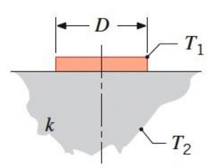
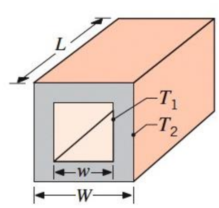
[b]$m=(4h/kD)^{1/2}$.

TABLE C.3 One-Dimensional, Steady-State Solutions to the Heat Equation for Uniform Generation in a Plane Wall with One Adiabatic Surface, a Solid Cylinder, and a Solid Sphere

	Temperature Distribution	
Plane Wall	$T(x) = \frac{\dot{q}L^2}{2k}\left(1 - \frac{x^2}{L^2}\right) + T_s$	(C.22)
Circular Rod	$T(r) = \frac{\dot{q}r_o^2}{4k}\left(1 - \frac{r^2}{r_o^2}\right) + T_s$	(C.23)
Sphere	$T(r) = \frac{\dot{q}r_o^2}{6k}\left(1 - \frac{r^2}{r_o^2}\right) + T_s$	(C.24)
	Heat Flux	
Plane Wall	$q''(x) = \dot{q}x$	(C.25)
Circular Rod	$q''(r) = \frac{\dot{q}r}{2}$	(C.26)
Sphere	$q''(r) = \frac{\dot{q}r}{3}$	(C.27)
	Heat Rate	
Plane Wall	$q(x) = \dot{q}xA_x$	(C.28)
Circular Rod	$q(r) = \dot{q}\pi Lr^2$	(C.29)
Sphere	$q(r) = \frac{\dot{q}4\pi r^3}{3}$	(C.30)

TABLE 4.1 Conduction shape factors and dimensionless conduction heat rates for selected systems.

(*a*) Shape factors [$q = Sk(T_1 - T_2)$]

System	Schematic	Restrictions	Shape Factor
Case 1 Isothermal sphere buried in a semi-infinite medium		$z > D/2$	$\frac{2\pi D}{1 - D/4z}$
Case 2 Horizontal isothermal cylinder of length L buried in a semi-infinite medium		$L \gg D$ $L \gg D$ $z > 3D/2$	$\frac{2\pi L}{\cosh^{-1}(2z/D)}$ $\frac{2\pi L}{\ln(4z/D)}$
Case 3 Vertical cylinder in a semi-infinite medium		$L \gg D$	$\frac{2\pi L}{\ln(4L/D)}$
Case 4 Conduction between two cylinders of length L in infinite medium		$L \gg D_1, D_2$ $L \gg w$	$\frac{2\pi L}{\cosh^{-1}\left(\frac{4w^2 - D_1^2 - D_2^2}{2D_1D_2}\right)}$
Case 8 Conduction through the edge of adjoining walls		$D > 5L$	$0.54D$
Case 9 Conduction through corner of three walls with a temperature difference ΔT_{1-2} across the walls		$L \ll$ length and width of wall	$0.15L$
Case 10 Disk of diameter D and temperature T_1 on a semi-infinite medium of thermal conductivity k and temperature T_2		None	$2D$
Case 11 Square channel of length L		$\frac{W}{w} < 1.4$ $\frac{W}{w} > 1.4$ $L \gg W$	$\frac{2\pi L}{0.785 \ln(W/w)}$ $\frac{2\pi L}{0.930 \ln(W/w) - 0.050}$