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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 February 28, 2018, 13:00 – 14:20**

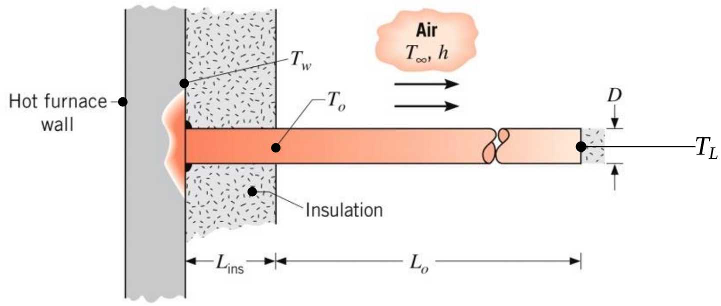
DURATION: **80 minutes**

PROFESSOR: **Dr. B. Kruczek**

1) Closed book examination
2) One double-sided 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!!!

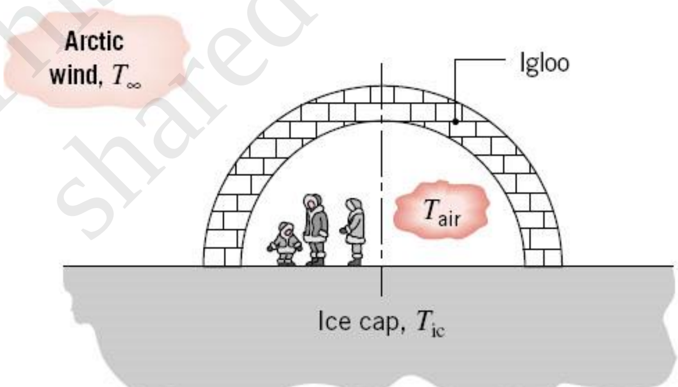
1. A rod of diameter D = 30 mm and thermal conductivity k = 80 W/m K protrudes normally from a furnace wall that is at T_w = 200°C and is covered by insulation of thickness L_{ins} = 250 mm. The rod is welded to the furnace wall and is used as a hanger for supplying instrumentation cables. The exposed length of the rod L_o = 400 mm, and its tip is well insulated. The ambient air temperature is T_∞ = 25°C, and the convection coefficient is h = 15 W/m^2 K.



a) Sketch the thermal circuit of the system assuming that there is no contact resistance between the rod and the furnace wall, and the temperature of the rod at the point of contact with the wall is T_W. **(5 points)**
b) Derive an expression for T_o (the temperature of the rod at the point it emerges from the insulation) as a function of the prescribed thermal and geometrical parameters. **(5 points)**
c) Calculate T_o from the expression derived in part b). **(7.5 points)**
d) Using the value of T_o calculated in part c), determine T_L, i.e., the temperature of the rod at the insulated tip. **(7.5 points)**

Hint: Assuming perfect insulation, there is a linear temperature profile in the insulated part of the rod of length L_{ins}.

2. An igloo is built in a shape of a hemisphere with an inner radius r_i = 2.0 m and walls of compacted snow that are t = 0.5 m thick. On the inside of the igloo the surface heat transfer coefficient is h_i = 5 W/m^2 K; on the outside under normal wind conditions, it is h_o = 20 W/m^2 K. The thermal conductivity of the igloo walls and the ice cap on which the igloo sits is the same and equal to k = 0.15 W/m K. The temperature of the ice cap is T_{ic} = -20°C while the temperature of the arctic air outside the igloo is T_∞ = -30°C. The occupants of the igloo provide a continuous heat source q = 320 W within the igloo as a result of which the temperature of air in the igloo T_{air} is greater than T_{ic} and T_∞.

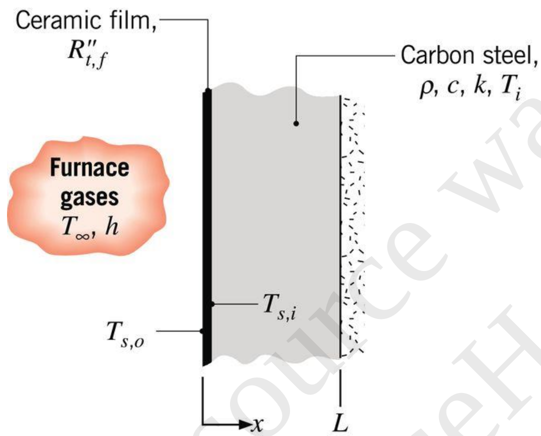


a) Please draw the thermal circuit for the above problem. *Hint:* keep in mind that although the temperature of air inside the igloo is uniform and the heat transfer coefficient between the air and the igloo's floor is the same as that between air and inside wall of igloo, the floor temperature ($T_{ic,f}$) and the inside wall temperature ($T_{s,i}$) are not necessarily the same. **(10 points)**

b) Calculate the inside air temperature in the igloo (T_{air}) **(15 points)**

Hint: Be sure to include heat loos through the floor of the igloo.

3. A plane wall of a furnace is fabricated from plain carbon steel (k = 60 W/m K, ρ = 7850 kg/m^3, c = 430 J/kg K) and thickness L = 8 mm. To protect it from the corrosive effects of the furnace combustion gasses, one surface of the wall is coated with a thin ceramic film that, for a unit surface area, has a thermal resistance of $R''_{t,f}$ = 0.01 m^2 K/W. The opposite surface is well insulated from the surroundings.



At furnace start-up the wall is at an initial temperature of T_i = 300 K. and combustion gases at T_∞ = 1300 K enter the furnace, providing a convection coefficient of h = 25 W/m^2 K at the ceramic film. You may assume the film to have negligible thermal capacitance (*Hint*: the film can be treated as a contact resistance).

a) Show that applicability of the LTCM approach is suitable to predict changes of the wall's temperature with time. **(10 points)**

b) How long would it take for the inner surface of the steel to achieve a temperature of $T_{s,i}$ = 1100 K? **(10 points)**

c) What is the temperature $T_{s,o}$ of the exposed surface of the ceramic film at this time? **(5 points)**

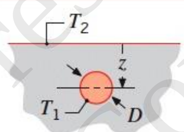
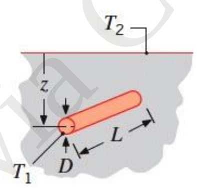
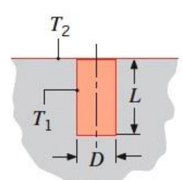
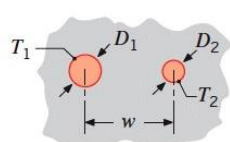
Appendix

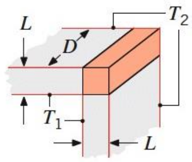
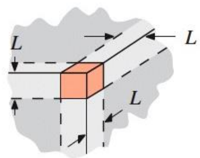
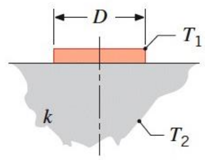
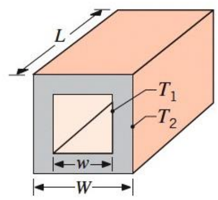
TABLE 3.4 Temperature distribution and heat loss for fins of uniform cross section

Case	Tip Condition ($x = L$)	Temperature Distribution θ/θ_b	Fin Heat Transfer Rate q_f
A	Convection heat transfer: $h\theta(L) = -kd\theta/dx\|_{x=L}$	$\dfrac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$ (3.75)	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$ (3.77)
B	Adiabatic: $d\theta/dx\|_{x=L} = 0$	$\dfrac{\cosh m(L-x)}{\cosh mL}$ (3.80)	$M \tanh mL$ (3.81)
C	Prescribed temperature: $\theta(L) = \theta_L$	$\dfrac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$ (3.82)	$M\dfrac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$ (3.83)
D	Infinite fin ($L \rightarrow \infty$): $\theta(L) = 0$	e^{-mx} (3.84)	M (3.85)

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		$z > D/2$	$\dfrac{2\pi D}{1 - D/4z}$
Case 2 Horizontal isothermal cylinder of length L buried in a semi-infinite medium		$L \gg D$	$\dfrac{2\pi L}{\cosh^{-1}(2z/D)}$
		$L \gg D$, $z > 3D/2$	$\dfrac{2\pi L}{\ln(4z/D)}$
Case 3 Vertical cylinder in a semi-infinite medium		$L \gg D$	$\dfrac{2\pi L}{\ln(4L/D)}$
Case 4 Conduction between two cylinders of length L in infinite medium		$L \gg D_1, D_2$, $L \gg w$	$\dfrac{2\pi L}{\cosh^{-1}\left(\dfrac{4w^2 - D_1^2 - D_2^2}{2D_1D_2}\right)}$

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		$\frac{W}{w} < 1.4$	$\frac{2\pi L}{0.785 \ln (W/w)}$
		$\frac{W}{w} > 1.4$	$\frac{2\pi L}{0.930 \ln (W/w) - 0.050}$
		$L \gg W$	