

MAE 310: Heat Transfer Fundamentals

Spring 2015

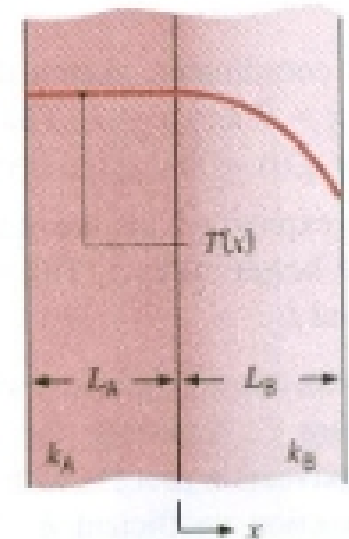
Quiz 1 (15% of final grade)

February 9, 2015

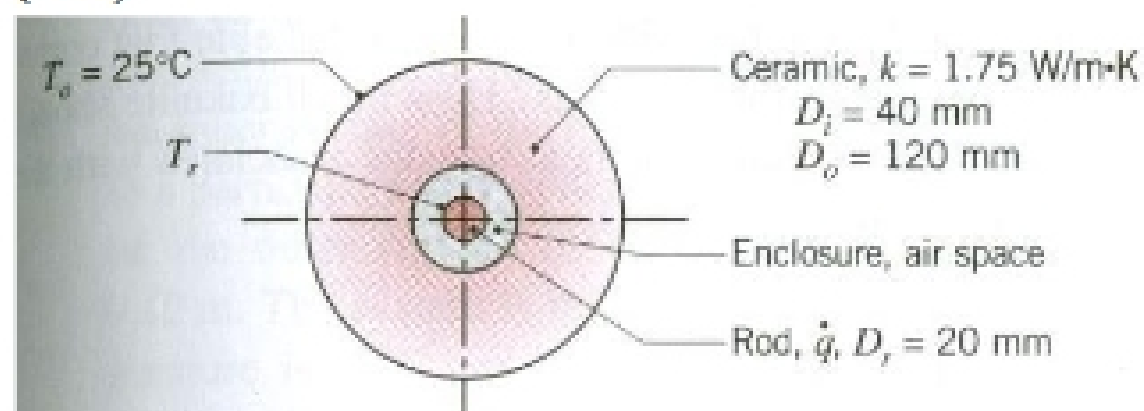
Closed books & notes

Problem 1. (30 points) Consider the steady-state temperature distribution within a composite wall composed of Materials A and B. The conduction process is one-dimensional.

- a) Within which material does uniform volumetric generation occur? (6 points)
- b) What is the boundary condition at $x = -L_A$? (6 points)
- c) How would the temperature distribution change if the thermal conductivity of Material A were doubled? (6 points)
- d) How would the temperature distribution change if the thermal conductivity of Material B were doubled? (6 points)
- e) Sketch the heat flux distribution $q''(x)$ through the composite wall. (6 points)



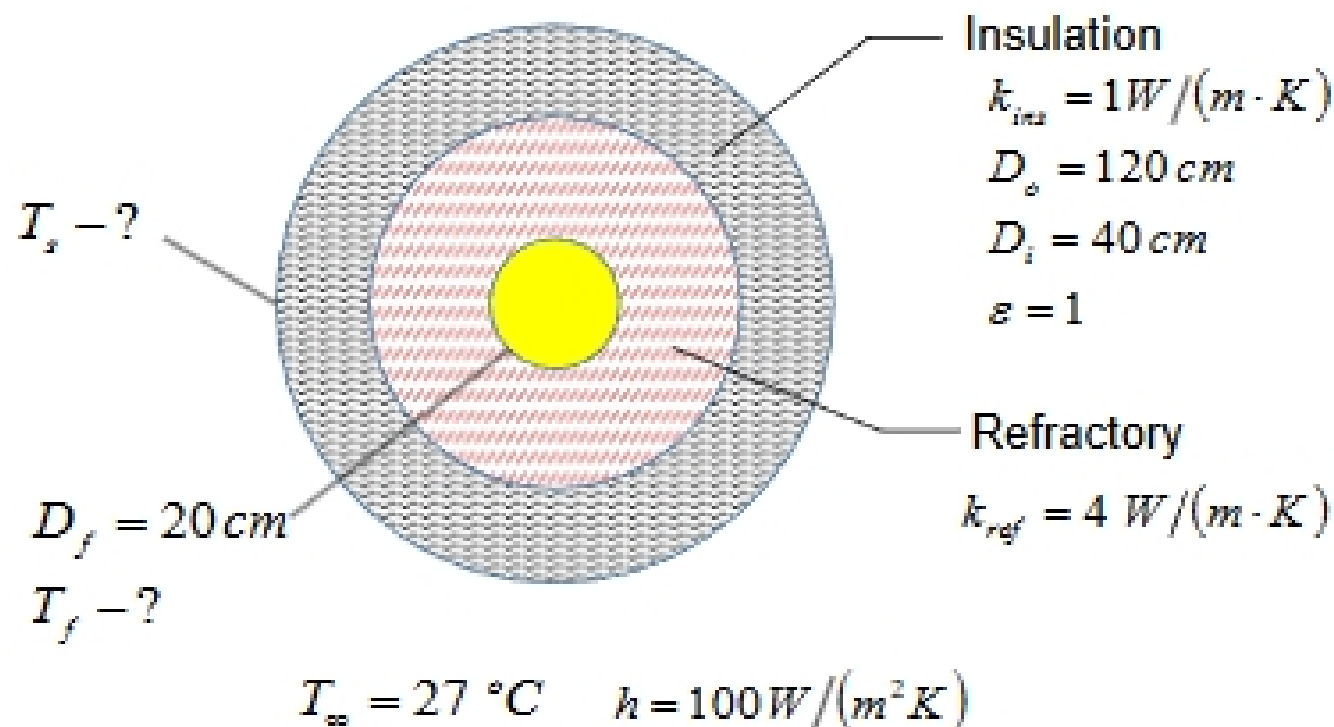
Problem 2. (30 points) Electric current flows through a long rod generating thermal energy at a uniform volumetric rate of $\dot{q} = 2 \cdot 10^6 \text{ W/m}^3$. The rod is concentric with a hollow ceramic cylinder, creating an enclosure that is filled with air. The thermal resistance per unit length due to radiation between the enclosure surfaces is $R'_{rad} = 0.3 \text{ (m}\cdot\text{K)/W}$, and the coefficient associated with free convection in the enclosure is $h = 20 \text{ W/(m}^2\text{K)}$.



- a) Construct a thermal circuit that can be used to calculate the surface temperature of the rod, T_r . Label all temperatures, heat rates, and thermal resistances, and evaluate each thermal resistance. (15 points)
- b) Calculate the surface temperature of the rod for the prescribed conditions. (15 points)

SAMPLE

Problem 3. (40 points) A spherical flame with a diameter of $D_f = 20$ cm generates thermal energy at a rate of $q = 5$ kW. The flame confined in a spherical combustor is covered by two insulation layers as shown in the figure below. The outside surface of the combustor is exposed to air with $T_\infty = 27$ °C and a convection coefficient $h = 100$ W/(m²K).



- Neglecting radiation on the outside surface of the combustor, construct a thermal circuit to evaluate T_f and T_s . Label all temperatures, heat rates, and thermal resistances, and evaluate each thermal resistance. (10 points)
- Calculate the surface temperature of the combustor T_s using this circuit. (10 points)
- Calculate the inner temperature of the combustor T_f using this circuit. (10 points)
- Modify the thermal circuit by considering thermal radiation on the outside surface of the combustor. Evaluate if the contribution of radiation should be considered in this problem. (10 points)

Physical Constants Conversion Factors

Universal Gas Constant:

$$\begin{aligned} \mathcal{R} &= 8.205 \times 10^{-2} \text{ m}^3 \cdot \text{atm/kmol} \cdot \text{K} \\ &= 8.314 \times 10^{-2} \text{ m}^3 \cdot \text{bar/kmol} \cdot \text{K} \\ &= 8.315 \text{ kJ/kmol} \cdot \text{K} \\ &= 1545 \text{ ft} \cdot \text{lb}_f/\text{lbmole} \cdot ^\circ\text{R} \\ &= 1.986 \text{ Btu/lbmole} \cdot ^\circ\text{R} \end{aligned}$$

Avogadro's Number:

$$N = 6.022 \times 10^{23} \text{ molecules/mol}$$

Planck's Constant:

$$h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$$

Boltzmann's Constant:

$$k_B = 1.381 \times 10^{-23} \text{ J/K}$$

Speed of Light in Vacuum:

$$c_0 = 2.998 \times 10^8 \text{ m/s}$$

Stefan-Boltzmann Constant:

$$\sigma = 5.670 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$$

Blackbody Radiation Constants:

$$C_1 = 3.742 \times 10^8 \text{ W} \cdot \mu\text{m}^4/\text{m}^2$$

$$C_2 = 1.439 \times 10^4 \mu\text{m} \cdot \text{K}$$

$$C_3 = 2898 \mu\text{m} \cdot \text{K}$$

Solar Constant:

$$S_0 = 1368 \text{ W/m}^2$$

Gravitational Acceleration (Sea Level):

$$g = 9.807 \text{ m/s}^2 = 32.174 \text{ ft/s}^2$$

Standard Atmospheric Pressure:

$$p = 101,325 \text{ N/m}^2 = 101.3 \text{ kPa}$$

Heat of Fusion of Water at Atmospheric Pressure:

$$h_{if} = 333.7 \text{ kJ/kg}$$

Heat of Vaporization of Water at Atmospheric Pressure:

$$h_{ig} = 2257 \text{ kJ/kg}$$

Acceleration	1 m/s ²	= 4.2520 × 10 ³ ft/h ²
Area	1 m ²	= 1550.0 in. ²
		= 10.764 ft ²
Density	1 kg/m ³	= 0.06243 lb _m /ft ³
Energy	1 J (0.2388 cal)	= 9.4782 × 10 ⁻⁴ Btu
Force	1 N	= 0.22481 lb _f
Heat transfer rate	1 W	= 3.4121 Btu/h
Heat flux	1 W/m ²	= 0.3170 Btu/h · ft ²
Heat generation rate	1 W/m ³	= 0.09662 Btu/h · ft ³
Heat transfer coefficient	1 W/m ² · K	= 0.17611 Btu/h · ft ² · °F
Kinematic viscosity and diffusivities	1 m ² /s	= 3.875 × 10 ⁴ ft ² /h
Latent heat	1 J/kg	= 4.2992 × 10 ⁻⁴ Btu/lb _m
		= 39.370 in.
Length		= 3.2808 ft
	1 km	= 0.62137 mile
Mass	1 kg	= 2.2046 lb _m
Mass density	1 kg/m ³	= 0.06243 lb _m /ft ³
Mass flow rate	1 kg/s	= 7936.6 lb _m /h
Mass transfer coefficient	1 m/s	= 1.1811 × 10 ⁴ ft/h
Power	1 kW	= 3412.1 Btu/h
		= 1.341 hp
Pressure and stress ¹	1 N/m ² (1 Pa)	= 0.020885 lb _f /ft ²
		= 1.4504 × 10 ⁻⁴ lb _f /in. ²
		= 4.015 × 10 ⁻³ in. water
		= 2.953 × 10 ⁻⁴ in. Hg
		= 1 standard atmosphere
		= 1 bar
Specific heat	1.0133 × 10 ³ N/m ²	= 1 bar
	1 × 10 ⁵ N/m ²	= 1 bar
Temperature	1 kJ/kg · K	= 0.2388 Btu/lb _m · °F
	K	= (5/9)°R
		= (5/9)(°F + 459.67)
		= °C + 273.15
Temperature difference	1 K	= 1°C
		= (9/5)°R = (9/5)°F
Thermal conductivity	1 W/m · K	= 0.57779 Btu/h · ft · °F
Thermal resistance	1 K/W	= 0.52753 °F/h · Btu
Viscosity (dynamic) ²	1 N · s/m ²	= 2419.1 lb _m /ft · h
		= 5.8015 × 10 ⁻⁶ lb _f · h/ft ²
Volume	1 m ³	= 6.1023 × 10 ³ in. ³
		= 35.315 ft ³
Volume flow rate		= 264.17 gal (U.S.)
	1 m ³ /s	= 1.2713 × 10 ³ ft ³ /h
		= 2.1189 × 10 ³ ft ³ /min
		= 1.5850 × 10 ⁴ gal/min

¹ The SI name for the quantity pressure is pascal (Pa) having units N/m² or kg/m · s².

² Also expressed in equivalent units of kg/s · m.