2017 Heat Transfer Final Exam

When is a good time for you?

Fri 09 Jun 10:00--13:00	1
Fri 09 Jun 12:00--15:00	2
Fri 09 Jun 15:00--18:00	3
Fri 09 Jun 18:00--21:00	8
Sat 10 Jun 10:00--13:00	4
Mon 12 Jun 18:00--21:00	2
Tue 13 Jun 07:30--10:30	2
Tue 13 Jun 18:00--21:00	2
Wed 14 Jun 18:00--21:00	2
Thu 15 Jun 18:00--21:00	2
Fri 16 Jun 10:00--13:00	0
Fri 16 Jun 12:00--15:00	2
Fri 16 Jun 15:00--18:00	6
Fri 16 Jun 18:00--21:00	8
Sat 17 Jun 10:00--13:00	10
Mon 19 Jun 18:00--21:00	10
Tue 20 Jun 18:00--21:00	15

Poll ended at 6:20 pm on Wednesday May 31st 2017. Total votes: 79. Total voters: 26.

Tuesday June 20th 2017
16:30 — 19:30

NO NOTES OR BOOKS; USE HEAT TRANSFER TABLES THAT WERE DISTRIBUTED; ALL QUESTIONS HAVE EQUAL VALUE; ANSWER ALL 6 QUESTIONS.

Question #1

The temperature distribution in a certain plane wall is

$$\frac{T - T_1}{T_2 - T_1} = C_1 + C_2 x^2 + C_3 x^3$$

where T_1 and T_2 are the temperatures on each side of the wall. If the thermal conductivity of the wall is constant and the wall thickness is L, derive an expression for the heat generation per unit volume as a function of x, the distance from the plane where $T = T_1$. Let the heat generation be S_0 at $x = 0$.

Question #2

The first design project given to you after you join a water distribution company is to prevent water flowing in an underground pipe from freezing. Consider a long 100 m pipe with a 0.15 m radius buried 2 m under ground (the center of the pipe is 2 m below the earth surface). Water flows in the pipe with the following properties:

$$\rho = 1000 \text{ kg/m}^3, \quad c_p = 4000 \text{ J/kgK}, \quad k = 0.6 \text{ W/m}^\circ\text{C}, \quad \mu = 10^{-3} \text{ kg/ms}$$

On a cold winter day, the surface of the ground is measured to be -10° C. Water enters the pipe at a bulk temperature of 20° C. To prevent freezing (with a safety margin), the water temperature should not drop below 3.3° C at any location. The ground conductivity can be taken as 1.5 W/m$^\circ$C, and the pipe walls can be assumed smooth and to oppose negligible resistance to heat flow. Do the following:

(a) Determine the minimum water mass flow rate through the pipe that prevents the water temperature to fall below 3.3°C *anywhere* within the pipe; make your design safe by taking into consideration that the ground surface temperature varies by as much as $\pm 2.4^\circ$ C and that the ground conductivity varies by as much as ± 0.5 W/m$^\circ$C.

(b) Determine the wall temperature of the pipe for the mass flow rate found in (a)

(c) Determine the bulk temperature of the water exiting the pipe for the mass flow rate found in (a)

Question #3

A thin rod of length L and constant cross section area has its two ends connected to two walls which are maintained at temperatures T_1 and T_2, respectively. The rod loses heat to the environment at T_∞ by convection. Derive an expression (i) for the temperature distribution in the rod and (ii) for the total heat lost by the rod through convection.

Question #4

Consider a hot 0.1 m radius sphere made of copper at an initial temperature of 800 $^\circ$C. The sphere is cooled by spraying it with liquid water at 20°C which instantly evaporates upon contact with the sphere. Knowing that the mass flow rate of liquid water hitting the sphere is of 0.364 kg/s do the following:

(a) Find the amount of energy lost by the sphere from $t = 0$ to $t = 3.73$ s.

(b) Find the effective convective heat transfer coefficient on the surface of the sphere between $t = 0$ and $t = 3.73$ s.

(c) Find the sphere surface temperature at $t = 3.73$ s.

You can use the following thermophysical properties for copper:

Property	Copper	Liquid water
c_p , kJ/kgK	0.4	4.2
k, W/mK	386	0.6
μ, kg/ms		10^{-3}
ρ, kg/m^3	9000	1000

Hints: $T_\infty = 20^\circ$C, ΔH_{vap} for water is 2260 kJ/kg, and $h = c_p T$.

Question #5

Consider a 1-m long copper cable with a diameter $D = 1.6$ mm, an electrical resistivity of $R_c = 30 \times 10^{-9}\,\Omega$m and with an emissivity $\epsilon = 0.5$. Air flows across the cable with a velocity $u_\infty = 40$ m/s, a density $\rho_\infty = 0.5$ kg/m^3, and a temperature $T_\infty = 230$ K. If a voltage difference $\Delta V = 3.4$V is applied to the cable extremities, do the following:

(a) Find the heat generated within the cable in Watt.

(b) Find the convective heat transfer coefficient in W/m^{2}K.

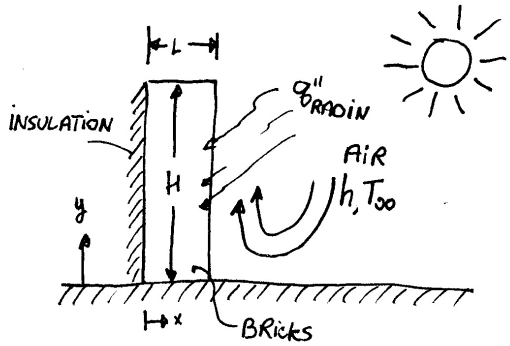
(c) Find the surface temperature of the cable in K.

You can assume that the film temperature is 400 K and use the following thermophysical data for air:

Matter	c_p, J/kg$^\circ$C	k, W/m$^\circ$C	μ, kg/ms
Air	1000	0.05	10^{-5}

Question #6

Consider a brick wall that is insulated on one side and exposed to radiation from the sun on the other side as follows:



For $H = 1$ m, $L = 0.1$ m, $T_\infty = 27^\circ$ C, $P_\infty = 1$ atm, and a radiation heat flux from the sun equal to $q''_{\text{radin}} = 700$ W/m^2, and an emissivity factor of the bricks of $\epsilon = 0.5$, do the following:

(a) Find the convective heat transfer coefficient due to free convection at $x = L$ and $y = H$.

(b) Find the surface temperature T_s at $x = L$ and $y = H$.

You can assume negligible heat transfer on the top surface of the wall and that the film temperature is equal to 300 K. Use the following thermophysical properties for the bricks and the air:

Matter	ρ, kg/m^3	c_p, J/kgK	k, W/mK	μ, kg/ms
Bricks	1600	840	0.7	--
Air	--	1000	0.02	10^{-5}

Answers

1. $S = S_0 - \frac{3xS_0}{L} - \frac{6xk}{L^3}(T_2 - T_1)$.
2. 0.12 kg/s, 3.3° C, 7° C.
3. $\frac{kA_{\text{cs}}m}{\sinh(mL)}(\cosh(mL) - 1)\,(T_2 + T_1 - 2T_\infty)$.
4. 3.52 MJ, 19300 W/m^{2}K, 176° C.
5. 775 W, 415 W/m^{2}K, 595 K.
6. 2.7 W/m^{2}K, 319 K.