# Heat Transfer Assignment 7 — Free & Forced Flow

### Instructions

$\xi$ is a parameter related to your student ID, with $\xi_1$ corresponding to the last digit, $\xi_2$ to the last two digits, $\xi_3$ to the last three digits, etc. For instance, if your ID is 199225962, then $\xi_1 = 2$, $\xi_2 = 62$, $\xi_3 = 962$, $\xi_4 = 5962$, etc. Keep a copy of the assignment — the assignment will not be handed back to you. You must be capable of remembering the solutions you hand in.

### Question #1

A tube bank uses an in-line arrangement with $S_p = S_n = 1.9$ cm and 6.33-mm-diameter tubes. The tube bank is 6 rows deep and 50 tubes high. The surface temperature of the tubes is constant at 90° C, and air at a pressure of 1 atmosphere, a temperature of 20° C, and a speed of 4.5 m/s is forced across them. Calculate the total heat transfer per unit length for the tube bank as well as the outlet temperature of the air.

### Question #2

Repeat the previous problem but with the tubes arranged in the "staggered" configuration with the same values of $S_p$ and $S_n$.

### Question #3

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°C | $k$, W/m°C | $\mu$, kg/ms |
|---|---|---|---|
| Air | 1000 | 0.05 | $10^{-5}$ |

## Question #4

You wish to cook some chicken optimally using a convection oven. A convection oven differs from standard ovens by blowing hot air at moderate speeds on the food. This results in the food being heated mostly through convective heat transfer rather than through radiation heat transfer. The chicken you wish to cook can be modeled as a solid sphere with a radius of 1 cm, a thermal conductivity of 0.5 W/m°C, a density of 1000 kg/m$^3$, and a heat capacity of 3200 J/kg °C. The convection oven blows hot air at atmospheric pressure, a temperature of 130°C and a speed of 5 m/s towards the chicken. The chicken is initially at a temperature of 5° C and stands on a grill through which the air can flow freely. You wish to cook the chicken optimally so that it is as tender as possible while being safe to eat. To be safe for eating, the temperature *at any location within the chicken* must have reached at least 70° C. To be as tender as possible, the chicken must not be overcooked and must therefore be taken out of the oven as soon as it is safe for eating. Knowing the latter, do the following:

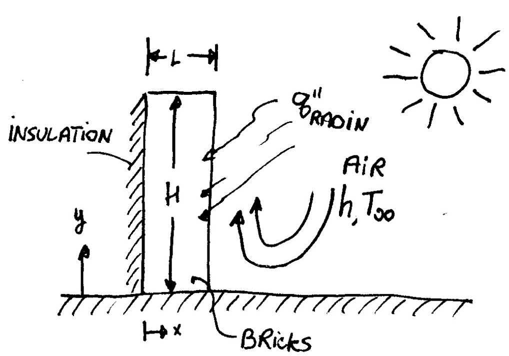
(a) Find the most accurate possible average convective heat transfer coefficient over the chicken when in the oven.

(b) Using the average convective heat transfer coefficient found in (a), determine the amount of time the chicken should be left in the oven to be optimally cooked.

(c) Find the surface temperature of the chicken when it is taken out of the oven.

## Question #5

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, $T_\infty = 27°$ C, $P_\infty = 1$ atm, and an incoming 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 | $\rho$, kg/m$^3$ | $c_p$ , J/kgK | $k$, W/mK | $\mu$, kg/ms |
|---|---|---|---|---|
| Bricks | 1600 | 840 | 0.7 | -- |
| Air | -- | 1000 | 0.02 | $10^{-5}$ |

## Question #6

Consider a 0.01 m diameter sphere made of magnesium initially at a uniform temperature of 80°C. The sphere is then immersed in a large pool of water with the water being still and at an initial temperature of 20°C. Because of the gravitational force, the sphere accelerates towards the bottom of the pool and quickly reaches a constant velocity. Knowing that the drag coefficient of the sphere is of 1.1, do the following:

(a) When the sphere velocity becomes constant, find the velocity of the sphere with respect to the water.

(b) Find the temperature at the center of the sphere after a time of 2 seconds.

(c) Find the temperature on the surface of the sphere after a time of 2 seconds.

(d) Find the amount of energy (in Joules) lost by the sphere to the water after a time of 2 seconds.

Hints: (i) the buoyancy force is equal to the weight of the displaced fluid; (ii) the drag coefficient is equal to $C_D = F_{\rm drag}/(\frac{1}{2}\rho_\infty u_\infty^2 A)$ with the frontal area $A = \pi R^2$ and $R$ the radius of the sphere.

Use the following data for magnesium and water:

| Property | Water | Magnesium |
|---|---|---|
| $\rho$, kg/m$^3$ | 1000 | 1700 |
| $c$, kJ/kgK | 4 | 1 |
| $k$, W/m°C | 0.6 | 171 |
| $\mu$, kg/ms | 0.001 | -- |

## Answers

1. 54.9 kW/m, 30.6°C.
2. 62.8 kW/m, 32.1°C.
3. 775 W, 415 W/m$^2$K, 595 K.
4. 61 W/m$^2$°C, 256 s, 97° C.
5. 2.7 W/m$^2$°C, 319 K.
6. 4436 W/m$^2$°C, 51.1 J.

**Due on Wednesday May 29th at 9:00. Do Questions #2, #5, and #6 only.**