UNIVERSITY OF RUHUNA

Faculty of Engineering

Mid-Semester 7 Examination in Engineering: June 2015

Module Number: ME7321 **Module Name: Heat Transfer**

[Two Hours]

[Answer all questions. Draw clear diagrams. State all assumptions]

Q1. Figure Q1 shows a composite wall consisting of four rectangular sections labeled A, B, C and D. Their thermal conductivities are; k_A =150 W/m°C, k_B = 30 W/m°C, k_C =50 W/m°C, and k_D = 70 W/m°C. Assume 1-D steady state heat conduction in the direction of $\dot{Q}$. Sections B and D are of equal heights and the cross sectional area perpendicular to heat flow (A_C) is 0.1m^2.

a) Construct the thermal circuit and find the total thermal resistance.

b) Find the heat transfer rate through the composite wall.

[04 marks]

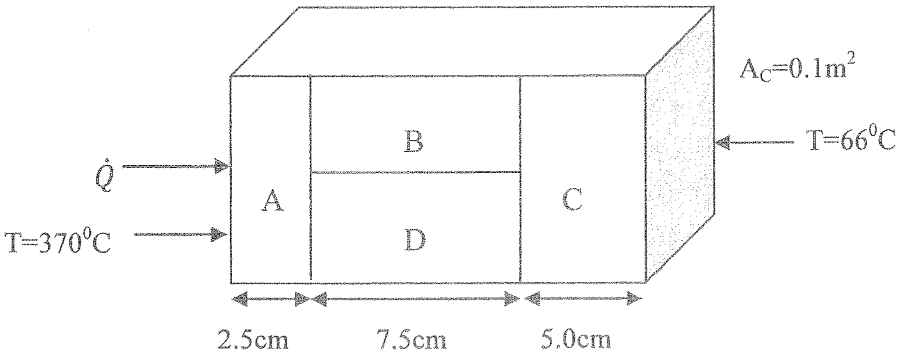

Figure Q1

Q2. a) What is the physical significance of Thermal Biot number?

b) Figure Q2 shows a production process. In this process Carbon Steel balls of 8mm diameter are annealed by first heating them to 900°C in a furnace and then allowing them to cool slowly to 100°C in ambient air at 35°C.

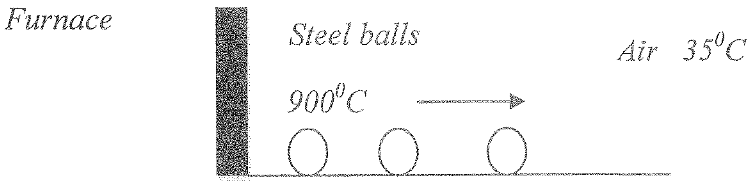

Figure Q2

If the average heat transfer coefficient is 75W/m²°C;

i) Determine how long the annealing process will take.

ii) If 2500 balls are to be annealed per hour, determine the rate of heat transfer from the balls to the ambient air.

With standard notations you may use the following equation for Biot number:

$$Bi = \frac{h\,L_c}{k}, \frac{T(t) - T_\infty}{T_i - T_\infty} = \exp[-\left(\frac{hA_s}{\rho V C_p}\right)t]$$

Properties of Carbon Steel balls:

$\rho = 7883\frac{kg}{m^3}$, k=54W/m°C, C_p=0.465kJ/kg°C, and, $\alpha = 1.474 \times 10^{-6} m^2/s$

[05 marks]

Q3. Figure Q3 shows a train moving at a velocity of 70km/h, with its top surface absorbing solar radiation at a rate of 200W/m². The area exposed to the sun is 2.8m wide and 8m long, while the ambient air temperature is 30°C. Assuming the roof of the train to be perfectly insulated and the radiation heat exchange with the surroundings to be small compared to convection;

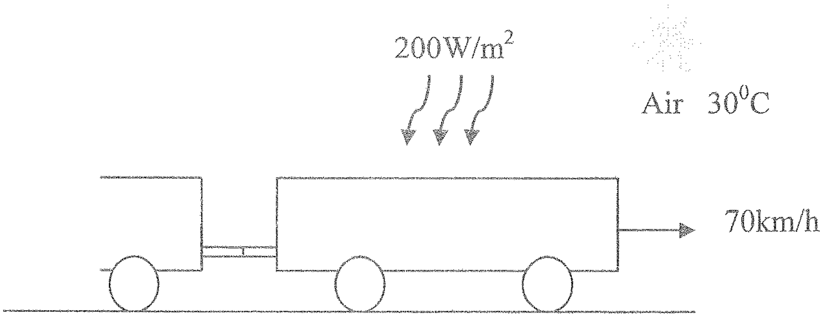

Figure Q3

a) What are the criteria to select the appropriate Nusselt number correlation for this system?

b) Determine the equilibrium temperature of the top surface of the train.

Nusselt number can be determined using: $Nu_L=(0.037Re_L^{0.8}-871)Pr^{1/3}$

Air properties at 30°C: $v = 1.608 \times 10^{-5} m^2/s$, k=0.02588 W/m°C, Pr=0.7282

[05 marks]

Q4. Figure Q4 illustrates a liquid food manufaturing process in a continuous flow sterilizer. The liquid enters the sterilizer at a temperature and flow rate of $T_{m,i,h}$=20°C, and 0.03456 kg/s respectively. A time-at-temperature constraint requires that the product be held at a mean temperature of T_m= 90°C for 10s to eliminate bacteria, while a second constraint is that the local product temperature cannot exceed T_{max}= 230°C in order to preserve a pleasing taste. The sterilizer consists of an upstream, L_h=5m heating section characterized by a uniform heat flux, an intermediate insulated sterilizing section, and a downstream cooling section of length L_c= 10m. The cooling section is composed of an uninsulated tube exposed to a quiescent environment at T_∞= 20°C.The thin-walled tubing is of diameter D = 40 mm. Food properties are similar to those of liquid water at T = 330K ($\rho = 1000\ kg/m^3$, k=0.65W/m°C, C_p=4.2kJ/kg°C, $\mu = 0.5 \times 10^{-3} N\ s/m^2$).

For laminar flow:
Constant heat flux condition Nu_D=4.36, Constant surface temperature condition Nu_D=3.66
For turbulent flow:
$Nu_D=0.023Re_D^{0.8}Pr^{1/3}$

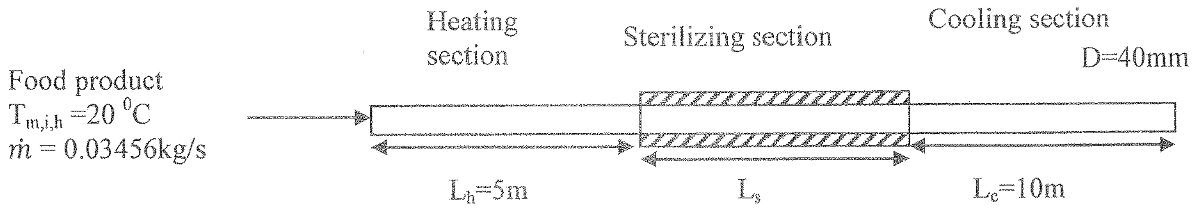

Figure Q4

a) What heat flux is required in the heating section to ensure a maximum mean product temperature of T_m= 90^{0}C?

b) Determine the location and value of the maximum local product temperature. Is the second constraint satisfied?

c) Determine the minimum length of the sterilizing section needed to satisfy the time-at-temperature constraint.

[06 marks]