MA3010 CA2 AY22S1 solution guide

Thermodynamics & Heat Transfer (Nanyang Technological University)

School of Mechanical & Aerospace Engineering
MA3010 – Thermodynamics & Heat Transfer
AY22S1 – Continual Assessment 2

Name: Tutorial Group:

Instructions:

- Please read the questions carefully before answering them.
- Please write your workings and answers neatly on blank or foolscap paper.

1. Cold atmospheric air at 1 atm, 13°C and 60% relative humidity is humidified by a steam spray to dry bulb and wet bulb temperatures of 25°C and 20°C, respectively. If the flow rate of the atmospheric air is 2.5 kg dry air per second, what is the flow rate of the steam spray? (10 marks)

   Mass balance for water vapour (m_v) and steam (m_w):

   $\dot{m}_{in} = \dot{m}_{out}$

   $\dot{m}_a\omega_1 + \dot{m}_w = \dot{m}_a\omega_2$

   $\dot{m}_w = \dot{m}_a\left(\omega_2 - \omega_1\right)$

   From psychrometric chart, ω_1 at conditions T_1 and ϕ_1, ω_2 at conditions T_2 and T_{2wb}.

2. Atmospheric air at 1 atm, 29°C and 90% relative humidity is cooled to 15°C at a rate of 1.2 kg dry air per second. If the condensate is removed at a temperature of 15°C, what is rate of heat removal for the cooling process? (15 marks)

   Mass balance for water vapour (m_v) and condensate (m_w):

   $\dot{m}_{in} = \dot{m}_{out}$

   $\dot{m}_a\omega_1 = \dot{m}_a\omega_2 + \dot{m}_w$

   $\dot{m}_w = \dot{m}_a\left(\omega_1 - \omega_2\right)$

   Energy balance:

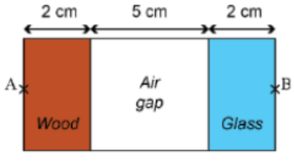
   $\dot{E}_{in} = \dot{E}_{out}$

   $\dot{m}_a h_1 = \dot{m}_a h_2 + \dot{Q} + \dot{m}_w h_w$

   $\dot{Q} = \dot{m}_a\left(h_1 - h_2\right) - \dot{m}_w h_f$, $h_w \approx h_f$ @ T_{cond} *(saturated liquid water state)*

   From psychrometric chart, ω_1 and h_1 at conditions T_1 and ϕ_1, ω_2 and h_2 at conditions T_2 and ϕ_2 = 100%.

3. A 1 m^2 by 2 cm thick wooden panel (k = 0.2 W/m·K) is used to cover up 1 m^2 by 2 cm thick glass window (k = 1.0 W/m·K), leaving a 5 cm air gap between the panel and the glass. The convection heat transfer coefficient in the air gap is 2 $W/m^2 \cdot K$. If the temperatures at point A and B are 40°C and 10°C respectively, what is the heat transfer rate through the window? (15 marks)



$$R_{total} = R_{wood} + R_{air,wood} + R_{air,glass} + R_{glass}$$

$$= \frac{L_{wood}}{K_{wood}A} + \frac{1}{hA} + \frac{1}{hA} + \frac{L_{glass}}{K_{glass}A}$$

$$\dot{Q} = \frac{\Delta T}{R_{total}}$$

4. A current of 8 A is passed through a 3 cm thick, 1.5 m long circular pipe with an internal diameter of 14 cm. The electrical resistance of the pipe wall is 2 Ω and assume all the heat generated is lost at the outer pipe to the surrounding only. What is the pipe surface temperature at steady state if the surrounding temperature is 25°C and the convection heat transfer coefficient in the surrounding is 10 W/m²·K? (15 marks)

$$\text{Power generated} = I^2 R$$

$$\text{Power generated} = h \times 2\pi r_o L \left(T_{surface} - T_{surr}\right)$$

5. A steel cube of length 5 mm (k = 43.0 W/m·K, ρ = 8000 kg/m³, c_p = 0.49 kJ/kg·K) initially at 27°C is placed into an oven maintained at the constant temperature of 800°C and the convective heat transfer coefficient in the oven is 120 W/m²·K. If 2 surfaces of the cube are insulated, determine the instantaneous heat transfer at t = 100 second. (15 marks)

$$L_c = \frac{V}{A}$$

$$\mathrm{b} = \frac{h}{\rho C L_c}$$

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt}$$

$$\text{Instantaneous Q} = \mathrm{hA}\left(T_{t=100s} - T_\infty\right)$$

6. A ski jacket made of multiple layers of synthetic fabric has a total thermal resistance of 0.3 K/W. Assuming inner surface temperature of the jacket is 28°C and the surface area is 1.25 m², determine the temperature at the outer jacket when the outdoor temperature is 0°C and the heat transfer coefficient at the outer surface is 25 W/m²·K. (15 marks)

$$R_{total} = R_{\text{ski jacket}} + R_{\text{conv, outside}}$$

$$\dot{Q} = \frac{\Delta T}{R_{total}}$$

$$\frac{T_0 - T_{\infty,0}}{R_{conv}} = \dot{Q}$$

7. Heat is internally generated in a wall (k = 0.750 W/m·K) of thickness 20 cm at a rate of $\dot{e}_g$ = 700 W/m³. The surface temperature on both sides of the wall are maintained at the same temperature (T_s) with equal convective heat losses on both sides. Assuming steady state 1D heat conduction and the origin is at the channel centre, sketch the temperature profile within the wall, and determine the value of T_s if the maximum internal temperature is 50°C. (15 marks)

General heat conduction equation (Cartesian coordinates)

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + \dot{e}_g = \rho c_p \frac{\partial T}{\partial t}$$

$$\frac{d^2T}{dx^2} + \frac{\dot{e}_g}{k} = 0$$

$$T = -\frac{\dot{e}_g}{2k}x^2 + T_s + \frac{\dot{e}_g}{2k}L^2$$

$$T_{max} = T_s + \frac{\dot{e}_g}{2k}L^2$$