MA3010 CA2 question solution guide 21S1 221029 094648

Thermodynamics & Heat Transfer (Nanyang Technological University)

School of Mechanical & Aerospace Engineering
MA3010 – Thermodynamics & Heat Transfer
AY21S1 – Continual Assessment 2

Instructions:

- Please read the questions carefully before answering them.
- There is no need to print this question sheet. Please write your workings and answers neatly on blank or foolscap paper.
- All workings and answers are to be scanned and uploaded before **11:14:59 am**.

T_1 ϕ_1

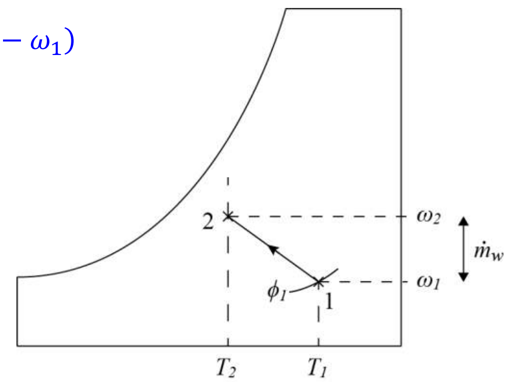
1. Hot desert air at 1 atm, 38°C, and 20% relative humidity is cooled and humidified with a water spray to 25°C. If the air flow rate is 2.5 kg dry air/s, determine the rate of water spray.

T_2 $\dot{m}_a$

(10 marks)

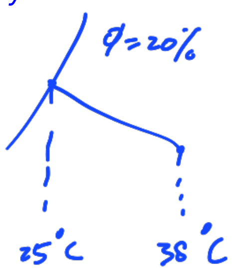
Obtain ω_1 and ω_2 from psychrometric chart; this is an evaporative process which occurs at constant wet-bulb temperature and intersects with T_2.
Mass balance for water:

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



Psychrometric chart:

$\dot{m}_w = \dot{m}_a(\omega_2 - \omega_1)$
$h = const$



2. 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. If the electrical resistance of the pipe is 2 Ω, what is the volumetric heat generation rate ($\dot{e}_g$) for the pipe?

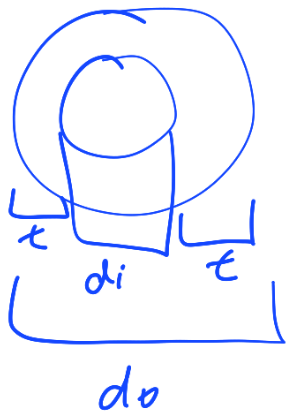
(10 marks)

$I = 8A$
$t = 3cm$
$L = 1.5m$
$d_i = 14cm$
$r = 2\ \Omega$

$V = \frac{\pi}{4}(d_o^2 - d_i^2)L$

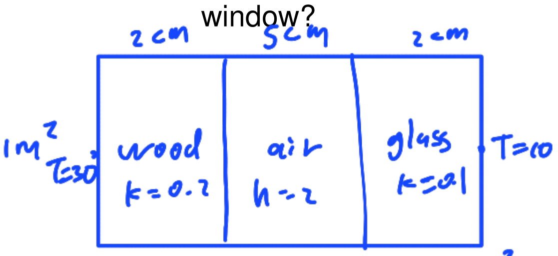
$\dot{E}_{gen} = IV = I^2R$

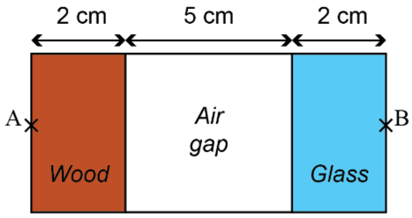
$d_o = d_i + 2t$



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·K. If the temperatures at point A and B are 30°C and 10°C respectively, what is the heat transfer rate through the window?

(15 marks)





$R_{wood} = \frac{L}{kA} = \frac{2\times10^{-3}}{0.2\times1} = 0.01$

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

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

$R_{air-wood} = \frac{1}{hA} = \frac{1}{2}$

$R_{air-glass} = \frac{1}{hA} = \frac{1}{2}$

$R_{glass} = \frac{2\times10^{-3}}{0.1} = 0.02$

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

$\dot{Q} = \frac{\Delta T}{R} = \frac{20}{0.13} = 153.85$ W

4. A steel ball (k = 43.0 W/m·K, ρ = 8000 kg/m^3, c_p = 0.49 kJ/kg·K) of radius 6 cm initially at 27°C is placed into an oven of 800°C. The oven is maintained at the constant temperature of 800°C and the convective heat transfer coefficient in the oven is 120 W/m^2·K. Determine the instantaneous heat transfer at t = 200 second.

(10 marks)

$L_c = \frac{V}{A} = \frac{\frac{4}{3}\pi r^3}{4\pi r^2} = \frac{r}{3} = 2\times10^{-3}$ m

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

$Bi = \frac{hL_c}{k} = \frac{120\times2\times10^{-3}}{43} = 0.005 < 0.1 \rightarrow$ lump

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

$-\frac{120}{8000\times2\times10^{-3}\times490}\cdot200 = \ln\left(\frac{T(200)-800}{27-800}\right)$

$-\frac{h}{\rho L_c C}t = \ln\left(\frac{T(t)-T_\infty}{T_i-T_\infty}\right)$

$\hookrightarrow \dot{Q} = hA(T_{200}-800)$

Instantaneous $\mathrm{Q} = \mathrm{hA}(T_{t=200s}-T_\infty)$

5. A cube of length 5 mm (k =1.5 W/m·K) is heated and left to cool in air with a heat transfer coefficient of 15 W/m^2·K. If 2 surfaces of the cube are insulated, calculate the Biot number.

(10 marks)

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

$$\mathrm{Bi}=\frac{hL_c}{k}$$

6. Moist air at 1 atm, 35°C, and 70% relative humidity is cooled to 20°C. Assuming that the condensate is also removed at 20°C, calculate the heat removal rate when the flow rate of the moist air is 1.2 kg dry air/s.

(15 marks)

Obtain ω_1, h_1, ω_2 and h_2 from psychrometric chart; state 2 is at 100% relative humidity and T_2.

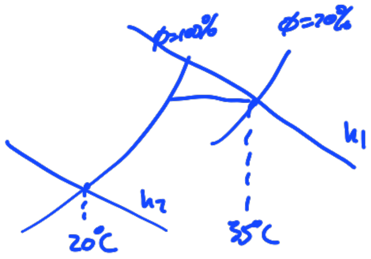
Mass balance (rate of condensate removed):

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

Energy balance (h_f = saturated liquid water enthalpy at T_2):

$$\dot{m}_a h_1=\dot{m}_a h_2+\dot{m}_w h_f+\dot{Q}_{out}$$

$$\dot{Q}_{out}=\dot{m}_a(h_1-h_2)-\dot{m}_w h_f$$



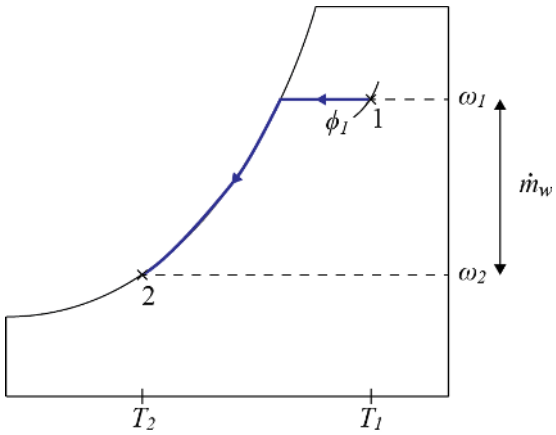
$\hookrightarrow \dot{Q} = ?$

$\dot{m}_a = 1.2$

$h_w = h_{sat}$ @ T_2

$\dot{Q} = \dot{m}_a(h_1-h_2) - \dot{m}_w h_w$

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



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/m^3. 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 1D heat conduction, sketch the temperature profile within the wall, and determine the value of T_s if the maximum internal temperature is 50°C. Hint: the temperature distribution of the wall along its thickness is $T = -\frac{\dot{e}_g}{2k}x^2 + T_S + \frac{\dot{e}_g}{2k}L^2$, where the origin is at the channel centre.

$\frac{dT}{dx} = 0$

(15 marks)

at $x = 0 \rightarrow T = T_{max}$

$50 = T_s + \frac{700}{2(0.75)}(0.1)^2$

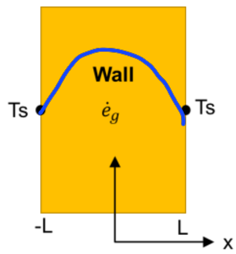
$T_s = 45.3°C$

Thickness = 2L

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

$T_{max} = T_S + \frac{\dot{e}_g}{2k}L^2$ at x = 0

L = 10cm



8. 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 m^2, 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/m^2·K.

(15 marks)

$R = 0.3$
$T_i = 28°C$
$A = 1.25\ m^2$
$T_o = ?$
$T_\infty = 0°C$
$h = 25$

$R_{air} = \frac{1}{hA} = \frac{1}{25(1.25)} = 0.032$

$R_t = 0.3 + 0.032 = 0.332$

$\dot{Q} = \frac{28-0}{R_t} = 84.337$

$\dot{Q} = \frac{28-T_o}{0.3} \rightarrow T_o = 2.698$

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