UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2015/2016

COURSE NAME	:	HEAT AND MASS TRANSFERS
COURSE CODE	:	BNQ 20204
PROGRAMME CODE	:	BNN
EXAMINATION DATE	:	JUNE / JULY 2016
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWERS FOUR (4) QUESTIONS ONLY

THIS QUESTION PAPER CONSISTS OF **ELEVEN (11)** PAGES

Q1 (a) (i) Define 'convective heat transfer' and 'convective mass transfer'.
(2 marks)

(ii) Explain the similarities between 'convective heat transfer' and 'convective mass transfer'.
(3 marks)

(b) Describe the significance of the Reynolds and Nusselt number to heat transfer calculation.
(4 marks)

(c) Explain the following statement: 'Countercurrent heat exchanger is more effective than a parallel flow exchanger'.
(6 marks)

(d) Illustrate and explain the mechanism of heat transfer between two fluids that occur in a heat exchanger.
(10 marks)

Q2 A counter-flow double pipe heat exchanger is to heat water (C_p= 4.18 kJ/kg.°C) from 20 °C to 80 °C at a rate of 1.2 kg/s. The heating is to be accomplished by geothermal water (C_p= 4.31 kJ/kg.°C) available at 160 °C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 1.5 cm. If the overall heat transfer coefficient of the heat exchanger is 640 W/m^2. °C,

(a) Propose the geothermal water outlet temperature.
(10 marks)

(b) Calculate the length of the heat exchanger required to achieve the desired heating.
(15 marks)

Q3 A tube bank use a staggered arrangement of 30 mm diameter tubes with $S_p=S_n=60$ mm and tube length of 1 m. There are 10 tube rows in the flow direction and 7 tubes per row. Air with upstream conditions of T = 27 °C and V= 15 m/s is in cross flow over the tubes, while a tube wall temperature of 100 °C is maintained by steam condensation inside the tubes.

(a) Determine the air temperature leaving the tube bank.

(10 marks)

(b) Calculate the heat transfer between air and tubes.

(15 marks)

(The physical properties of air could be extracted from **Table Q3 (i)** and the additional data could be obtained in **Table Q3 (ii)** and **(iii)**).

Q4 A solid nonporous spherical ball, naphthalene, with diameter of 2 cm is suspended in still air at 347 K and 1.01325 X 10^5 Pa (1 atm). The naphthalene slowly evaporates, releasing the naphthalene into the surrounding air by molecular diffusion process. Naphthalene has a molecular weight of 128 g/mol, a solid density of 1.145 g/cm^3, diffusivity in air of 8.19 x 10^{-6} m^2/s and exerts a vapor pressure of 666 Pa at 347 K.

(a) Draw and label the process mentioned above.

(5 marks)

(b) Estimate the time required for the naphthalene to completely evaporate.

(20 marks)

Q5 A 2 cm diameter, stainless steel ball (ρ = 7865 kg/m^3, C_p = 0.46 kJ/kg °C and k = 61 W/m.°C) is uniformly heated to T_i = 800 °C. It is to be hardened by suddenly dropping it into an oil bath at T_∞ = 50 °C. The heat transfer coefficient between the surface of steel ball and the oil is h = 45 W/m^2.°C. If the hardening process completed when the temperature of steel ball reach 100 °C,

(a) Calculate the characteristic length and biot number for the case above.

(5 marks)

(b) Determine the time for the ball to be keep in the oil bath.

(20 marks)

- END OF QUESTION –

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Unit Conversion

R value

R= 8.31451 J K^{-1} mol^{-1} = 8.20578x10^{-2} L atm K^{-1} mol^{-1} = 8.31451x10^{-2} L bar K^{-1} mol^{-1}
= 8.31451 Pa m^3 K^{-1} mol^{-1} = 62.364 L Torr K^{-1} mol^{-1} = 1.98722 cal K^{-1} mol^{-1}

Liquid water properties at 4 °C (277.2 K)

Density (ρ) = 1000 kg/m^3
= 1 g/cm^3
= 62.43 lb_m/ft^3

Temperature

K = °C + 273.15
°F= 32 + 1.8(°C)
°R= °F + 459.67
100 °C = 212 °F + 373.15 K = 671.67 °R
0 °C = 32 °F = 273.15 K = 491.67 °R

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FACTORS FOR UNIT CONVERSIONS

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Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 L = 28,317 cm^3
Force	1 N = 1 kg·m/s^2 = 10^5 dynes = 10^5 g·cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m·ft/s^2 = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bar = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/$in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

Example: The factor to convert grams to lb_m is $\left(\frac{2.20462\ lb_m}{1000\ g}\right)$.

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Table Q3 (i)

A.3-3 Physical Properties of Air at 101.325 kPa (1 Atm Abs), SI Units

T (°C)	T (K)	ρ (kg/m^3)	c_p ($kJ/kg \cdot K$)	$\mu \times 10^5$ ($Pa \cdot s$, or $kg/m \cdot s$)	k ($W/m \cdot K$)	N_{Pr}	$\beta \times 10^3$ ($1/K$)	$g\beta\rho^2/\mu^2$ ($1/K \cdot m^3$)
−17.8	255.4	1.379	1.0048	1.62	0.02250	0.720	3.92	2.79×10^8
0	273.2	1.293	1.0048	1.72	0.02423	0.715	3.65	2.04×10^8
10.0	283.2	1.246	1.0048	1.78	0.02492	0.713	3.53	1.72×10^8
37.8	311.0	1.137	1.0048	1.90	0.02700	0.705	3.22	1.12×10^8
65.6	338.8	1.043	1.0090	2.03	0.02925	0.702	2.95	0.775×10^8
93.3	366.5	0.964	1.0090	2.15	0.03115	0.694	2.74	0.534×10^8
121.1	394.3	0.895	1.0132	2.27	0.03323	0.692	2.54	0.386×10^8
148.9	422.1	0.838	1.0174	2.37	0.03531	0.689	2.38	0.289×10^8
176.7	449.9	0.785	1.0216	2.50	0.03721	0.687	2.21	0.214×10^8
204.4	477.6	0.740	1.0258	2.60	0.03894	0.686	2.09	0.168×10^8
232.2	505.4	0.700	1.0300	2.71	0.04084	0.684	1.98	0.130×10^8
260.0	533.2	0.662	1.0341	2.80	0.04258	0.680	1.87	0.104×10^8

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Table Q3 (ii)

TABLE 4.6-2. *Values of C and m To Be Used in Eq. (4.6-1) for Heat Transfer to Banks of Tubes Containing More Than 10 Transverse Rows*

	$\frac{S_n}{D} = \frac{S_p}{D} = 1.25$		$\frac{S_n}{D} = \frac{S_p}{D} = 1.50$		$\frac{S_n}{D} = \frac{S_p}{D} = 2.0$	
Arrangement	*C*	*m*	*C*	*m*	*C*	*m*
In-line	0.386	0.592	0.278	0.620	0.254	0.632
Staggered	0.575	0.556	0.511	0.562	0.535	0.556

Source: E. D. Grimison, *Trans. ASME*, **59**, 583 (1937).

Table Q3 (iii)

TABLE 4.6-3. *Ratio of h for N Transverse Rows Deep to h for 10 Transverse Rows Deep (for Use with Table 4.6-2)*

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Ratio for staggered tubes	0.68	0.75	0.83	0.89	0.92	0.95	0.97	0.98	0.99	1.00
Ratio for in-line tubes	0.64	0.80	0.87	0.90	0.92	0.94	0.96	0.98	0.99	1.00

Source: W. M. Kays and R. K. Lo, *Stanford Univ. Tech. Rept. 15*, Navy Contract N6-ONR-251 T.O.6, 1952.

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FORMULA

HEAT EXCHANGER

Cold stream $$Q_c = m_c c_{pc}(T_{co} - T_{ci})$$

Hot stream $$Q_H = m_H c_{pH}(T_{Hi} - T_{Ho})$$

$$Q = U.A.(\Delta T_{lm})$$

$$\frac{1}{(UA)_o} = \frac{1}{(hA)_i} + \frac{\ln(r_o / r_i)}{(2\pi L)k} = \frac{1}{(hA)_o}$$

CO-CURRENT HEAT EXCHANGER

$$\Delta T_{lm} = \frac{(T_{hi} - T_{ci}) - (T_{ho} - T_{co})}{\ln(\frac{(T_{hi} - T_{ci})}{(T_{ho} - T_{co})})}$$

COUNTER CURRENT HEAT EXCHANGER

$$\Delta T_{lm} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln(\frac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})})}$$

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Flow Past Banks of Tubes or Cylinders

$$N_{NU} = CN_{RE}{}^{m} N_{\mathrm{Pr}}{}^{\frac{1}{3}}$$

$$N_{RE,\max} = \frac{\rho V_{\max} D}{\mu}$$

$$V_{\max} = \frac{VS_n}{S_n - D}$$

$$N_{NU}\Big|_{N<10} = c_1 N_{NU}$$

$$N_{NU_D} = \frac{hD}{k}$$

$$q = Ah(T_w - T_b)$$

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MOLECULAR DIFFUSION

$$N_A = \frac{D_{AB}P}{RT(z_2 - z_1)p_{BM}}(p_{A1} - p_{A2})$$

$$p_{BM} = \frac{p_{B2} - p_{B1}}{\ln(p_{B2}/p_{B1})} = \frac{p_{A1} - p_{A2}}{\ln(P - p_{A1}/P - p_{A2})}$$

$$p_{BM} = \frac{p_{B1} + p_{B2}}{2}$$

$$t_F = \frac{\rho_A r_1^2 RT p_{BM}}{2M_A D_{AB} P(p_{A_1} - p_{A_2})}$$

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UNSTEADY STATE HEAT TRANSFER

$$N_{Bi} = \frac{hx_1}{k}$$

$$x_1 = \frac{V}{A_s}$$

cylinder

$$x_1 = \frac{r}{2}$$

sphere

$$x_1 = \frac{r}{3}$$

$$\frac{(T - T_\infty)}{(T_o - T_\infty)} = e^{-(hA/\rho V c_p)t}$$