Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	HEAT TRANSFER
COURSE CODE	:	BNQ 20203
PROGRAMME CODE	:	BNN
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER **ALL** QUESTIONS 2.THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☑ Closed book 3.STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

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

Q1 (a) Define the terms "convection" and "conduction".

(2 marks)

(b) Explain "forced convection" and "natural or free convection".

(3 marks)

(c) Compare the terms "turbulent" and "laminar" flow by giving **ONE (1)** example for each terms.

(6 marks)

(d) Air at 1 atm Abs and an average of 450.2 K is being heated as it flows at a velocity of 6.7 m/s through a tube of 30 mm inside diameter. Outside of the tube, the heating medium is 492.2 K steam condensing on the outside of the tube. Assume that the surface wall temperature of the metal in contact with the air if 492.2 K.

(i) Calculate heat transfer flux.

(12 marks)

(ii) Explain why you can make the above assumption.

(2 marks)

Q2 (a) Explain the terms "film condensation" and "droplet condensation".

(2 marks)

(b) Discuss internal flow boiling in heat transfer.

(5 marks)

(c) A 1 m long of a small oxidized horizontal polished aluminum tube is in a very large furnace enclosure with fire brick wall where the surrounding air is at 835 K. The OD of the metal tube is 27 mm and the surface temperature is 550 K.

(i) Determine the heat transfer to the tube by radiation.

(7 marks)

(ii) Determine the heat transfer to the tube by radiation plus natural convection.

(7 marks)

(d) Describe the mechanism of radiation heat transfer.

(2 marks)

(e) Consider a vertical tube with outer diameter of 0.032 m. Steam saturated at 10 psia is condensing on the tube where the surface temperature is at 84 °C. The heat transfer coefficient is 13 000 W/m^2.K, k is 0.7 W/m.K, and Nusselt number is 5900. Determine the length of the tube.

(2 marks)

Q3 (a) Explain the terms "steady state" and "unsteady state".

(2 marks)

(b) Demonstrate the relationship between temperature and time for the steady state and unsteady state condition by plotting a graph.

(4 marks)

(c) Consider that you are taking out a rectangular box of potatoes which is 12 cm thick at a temperature of 260.4 K from a freezer and place it in an environment where the temperature is at 303 K. Only the top of the potato container is not insulated. After 3 h of exposing the potato to the environment, calculate what is the temperature in the potato at the top of the surface and at 12 cm below the top surface. The convective coefficient is constant and is 9 W/m^2.K.

(13 marks)

(d) A cylindrical can of tomato soup is in the centre of the vertical stack of cans and is insulated on its two end by the other cans where the heat capacity of the metal wall of the can, can be neglected. The can has a diameter of 7 cm and a height of 10 cm and its initially at a uniform temperature of 28.5 °C. The cans are stacked vertically in a retort and steam at 120 °C is admitted. For a heating temperature at 120 °C, with the temperature at the centre of the can of 102 °C, determine the time of heating. The heat transfer coefficient of the steam is estimated as 4490 W/m^2.K. Physical properties of the soup are k = 0.815 W/m.K and α = 2.003 x 10-7 m^2/s.

(6 marks)

Q4 (a) Demonstrate a spiral heat exchanger by drawing a shematic diagram.

(2 marks)

(b) Explain the differences between a cocurrent heat exchanger and a counter current heat exchanger. Demonstrate each of the heat exchangers by using a schematic diagram.

(7 marks)

(c) State **FOUR (4)** types of foulings and **FOUR (4)** ways to minimize the foulings.

(4 marks)

(d) Consider a stainless steel double pipe heat exchanger. Determine the length and diameter inside and outside of the stainless steel double pipe heat exchanger if the ratio of the diameter outside to the diameter inside is 1.32, the overall heat transfer coefficient inside and outside are 415 W/ m^2.K and 309 W/m^2.K, respectively, the fouling factor tube inside is 0.0005 m^2.K /W, fouling factors shell tube outside is 0.00015 m^2.K /W, area inside is 0.0522 m2, k=15.1 W/mK, hi is 821 W/m^2.K and ho is 1199 W/m2K.

(12 marks)

-END OF QUESTIONS-

APPENDIX

Table 1: Conversion factor

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 μm = 10^{10} Å 1 m = 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 liters = 10^6 cm^3 = 10^6 ml 1 m^3 = 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 liters = 28317 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
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bars 1 atm = 1.01325×10^6 dynes/cm^2 1 atm = 760 mmHg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/in^2 (psi) 1 atm = 33.9 ft H_20 at 4°C = 29.921 inHg at 0°C
Energy	1 J = 1 N·m = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h 1 J = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 1.341×10^{-3} hp

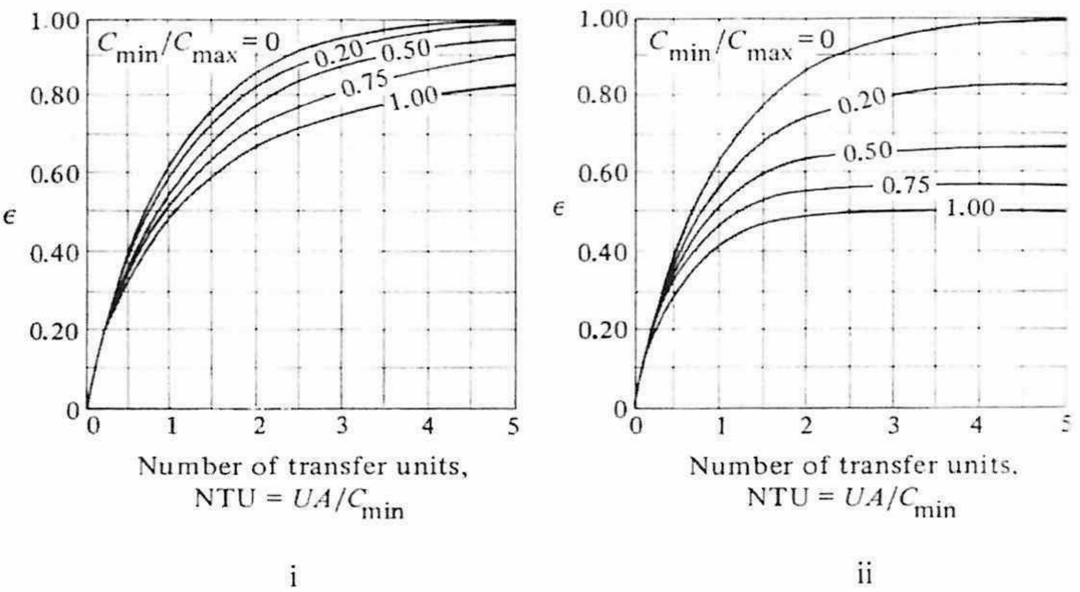

Figure 1: Heat exchanger effectiveness: (i) counterflow exchanger, (ii) parallel flow exchanger

Table 2: Dimensionless parameters for use in unsteady-state consduction charts

$$Y = \frac{T_1 - T}{T_1 - T_0} \qquad m = \frac{k}{hx_1}$$

$$1 - Y = \frac{T - T_0}{T_1 - T_0} \qquad n = \frac{x}{x_1}$$

$$X = \frac{\alpha t}{x_1^2} \qquad \alpha = \frac{k}{\rho c_p}$$

SI units: $\alpha = \text{m}^2/\text{s}$, $T = \text{K}$, $t = \text{s}$, $x = \text{m}$, $x_1 = \text{m}$, $k = \text{W/m} \cdot \text{K}$, $h = \text{W/m}^2 \cdot \text{K}$

English units: $\alpha = \text{ft}^2/\text{h}$, $T = {}^\circ\text{F}$, $t = \text{h}$, $x = \text{ft}$, $x_1 = \text{ft}$, $k = \text{btu/h} \cdot \text{ft} \cdot {}^\circ\text{F}$,
$h = \text{btu/h} \cdot \text{ft}^2 \cdot {}^\circ\text{F}$

Cgs units: $\alpha = \text{cm}^2/\text{s}$, $T = {}^\circ\text{C}$, $t = \text{s}$, $x = \text{cm}$, $x_1 = \text{cm}$, $k = \text{cal/s} \cdot \text{cm} \cdot {}^\circ\text{C}$,
$h = \text{cal/s} \cdot \text{cm}^2 \cdot {}^\circ\text{C}$

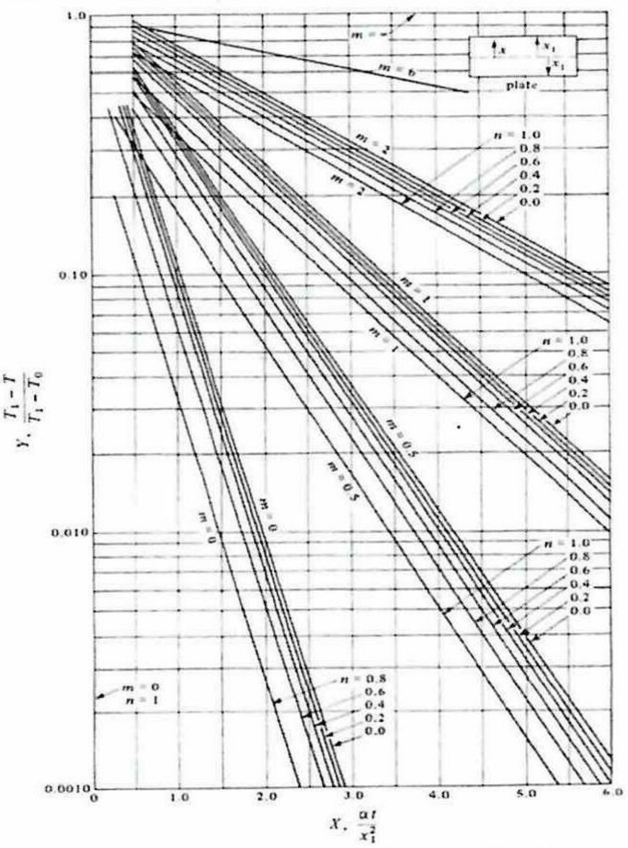

Figure 2: Unsteady-state heat conduction in a large flat plat

Table 3: Physical properties of Air at 101.325 kPa (1 Atm Abs) in 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

Table 4: Simplified equations for natural convection from various surfaces

Physical Geometry	$N_{Gr} N_{Pr}$	Equation: $h = btu/h \cdot ft^2 \cdot °F$, $L = ft$, $\Delta T = °F$, $D = ft$	Equation: $h = W/m^2 \cdot K$, $L = m$, $\Delta T = K$, $D = m$	Ref.
	Air at 101.32 kPa (1 atm) abs pressure			
Vertical planes and cylinders	10^4–10^9	$h = 0.28(\Delta T/L)^{1/4}$	$h = 1.37(\Delta T/L)^{1/4}$	(P1)
	$>10^9$	$h = 0.18(\Delta T)^{1/3}$	$h = 1.24\ \Delta T^{1/3}$	(P1)
Horizontal cylinders	10^3–10^9	$h = 0.27(\Delta T/D)^{1/4}$	$h = 1.32(\Delta T/D)^{1/4}$	(M1)
	$>10^9$	$h = 0.18(\Delta T)^{1/3}$	$h = 1.24\ \Delta T^{1/3}$	(M1)
Horizontal plates				
Heated plate facing upward or cooled plate facing downward	10^5–2×10^7	$h = 0.27(\Delta T/L)^{1/4}$	$h = 1.32(\Delta T/L)^{1/4}$	(M1)
	2×10^7–3×10^{10}	$h = 0.22(\Delta T)^{1/3}$	$h = 1.52\ \Delta T^{1/3}$	(M1)
Heated plate facing downward or cooled plate facing upward	3×10^5–3×10^{10}	$h = 0.12(\Delta T/L)^{1/4}$	$h = 0.59(\Delta T/L)^{1/4}$	(M1)
	Water at 70°F (294 K)			
Vertical planes and cylinders	10^4–10^9	$h = 26(\Delta T/L)^{1/4}$	$h = 127(\Delta T/L)^{1/4}$	(P1)
	Organic liquids at 70°F (294 K)			
Vertical planes and cylinders	10^4–10^9	$h = 12(\Delta T/L)^{1/4}$	$h = 59(\Delta T/L)^{1/4}$	(P1)

Table 5: Heat capacities of foods (Average c_p 273-373 K or 0-100 °C)

Material	H_2O (wt %)	c_p (kJ/kg · K)
Apples	75–85	3.73–4.02
Apple sauce		4.02*
Asparagus		
Fresh	93	3.94†
Frozen	93	2.01‡
Bacon, lean	51	3.43
Banana purée		3.66§
Beef, lean	72	3.43
Bread, white	44–45	2.72–2.85
Butter	15	2.30¶
Cantaloupe	92.7	3.94†
Cheese, Swiss	55	2.68†
Corn, sweet		
Fresh		3.32†
Frozen		1.77‡
Cream, 45–60% fat	57–73	3.06–3.27
Cucumber	97	4.10
Eggs		
Fresh		3.18†
Frozen		1.68‡
Fish, cod		
Fresh	70	3.18
Frozen	70	1.72‡
Flour	12–13.5	1.80–1.88
Ice	100	1.958‖
Ice cream		
Fresh	58–66	3.27†
Frozen	58–66	1.88‡
Lamb	70	3.18*
Macaroni	12.5–13.5	1.84–1.88
Milk, cows'		
Whole	87.5	3.85
Skim	91	3.98–4.02
Olive oil		2.01**
Oranges		
Fresh	87.2	3.77†
Frozen	87.2	1.93‡
Peas, air-dried	14	1.84
Peas, green		
Fresh	74.3	3.31†
Frozen	74.3	1.76‡
Pea soup		4.10
Plums	75–78	3.52
Pork		
Fresh	60	2.85†
Frozen	60	1.34‡
Potatoes	75	3.52
Poultry		
Fresh	74	3.31†
Frozen	74	1.55‡
Sausage, franks		
Fresh	60	3.60†
Frozen	60	2.35‡
String beans		
Fresh	88.9	3.81†
Frozen	88.9	1.97‡
Tomatoes	95	3.98†
Veal	63	3.22
Water	100	4.185**

* 32.8°C.
† Above freezing.
‡ Below freezing.
§ 24.4°C.
¶ 4.4°C.
‖ −20°C.
** 20°C.

Table 6: Total emissivity of various surfaces

Surface	T(K)	T(°F)	Emissivity, ε
Polished aluminum	500	440	0.039
	850	1070	0.057
Polished iron	450	350	0.052
Oxidized iron	373	212	0.74
Polished copper	353	176	0.018
Asbestos board	296	74	0.96
Oil paints, all colors	373	212	0.92–0.96
Water	273	32	0.95

Table 7: Thermal conductivities, densities, and viscosities of foods

Material	H_2O (wt %)	Temperature (K)	k ($W/m \cdot K$)	ρ (kg/m^3)	μ [$(Pa \cdot s)10^3$, or cp]
Apple sauce		295.7	0.692		
Butter	15	277.6	0.197	998	
Cantaloupe			0.571		
Fish					
Fresh		273.2	0.431		
Frozen		263.2	1.22		
Flour, wheat	8.8		0.450		
Honey	12.6	275.4	0.50		
Ice	100	273.2	2.25		
	100	253.2	2.42		
Lamb	71	278.8	0.415		
Milk					
Whole		293.2		1030	2.12
Skim		274.7	0.538		
		298.2		1041	1.4
Oil					
Cod liver		298.2		924	
Corn		288.2		921	
Olive		293.2	0.168	919	84
Peanut		277.1	0.168		
Soybean		303.2		919	40
Oranges	61.2	303.5	0.431		
Pears		281.9	0.595		
Pork, lean					
Fresh	74	275.4	0.460		
Frozen		258.2	1.109		
Potatoes					
Raw			0.554		
Frozen		260.4	1.09	977	
Salmon					
Fresh	67	277.1	0.50		
Frozen	67	248.2	1.30		
Sucrose solution	80	294.3		1073	1.92
Turkey					
Fresh	74	276.0	0.502		
Frozen		248.2	1.675		
Veal					
Fresh	75	335.4	0.485		
Frozen	75	263.6	1.30		
Water	100	293.2	0.602		
	100	273.2	0.569		

Formulas

$$U_i = \frac{1}{A_i\left[\dfrac{1}{h_o A_o} + \dfrac{\ln(r_o / r_i)}{2\pi k L} + \dfrac{1}{h_i A_i} + \dfrac{1}{h_{di} A_i} + \dfrac{1}{h_{do} A_o}\right]}$$

$$U_i = \frac{1}{A_i \sum R} = \frac{1}{A_i\left[R_o + R_{wall} + R_i + R_{fi} + R_{fo}\right]}$$

$$q_{\max} = \left(\dot{m} c_p\right)_{\min}\left(T_{hi} - T_{ci}\right) = C_{\min}\left(T_{hi} - T_{ci}\right) = C_{\min}\Delta T_{\max}$$

$$N_{\Pr} = \frac{C_p \mu}{k} \quad N_{RE_D} = \frac{\rho V D}{\mu_b} \quad N_{RE_L} = \frac{\rho V L}{\mu_b} \quad N_{NU_D} = \frac{hD}{k} \quad N_{NU_L} = \frac{hL}{k}$$

$$N_{NU_D} = 1.86\left(N_{RE_D} N_{\Pr} \frac{D}{L}\right)^{1/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14} = \frac{hD}{k} \quad N_{NU_D} = 0.027 N_{RE_D}^{\ 0.8} N_{\Pr}^{\ 1/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14} = \frac{hD}{k}$$

$$h_r = \frac{\varepsilon\sigma(T_1^4 - T_2^4)}{(T_1 - T_2)}$$

$$q = A_1 \varepsilon_1 \sigma T_1^{\ 4} - A_1 \alpha_{12}\, \sigma T_2^{\ 4}$$

$$q = A_1 \varepsilon \sigma (T_1^{\ 4} - T_2^{\ 4})$$

$$\alpha_1 = \varepsilon_1$$

$$q = A_1 h_r (T_1 - T_2)$$

$$h_r = \varepsilon(5.676)\frac{\left(\dfrac{T_1}{100}\right)^4 - \left(\dfrac{T_2}{100}\right)^4}{T_1 - T_2}$$

$$q = q_{conv} + q_{rad} = h_c A_1 \left(T_1 - T_2\right) + h_r A_1 \left(T_1 - T_2\right)$$

$$q = Ah(T_w - T_b) \quad N_{Nu} = 2 + 0.60 N_{\mathrm{Re}}^{\ 0.5} N_{\Pr}^{\ \frac{1}{3}}$$

$$h = 0.62\left[\frac{k_v^{\ 3} \rho_v (\rho_L - \rho_v) g \left(h_{fg} + 0.4 c_{p_v} \Delta T\right)}{D \mu_v \Delta T}\right]^{\frac{1}{4}}$$

$$N_{Nu} = \frac{hL}{k_l} = 1.13\left[\frac{\rho_l(\rho_l - \rho_v)gh_{fg}L^3}{\mu_l k_l \Delta T}\right]^{\frac{1}{4}}$$

$\Delta T = T_{sat} - T_{wall}$

$\rho_l =$ *liquid* density

$\rho_v =$ saturated vapor density

$h_{fg} =$ *latent* heat of vaporization

Vertical surface :- $N_{Nu} = \dfrac{hL}{k_l} = 0.0077\left(\dfrac{g\rho_l^{\,2}L^3}{\mu_l^{\,2}}\right)^{\frac{1}{3}}(N_{Re})^{0.4}$

Where $N_{Re} = \dfrac{4\dot{m}}{\pi D\mu_l} = \dfrac{4\Gamma}{\mu_l}$ (vertical tube, diameter D)

$N_{Re} = \dfrac{4\dot{m}}{W\mu_l} = \dfrac{4\Gamma}{\mu_l}$ (vertical plate, width W)