Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
(ONLINE)
SEMESTER II
SESSION 2020/2021

COURSE NAME	:	HEAT TRANSFER
COURSE CODE	:	BDA 30603
PROGRAMME	:	BDD
EXAMINATION DATE	:	JULY 2021
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER ONLY **FOUR (4)** QUESTIONS

THIS QUESTION PAPER CONSISTS OF **TWELVE (12)** PAGES

Q1 (a) Consider a stainless-steel spoon (k = 15.1 W/m•°C) partially immersed in boiling water at 95°C in a kitchen at 25°C (**Figure 1a**). The handle of the spoon has a cross section of 0.2-cm x 1.3-cm, and extends 18 cm in the air from the free surface of the water. If the heat transfer coefficient at the exposed surfaces of the spoon handle is 17 W/m^2.°C, determine the temperature difference across the exposed surface of the spoon handle.

(10 marks)

(b) A 4-mm thick and 10-cm long straight aluminum rectangular fin (k = 273 W/m·°C) is attached to a surface. The heat transfer coefficient of the surrounding air is 20 W/m^2·K. Taken the width of the fin at 1-m, determine the efficiency of the fin.

(5 marks)

(c) Steel rods (ρ = 7832 kg/m^3, c = 434 J/kg.K, and k = 63.9 W/m·K) are heated in a furnace to 850°C and then quenched in a water bath at 50°C for a period of 40 seconds as part of a hardening process. The convection heat transfer coefficient is 650 W/m^2.K. If the steel rods have diameter of 40-mm and length of 2-m, determine their average temperature when they are taken out of the water bath.

(10 marks)

Q2 (a) A piece of thin, corrugated, AISI 1010 steel plate is heat-treated to an initial surface temperature of T_i = 324°C and then left to cool at atmospheric condition with air temperature T_∞ = 30°C. The surrounding air is assumed to be quiescent (static). The corrugations on the sheet are formed by a series of alternating semi-circles with identical radius of 100mm as shown in **Figure Q2a**. The surface of the plate has a uniform emissivity of ε = 0.95. The plate has a height of 500 mm. Determine:

i) the initial rate of convective heat transfer from the steel plate to the surroundings; and

ii) the total rate of heat transfer from the steel plate to the surroundings.

(15 marks)

(b) Assuming constant thermal conductivity, express the most suitable heat conduction equation for the each of the following cases;

i) A thin circular disc with uniform steady heat flow from the top face to the bottom face;

ii) A long insulated circular copper cable with steady heat flowing from one end to another; and

iii) A cylindrical battery with time-dependent exothermic chemical reaction at the core.

(6 marks)

(c) Consider laminar natural convection from a vertical hot plate. Will the heat flux be higher at the top or at the bottom? Explain your answer by using illustration (drawing).

(4 marks)

Q3 (a) How is the hydrodynamic entry length defined for flow in tube? Is the entry length longer in laminar or turbulent flow?

(3 marks)

(b) A thin flat plate of length 1 m separates two air streams flowing in parallel over the opposite surfaces of the plate. One air stream has a temperature of 200°C and a velocity of 60 m/s, whereas the other has a temperature of 25°C and a velocity of 10 m/s. Assuming negligible conduction resistances and the surface temperature of the plate is 188°C,

i) determine the convection heat transfer coefficient of each stream at the mid-point of the plate; and

ii) estimate the value of heat flux at the mid-point of the plate.

(13 marks)

(c) Water flows at 2 kg/s through a 40 mm diameter tube to be heated from 25°C to 75°C. The tube surface is maintained at a temperature of 100°C. What is the required length of the tube?

(9 marks)

Q4 (a) The simplest heat exchanger are parallel flow and counter flow heat exchanger. With the help of illustration, distinguish the difference between these two heat exchanger in terms of its fluid flow direction and temperature profile along the heat exchanger tube.

(3 marks)

(b) Hot chemical products (c_{ph} = 2.5 kJ/kg.K) at 600°C and at a flow rate of 30 kg/s are used to heat cold chemical products (c_{pc} = 4.2 kJ/kg.K) at 200°C and at a flow rate 20 kg/s in a parallel flow heat exchanger. The total heat transfer area is 50 m^2 and the overall heat transfer coefficient may be taken as 1500 $W/m^2.K$. Calculate the outlet temperatures of the hot, and cold chemical products, T_{h2} and T_{c2} ?

(10 marks)

(c) A heat exchanger is to be designed to condense an organic vapour at a rate of 500 kg/min. Which is available at its saturation temperature of 355 K. Cooling water at 286 K is available at a flow rate of 60 kg/s. The overall heat transfer coefficient is 475 $W/m^2.C$. Latent heat of condensation of the organic vapour is 600 kJ/kg. Calculate

i) the number of tubes required, if the tubes measured to, outer diameter of 25-mm, 2-mm thick and 4.87-m long; and

ii) the number of tube passes, if cooling water velocity (tube side) should not exceed 2 m/s.

For reference, given below is the formulation to find number of passes N.

$N = P \times N_p$
N : No. of tubes
P : No. of passes
N_p : No. of tubes in each passes

(12 marks)

Q5 (a) Absorptivity, reflectivity and transmissivity are three main properties in radiation heat transfer. With the help of illustration distinguished the different between these three properties and conclude the relationship between them.

(8 marks)

(b) The absorber surface of a solar collector (**Figure Q5b**) is made of aluminum coated with black chrome ($\alpha_s = 0.87$ and $\varepsilon = 0.09$). Solar radiation is incident on the surface at a rate of 720 W/m^2. The air and the effective sky temperatures are at 25°C and 15°C respectively and the convection heat transfer coefficient is 10 W/m^2·K. If the absorber surface temperature is at 70°C, determine the net rate of solar energy delivered by the absorber plate to the water circulating behind it.

(8 marks)

(c) Considering the solar collector in **Figure Q5b** to be malfunction in which the water inside the pipe has not been able to be circulated. Provide your conclusion on the surface temperature of the absorber in comparison its initial value, and justify your answer.

(3 marks)

(d) View factor is one of the important variable in determining heat radiation rate between two surfaces. With a help of an illustration describe the reciprocity relation on the view factor between two surfaces.

(3 marks)

(e) Two very large parallel plates are maintained at uniform temperature of T_1 = 950K and T_2 = 500K and have emissivity of $\varepsilon_1 = 1$ and $\varepsilon_2 = 0.55$, respectively. Determine the net rate of heat transfer between the two plates.

(3 marks)

- **END OF QUESTION** -

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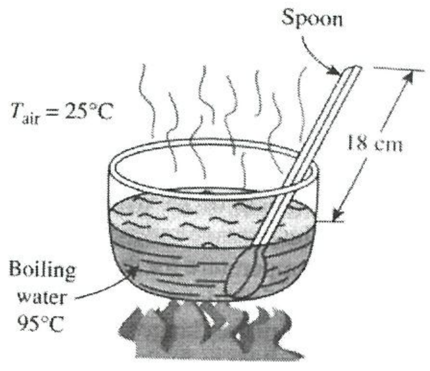

Figure Q1a

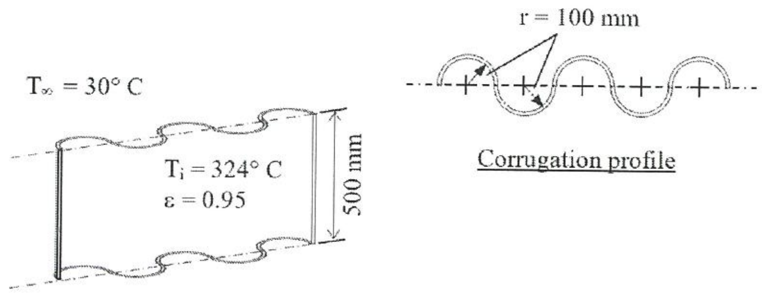

Figure Q2a

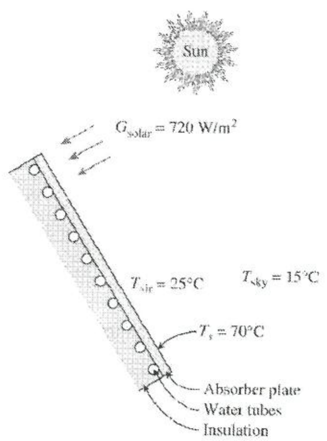

Figure Q5b

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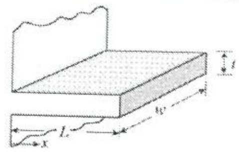
TABLE 3–3

Efficiency and surface areas of common fin configurations

Straight rectangular fins

$m = \sqrt{2h/kt}$
$L_c = L + t/2$
$A_{fin} = 2wL_c$

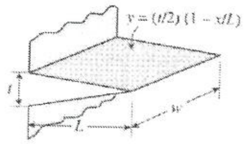
$$\eta_{fin} = \frac{\tanh mL_c}{mL_c}$$



Straight triangular fins

$m = \sqrt{2h/kt}$
$A_{fin} = 2w\sqrt{L^2 + (t/2)^2}$

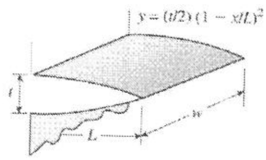
$$\eta_{fin} = \frac{1}{mL}\frac{I_1(2mL)}{I_0(2mL)}$$



Straight parabolic fins

$m = \sqrt{2h/kt}$
$A_{fin} = wL[C_1 + (L/t)\ln(t/L + C_1)]$
$C_1 = \sqrt{1 + (t/L)^2}$

$$\eta_{fin} = \frac{2}{1 + \sqrt{(2mL)^2 + 1}}$$

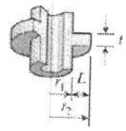


Circular fins of rectangular profile

$m = \sqrt{2h/kt}$
$r_{2c} = r_2 + t/2$
$A_{fin} = 2\pi(r_{2c}^2 - r_1^2)$

$$\eta_{fin} = C_2\frac{K_1(mr_1)I_1(mr_{2c}) - I_1(mr_1)K_1(mr_{2c})}{I_0(mr_1)K_1(mr_{2c}) + K_0(mr_1)I_1(mr_{2c})}$$

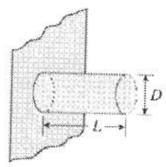
$$C_2 = \frac{2r_1/m}{r_{2c}^2 - r_1^2}$$



Pin fins of rectangular profile

$m = \sqrt{4h/kD}$
$L_c = L + D/4$
$A_{fin} = \pi DL_c$

$$\eta_{fin} = \frac{\tanh mL_c}{mL_c}$$

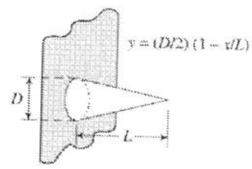


Pin fins of triangular profile

$m = \sqrt{4h/kD}$
$A_{fin} = \frac{\pi D}{2}\sqrt{L^2 + (D/2)^2}$

$$\eta_{fin} = \frac{2}{mL}\frac{I_2(2mL)}{I_1(2mL)}$$

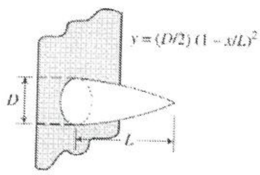
$I_2(x) = I_0(x) - (2/x)I_1(x)$ where $x = 2mL$



Pin fins of parabolic profile

$m = \sqrt{4h/kD}$
$A_{fin} = \frac{\pi L^3}{8D}\left[C_3C_4 - \frac{L}{2D}\ln(2DC_4/L + C_3)\right]$
$C_3 = 1 + 2(D/L)^2$
$C_4 = \sqrt{1 + (D/L)^2}$

$$\eta_{fin} = \frac{2}{1 + \sqrt{(2mL/3)^2 + 1}}$$



Pin fins of parabolic profile (blunt tip)

$m = \sqrt{4h/kD}$
$A_{fin} = \frac{\pi D^4}{96L^2}\left\{[16(L/D)^2 + 1]^{3/2} - 1\right\}$

$$\eta_{fin} = \frac{3}{2mL}\frac{I_1(4mL/3)}{I_0(4mL/3)}$$

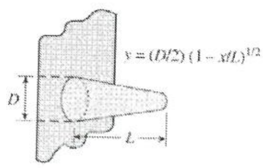


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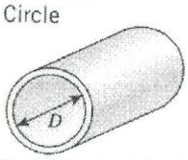
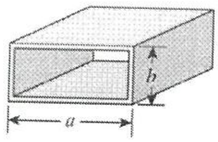
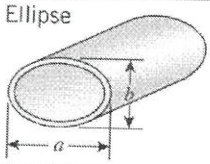
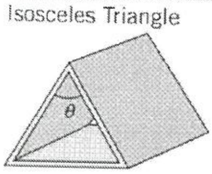
TABLE 8–1

Nusselt number and friction factor for fully developed laminar flow in tubes of various cross sections ($D_h = 4A_c/p$, $Re = V_{avg}D_h/\nu$, and $Nu = hD_h/k$)

Tube Geometry	a/b or θ°	Nusselt Number T_s = Const.	Nusselt Number $\dot{q}_s$ = Const.	Friction Factor f
Circle 	—	3.66	4.36	64.00/Re
Rectangle 	a/b			
	1	2.98	3.61	56.92/Re
	2	3.39	4.12	62.20/Re
	3	3.96	4.79	68.36/Re
	4	4.44	5.33	72.92/Re
	6	5.14	6.05	78.80/Re
	8	5.60	6.49	82.32/Re
	∞	7.54	8.24	96.00/Re
Ellipse 	a/b			
	1	3.66	4.36	64.00/Re
	2	3.74	4.56	67.28/Re
	4	3.79	4.88	72.96/Re
	8	3.72	5.09	76.60/Re
	16	3.65	5.18	78.16/Re
Isosceles Triangle 	θ			
	10°	1.61	2.45	50.80/Re
	30°	2.26	2.91	52.28/Re
	60°	2.47	3.11	53.32/Re
	90°	2.34	2.98	52.60/Re
	120°	2.00	2.68	50.96/Re

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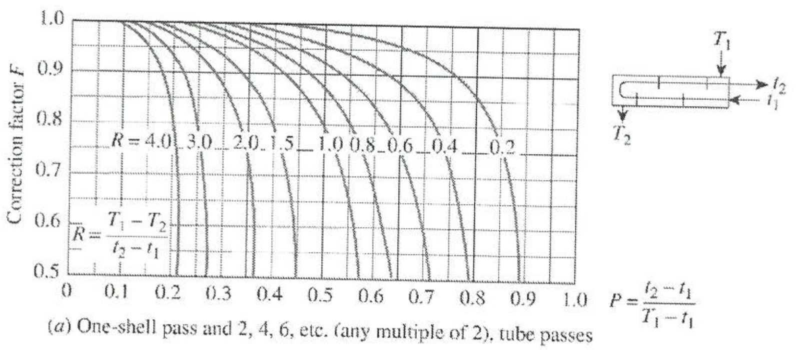
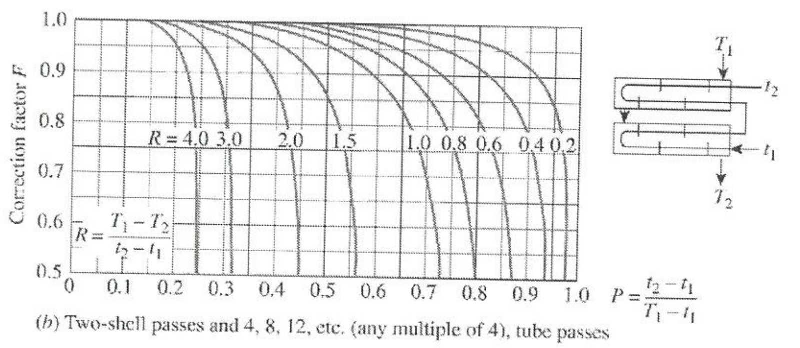
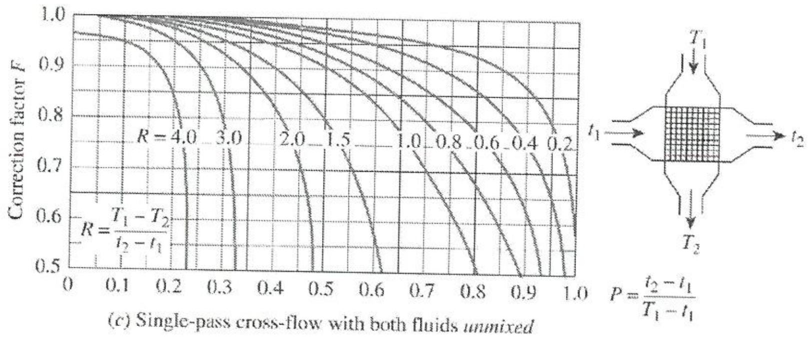


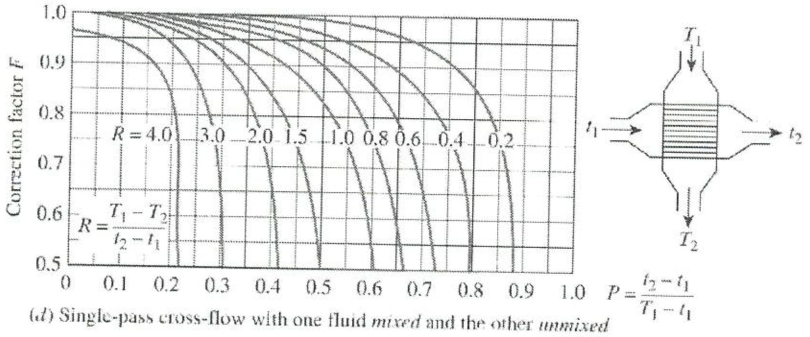
(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



(*b*) Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes



(*c*) Single-pass cross-flow with both fluids *unmixed*



(*d*) Single-pass cross-flow with one fluid *mixed* and the other *unmixed*

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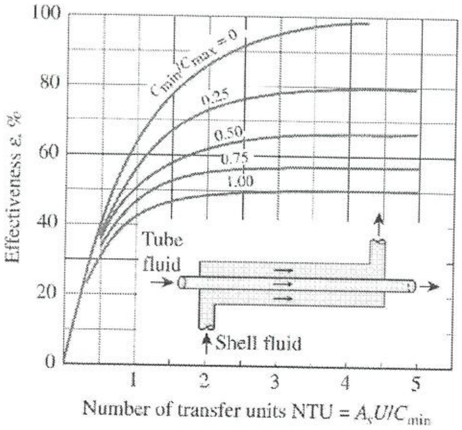
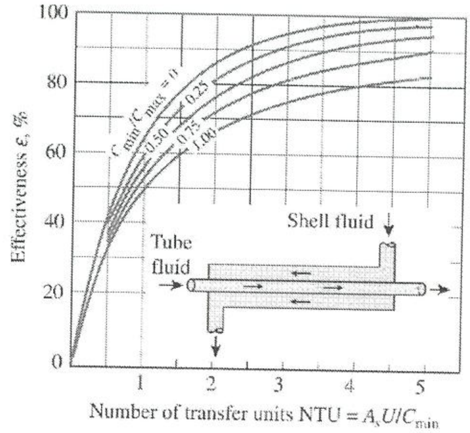
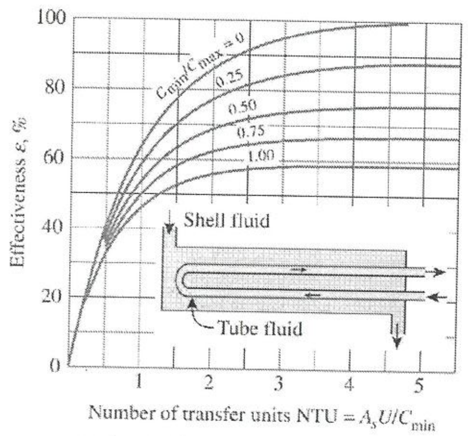


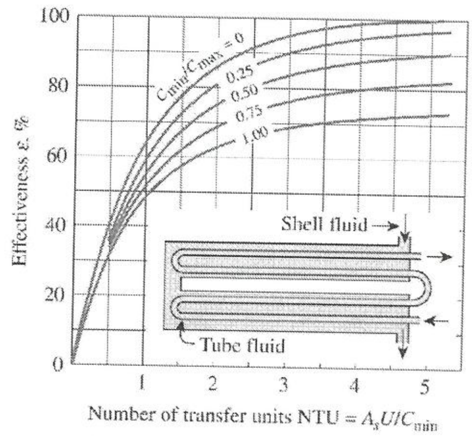
(*a*) Parallel-flow



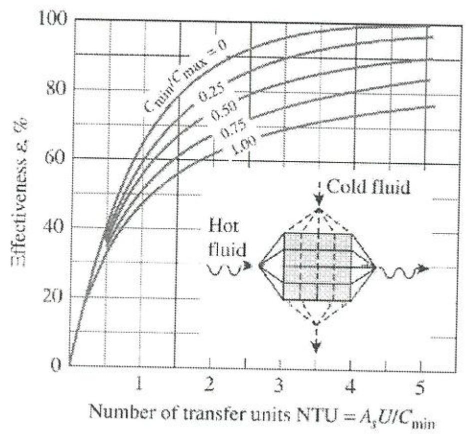
(*b*) Counter-flow



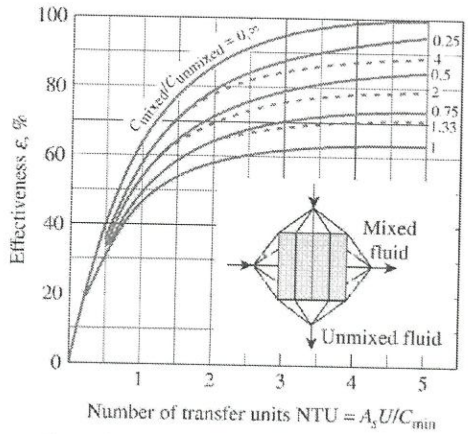
(*c*) One-shell pass and 2, 4, 6, … tube passes



(*d*) Two-shell passes and 4, 8, 12, … tube passes



(*e*) Cross-flow with both fluids unmixed



(*f*) Cross-flow with one fluid mixed and the other unmixed

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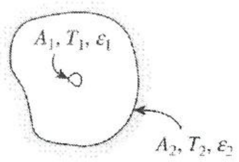
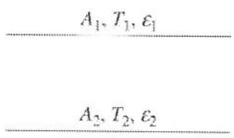
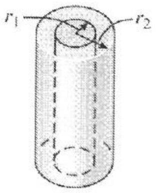
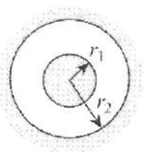
TABLE 13–3

Radiation heat transfer relations for some familiar two-surface arrangments.

Small object in a large cavity 	$\frac{A_1}{A_2} \approx 0$ $F_{12} = 1$	$\dot{Q}_{12} = A_1 \sigma \varepsilon_1 (T_1^4 - T_2^4)$	(13–37)
Infinitely large parallel plates 	$A_1 = A_2 = A$ $F_{12} = 1$	$\dot{Q}_{12} = \frac{A\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$	(13–38)
Infinitely long concentric cylinders 	$\frac{A_1}{A_2} = \frac{r_1}{r_2}$ $F_{12} = 1$	$\dot{Q}_{12} = \frac{A_1\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1 - \varepsilon_2}{\varepsilon_2}\left(\frac{r_1}{r_2}\right)}$	(13–39)
Concentric spheres 	$\frac{A_1}{A_2} = \left(\frac{r_1}{r_2}\right)^2$ $F_{12} = 1$	$\dot{Q}_{12} = \frac{A_1\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_2} + \frac{1 - \varepsilon_2}{\varepsilon_2}\left(\frac{r_1}{r_2}\right)^2}$	(13–40)