UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	HEAT TRANSFER
COURSE CODE	:	BDA 30603
PROGRAMME	:	BDD
EXAMINATION DATE	:	JULY / AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTION	:	

1. ANSWER **FIVE (5)** QUESTIONS FROM SIX (6) QUESTIONS PROVIDED.
2. THE FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK**.
3. STUDENT ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK.

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

Q1 (a) An experimental device that produces excess heat is passively cooled. The addition of pin fins (circular fin) to the casing of this device is being considered to augment the rate of cooling. Consider a copper pin fin with 2.5 cm length, 0.25 cm diameter and 396 W/m.K thermal conductivity that protrudes from a wall at 95°C into ambient air at 25°C as shown in **Figure Q1(a)**. The heat transfer is mainly by natural convection with a coefficient 10 W/m^2. K. Calculate the heat transfer rate for

(i) Fin with convecting tip,
(ii) Adiabatic fin with length correction,
(iii) Compare the answer between (i) and (ii). Give your thought, and;
(iv) Find the efficiency of the fin.

(16 marks)

(b) When a thermocouple is moved from one medium at a different temperature, the thermocouple must be given sufficient time to come to thermal equilibrium with the new conditions before a reading is taken. Consider a 0.10 cm diameter copper thermocouple wire originally at 150°C. Show that we can consider and solve this problem by using lump system analysis method by calculating its Biot Number.

Assume, $h = 80$ $W/m^2.K$, $k = 391$ W/m. K, $c_p = 383$ J/kg.K and $\rho = 8930$ kg/m^3.

(4 marks)

Q2 (a) A 4-mm-diameter spherical ball at 50°C is covered by a l-mm-thick plastic insulation (k = 0.13 W/m.K). The ball is exposed to a medium at 15°C, with a combined convection and radiation heat transfer coefficient of 20 $W/m^2.K$.

(i) Calculate the critical radius of the plastic insulation, and;
(ii) Explain whether the plastic insulation on the ball will help or hurt heat transfer from the ball.

(6 marks)

(b) Carbon steel balls ($\rho = 7833$ kg/m^3, $k = 54$ W/m.K, $c_p = 0.465$ kJ/kg.C, $\alpha = 1.474 \times 10^{-6}$ m^2/s) 8 mm in diameter are annealed by heating them first to 900°C in a furnace and then allowing them to cool slowly to 100°C in ambient air at 35°C. If the average heat transfer coefficient is 75 $W/m^2.K$,

(i) Determine if this problem should be treated with lumped system analysis,
(ii) Determine how long the annealing process will take, and;
(iii) Determine the total rate of heat transfer from the ball to the ambient air.

(14 marks)

Q3 (a) A pump is used to pump oil to a tank located 10-m-high at room temperature. The oil flow is laminar. Now, if the oil is pre-heated while the oil flowrate is maintained, discuss whether the pumping power of the pump will increase or decrease.

(3 marks)

(b) Consider two tubes, one with smooth inner surface while the other one with rough inner surface. Which tube is better in terms of heat transfer and explain your reasoning.

(3 marks)

(c) A new research office in FKMP called "Zero Energy Office" was designed with a cooling system to reduce its temperature during daytime. The cooling system uses a duct which introduces cool air to the office, in which is the air was pre-cooled in a water pond at 15°C. The duct length is 15 m and its diameter is 200 mm. Air enters the underwater section of the duct at 25°C at a velocity of 3 m/s as in **Figure Q3 (c)**. Assuming the surface of the duct is having same temperature of water, determine the outlet temperature of air, entering the office.

(14 marks)

Q4 (a) A 12-m-long section of a 10-cm-diameter steam pipe is completely exposed to the ambient air winds at 10 km/h. The temperature of the outer surface of the steam pipe is 75°C when the ambient temperature is 5°C. Determine the amount of heat lost from the steam during a 10-hours-long workday.

(8 marks)

(b) Air at 30°C flows with a velocity of 6 m/s over a 2.5-m-width, 8-m-long flat plate whose temperature is 110°C. Determine:

(i) The total friction drag force, and;
(ii) The rate of heat transfer per unit width of the entire plate.

(12 marks)

Q5 (a) A concentric tube heat exchanger uses water, which is available at 15°C, to cool ethylene glycol from 100°C to 60°C, as shown in **Figure Q5 (a)**. The water and glycol flow rates are each 0.5 kg/s. Assume ethylene glycol (c_p = 2650 J/kg.K) at 80°C.

(i) Determine the maximum possible heat transfer rate and effectiveness of the exchanger, and;

(ii) Determine which is preferred, a parallel–flow or counter flow mode of operation?

(10 marks)

(b) A double pipe parallel flow heat exchanger use oil (c_p = 1.88 kJ/kg.K) at an initial temperature of 205°C to heat water, flowing at 225 kg/hr from 16°C to 44°C. The oil flow rate is 270 kg/hr.

(i) What is the heat transfer area required for an overall heat transfer coefficient of 340 W/m^2K,

(ii) Determine the number of transfer unit (NTU), and;

(iii) Calculate the effectiveness of the heat exchanger.

(10 marks)

Q6 (a) Explain the difference between a cross-flow and counter-flow heat exchanger. Show in diagram.

(3 marks)

(b) How does the mixed and unmixed fluids differ in a cross-flow heat exchanger? Please illustrate.

(4 marks)

(c) A shell-and-tube heat exchanger with 2-shell passes and 12-tube passes as shown in **Figure Q6(c)**, is used to heat water (c_p = 4180 J/kg.K) in the tubes from 20°C to 70°C at a rate of 4.5 kg/s. Heat is supplied by hot oil (c_p = 2300 J/kg.K) that enters the shell side at 170°C at a rate of 10 kg/s. For a tube-side overall heat transfer coefficient of 350 $W/m^2{\cdot}K$, determine the heat transfer surface area on the tube side.

(13 marks)

END OF QUESTION

SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603

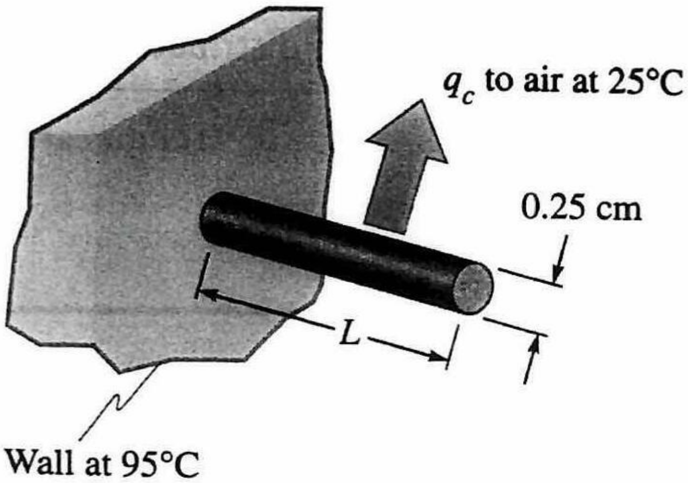


Figure Q1 (a)

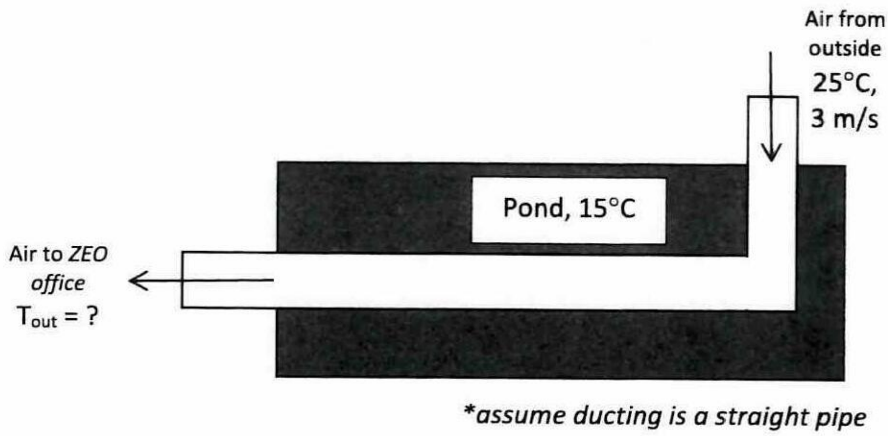


Figure Q3 (c)

SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603

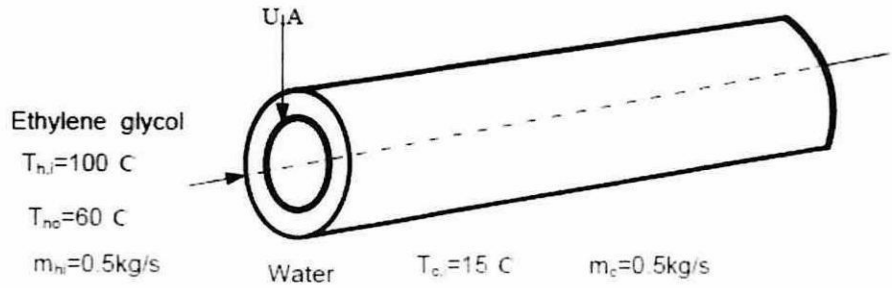


Figure Q5 (a)

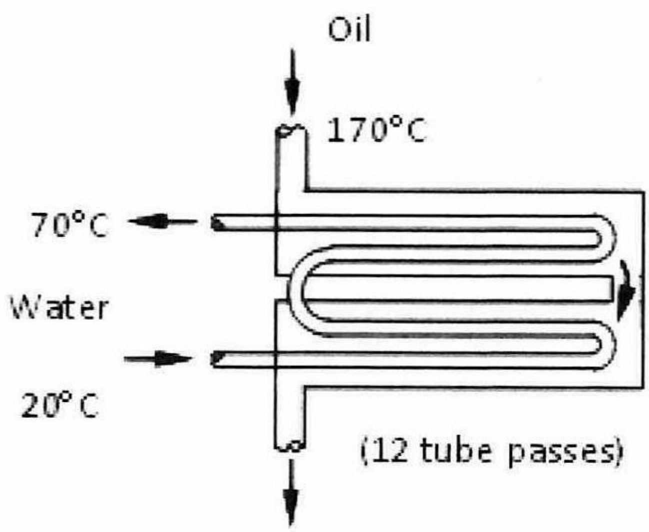


Figure Q6 (c)

SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603

Efficiency and surface areas of common fin configurations

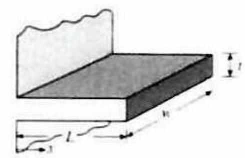
Straight rectangular fins

$m = \sqrt{2h/kt}$

$L_c = L + t/2$

$A_{fin} = 2wL_c$

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

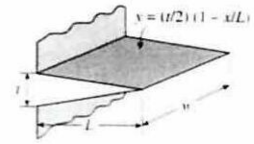


Straight triangular fins

$m = \sqrt{2h/kt}$

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

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



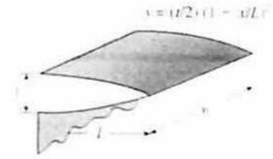
Straight parabolic fins

$m = \sqrt{2h/kt}$

$A_{fin} = wL[C_1 + (L/t)\ln(t/L + C_1)]$

$C_1 = \sqrt{1 + (t/L)^2}$

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



Circular fins of rectangular profile

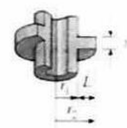
$m = \sqrt{2h/kt}$

$r_{2c} = r_2 + t/2$

$A_{fin} = 2\pi(r_{2c}^2 - r_1^2)$

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

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



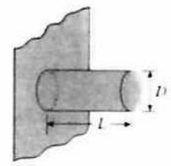
Pin fins of rectangular profile

$m = \sqrt{4h/kD}$

$L_c = L + D/4$

$A_{fin} = \pi D L_c$

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



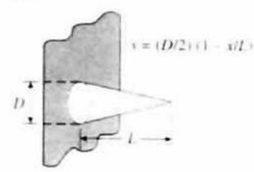
Pin fins of triangular profile

$m = \sqrt{4h/kD}$

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

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

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



Pin fins of parabolic profile

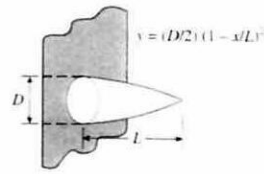
$m = \sqrt{4h/kD}$

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

$C_3 = 1 + 2(D/L)^2$

$C_4 = \sqrt{1 + (D/L)^2}$

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

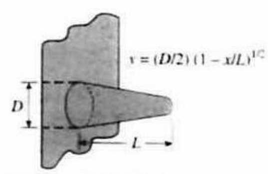


Pin fins of parabolic profile (blunt tip)

$m = \sqrt{4h/kD}$

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

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



TERBUKA

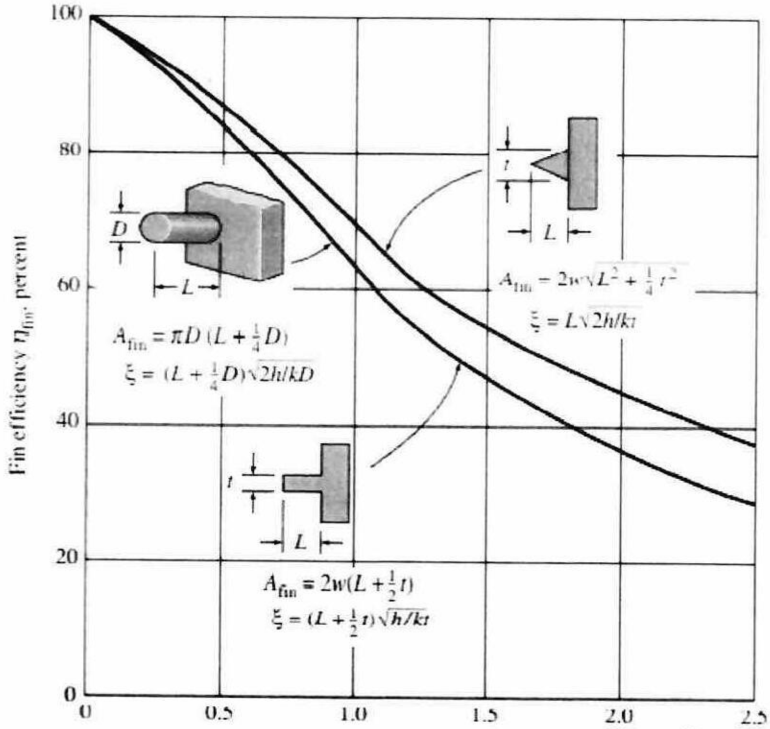
SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603

Temperature distribution and heat loss for fins of uniform cross section

Case	Tip Condition ($x = L$)	Temperature Distribution θ/θ_b	Fin Heat Transfer Rate q_f
A	Convection heat transfer: $h\theta(L) = -kd\theta/dx\vert_{x=L}$	$\dfrac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$ (3.75)	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$ (3.77)
B	Adiabatic: $d\theta/dx\vert_{x=L} = 0$	$\dfrac{\cosh m(L-x)}{\cosh mL}$ (3.80)	$M \tanh mL$ (3.81)
C	Prescribed temperature: $\theta(L) = \theta_L$	$\dfrac{(\theta_L/\theta_b)\sinh mx + \sinh m(L-x)}{\sinh mL}$ (3.82)	$M\dfrac{(\cosh mL - \theta_L/\theta_b)}{\sinh mL}$ (3.83)
D	Infinite fin ($L \rightarrow \infty$): $\theta(L) = 0$	e^{-mx} (3.84)	M (3.85)

$\theta \equiv T - T_\infty$ $\quad m^2 \equiv hP/kA_c$

$\theta_b = \theta(0) = T_b - T_\infty$ $\quad M \equiv \sqrt{hPkA_c}\,\theta_b$

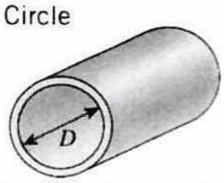
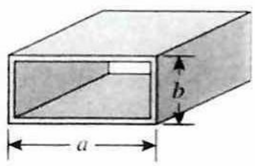
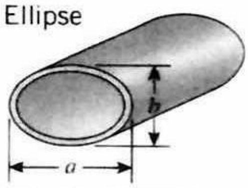
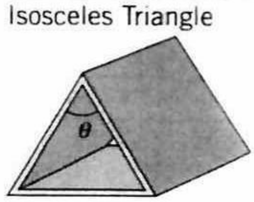


Efficiency of circular, rectangular, and triangular fins on a plain surface of width w (from Gardner, Ref. 6).

SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603

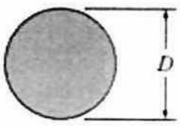
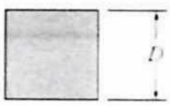
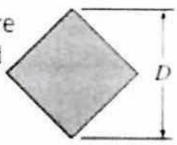
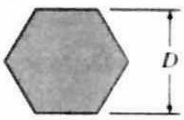
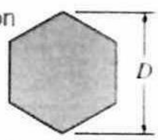
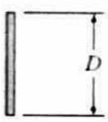
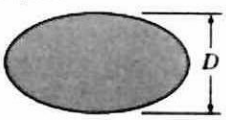
TABLE 8–1

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 $Nu = hD_h/k$)

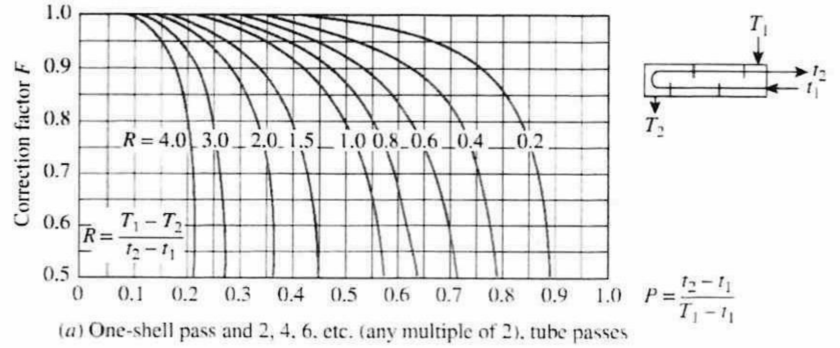
Tube Geometry	a/b or $\theta°$	*Nusselt Number*		Friction Factor
		T_s = Const.	$\dot{q}_s$ = Const.	f
Circle 	—	3.66	4.36	64.00/Re
Rectangle 	a/b			
	1	2.98	3.61	56.92/Re
	2	3.39	4.12	62.20/Re
	3	3.96	4.79	68.36/Re
	4	4.44	5.33	72.92/Re
	6	5.14	6.05	78.80/Re
	8	5.60	6.49	82.32/Re
	∞	7.54	8.24	96.00/Re
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

SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603

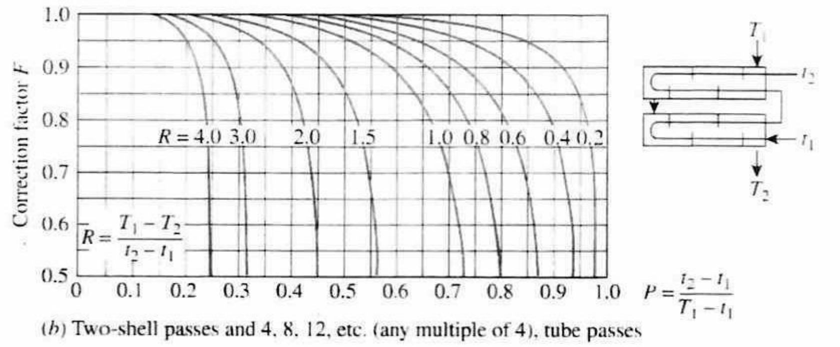
Empirical correlations for the average Nusselt number for forced convection over circular and noncircular cylinders in cross flow (from Zukauskas, Ref. 14, and Jakob, Ref. 6)

Cross-section of the cylinder	Fluid	Range of Re	Nusselt number
Circle 	Gas or liquid	0.4–4 4–40 40–4000 4000–40,000 40,000–400,000	$Nu = 0.989Re^{0.330} Pr^{1/3}$ $Nu = 0.911Re^{0.385} Pr^{1/3}$ $Nu = 0.683Re^{0.466} Pr^{1/3}$ $Nu = 0.193Re^{0.618} Pr^{1/3}$ $Nu = 0.027Re^{0.805} Pr^{1/3}$
Square 	Gas	5000–100,000	$Nu = 0.102Re^{0.675} Pr^{1/3}$
Square (tilted 45°) 	Gas	5000–100,000	$Nu = 0.246Re^{0.588} Pr^{1/3}$
Hexagon 	Gas	5000–100,000	$Nu = 0.153Re^{0.638} Pr^{1/3}$
Hexagon (tilted 45°) 	Gas	5000–19,500 19,500–100,000	$Nu = 0.160Re^{0.638} Pr^{1/3}$ $Nu = 0.0385Re^{0.782} Pr^{1/3}$
Vertical plate 	Gas	4000–15,000	$Nu = 0.228Re^{0.731} Pr^{1/3}$
Ellipse 	Gas	2500–15,000	$Nu = 0.248Re^{0.612} Pr^{1/3}$

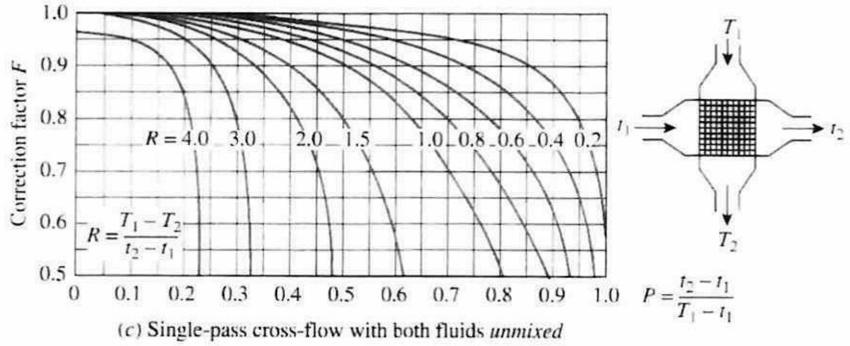
SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603



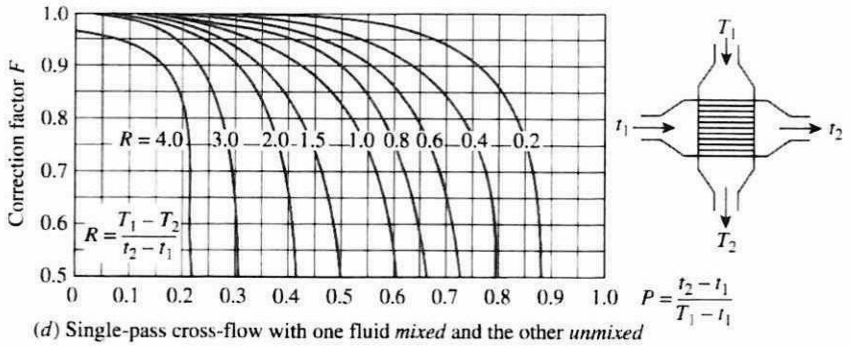
(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



(*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*

TERBUKA

SEMSTER/SESSION: SEM II / 2022/2023	PROGRAMME CODE: BDD
COURSE NAME: HEAT TRANSFER	COURSE CODE: BDA 30603