Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	HEAT TRANSFER
COURSE CODE	:	BDA 30603
PROGRAMME CODE	:	BDD
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER **FIVE (5)** QUESTIONS FROM SIX (6) QUESTIONS ONLY. 2. THE FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ 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 **THIRTEEN (13)** PAGES

Q1 (a) What is the different between *Fin Efficiency* vs. *Fin Effectiveness*. Explain and state the related equations.

(4 marks)

(b) Explain the concept of *corrected fin length* in solving fin problem. State the related equations.

(3 marks)

(c) 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 APPENDIX A.1**. The heat transfer is mainly by natural convection with a coefficient 10 W/m^2. K. Calculate the heat transfer rate for

(i) Adiabatic fin with length correction,

(8 marks)

(ii) When calculated using the convecting fin condition, the heat transfer rate is 0.1397 W. Compare this answer to the one you calculated. Give your thought, and;

(2 marks)

(iii) Find the efficiency of the fin.

(3 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;

(3 marks)

(ii) Explain whether the plastic insulation on the ball will help or hurt heat transfer from the ball.

(2 marks)

(b) Carbon steel balls (ρ = 7833 kg/m^3, k = 54 W/m.K, c_p = 0.465 kJ/kg.C, α = 1.474 x 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,

(3 marks)

(ii) Determine how long the annealing process will take, and;

(10 marks)

(iii) Determine the total rate of heat transfer from the ball to the ambient air.

(2 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 circular 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 APPENDIX B.1**. 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) Air at a temperature of 300°C flows with a velocity of 10 m/s over a flat plate 0.5 m long shown in **Figure APPENDIX C.1**. If the surface temperature is 27°C, determine:

(i) The total friction drag force, and;

(6 marks)

(ii) The cooling rate needed to maintain the surface temperature.

(6 marks)

(b) A 0.4-W cylindrical electronic component with diameter 0.3 cm and length 1.8 cm and mounted on a circuit board is cooled by air flowing across it at a velocity of 150 m/min shown in **Figure APPENDIX C.2**. If the air temperature is 50°C, determine the surface temperature of the component.

(8 marks)

Q5 (a) A counter-flow double-pipe heat exchanger is to heat water from 20°C to 80°C at a rate of 1.2 kg/s, as shown in **Figure APPENDIX D.1.** The heating is to be accomplished by geo-thermal water 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. The overall heat transfer coefficient of the heat exchanger is 640 W/m^{2}K. Assuming the heat capacity for the cold fluid is given by c_{pc} = 4.18 kJ/kg.K and hot fluid c_{ph} = 4.31 kJ/kg.K. Using the effectiveness-NTU method, determine

(i) The effectiveness of the heat exchanger, and;

(12 marks)

(ii) The length of the heat exchanger required to achieve the desired heating.

(8 marks)

Q6 (a) Explain the difference between a parallel-flow and counter-flow heat exchanger. Draw the temperature profile for reference.

(4 marks)

(b) Draw a schematic figure of a 2-shell-passes and 8-tubes-passes shell-and-tube heat exchanger. What the primary reason for using so many tube passes?

(3 marks)

(c) A shell-and-tube heat exchanger with 2-shell passes and 12-tube passes as shown in **Figure APPENDIX E.1**, 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·K, determine the heat transfer surface area on the tube side.

(13 marks)

- END OF QUESTIONS -

APPENDIX A

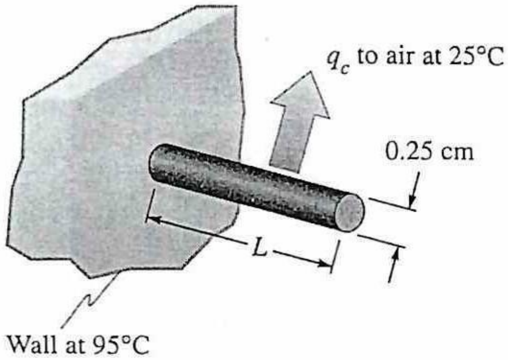


Figure APPENDIX A.1

APPENDIX B

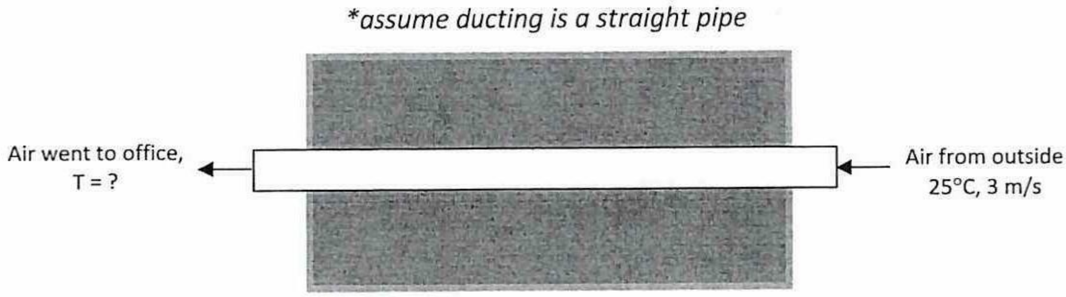


Figure APPENDIX B.1

APPENDIX C

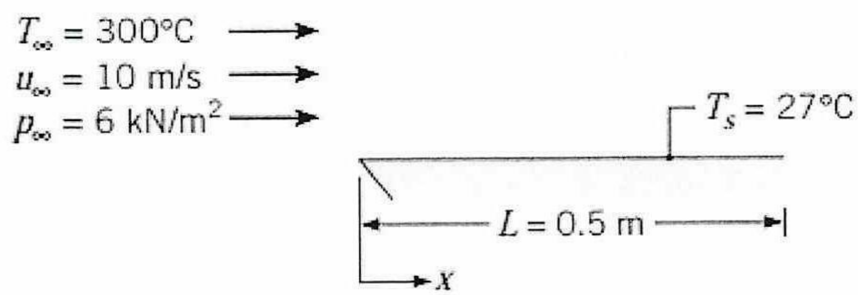


Figure APPENDIX C.1

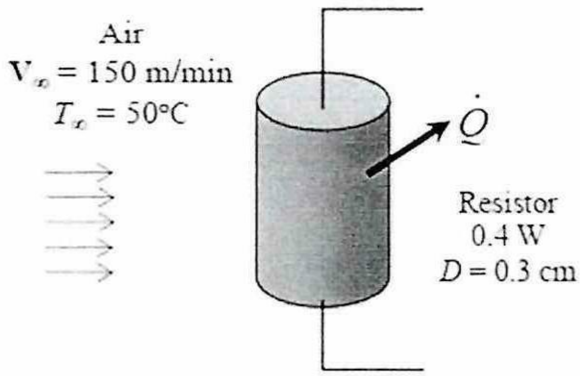


Figure APPENDIX C.2

APPENDIX D

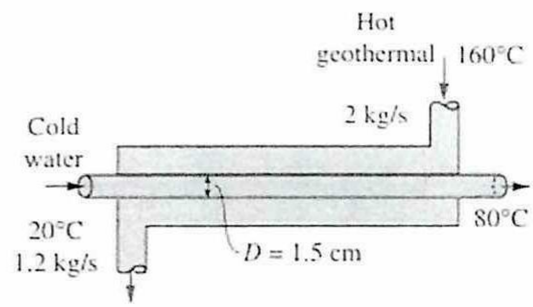


Figure APPENDIX D.1

APPENDIX E

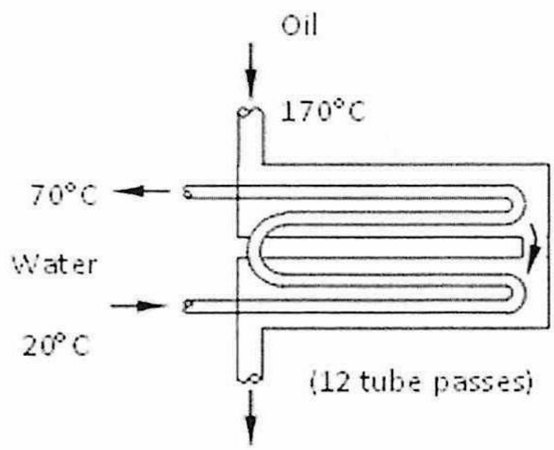


Figure APPENDIX E.1

REFERENCE

Efficiency and surface areas of common fin configurations

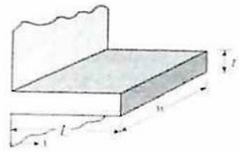
Straight rectangular fins

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

$L_c = L + t/2$

$A_{fin} = 2wL_c$

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

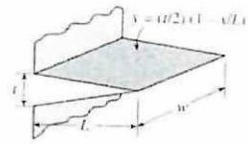


Straight triangular fins

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

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

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



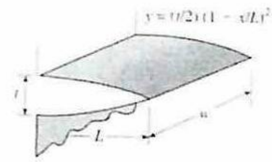
Straight parabolic fins

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

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

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

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



Circular fins of rectangular profile

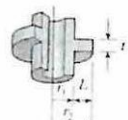
$m = \sqrt{2h/kt}$

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

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

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

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



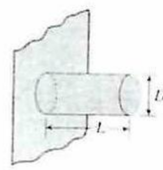
Pin fins of rectangular profile

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

$L_c = L + D/4$

$A_{fin} = \pi DL_c$

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



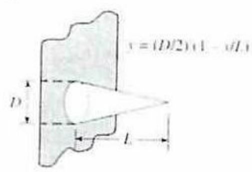
Pin fins of triangular profile

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

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

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

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



Pin fins of parabolic profile

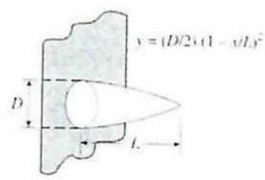
$m = \sqrt{4h/kD}$

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

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

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

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

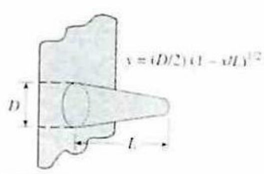


Pin fins of parabolic profile (blunt tip)

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

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

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



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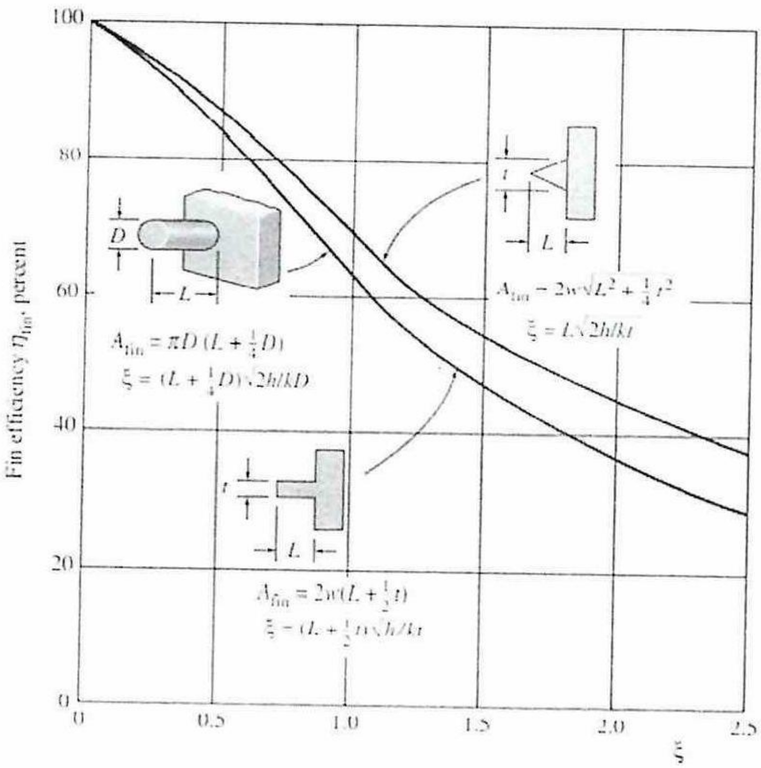
Temperature distribution and heat loss for fins of uniform cross section

Case	Tip Condition ($x = L$)	Temperature Distribution θ/θ_b		Fin Heat Transfer Rate q_f	
A	Convection heat transfer: $h\theta(L) = -k\,d\theta/dx\|_{x=L}$	$\dfrac{\cosh m(L-x) + (h/mk)\sinh m(L-x)}{\cosh mL + (h/mk)\sinh mL}$	(3.75)	$M\dfrac{\sinh mL + (h/mk)\cosh mL}{\cosh mL + (h/mk)\sinh mL}$	(3.77)
B	Adiabatic: $d\theta/dx\|_{x=L} = 0$	$\dfrac{\cosh m(L-x)}{\cosh mL}$	(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 ($L \to \infty$): $\theta(L) = 0$	e^{-mx}	(3.84)	M	(3.85)

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

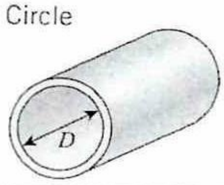
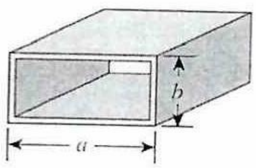
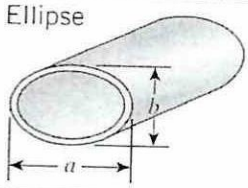
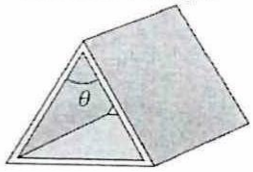
$\theta_b = \theta(0) = T_b - T_\infty$ $\quad M \equiv \sqrt{hPkA_c}\,\theta_b$



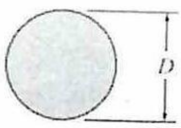
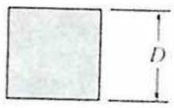
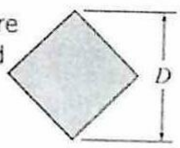
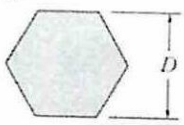
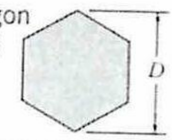
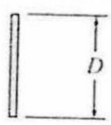
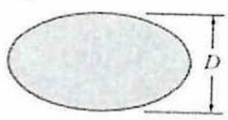
Efficiency of circular, rectangular, and triangular fins on a plain surface of width w (from Gardner, Ref. 6).

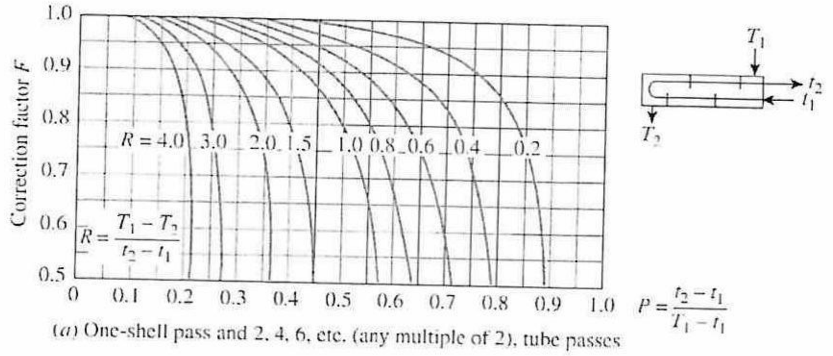
TABLE 8–1

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 $Nu = hD_h/k$)

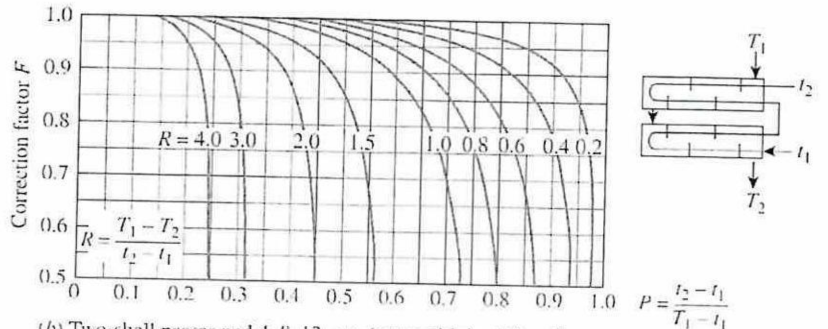
Tube Geometry	a/b or $\theta°$	Nusselt Number T_s = Const.	Nusselt Number $\dot{q}_s$ = Const.	Friction Factor f
Circle 	—	3.66	4.36	64.00/Re
Rectangle 	a/b			
	1	2.98	3.61	56.92/Re
	2	3.39	4.12	62.20/Re
	3	3.96	4.79	68.36/Re
	4	4.44	5.33	72.92/Re
	6	5.14	6.05	78.80/Re
	8	5.60	6.49	82.32/Re
	∞	7.54	8.24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

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)

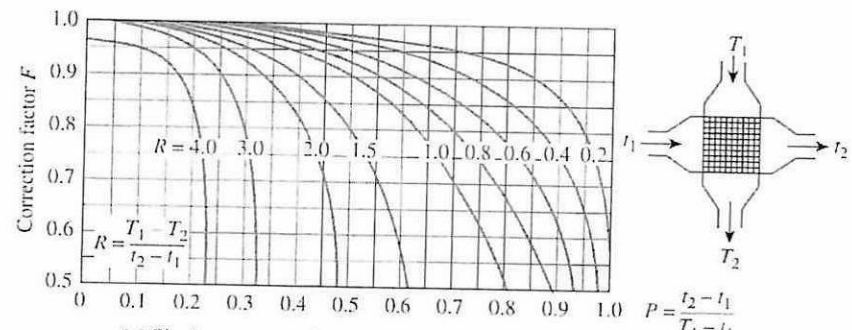
Cross-section of the cylinder	Fluid	Range of Re	Nusselt number
Circle 	Gas or liquid	0.4–4 4–40 40–4000 4000–40,000 40,000–400,000	$Nu = 0.989Re^{0.330} Pr^{1/3}$ $Nu = 0.911Re^{0.385} Pr^{1/3}$ $Nu = 0.683Re^{0.466} Pr^{1/3}$ $Nu = 0.193Re^{0.618} Pr^{1/3}$ $Nu = 0.027Re^{0.805} Pr^{1/3}$
Square 	Gas	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	$Nu = 0.248Re^{0.612} Pr^{1/3}$



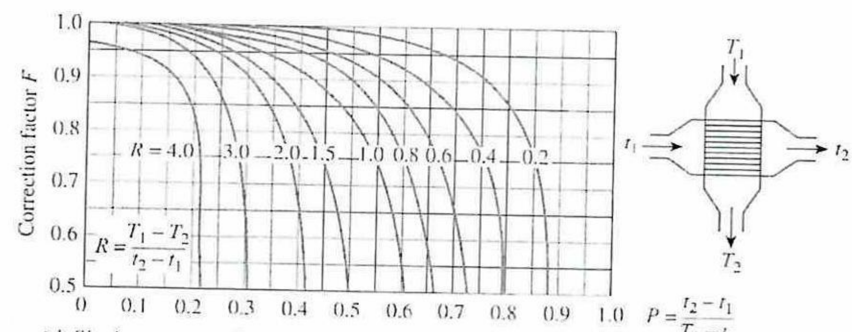
(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



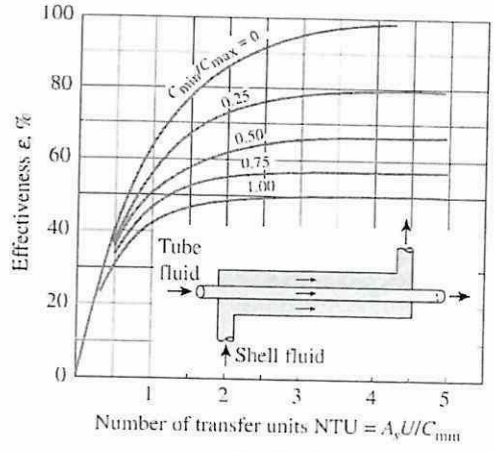
(*b*) Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes



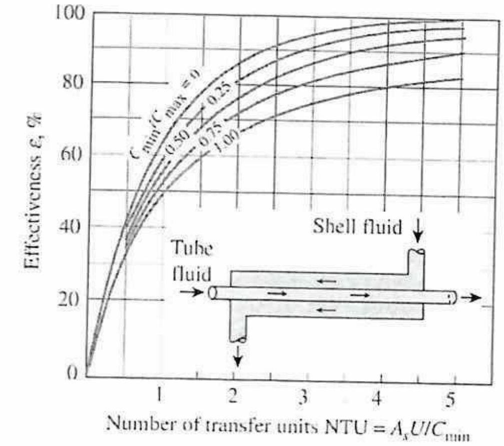
(*c*) Single-pass cross-flow with both fluids *unmixed*



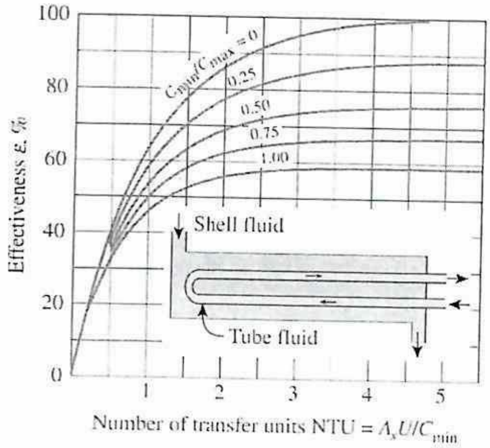
(*d*) Single-pass cross-flow with one fluid *mixed* and the other *unmixed*



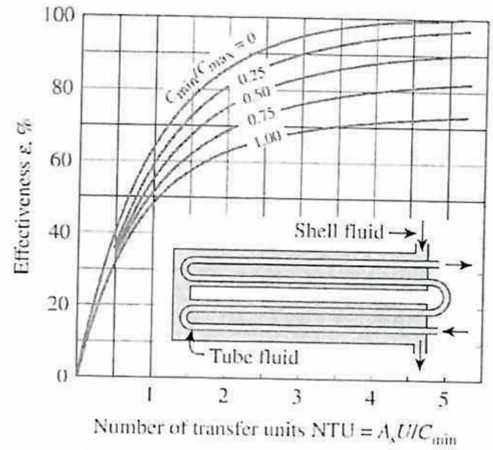
(a) Parallel-flow



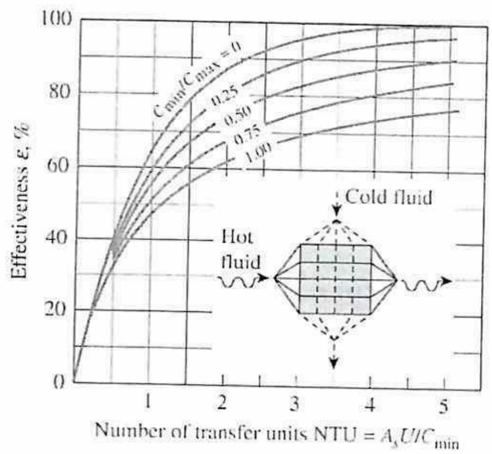
(b) Counter-flow



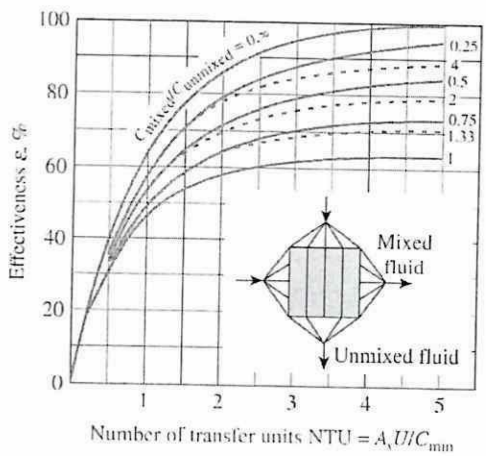
(c) One-shell pass and 2, 4, 6, … tube passes



(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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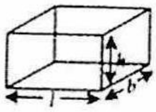
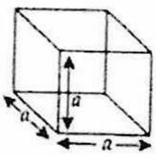
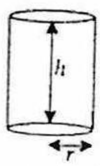
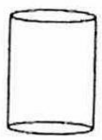
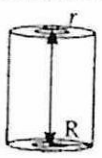
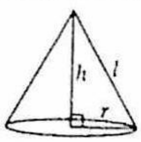
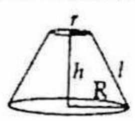
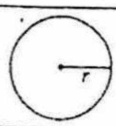
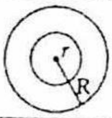
TABLE FOR SURFACE AREA AND VOLUME

Solid	Figures	Curved surface area (1)	Plane area (2)	Total area [1 + 2]	Volume	Remarks
Cuboid		Also known as lateral surface area $= 2(lh + bh)$	Area of: Top face $= lb$ Bottom face $= lb$ $\therefore lb + lb = 2lb$	$2(lb + bh + hl)$	$l.b.h$	l : length b : breadth h : height
Cube		Lateral surface area $= 4a^2$	Area of: Top face $= a^2$ Bottom face $= a^2$ $\therefore a^2 + a^2 = 2a^2$	$4a^2 + 2a^2 = 6a^2$	a^3	a : Side of cube
Right circular cylinder closed at top		Curved surface area $= 2\pi rh$	Area of: Top face $= \pi r^2$ Bottom face $= \pi r^2$ $\therefore \pi r^2 + \pi r^2 = 2\pi r^2$	$2\pi r^2 + 2\pi rh$ Or, $2\pi r(r + h)$	$\pi r^2 h$	r : radius h : height of cylinder
Right circular cylinder open at top		Curved surface area $= 2\pi rh$	Area of: Top face $= 0$ Bottom face $= \pi r^2$ $\therefore 0 + \pi r^2 = \pi r^2$	$2\pi rh + \pi r^2$ Or, $\pi r(2h + r)$	$\pi r^2 h$	r : radius h : height of cylinder
Hollow cylinder (Pipe)		$2\pi Rh$ • External surface area $= 2\pi Rh$ • Internal surface area $= 2\pi rh$	Area of: Top face $= \pi(R^2 - r^2)$ Bottom face $= \pi(R^2 - r^2)$	$2\pi Rh + 2\pi rh + 2\pi(R^2 - r^2)$	$\pi R^2 h - \pi r^2 h$ (External Vol. - Internal Vol.)	R : Radius of outer base r : radius of inner base h = height
Cone		πrl	Area of: Bottom Face $= \pi r^2$	$\pi r^2 + \pi rl$ Or, $\pi r(r + l)$	$\frac{1}{3}\pi r^2 h$	h = height of cone r = radius of cone l = slant height $= \sqrt{h^2 + r^2}$
Frustum		$\pi l(R + r)$	Area of: Top Face $= \pi r^2$ Bottom Face $= \pi R^2$	$\pi r^2 + \pi R^2 + \pi l(R + r)$	$\frac{1}{3}\pi h \cdot (R^2 + r^2 + Rr)$	h = height of frustum r = radius of top face R = Radius of base l = slant height
Sphere		$4\pi r^2$	None	$4\pi r^2$	$\frac{4}{3}\pi r^3$	r : radius of sphere
Hemisphere		$2\pi r^2$	πr^2	$3\pi r^2$	$\frac{2}{3}\pi r^3$	r : radius of hemisphere
Spherical shell		$4\pi R^2$ (Outer) $4\pi r^2$ (Inner)	None	$4\pi R^2 + 4\pi r^2$	$\frac{4}{3}\pi \cdot (R^3 - r^3)$	R:Radius of outer shell r:Radius of inner shell