UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2016/2017 Academic Session

June 2017

EKC 216 – Process Heat Transfer
[Pemindahan Haba Proses]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains FIVE printed pages and SIX printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi LIMA muka surat yang bercetak dan ENAM muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai].

Answer ALL questions.

1. [a] Differentiate between conduction, convection and radiation heat transfer.

[3 marks]

[b] Steam at a temperature of 680 ^{o}C flows through a pipe (k = 0.90 W/m.K) of 8.2 cm OD, 6.4 cm ID and 30 m length. The convection heat transfer coefficients at the inside and outside are 350 W/m^2.K and 18 W/m^2.K, respectively. The pipe is located in a room at 25 ^{o}C. Calculate heat loss from the pipe.

[3 marks]

[c] Draw and compare the temperature distributions through a 16 cm long, 2 cm wide and 1 cm thick straight fin and exposed to an environment (h = 11.4 W/m^{2}K) at room temperature of 30 ^{o}C, for two fin materials : (i) stainless steel [k = 20 W/m.K] and (ii) aluminium [k = 320 W/m.K]. The base temperature is maintained at 200 ^{o}C. Assume adiabatic tip condition.

[12 marks]

[d] Two parallel 60 cm-diameter disks are separated by distance of 2 m in an infinite medium having k = 2.5 W/m.K. One disk is maintained at 90 ^{o}C and the other at 25 ^{o}C. Calculate the heat transfer between the disks.

[3 marks]

[e] An aluminium ball [C = 0.9 kJ/kg.K, ρ = 3000 kg/m^3, k = 200 W/m.K] 1.0 m in diameter and initially at a uniform temperature of 700 ^{o}C is suddenly immersed in a fluid at 30 ^{o}C. The convection coefficient is 80 W/m^2.K. Calculate the time required for the ball to attain a temperature of 300 ^{o}C.

[4 marks]

2. [a] [i] Explain the theory of boundary layer for flat plate with schematic diagram.

[2 marks]

[ii] Air at 77 ºC and 1 atm flows over a flat plate at a speed of 10 m/s. Calculate the boundary layer thickness at distance of 40 cm from the leading edge of the plate.

[3 marks]

[b] Air at 176 ºC and 2 atm is heated as it flows through a tube with a diameter of 30 mm at a velocity of 12 m/s. The wall temperature is 25 °C above the air temperature, all along the length of the tube. Calculate the bulk temperature increase over a 5 m length of the tube. Given R = 287 J/kg.K.

[5 marks]

Jawab SEMUA soalan.

1. [a] *Bezakan di antara pemindahan haba konduksi, perolakan dan radiasi.*

[3 markah]

[b] *Stim bersuhu 680 ^oC mengalir melalui paip (k= 0.90 W/m.K) 30 m panjang serta berdiameter luar dan dalam masing-masing 8.2 sm dan 6.4 sm. Pekali pemindahan haba perolakan disebelah dalam dan luar masing-masing 350 W/m^2.K dan 18 W/m^2.K. Paip terletak di dalam bilik bersuhu 25 ^oC. Kirakan kehilangan haba daripada paip tersebut.*

[3 markah]

[c] *Lukiskan dan bandingkan taburan suhu bagi sirip lurus yang panjang, lebar dan tebal masing-masing 16 sm, 2 sm dan 1 sm serta terdedah kepada persekitaran (h = 11.4 W/m^{2}K) pada suhu bilik 30 ^oC bagi dua jenis sirip : (i) keluli tahan karat [k=20 W/m.K] dan (ii) aluminium [k = 320 W/m.K]. Suhu tapak kekal pada 200 ^oC. Anggap keadaan hujung adiabatik.*

[12 markah]

[d] *Dua cakera selari berdiameter 60 sm dipisahkan sejauh 2 m dalam medium tak terhingga dengan k = 2.5 W/m.K. Cakera pertama dan kedua masing-masing pada suhu tetap 90 ^oC dan 25 ^oC. Kirakan pemindahan haba antara kedua-dua cakera tersebut.*

[3 markah]

[e] *Bebola aluminium [C = 0.9 kJ/kg.K, ρ = 3000 kg/m^3, k = 200 W/m.K] berdiameter 1.0 m dan bersuhu awal 700 ^oC direndam secara mengejut dalam bendalir bersuhu 30 ^oC. Pekali perolakan ialah 80 W/m^2.K. Kirakan masa yang diperlukan untuk bebola tersebut mencapai suhu 300 ^oC.*

[4 markah]

2. [a] [i] *Terangkan dengan rajah skematik teori lapisan sempadan untuk plat rata.*

[2 markah]

[ii] *Udara bersuhu 77 ºC dan 1 atm mengalir melalui plat rata pada kelajuan 10 m/s. Kirakan ketebalan lapisan sempadan pada kedudukan 40 sm dari permulaan plat.*

[3 markah]

[b] *Udara bersuhu 176 ºC dan 2 atm dipanaskan semasa mengalir melalui tiub berdiameter 30 mm pada kelajuan 12 m/s. Suhu dinding sepanjang tiub ialah 25 °C melebihi suhu udara. Kirakan penambahan suhu pukal untuk paip ini yang panjangnya 5 m. Diberi R = 287 J/kg.K.*

[5 markah]

[c] Air at 1 atm and 8 °C flows across a bank of tubes 18 rows high and 8 rows deep at a velocity of 6.2 m/s measured at a point in the flow before the air enters the tube bank. The surfaces of the tubes are maintained at 60 °C. The diameter of the tube is 2.54 cm. They are arranged in an in-line manner so that the spacing in both the normal and parallel direction to the flow is 7.62 cm. Calculate the total heat transfer per unit length for the tube bank.

[10 marks]

[d] A vertical cylinder 1.5 m high and 4.2 cm in diameter is maintained at a temperature of 60 ^{o}C in an atmospheric environment of 10 ^{o}C. Calculate the heat lost by free convection from this cylinder.

[5 marks]

3. [a] Saturated steam at 100 lb/in^2 abs condenses on the outside of a horizontal 1-in diameter tube. The tube wall temperature is maintained at 280 °F. Calculate the heat transfer coefficient and the condensate flow per unit length of tube. Take T_{sat} = 328 °F and h_{fg} = 889 Btu/lb.

[14 marks]

[b] Heat-transfer coefficients for boiling are usually large compared with those for ordinary convection. Estimate the flow velocity that would be necessary to produce a value of *h* for forced convection through a smooth 6.5 mm diameter brass tube comparable with that which could be obtained by pool boiling with ΔT_x = 16.7 °C, *p* = 690 kPa, and water as the fluid using the properties of water obtained in part Q.3.[a].

[11 marks]

4. A light fuel oil is used in the tube side of a shell-and-tube heat exchanger with two shell passes and four tube passes. Water is heated in the shell side from 10 °C to 50 °C while the oil is cooled from 90 °C to 60 °C. The overall heat-transfer coefficient is 53 W/m^2.°C. The specific heat of the oil is 2.0 kJ/kg.°C.

[a] Using both the *NTU* and *LMTD* methods, calculate the area of the heat exchanger for a total energy transfer of 500 kW.

[15 marks]

[b] What is the water flow rate for this heat transfer?

[2 marks]

[c] What percentage reduction in water flow is necessary to reduce the total heat transfer rate in half while maintaining the oil flow constant?

[8 marks]

[c] *Udara pada 1 atm dan 8 °C mengalir merentasi bank tiub 18 baris menegak dan 8 baris kedalam pada kelajuan 6.2 m/s diukur pada kedudukan aliran udara sebelum memasuki bank tiub tersebut. Suhu permukaan tiub dikekalkan pada 60 °C. Diameter tiub ialah 2.54 sm. Tiub-tiub ini disusun dengan aturan segiempat. Jarak antara tiub dalam arah menegak dan selari kepada aliran ialah 7.62 sm. Kirakan jumlah pemindahan haba per unit panjang bagi bank tiub tersebut.*

[10 markah]

[d] *Suatu silinder menegak bersuhu tetap 60 ^oC dengan ketinggian 1.5 m dan berdiameter 4.2 sm diletak pada persekitaran atmosfera 10 ^oC. Kirakan kehilangan haba perolakan bebas daripada silider tersebut.*

[5 markah]

3. [a] *Wap tepu pada 100 lb/in^2 abs terpeluwap di luar tiub mendatar berdiameter 1 inci. Suhu dinding tiub ditetapkan pada 280 °F. Kirakan pekali pemindahan haba dan aliran peluwap per unit panjang tiub. Ambil* T_{sat} *sebagai 328 °F dan* h_{fg} = *889 Btu/lb.*

[14 markah]

[b] *Pekali pemindahan haba bagi pendidihan kebiasaannya adalah besar jika dibandingkan dengan olakan biasa. Anggarkan halaju aliran yang bersesuaian untuk menghasilkan nilai* h *bagi olakan paksa melalui tiub tembaga licin berdiameter 6.5 mm yang boleh diperolehi melalui pendidihan kolam dengan* ΔT_x = *16.7 °C,* p = *690 kPa, dan air sebagai bendalir dengan menggunakan ciri air yang diperolehi di bahagian S.3.[a].*

[11 markah]

4. *Suatu minyak bahan api ringan digunakan dalam sisi tiub bagi satu pemindah haba kelompang-dan-tiub yang mempunyai dua laluan kelompang dan empat laluan tiub. Air dipanaskan dalam sisi kelompang dari 10 °C kepada 50 °C manakala minyak disejukkan dari 90 °C kepada 60 °C. Pekali pemindahan haba keseluruhan ialah 53 W/m^2.°C. Haba tentu bagi minyak ialah 2.0 kJ/kg.°C.*

[a] *Dengan menggunakan kedua-dua kaedah* NTU *dan* LMTD, *kirakan luas kawasan pemindah haba bagi jumlah pemindahan tenaga sebanyak 500 kW.*

[15 markah]

[b] *Apakah kadar aliran air bagi pemindahan haba ini?*

[2 markah]

[c] *Apakah peratusan penurunan dalam aliran air yang bersesuaian bagi menurunkan separuh jumlah kadar pemindahan haba pada masa sama mengekalkan aliran minyak pada kadar yang malar.*

[8 markah]

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Appendix

$$U_o = \frac{1}{\frac{r_2}{r_1 . h_1} + \frac{r_2 \ln(r_2/r_1)}{k} + \frac{1}{h_2}} \; ; \; q = U_o (2\pi r_o L)(T_{\infty 1} - T_{\infty 2})$$

$$m^2 \equiv \frac{hP}{kA_C} \; ; \; \frac{T_x - T_\infty}{T_b - T_\infty} = \frac{\cosh m(L-x)}{\cosh mL}$$

$$S_{buriedparalleldisc} = \frac{4\pi r}{\left[\frac{\pi}{2} - \tan^{-1}\left(\frac{r}{D}\right)\right]}$$; Note : $\tan^{-1}$ (r/D) in radians

$$Bi = \frac{hL_c}{k} \; ; \; \tau_c = \frac{C\rho L_c}{h} \; ; \; \frac{T - T_\infty}{T_o - T_\infty} = e^{-\tau/\tau_c}$$

$$Nu_{plate,laminar} = 0.66 \Pr^{1/3} \mathrm{Re}_x^{1/2}$$

$$Nu_{plate,turbulent} = \Pr^{1/3} (0.037 \mathrm{Re}_x^{0.8} - 871)$$

$$Nu_{tube,laminar} = 3.66 + \frac{0.0668 (d/L) \mathrm{Re}_d \Pr}{1 + 0.04[(d/L) \mathrm{Re}_d \Pr]^{2/3}} \; ;$$

$$Nu_{tube,turbulent} = 0.023 \mathrm{Re}_d^{0.8} \Pr^{0.4}$$

$$Nu_{cylinder,across} = \frac{hd}{k} = 0.0266 (\mathrm{Re})^{0.805} \Pr^{1/3} \; ; \quad q = hA(T_w - T_\infty)$$

$$h = Nu_d \left(\frac{k}{d}\right) ; \; q = hA(T_w - T_b) = mc_P \Delta T_b$$

$$Nu_{tubebank} = C(\mathrm{Re})^n \Pr^{1/3} \; ; \; u_{\max,inline} = u_\infty [S_n /(S_n - d)]$$

$$q_{tubebank} = hA(T_w - \frac{T_{\infty 1} + T_{\infty 2}}{2}) = m_{\infty 1} c_p (T_{\infty 2} - T_{\infty 1})$$

$$Gr \Pr_{free\ convection} = \left(\frac{g\beta(T_w - T_\infty)x^3}{v^2}\right) \Pr \; ; \; \beta = \frac{1}{T_f} \; ; \; Nu = C(Gr \Pr)^m$$

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Properties of air at atmospheric pressure†

The values of μ, k, c_p, and Pr are not strongly pressure-dependent and may be used over a fairly wide range of pressures.

T, K	ρ kg/m^3	c_p, kJ/kg · K	$\mu \times 10^5$, kg/m · s	$\nu \times 10^6$, m^2/s	k, W/m · K	$\alpha \times 10^4$, m^2/s	Pr
100	3.6010	1.0266	0.6924	1.923	0.009246	0.02501	0.770
150	2.3675	1.0099	1.0283	4.343	0.013735	0.05745	0.753
200	1.7684	1.0061	1.3289	7.490	0.01809	0.10165	0.739
250	1.4128	1.0053	1.5990	11.31	0.02227	0.15675	0.722
300	1.1774	1.0057	1.8462	15.69	0.02624	0.22160	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4222	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680

Modified correlation of Grimson for heat transfer in tube banks of 10 rows or more

	$\frac{S_n}{d}$							
	1.25		1.5		2.0		3.0	
$\frac{S_p}{d}$	C	n	C	n	C	n	C	n
				In line				
1.25	0.386	0.592	0.305	0.608	0.111	0.704	0.0703	0.752
1.5	0.407	0.586	0.278	0.620	0.112	0.702	0.0753	0.744
2.0	0.464	0.570	0.332	0.602	0.254	0.632	0.220	0.648
3.0	0.322	0.601	0.396	0.584	0.415	0.581	0.317	0.608

Ratio of h for N Rows Deep to That for 10 Rows Deep

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	1.0
Ratio for in-line tubes	0.64	0.80	0.87	0.90	0.92	0.94	0.96	0.98	0.99	1.0

Geometry	$Gr_f Pr_f$	C	m
Vertical planes and cylinders	10^{-1}–10^4	Use Fig. 7-7	Use Fig. 7-7
	10^4–10^9	0.59	$\frac{1}{4}$
	10^9–10^{13}	0.021	$\frac{2}{5}$
	10^9–10^{13}	0.10	$\frac{1}{3}$
Horizontal cylinders	0–10^{-5}	0.4	0
	10^{-5}–10^4	Use Fig. 7-8	Use Fig. 7-8
	10^4–10^9	0.53	$\frac{1}{4}$
	10^9–10^{12}	0.13	$\frac{1}{3}$
	10^{-10}–10^{-2}	0.675	0.058

Table 9-3 | Simplified relations for boiling heat-transfer coefficients to water at atmospheric pressure, $\Delta T_x = T_w - T_{sat}$, °C.

Surface	$\frac{q}{A}$, kW/m^2	h, W/m$^2 \cdot$°C	Approximate range of ΔT, °C	Approximate range of h, W/m$^2 \cdot$°C
Horizontal	$\frac{q}{A} < 16$	$1042(\Delta T_x)^{1/3}$	0–7.76	0–2060
	$16 < \frac{q}{A} < 240$	$5.56(\Delta T_x)^3$	7.32–14.4	2180–16,600
Vertical	$\frac{q}{A} < 3$	$537(\Delta T_{ax})^{1/7}$	0–4.51	0–670
	$3 < \frac{q}{A} < 63$	$7.96(\Delta T_x)^3$	4.41–9.43	680–6680

Table A1. Heat-exchanger effectiveness relations

$N = \text{NTU} = \frac{UA}{C_{min}}$ $\quad C = \frac{C_{min}}{C_{max}}$

Flow geometry	Relation
Double pipe:	
Parallel flow	$\epsilon = \frac{1 - \exp[-N(1+C)]}{1+C}$
Counterflow	$\epsilon = \frac{1 - \exp[-N(1-C)]}{1 - C\exp[-N(1-C)]}$
Counterflow, $C = 1$	$\epsilon = \frac{N}{N+1}$
Cross flow:	
Both fluids unmixed	$\epsilon = 1 - \exp\left[\frac{\exp(-NCn) - 1}{Cn}\right]$ where $n = N^{-0.22}$
Both fluids mixed	$\epsilon = \left[\frac{1}{1-\exp(-N)} + \frac{C}{1-\exp(-NC)} - \frac{1}{N}\right]^{-1}$
C_{max} mixed, C_{min} unmixed	$\epsilon = (1/C)\{1 - \exp[-C(1 - e^{-N})]\}$
C_{max} unmixed, C_{min} mixed	$\epsilon = 1 - \exp\{-(1/C)[1 - \exp(-NC)]\}$
Shell and tube:	
One shell pass, 2, 4, 6, tube passes	$\epsilon = 2\left\{1 + C + (1+C^2)^{1/2} \times \frac{1 + \exp[-N(1+C^2)^{1/2}]}{1 - \exp[-N(1+C^2)^{1/2}]}\right\}^{-1}$
Multiple shell passes, $2n$, $4n$, $6n$ tube passes ($\epsilon_p =$ effectiveness of each shell pass, $n =$ number of shell passes)	$\epsilon = \frac{[(1-\epsilon_p C)/(1-\epsilon_p)]^n - 1}{[(1-\epsilon_p C)/(1-\epsilon_p)]^n - C}$
Special case for $C = 1$	$\epsilon = \frac{n\epsilon_p}{1 + (n-1)\epsilon_p}$
All exchangers with $C = 0$	$\epsilon = 1 - e^{-N}$

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Table A2. NTU relations for heat exchangers

$C = C_{min}/C_{max}$	ϵ = effectiveness	$N = NTU = UA/C_{min}$
Flow geometry		**Relation**
Double pipe:		
Parallel flow		$N = \frac{-\ln[1-(1+C)\epsilon]}{1+C}$
Counterflow		$N = \frac{1}{C-1}\ln\left(\frac{\epsilon-1}{C\epsilon-1}\right)$
Counterflow, $C = 1$		$N = \frac{\epsilon}{1-\epsilon}$
Cross flow:		
C_{max} mixed, C_{min} unmixed		$N = -\ln\left[1+\frac{1}{C}\ln(1-C\epsilon)\right]$
C_{max} unmixed, C_{min} mixed		$N = \frac{-1}{C}\ln[1+C\ln(1-\epsilon)]$
Shell and tube:		
One shell pass, 2, 4, 6, tube passes		$N = -(1+C^2)^{-1/2} \times \ln\left[\frac{2/\epsilon-1-C-(1+C^2)^{1/2}}{2/\epsilon-1-C+(1+C^2)^{1/2}}\right]$
All exchangers, $C = 0$		$N = -\ln(1-\epsilon)$

Table | Properties of water (saturated liquid).†

Note: $Gr_x Pr = \left(\frac{g\beta\rho^2 c_p}{\mu k}\right) x^3 \Delta T$

°F	°C	c_p kJ/kg · °C	ρ kg/m³	μ kg/m · s	k W/m · °C	Pr	$\frac{g\beta\rho^2 c_p}{\mu k}$ 1/m³ · °C
32	0	4.225	999.8	1.79×10^{-3}	0.566	13.25	
40	4.44	4.208	999.8	1.55	0.575	11.35	1.91×10^{9}
50	10	4.195	999.2	1.31	0.585	9.40	6.34×10^{9}
60	15.56	4.186	998.6	1.12	0.595	7.88	1.08×10^{10}
70	21.11	4.179	997.4	9.8×10^{-4}	0.604	6.78	1.46×10^{10}
80	26.67	4.179	995.8	8.6	0.614	5.85	1.91×10^{10}
90	32.22	4.174	994.9	7.65	0.623	5.12	2.48×10^{10}
100	37.78	4.174	993.0	6.82	0.630	4.53	3.3×10^{10}
110	43.33	4.174	990.6	6.16	0.637	4.04	4.19×10^{10}
120	48.89	4.174	988.8	5.62	0.644	3.64	4.89×10^{10}
130	54.44	4.179	985.7	5.13	0.649	3.30	5.66×10^{10}
140	60	4.179	983.3	4.71	0.654	3.01	6.48×10^{10}
150	65.55	4.183	980.3	4.3	0.659	2.73	7.62×10^{10}
160	71.11	4.186	977.3	4.01	0.665	2.53	8.84×10^{10}
170	76.67	4.191	973.7	3.72	0.668	2.33	9.85×10^{10}
180	82.22	4.195	970.2	3.47	0.673	2.16	1.09×10^{11}
190	87.78	4.199	966.7	3.27	0.675	2.03	
200	93.33	4.204	963.2	3.06	0.678	1.90	
220	104.4	4.216	955.1	2.67	0.684	1.66	
240	115.6	4.229	946.7	2.44	0.685	1.51	
260	126.7	4.250	937.2	2.19	0.685	1.36	
280	137.8	4.271	928.1	1.98	0.685	1.24	
300	148.9	4.296	918.0	1.86	0.684	1.17	
350	176.7	4.371	890.4	1.57	0.677	1.02	
400	204.4	4.467	859.4	1.36	0.665	1.00	
450	232.2	4.585	825.7	1.20	0.646	0.85	
500	260	4.731	785.2	1.07	0.616	0.83	
550	287.7	5.024	735.5	9.51×10^{-5}			
600	315.6	5.703	678.7	8.68			

†Adapted to SI units from A. I. Brown and S. M. Marco, *Introduction to Heat Transfer*, 3rd ed. New York: McGraw-Hill, 1958.

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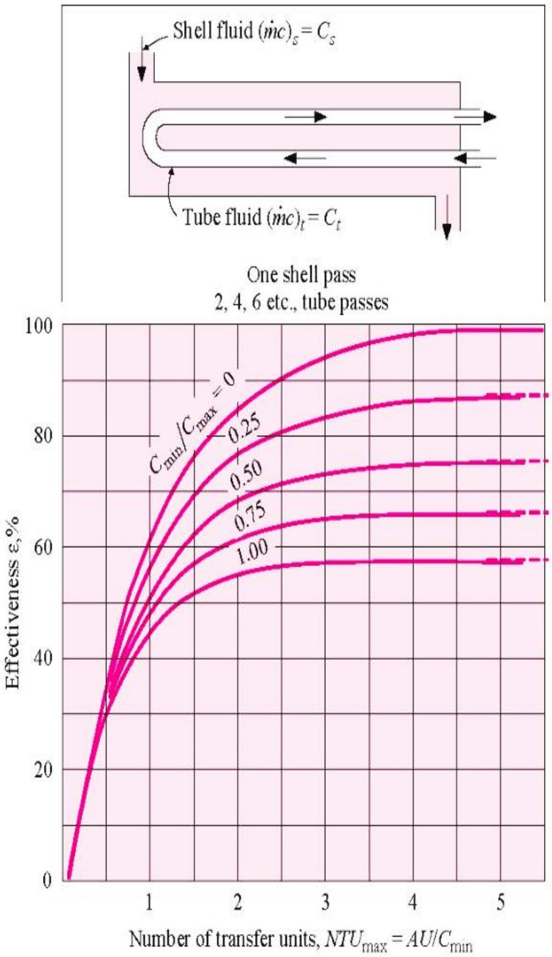
Figure A1. Effectiveness for 1-2 parallel counter-flow exchanger performance.

Figure A2. Effectiveness for 2-4 multipass counter-flow exchanger performance.



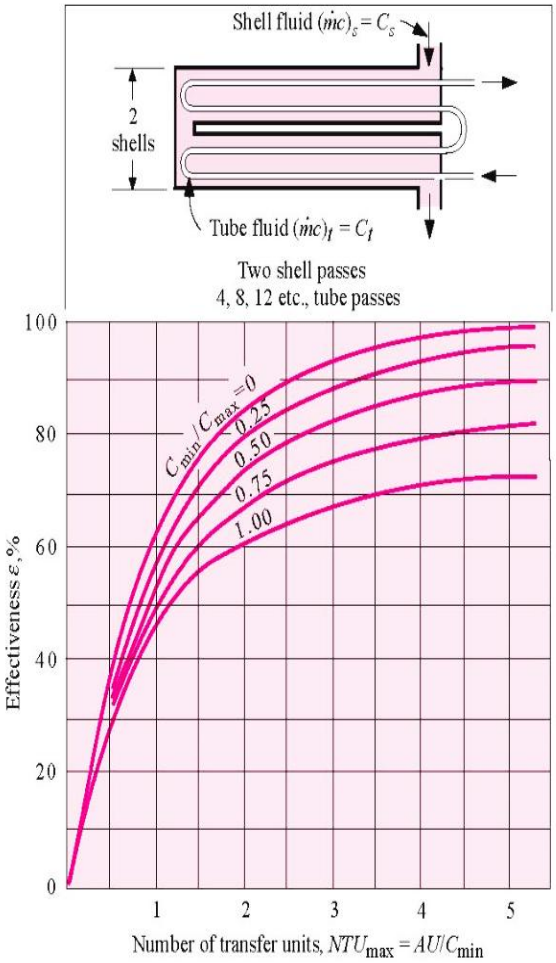


Figure B1 | Correction-factor plot for exchanger with one shell pass and two, four, or any multiple of tube passes.

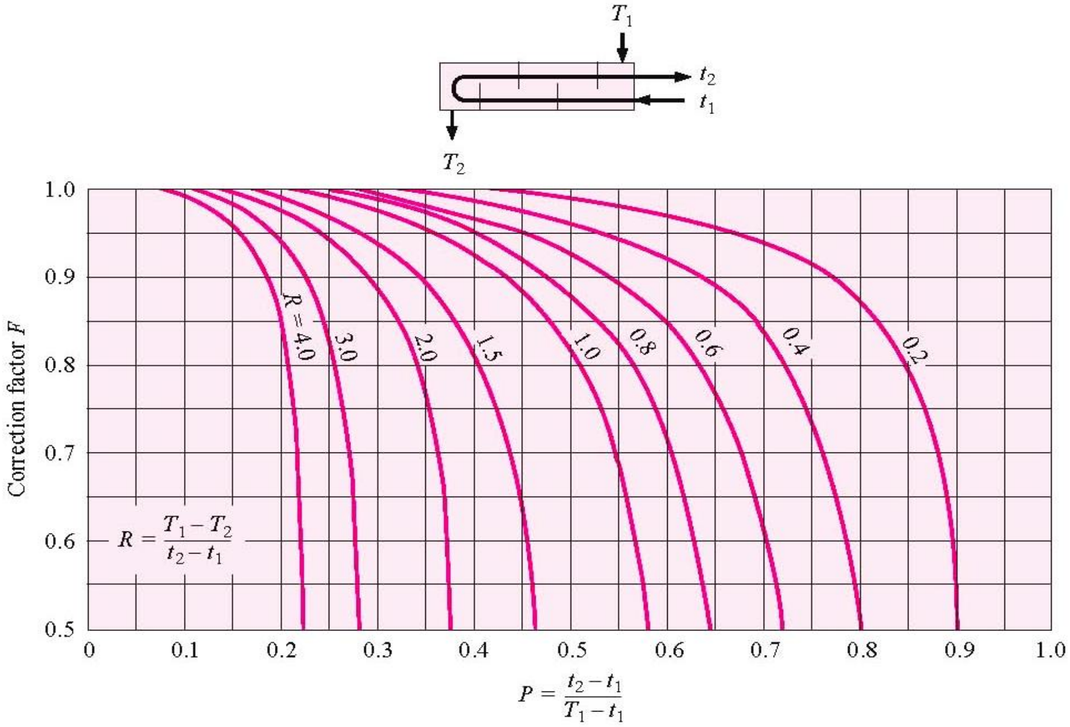


Figure B2 | Correction-factor plot for exchanger with two shell passes and four, eight, or any multiple of tube passes.