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UNIVERSITI SAINS MALAYSIA

Second Semester Examination  
2015/2016 Academic Session

June 2016

**EKC 216 – Process Heat Transfer**  
***[Pemindahan Haba Proses]***

Duration : 3 hours  
*[Masa : 3 jam]*

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

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

**Instruction:** Answer **ALL** questions.

**Arahan:** Jawab **SEMUA** 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] A wall with a cross sectional area of  $3.5 \text{ m}^2$  consists of 14 cm of concrete ( $k = 1.2 \text{ W/m.K}$ ), 9.0 cm of fiberglass insulation ( $k = 0.04 \text{ W/m.K}$ ), and 2.2 cm of gypsum board ( $k = 0.05 \text{ W/m.K}$ ). The inside and outside convection coefficients are  $15.3$  and  $28.7 \text{ W/m}^2.\text{K}$ , respectively. The inside air and outside temperature are  $25 \text{ }^\circ\text{C}$  and  $-4 \text{ }^\circ\text{C}$  respectively. Calculate the temperature at the interface between concrete and fiberglass.

[8 marks]

- [b] A steel plate 1.2 cm thick is taken from a furnace at  $620 \text{ }^\circ\text{C}$  and quenched in a bath of oil at  $40 \text{ }^\circ\text{C}$ . If the heat transfer coefficient is estimated to be  $410 \text{ W/m}^2.\text{K}$ , how long will it take for the plate to cool to  $250 \text{ }^\circ\text{C}$ ?

Given:  $k$ ,  $\rho$  and  $C_p$  for the steel as  $50 \text{ W/m.K}$ ,  $7800 \text{ kg/m}^3$ , and  $450 \text{ J/kg.K}$ , respectively.

[3 marks]

- [c] An electric motor is connected by a horizontal steel shaft ( $k = 42.6 \text{ W/m.K}$ ) of 25 mm in diameter to an impeller of a pump that circulates liquid at a temperature of  $540 \text{ }^\circ\text{C}$  as shown in Figure Q.1.[c]. If the temperature of the electric motor is limited to  $52 \text{ }^\circ\text{C}$  with the ambient air at  $27 \text{ }^\circ\text{C}$  and heat transfer coefficient of  $40.7 \text{ W/m}^2.\text{K}$ , what length of shaft should be specified between the motor and the pump? State your assumptions.

[14 marks]

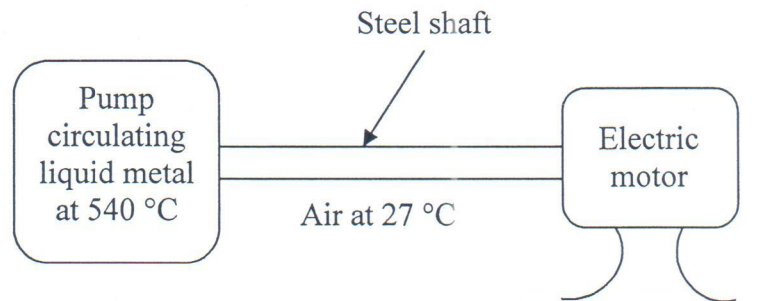


Figure Q.1.[c]

Jawab SEMUA soalan.

1. [a] Sebuah dinding berkeluasan  $3.5 \text{ m}^2$  terdiri daripada konkrit [ $k = 1.2 \text{ W/m.K}$ ] berketebalan  $14 \text{ sm}$ , penebat kaca gentian [ $k = 0.04 \text{ W/m.K}$ ] berketebalan  $9.0 \text{ sm}$  dan papan gipsum [ $k = 0.05 \text{ W/m.K}$ ] berketebalan  $2.2 \text{ sm}$ . Pemalar olakan dalam dan luar masing-masing ialah  $15.3$  dan  $28.7 \text{ W/m}^2.\text{K}$ . Suhu udara di dalam dan di luar masing-masing ialah  $25 \text{ }^\circ\text{C}$  dan  $-4 \text{ }^\circ\text{C}$ . Kirakan suhu di antara permukaan konkrit dan gentian kaca.

[8 markah]

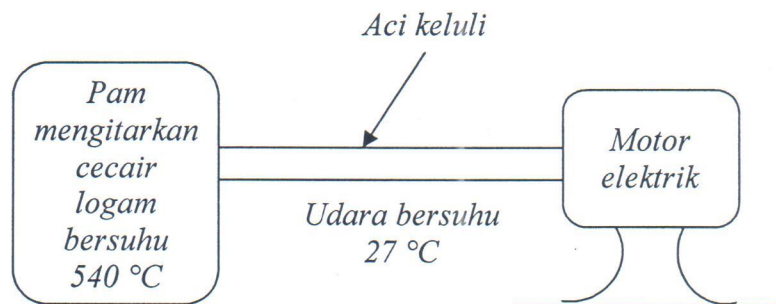
[b] Sebuah plat keluli berketebalan  $1.2 \text{ sm}$  dikeluarkan dari relau pada suhu  $620 \text{ }^\circ\text{C}$  dan dilindap-kejut di dalam takungan minyak yang bersuhu  $40 \text{ }^\circ\text{C}$ . Sekiranya pemalar pemindahan haba ialah  $410 \text{ W/m}^2.\text{K}$ , berapakah masa yang diperlukan oleh plat tersebut untuk mencapai suhu  $250 \text{ }^\circ\text{C}$ ?

Diberi:  $k$ ,  $\rho$  dan  $C_p$  untuk keluli masing-masing sebagai  $50 \text{ W/m.K}$ ,  $7800 \text{ kg/m}^3$  dan  $450 \text{ J/kg.K}$ .

[3 markah]

[c] Sebuah motor elektrik disambung dengan menggunakan aci keluli [ $k = 42.6 \text{ W/m.K}$ ] berdiameter  $25 \text{ mm}$  secara mendatar kepada bilah pam yang mengitaran cecair bersuhu  $540 \text{ }^\circ\text{C}$  seperti di dalam Rajah S.1.[c]. Sekiranya suhu motor elektrik dihad kepada  $52 \text{ }^\circ\text{C}$  dengan suhu persekitaran  $27 \text{ }^\circ\text{C}$  dan pekali pemindahan haba  $40.7 \text{ W/m}^2.\text{K}$ , berapakah panjang aci yang diperlukan antara motor dan pam? Kemukan andaian bagi menyelesaikan masalah ini.

[14 markah]



Rajah S.1.[c].

2. [a] Air at 20 °C and 1 atm flows over a flat plate at 45 m/s. The plate is 75 cm long and is maintained at 60 °C. Assume unit depth in the  $z$  direction. Calculate the heat transfer from the plate. *[6 marks]*
- [b] Air at 1 atm and 35 °C flows across a 5.0 cm diameter and 1 m length cylinder at a velocity of 50 m/s. The cylinder surface is maintained at a temperature of 150 °C. Calculate the heat loss of the cylinder. *[6 marks]*
- [c] A horizontal pipe 0.305 m in diameter is maintained at a temperature of 250 °C in a room where the ambient air is at 15 °C. Calculate the free-convection heat loss per meter of length. *[6 marks]*
- [d] Air at atmospheric pressure is contained between two 0.5 m<sup>2</sup> vertical plates separated by a distance of 1.5 cm. The temperatures of the plates are 100 °C and 40 °C, respectively. Calculate the free-convection heat transfer across the air space. *[7 marks]*
3. You have been consulted by a petrochemical company to design their heat exchange unit. You have been informed that the process stream needs to be cooled down from 350 °C to about below 60 °C. The utility to be used is water at ambient condition. Your task is to seek as much as possible information required designing the heat exchange unit, plan ahead on how to design the unit.
- [a] List down what are the minimum required information in order to design the heat exchange unit. *[5 marks]*
- [b] Assuming that you have the minimum required information as in part [a], list down the important parameters need to be calculated for you to decide what type of heat exchange unit to be designed. *[5 marks]*
- [c] Based on part [b], list down the steps required and assumptions to design the heat exchanger. Please include (in your steps) all the related equations and graphs or tables used in order to design the heat exchange unit. *[10 marks]*
- [d] Based on your initial judgment, what would be the best material of construction to be used? Briefly describe the reason of your choice. *[5 marks]*

2. [a] Udara pada  $20\text{ }^{\circ}\text{C}$  dan  $1\text{ atm}$  mengalir di atas plat mendatar dengan kelajuan  $45\text{ m/s}$ . Panjang plat tersebut ialah  $75\text{ sm}$  dan bersuhu tetap  $60\text{ }^{\circ}\text{C}$ . Anggap unit kedalaman adalah dalam arah  $z$ . Kirakan pemindahan haba dari plat tersebut.  
[6 markah]
- [b] Udara pada  $1\text{ atm}$  dan  $35\text{ }^{\circ}\text{C}$  mengalir merentasi sebuah silinder yang berdiameter  $5.0\text{ sm}$  dan  $1\text{ m}$  panjang pada kelajuan  $50\text{ m/s}$ . Suhu permukaan silinder adalah tetap pada  $150\text{ }^{\circ}\text{C}$ . Kirakan kehilangan haba dari silinder tersebut.  
[6 markah]
- [c] Sebuah paip mendatar berdiameter  $0.305\text{ m}$  dan bersuhu tetap  $250\text{ }^{\circ}\text{C}$  diletakkan di dalam sebuah bilik di mana suhu persekitarannya ialah  $15\text{ }^{\circ}\text{C}$ . Kirakan kehilangan haba secara perolakan bebas per meter panjang paip tersebut.  
[6 markah]
- [d] Udara pada tekanan atmosfera terletak di antara dua plat  $0.5\text{ m}^2$  secara menegak dengan jarak di antara kedua-dua plat tersebut ialah  $1.5\text{ sm}$ . Suhu plat adalah masing-masing  $100\text{ }^{\circ}\text{C}$  dan  $40\text{ }^{\circ}\text{C}$ . Kirakan pemindahan haba perolakan bebas sepanjang ruang udara tersebut.  
[7 markah]
3. Anda telah dirujuk oleh sebuah syarikat petrokimia untuk mereka bentuk unit penukar haba. Anda telah dimaklumkan bahawa aliran proses perlu disejukkan daripada  $350\text{ }^{\circ}\text{C}$  ke suatu suhu di bawah  $60\text{ }^{\circ}\text{C}$ . Bahan kegunaan adalah air pada keadaan ambien. Tugas anda adalah untuk mencari sebanyak mungkin maklumat yang diperlukan untuk mereka bentuk unit penukar haba tersebut, rancang kehadapan bagaimana untuk mereka bentuk unit tersebut.
- [a] Senaraikan maklumat yang paling minima diperlukan untuk mereka bentuk unit penukar haba tersebut.  
[5 markah]
- [b] Andaikan anda telah mempunyai maklumat minima yang diperlukan seperti di bahagian [a], senaraikan parameter-parameter penting yang perlu dikira untuk anda tentukan jenis apakah unit penukar haba yang perlu direka bentuk.  
[5 markah]
- [c] Berdasarkan kepada bahagian [b], senaraikan langkah-langkah yang diperlukan serta andaian-andaian yang diguna pakai bagi mereka bentuk penukar haba tersebut. Sila sertakan (dalam langkah-langkah anda) kesemua persamaan-persamaan yang berkaitan dan graf atau jadual-jadual yang digunakan untuk mereka bentuk unit penukar haba tersebut.  
[10 markah]
- [d] Berdasarkan penilaian awal anda, apakah bahan binaan yang terbaik perlu digunakan. Terangkan secara ringkas alasan pilihan anda.  
[5 markah]

4. [a] Describe briefly the phenomenon of condensation and boiling in the terms of:
- [i] What constitute the phenomenon to happen?
  - [ii] How does the phenomenon take place?
  - [iii] What are the modes of the process? *[12 marks]*
- [b] [i] Saturated steam at 1 atm condenses on the outside of a horizontal 30 cm diameter tube whose surface is maintained at 95 °C. The tube is 15 m long. Calculate the amount of steam condensed per hour. *[6 marks]*
- [ii] A horizontal tube 3mm in diameter and 7.5 cm long is submerged in water at 1.6 atm. Calculate the surface temperature necessary to generate a heat flux of 0.2 MW/m<sup>2</sup>. *[7 marks]*

4. [a] *Terangkan secara ringkas fenomena pemeluwapan dan pendidihan di dalam konteks berikut:*

[i] *Apakah yang diperlukan untuk fenomena tersebut berlaku?*

[ii] *Bagaimana fenomena tersebut terjadi?*

[iii] *Apakah mod-mod proses tersebut?* [12 markah]

[b] [i] *Stim terpepu pada 1 atm memeluwap pada luaran tiub mendatar berdiameter 30 sm yang mana suhu permukaannya ditetapkan pada 95 °C. Panjang tiub tersebut ialah 15 m. Kirakan jumlah stim yang terpeluwap per jam.*

[6 markah]

[ii] *Satu tiub mendatar berdiameter 3 mm dan 7.5 sm panjang tertenggelam di dalam air pada 1.6 atm. Kirakan suhu permukaan yang sepatutnya untuk menghasilkan fluks haba sebanyak 0.2 MW/m<sup>2</sup>.*

[7 markah]

Appendix

$$R_k = \frac{\Delta x}{k.A} ; q = \frac{kA}{\Delta x} (T_1 - T_2)$$

$$Bi = \frac{h(V/A)}{k} ; \tau_c = \frac{\rho c V}{h A_{conv}} = \frac{\rho c L_c}{h} ; \frac{T - T_\infty}{T_o - T_\infty} = e^{-t/\tau_c}$$

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

$$Nu_{plate, laminar} = 0.66 Pr^{1/3} Re_x^{1/2}$$

$$Nu_{plate, turbulent} = Pr^{1/3} (0.037 Re_x^{0.8} - 871)$$

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

$$Gr Pr = \left( \frac{g\beta(T_w - T_\infty)d^3}{\nu^2} \right) Pr ; Nu_{free convection, horizontal pipe} = 0.53 (Gr Pr)^{1/4}$$

$$Gr Pr_{enclosed space} = \left( \frac{g\beta(T_1 - T_2)\delta^3}{\nu^2} \right) Pr ; k_e = 0.197k (Gr Pr)^{1/4} \left( \frac{L}{\delta} \right)^{-1/9} ; q = \frac{k_e A (T_1 - T_2)}{\delta}$$

Properties of air at atmospheric pressure†

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

T, K	$\rho$ kg/m <sup>3</sup>	$c_p$ , kJ/kg · K	$\mu \times 10^5$ , kg/m · s	$\nu \times 10^6$ , m <sup>2</sup> /s	$k$ , W/m · K	$\alpha \times 10^4$ , m <sup>2</sup> /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

**Useful conversion factors**

Physical quantity	Symbol	SI to English conversion	English to SI conversion
Length	$L$	1 m = 3.2808 ft	1 ft = 0.3048 m
Area	$A$	1 m <sup>2</sup> = 10.7639 ft <sup>2</sup>	1 ft <sup>2</sup> = 0.092903 m <sup>2</sup>
Volume	$V$	1 m <sup>3</sup> = 35.3134 ft <sup>3</sup>	1 ft <sup>3</sup> = 0.028317 m <sup>3</sup>
Velocity	$v$	1 m/s = 3.2808 ft/s	1 ft/s = 0.3048 m/s
Density	$\rho$	1 kg/m <sup>3</sup> = 0.06243 lb <sub>m</sub> /ft <sup>3</sup>	1 lb <sub>m</sub> /ft <sup>3</sup> = 16.018 kg/m <sup>3</sup>
Force	$F$	1 N = 0.2248 lb <sub>f</sub>	1 lb <sub>f</sub> = 4.4482 N
Mass	$m$	1 kg = 2.20462 lb <sub>m</sub>	1 lb <sub>m</sub> = 0.45359237 kg
Pressure	$p$	1 N/m <sup>2</sup> = 1.45038 × 10 <sup>-4</sup> lb <sub>f</sub> /in <sup>2</sup>	1 lb <sub>f</sub> /in <sup>2</sup> = 6894.76 N/m <sup>2</sup>
Energy, heat	$q$	1 kJ = 0.94783 Btu	1 Btu = 1.05504 kJ
Heat flow	$q$	1 W = 3.4121 Btu/h	1 Btu/h = 0.29307 W
Heat flux per unit area	$q/A$	1 W/m <sup>2</sup> = 0.317 Btu/h · ft <sup>2</sup>	1 Btu/h · ft <sup>2</sup> = 3.154 W/m <sup>2</sup>
Heat flux per unit length	$q/L$	1 W/m = 1.0403 Btu/h · ft	1 Btu/h · ft = 0.9613 W/m
Heat generation per unit volume	$\dot{q}$	1 W/m <sup>3</sup> = 0.096623 Btu/h · ft <sup>3</sup>	1 Btu/h · ft <sup>3</sup> = 10.35 W/m <sup>3</sup>
Energy per unit mass	$q/m$	1 kJ/kg = 0.4299 Btu/lb <sub>m</sub>	1 Btu/lb <sub>m</sub> = 2.326 kJ/kg
Specific heat	$c$	1 kJ/kg · °C = 0.23884 Btu/lb <sub>m</sub> · °F	1 Btu/lb <sub>m</sub> · °F = 4.1869 kJ/kg · °C
Thermal conductivity	$k$	1 W/m · °C = 0.5778 Btu/h · ft · °F	1 Btu/h · ft · °F = 1.7307 W/m · °C
Convection heat-transfer coefficient	$h$	1 W/m <sup>2</sup> · °C = 0.1761 Btu/h · ft <sup>2</sup> · °F	1 Btu/h · ft <sup>2</sup> · °F = 5.6782 W/m <sup>2</sup> · °C
Dynamic viscosity	$\mu$	1 kg/m · s = 0.672 lb <sub>m</sub> /ft · s	1 lb <sub>m</sub> /ft · s = 1.4881 kg/m · s
Kinematic viscosity and thermal diffusivity	$\nu, \alpha$	= 2419.2 lb <sub>m</sub> /ft · h 1 m <sup>2</sup> /s = 10.7639 ft <sup>2</sup> /s	1 ft <sup>2</sup> /s = 0.092903 m <sup>2</sup> /s

**Important physical constants**

Avogadro's number	$N_0 = 6.022045 \times 10^{26}$ molecules/kg mol
Universal gas constant	$R = 1545.35$ ft · lbf/lb <sub>m</sub> · mol · °R = 8314.41 J/kg mol · K = 1.986 Btu/lb <sub>m</sub> · mol · °R = 1.986 kcal/kg mol · K Planck's constant
constant	$h = 6.626176 \times 10^{-34}$ J · sec
Boltzmann's constant	$k = 1.380662 \times 10^{-23}$ J/molecule · K = 8.6173 × 10 <sup>-5</sup> eV/molecule · K
Speed of light in vacuum	$c = 2.997925 \times 10^8$ m/s
Standard gravitational acceleration	$g = 32.174$ ft/s <sup>2</sup> = 9.80665 m/s <sup>2</sup>
Electron mass	$m_e = 9.1095 \times 10^{-31}$ kg
Charge on the electron	$e = 1.602189 \times 10^{-19}$ C
Stefan-Boltzmann constant	$\sigma = 0.1714 \times 10^{-8}$ Btu/hr · ft <sup>2</sup> · R <sup>4</sup> = 5.669 × 10 <sup>-8</sup> W/m <sup>2</sup> · K <sup>4</sup>
1 atm	= 14.69595 lb <sub>f</sub> /in <sup>2</sup> = 760 mmHg at 32°F = 29.92 inHg at 32°F = 2116.21 lb <sub>f</sub> /ft <sup>2</sup> = 1.01325 × 10 <sup>5</sup> N/m <sup>2</sup>

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

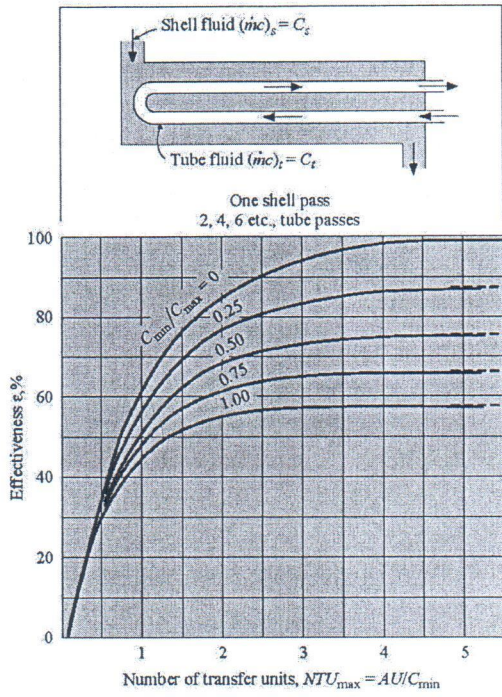


Figure A2. Effectiveness for 2-4 multipass counter-flow exchanger performance.

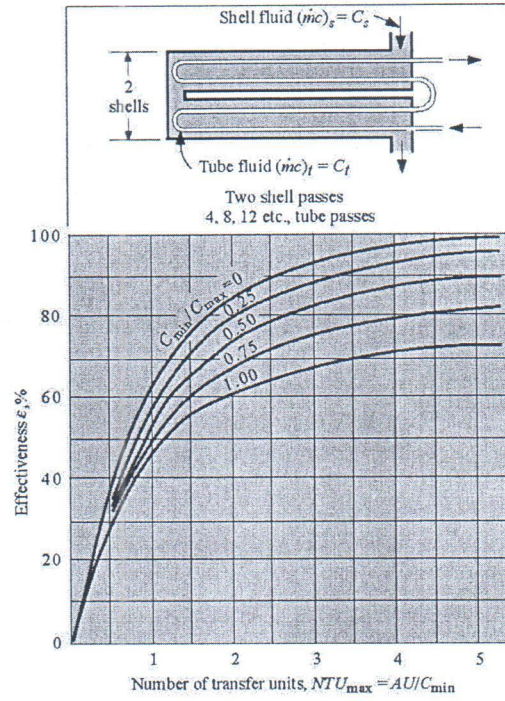


Table A1. Heat-exchanger effectiveness relations

$N = NTU = \frac{UA}{C_{min}}$ $C = \frac{C_{min}}{C_{max}}$	
Flow geometry	Relation
<b>Double pipe:</b>	
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, $C = 1$	$\epsilon = \frac{N}{N + 1}$
<b>Cross flow:</b>	
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	$\epsilon = 1 - \exp\{-(1/C)[1 - \exp(-NC)]\}$
<b>Shell and tube:</b>	
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 $C = 0$	$\epsilon = 1 - e^{-N}$

Table A2. NTU relations for heat exchangers

$C = C_{\min}/C_{\max}$	$\epsilon = \text{effectiveness}$	$N = \text{NTU} = UA/C_{\min}$
Flow geometry		Relation
<b>Double pipe:</b>		
	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, $C = 1$	$N = \frac{\epsilon}{1 - \epsilon}$
<b>Cross flow:</b>		
	$C_{\max}$ mixed, $C_{\min}$ unmixed	$N = -\ln\left[1 + \frac{1}{C} \ln(1 - C\epsilon)\right]$
	$C_{\max}$ unmixed, $C_{\min}$ mixed	$N = \frac{-1}{C} \ln[1 + C \ln(1 - \epsilon)]$
<b>Shell and tube:</b>		
	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).<sup>†</sup>

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	$\rho$ kg/m <sup>3</sup>	$\mu$ kg/m·s	$k$ W/m·°C	Pr	$\frac{g\beta\rho^2 c_p}{\mu k}$ 1/m <sup>3</sup> ·°C
32	0	4.225	999.8	$1.79 \times 10^{-3}$	0.566	13.25	
40	4.44	4.208	999.8	1.55	0.575	11.35	$1.91 \times 10^9$
50	10	4.195	999.2	1.31	0.585	9.40	$6.34 \times 10^9$
60	15.56	4.186	998.6	1.12	0.595	7.88	$1.08 \times 10^{10}$
70	21.11	4.179	997.4	$9.8 \times 10^{-4}$	0.604	6.78	$1.46 \times 10^{10}$
80	26.67	4.179	995.8	8.6	0.614	5.85	$1.91 \times 10^{10}$
90	32.22	4.174	994.9	7.65	0.623	5.12	$2.48 \times 10^{10}$
100	37.78	4.174	993.0	6.82	0.630	4.53	$3.3 \times 10^{10}$
110	43.33	4.174	990.6	6.16	0.637	4.04	$4.19 \times 10^{10}$
120	48.89	4.174	988.8	5.62	0.644	3.64	$4.89 \times 10^{10}$
130	54.44	4.179	985.7	5.13	0.649	3.30	$5.66 \times 10^{10}$
140	60	4.179	983.3	4.71	0.654	3.01	$6.48 \times 10^{10}$
150	65.55	4.183	980.3	4.3	0.659	2.73	$7.62 \times 10^{10}$
160	71.11	4.186	977.3	4.01	0.665	2.53	$8.84 \times 10^{10}$
170	76.67	4.191	973.7	3.72	0.668	2.33	$9.85 \times 10^{10}$
180	82.22	4.195	970.2	3.47	0.673	2.16	$1.09 \times 10^{11}$
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	$9.51 \times 10^{-5}$			
600	315.6	5.703	678.7	8.68			

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