



**UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF CHEMICAL AND BIOENGINEERING
TECHNOLOGY**

**FINAL EXAMINATION
OCTOBER 2025 SEMESTER**

COURSE CODE	: CCB20303
COURSE NAME	: PROCESS HEAT TRANSFER
PROGRAMME NAME	: BACHELOR OF CHEMICAL ENGINEERING WITH HONOURS
DATE	: 31 JANUARY 2026
TIME	: 9.00 AM – 12.00 PM
DURATION	: 3 HOURS

INSTRUCTIONS TO CANDIDATES

1. Please read CAREFULLY the instructions given in the question paper.
2. This question paper has information printed on both sides of the paper.
3. This question paper contains a total of FOUR (4) questions. Answer ALL questions.
4. Answer ALL questions in English language only.
5. Please write your answers on the answer booklet provided.

THERE ARE 15 PAGES OF QUESTIONS AND APPENDICES, EXCLUDING THIS PAGE.

(Total: 100 marks)

INSTRUCTION: Answer ALL questions**Please use the answer booklet provided.****QUESTION 1**

Consider a sub-unit of a composite wall as shown in Figure 1. The thermal conductivities of various materials used, in $\text{W/m}\cdot^\circ\text{C}$, are $k_S = 5$, $k_T = 2$, $k_U = 15$ and $k_V = 10$. The top and bottom surfaces of the wall are maintained at uniform temperatures of 75°C and 200°C , respectively. Assuming heat transfer through the wall to be one-dimensional, evaluate:

- (a) the rate of heat transfer through the wall (in **W**) (17 marks)
- (b) the temperature drops across the material S (in $^\circ\text{C}$) (3 marks)
- (c) the interface temperature between material T, U and V (in $^\circ\text{C}$) (5 marks)

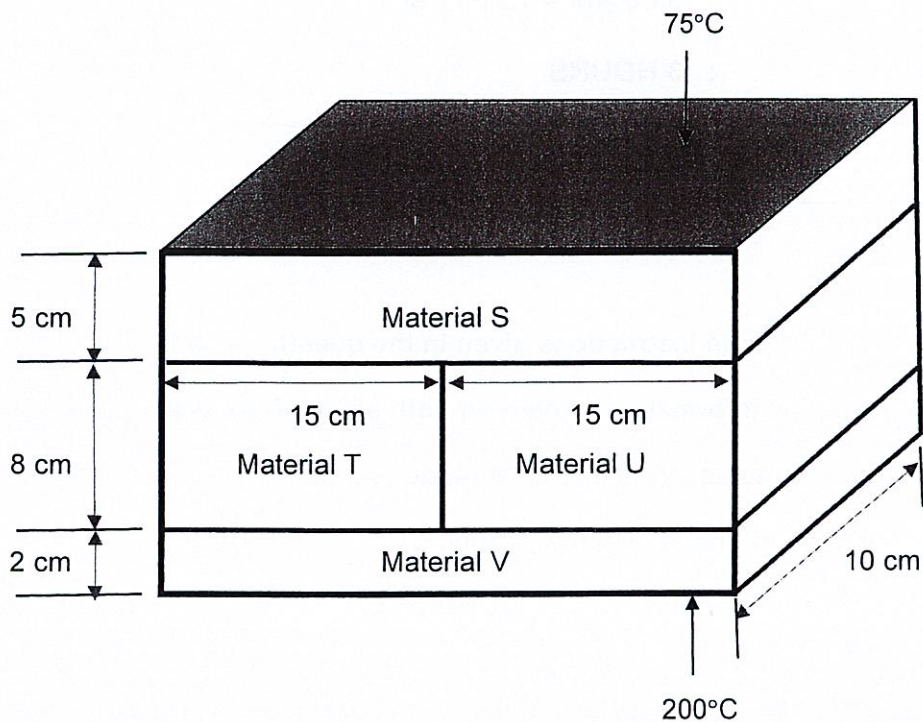


Figure 1. A composite wall made of materials S, T, U and V

QUESTION 2

A 1.5-m-diameter, 4-m-long cylindrical propane tank (Figure 2) is initially filled with liquid propane, whose density is 581 kg/m^3 . The tank is exposed to the ambient air at 25°C in calm weather. The outer surface of the tank is polished so that the radiation heat transfer is negligible. Now a crack develops at the top of the tank, and the pressure inside drops to 1 atm while the temperature drops to -42°C , which is the boiling temperature of propane at 1 atm. The heat of vaporization of propane at 1 atm is 425 kJ/kg . The propane is slowly vaporized as a result of the heat transfer from the ambient air into the tank, and the propane vapor escapes the tank at -42°C through the crack. Assuming the propane tank to be at about the same temperature as the propane inside at all times, estimate how long (in **hours**) it will take for the tank to empty if it is not insulated.

Properties of air at 1 atm and film temperature ($T_f = -8.5^\circ\text{C}$) are given as follows:

$$k = 0.02299 \text{ W/m}\cdot^\circ\text{C}$$

$$\nu = 1.265 \times 10^{-5} \text{ m}^2/\text{s}$$

$$Pr = 0.7383$$

(25 marks)

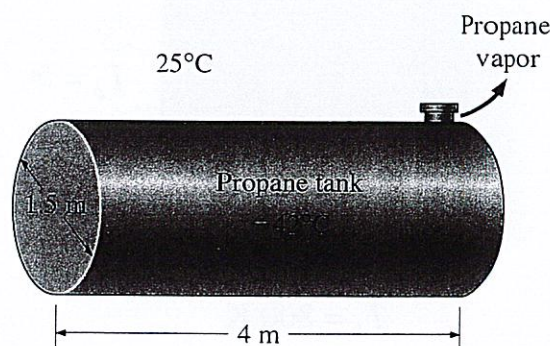


Figure 2. A 4-m-long cylindrical propane tank

QUESTION 3

- (a) Consider the 5-m x 5-m x 5-m cubical furnace shown in Figure 3, whose surfaces closely approximate black surfaces. The base, top, and side surfaces of the furnace are maintained at uniform temperatures of 800 K, 1500 K, and 500 K, respectively. Determine:

- the net rate of radiation heat transfer between the base and the side surfaces (in kW),
(8 marks)
- the net rate of radiation heat transfer between the base and the top surface (in kW), and
(3 marks)
- the net radiation heat transfer from the base surface (in kW).
(3 marks)

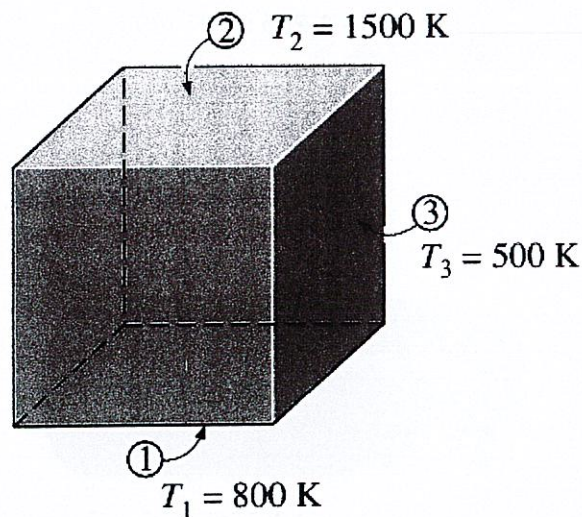


Figure 3. The cubical furnace with black surfaces

- (b) Two coaxial cylinders of diameters $D_1 = 0.10$ m and $D_2 = 0.30$ m and emissivities $\varepsilon_1 = 0.7$ and $\varepsilon_2 = 0.4$ are maintained at uniform temperatures of $T_1 = 750$ K and $T_2 = 500$ K, respectively. Now a coaxial radiation shield of diameter $D_3 = 0.20$ m and emissivity $\varepsilon_3 = 0.2$ is placed between the two cylinders. Determine the net rate of radiation heat transfer between the two cylinders per unit length of the cylinders (in **W**) and compare the result with that without the shield.

(11 marks)

QUESTION 4

Glycerin ($c_p = 2400$ J/kg.°C) at 20°C and 0.3 kg/s is to be heated by ethylene glycol ($c_p = 2500$ J/kg.°C) at 60°C and the same mass flow rate in a thin-walled double-pipe parallel-flow heat exchanger. Given the overall heat transfer coefficient is 380 W/m².°C and the heat transfer surface area is 5.3 m².

- (a) Determine the following by using the **Effectiveness – Number of Transfer Units (ε - NTU)** method:
- the rate of heat transfer (in **kW**) and
(18 marks)
 - the outlet temperatures of the glycerin and the glycol (in °C).
(5 marks)
- (b) Identify the condition where ε – NTU method is preferable than the log mean temperature difference (LMTD) method in the heat exchanger analysis.
(2 marks)

END OF EXAMINATION PAPER

Appendix

Appendix A1: List of Equations

Heat Conduction:

$$Q = 2\pi kL \frac{(T_1 - T_2)}{\left(\ln \frac{r_2}{r_1}\right)}$$

$$Q = 4\pi k \frac{(T_1 - T_2)}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}$$

$$\frac{1}{R_{AB}} = \frac{1}{R_A} + \frac{1}{R_B}$$

$$L_c = \frac{V}{A_{surface}}$$

$$Bi = \frac{hL_c}{k}$$

$$\frac{T(t) - T_\infty}{T_i - T_\infty} = e^{-bt}; \quad b = \frac{hA_s}{\rho V C_p}$$

Free Convection:

$$Nu = \frac{hL_c}{k} = C(Gr \cdot Pr)^n = C \left(\frac{L_c^3 \rho^2 g \beta \Delta T}{\mu^2} \frac{C_p \mu}{k} \right)^n$$

Vertical Plate and Vertical Cylinder:

$$Nu = \left\{ 0.825 + \frac{0.387 Ra_L^{1/6}}{\left[1 + (0.492 / Pr)^{9/16} \right]^{8/27}} \right\}^2$$

Range of Ra: Entire Range

Note: A vertical cylinder can be treated as a vertical plate when

$$D \geq \frac{35L}{Gr_L^{1/4}}$$

Horizontal Cylinder:

$$Nu = \left\{ 0.6 + \frac{0.387 Ra_D^{1/6}}{\left[1 + (0.559 / Pr)^{9/16} \right]^{8/27}} \right\}^2$$

Range of Ra: $Ra_D \leq 10^{12}$

Sphere:

$$Nu = 2 + \frac{0.589 Ra_D^{1/4}}{\left[1 + (0.469 / Pr)^{9/16}\right]^{4/9}}$$

Range of Ra: $Ra_D \leq 10^{11}$
($Pr \geq 0.7$)

Force Convection:

$$Re = \frac{\rho V L_c}{\mu} = \frac{V L_c}{\nu} \quad L_c = L \text{ or } D$$

Flat Plate:

Laminar Flow ($Re < 5 \times 10^5$):

$$Nu = \frac{hL}{k} = 0.664 Re^{0.5} Pr^{1/3}$$

Turbulent Flow ($5 \times 10^5 < Re < 10^7$):

$$Nu = \frac{hL}{k} = 0.0366 Re^{0.8} Pr^{1/3}$$

Cylinder:

$$Nu = \frac{hD}{k} = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1 + (0.4 / Pr)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{282,000}\right)^{5/8}\right]^{4/5}$$

$Re.Pr > 0.2$

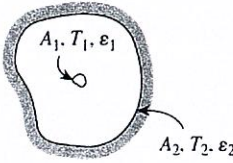
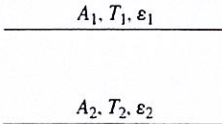
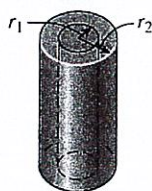
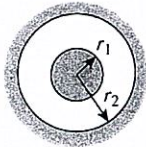
Sphere:

$$Nu = \frac{hD}{k} = 2.0 + \left[0.4 Re^{1/2} + 0.06 Re^{2/3}\right] Pr^{0.4} \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$$

Valid for: $3.5 \leq Re \leq 80,000$ and $0.7 \leq Pr \leq 380$

Radiation:

Radiation heat transfer relations for some familiar two-surface arrangements

Small object in a large cavity  $\frac{A_1}{A_2} \approx 0$ $F_{12} = 1$			$\dot{Q}_{12} = A_1 \sigma \epsilon_1 (T_1^4 - T_2^4)$	(13-37)
Infinitely large parallel plates  $A_1 = A_2 = A$ $F_{12} = 1$			$\dot{Q}_{12} = \frac{A \sigma (T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$	(13-38)
Infinitely long concentric cylinders  $\frac{A_1}{A_2} = \frac{r_1}{r_2}$ $F_{12} = 1$			$\dot{Q}_{12} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} + \frac{1 - \epsilon_2}{\epsilon_2} \left(\frac{r_1}{r_2} \right)}$	(13-39)
Concentric spheres  $\frac{A_1}{A_2} = \left(\frac{r_1}{r_2} \right)^2$ $F_{12} = 1$			$\dot{Q}_{12} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} + \frac{1 - \epsilon_2}{\epsilon_2} \left(\frac{r_1}{r_2} \right)^2}$	(13-40)

$$\sigma = 5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$$

Radiation heat transfer in two-surface enclosures:

$$q_{12} = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1 - \epsilon_1}{A_1 \epsilon_1} + \frac{1}{A_1 F_{12}} + \frac{1 - \epsilon_2}{A_2 \epsilon_2}}$$

Radiation heat transfer between two large parallel plates:

$$q_{12, \text{no shield}} = \frac{A \sigma (T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$$

If a radiation shield placed between two plates:

$$q_{12} \text{ one shield} = \frac{E_{b1} - E_{b2}}{\frac{1 - \varepsilon_1}{A_1 \varepsilon_1} + \frac{1}{A_1 F_{12}} + \frac{1 - \varepsilon_{3,1}}{A_3 \varepsilon_{3,1}} + \frac{1 - \varepsilon_{3,2}}{A_3 \varepsilon_{3,2}} + \frac{1}{A_3 F_{32}} + \frac{1 - \varepsilon_2}{A_2 \varepsilon_2}}$$

$$q_{12} \text{ one shield} = \frac{\sigma [(T_1)^4 - (T_2)^4]}{\frac{1 - \varepsilon_1}{A_1 \varepsilon_1} + \frac{1}{A_1 F_{12}} + \frac{1 - \varepsilon_{3,1}}{A_3 \varepsilon_{3,1}} + \frac{1 - \varepsilon_{3,2}}{A_3 \varepsilon_{3,2}} + \frac{1}{A_3 F_{32}} + \frac{1 - \varepsilon_2}{A_2 \varepsilon_2}}$$

If $F_{13} = F_{23} = 1$ and $A_1 = A_2 = A_3 = A$ for infinite parallel plates:

$$q_{12} \text{ one shield} = \frac{A\sigma(T_1^4 - T_2^4)}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right) + \left(\frac{1}{\varepsilon_{3,1}} + \frac{1}{\varepsilon_{3,2}} - 1\right)}$$

If the emissivities of all surfaces are equal:

$$q_{12 \text{ } N\text{-shields}} = \frac{A\sigma(T_1^4 - T_2^4)}{(N+1)\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1\right)} = \frac{1}{N+1} Q_{12, \text{no-shields}}$$

Heat Exchanger:

Overall heat transfer coefficient:

$$\frac{1}{UA_s} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = R = \frac{1}{h_i A_i} + R_{wall} + \frac{1}{h_o A_o}$$

If $R_{wall} = 0$ and $A_i \approx A_o \approx A_s$:

$$\frac{1}{U} \approx \frac{1}{h_i} + \frac{1}{h_o}$$

$$R = \frac{1}{h_i A_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{R_{f,o}}{A_o} + \frac{1}{h_o A_o}$$

Effectiveness relations for heat exchangers: $NTU = UA_s/C_{\min}$ and $c = C_{\min}/C_{\max} = (\dot{m}c_p)_{\min}/(\dot{m}c_p)_{\max}$

Heat exchanger type	Effectiveness relation
1 Double pipe:	
Parallel-flow	$\varepsilon = \frac{1 - \exp[-NTU(1 + c)]}{1 + c}$
Counter-flow	$\varepsilon = \frac{1 - \exp[-NTU(1 - c)]}{1 - c \exp[-NTU(1 - c)]}$ (for $c < 1$)
	$\varepsilon = \frac{NTU}{1 + NTU}$ (for $c = 1$)
2 Shell-and-tube:	
One-shell pass 2, 4, ... tube passes	$\varepsilon_1 = 2 \left\{ 1 + c + \sqrt{1 + c^2} \frac{1 + \exp[-NTU_1 \sqrt{1 + c^2}]}{1 - \exp[-NTU_1 \sqrt{1 + c^2}]} \right\}^{-1}$
n -shell passes $2n, 4n, \dots$ tube passes	$\varepsilon_n = \left[\left(\frac{1 - \varepsilon_1 c}{1 - \varepsilon_1} \right)^n - 1 \right] \left[\left(\frac{1 - \varepsilon_1 c}{1 - \varepsilon_1} \right)^n - c \right]^{-1}$
3 Cross-flow (single-pass)	
Both fluids unmixed	$\varepsilon = 1 - \exp \left\{ \frac{NTU^{0.22}}{c} [\exp(-cNTU^{0.78}) - 1] \right\}$
$C_{\max}$ mixed, $C_{\min}$ unmixed	$\varepsilon = \frac{1}{c} (1 - \exp \{-c[1 - \exp(-NTU)]\})$
$C_{\min}$ mixed, $C_{\max}$ unmixed	$\varepsilon = 1 - \exp \left\{ -\frac{1}{c} [1 - \exp(-cNTU)] \right\}$
4 All heat exchangers with $c = 0$	$\varepsilon = 1 - \exp(-NTU)$

From W. M. Kays and A. L. London. *Compact Heat Exchangers*, 3/e. McGraw-Hill, 1984. Reprinted by permission of William M. Kays.

NTU relations for heat exchangers: $NTU = UA_s/C_{\min}$ and $c = C_{\min}/C_{\max} = (\dot{m}c_p)_{\min}/(\dot{m}c_p)_{\max}$

Heat exchanger type	NTU relation
1 Double-pipe:	
Parallel-flow	$NTU = -\frac{\ln[1 - \varepsilon(1 + c)]}{1 + c}$
Counter-flow	$NTU = \frac{1}{c - 1} \ln\left(\frac{\varepsilon - 1}{\varepsilon c - 1}\right)$ (for $c < 1$)
	$NTU = \frac{\varepsilon}{1 - \varepsilon}$ (for $c = 1$)
2 Shell and tube:	
One-shell pass 2, 4, ... tube passes	$NTU_1 = -\frac{1}{\sqrt{1 + c^2}} \ln\left(\frac{2/\varepsilon_1 - 1 - c - \sqrt{1 + c^2}}{2/\varepsilon_1 - 1 - c + \sqrt{1 + c^2}}\right)$
n -shell passes $2n, 4n, \dots$ tube passes	$NTU_n = n(NTU)_1$
To find effectiveness of the heat exchanger with one-shell pass use, $\varepsilon_1 = \frac{F - 1}{F - c}$	
where $F = \left(\frac{\varepsilon_n c - 1}{\varepsilon_n - 1}\right)^{1/n}$	
3 Cross-flow (single-pass):	
$C_{\max}$ mixed, $C_{\min}$ unmixed	$NTU = -\ln\left[1 + \frac{\ln(1 - \varepsilon c)}{c}\right]$
$C_{\min}$ mixed, $C_{\max}$ unmixed	$NTU = -\frac{\ln[c \ln(1 - \varepsilon) + 1]}{c}$
4 All heat exchangers with $c = 0$	$NTU = -\ln(1 - \varepsilon)$

From W. M. Kays and A. L. London. *Compact Heat Exchangers*, 3/e. McGraw-Hill, 1984. Reprinted by permission of William M. Kays.

Appendix A2: Table Properties of Water

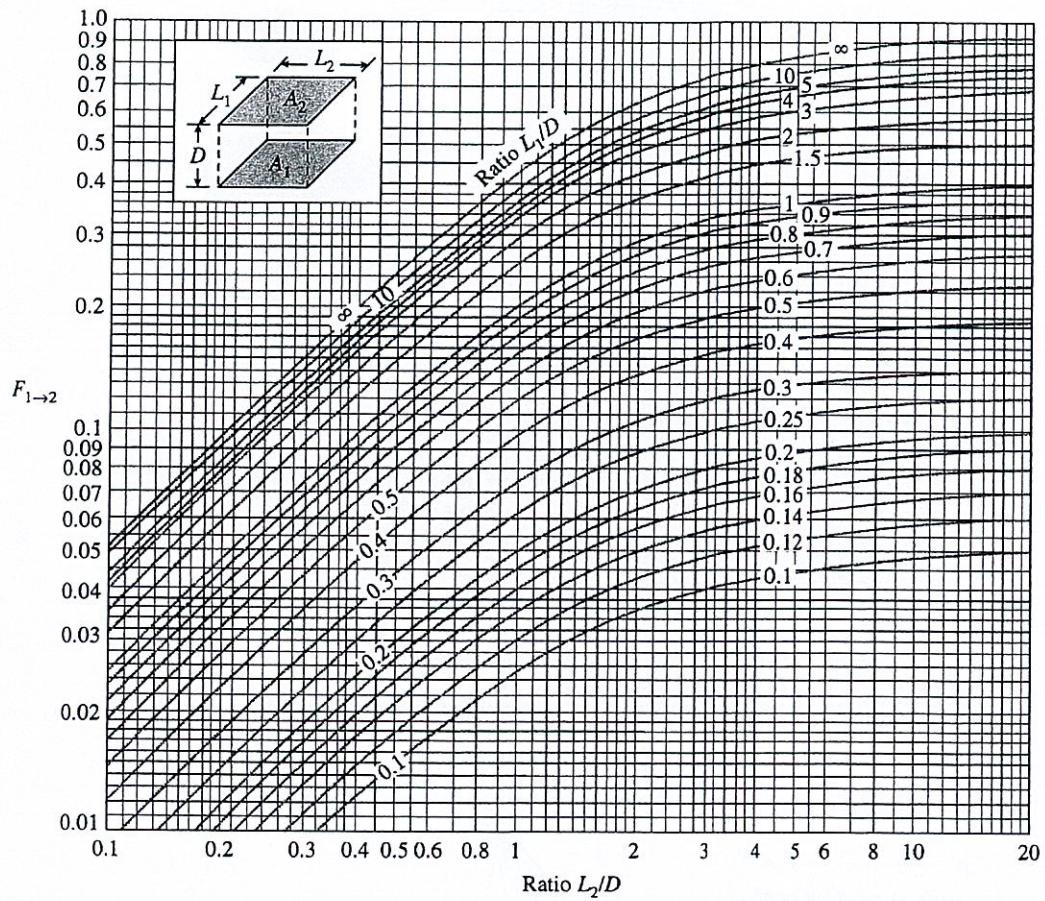
Properties of saturated water

Temp. <i>T</i> , °C	Saturation Pressure <i>P</i> _{sat} , kPa	Density <i>ρ</i> , kg/m ³		Enthalpy of Vaporization <i>h</i> _{fg} , kJ/kg	Specific Heat <i>c_p</i> , J/kg·K		Thermal Conductivity <i>k</i> , W/m·K		Dynamic Viscosity <i>μ</i> , kg/m·s		Prandtl Number <i>Pr</i>		Volume Expansion Coefficient <i>β</i> , 1/K
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792 × 10 ⁻³	0.922 × 10 ⁻⁵	13.5	1.00	-0.068 × 10 ⁻³
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519 × 10 ⁻³	0.934 × 10 ⁻⁵	11.2	1.00	0.015 × 10 ⁻³
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307 × 10 ⁻³	0.946 × 10 ⁻⁵	9.45	1.00	0.733 × 10 ⁻³
15	1.7051	999.1	0.0128	2466	4185	1863	0.589	0.0179	1.138 × 10 ⁻³	0.959 × 10 ⁻⁵	8.09	1.00	0.138 × 10 ⁻³
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002 × 10 ⁻³	0.973 × 10 ⁻⁵	7.01	1.00	0.195 × 10 ⁻³
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891 × 10 ⁻³	0.987 × 10 ⁻⁵	6.14	1.00	0.247 × 10 ⁻³
30	4.246	996.0	0.0304	2431	4178	1875	0.615	0.0189	0.798 × 10 ⁻³	1.001 × 10 ⁻⁵	5.42	1.00	0.294 × 10 ⁻³
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720 × 10 ⁻³	1.016 × 10 ⁻⁵	4.83	1.00	0.337 × 10 ⁻³
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653 × 10 ⁻³	1.031 × 10 ⁻⁵	4.32	1.00	0.377 × 10 ⁻³
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596 × 10 ⁻³	1.046 × 10 ⁻⁵	3.91	1.00	0.415 × 10 ⁻³
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547 × 10 ⁻³	1.062 × 10 ⁻⁵	3.55	1.00	0.451 × 10 ⁻³
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504 × 10 ⁻³	1.077 × 10 ⁻⁵	3.25	1.00	0.484 × 10 ⁻³
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467 × 10 ⁻³	1.093 × 10 ⁻⁵	2.99	1.00	0.517 × 10 ⁻³
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433 × 10 ⁻³	1.110 × 10 ⁻⁵	2.75	1.00	0.548 × 10 ⁻³
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404 × 10 ⁻³	1.126 × 10 ⁻⁵	2.55	1.00	0.578 × 10 ⁻³
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378 × 10 ⁻³	1.142 × 10 ⁻⁵	2.38	1.00	0.607 × 10 ⁻³
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355 × 10 ⁻³	1.159 × 10 ⁻⁵	2.22	1.00	0.633 × 10 ⁻³
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333 × 10 ⁻³	1.176 × 10 ⁻⁵	2.08	1.00	0.670 × 10 ⁻³
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315 × 10 ⁻³	1.193 × 10 ⁻⁵	1.96	1.00	0.702 × 10 ⁻³
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297 × 10 ⁻³	1.210 × 10 ⁻⁵	1.85	1.00	0.716 × 10 ⁻³
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282 × 10 ⁻³	1.227 × 10 ⁻⁵	1.75	1.00	0.750 × 10 ⁻³
110	143.27	950.6	0.8263	2230	4229	2071	0.682	0.0262	0.255 × 10 ⁻³	1.261 × 10 ⁻⁵	1.58	1.00	0.798 × 10 ⁻³
120	198.53	943.4	1.121	2203	4244	2120	0.683	0.0275	0.232 × 10 ⁻³	1.296 × 10 ⁻⁵	1.44	1.00	0.858 × 10 ⁻³
130	270.1	934.6	1.496	2174	4263	2177	0.684	0.0288	0.213 × 10 ⁻³	1.330 × 10 ⁻⁵	1.33	1.01	0.913 × 10 ⁻³
140	361.3	921.7	1.965	2145	4286	2244	0.683	0.0301	0.197 × 10 ⁻³	1.365 × 10 ⁻⁵	1.24	1.02	0.970 × 10 ⁻³
150	475.8	916.6	2.546	2114	4311	2314	0.682	0.0316	0.183 × 10 ⁻³	1.399 × 10 ⁻⁵	1.16	1.02	1.025 × 10 ⁻³
160	617.8	907.4	3.256	2083	4340	2420	0.680	0.0331	0.170 × 10 ⁻³	1.434 × 10 ⁻⁵	1.09	1.05	1.145 × 10 ⁻³
170	791.7	897.7	4.119	2050	4370	2490	0.677	0.0347	0.160 × 10 ⁻³	1.468 × 10 ⁻⁵	1.03	1.05	1.178 × 10 ⁻³
180	1,002.1	887.3	5.153	2015	4410	2590	0.673	0.0364	0.150 × 10 ⁻³	1.502 × 10 ⁻⁵	0.983	1.07	1.210 × 10 ⁻³
190	1,254.4	876.4	6.388	1979	4460	2710	0.669	0.0382	0.142 × 10 ⁻³	1.537 × 10 ⁻⁵	0.947	1.09	1.280 × 10 ⁻³
200	1,553.8	864.3	7.852	1941	4500	2840	0.663	0.0401	0.134 × 10 ⁻³	1.571 × 10 ⁻⁵	0.910	1.11	1.350 × 10 ⁻³
220	2,318	840.3	11.60	1859	4610	3110	0.650	0.0442	0.122 × 10 ⁻³	1.641 × 10 ⁻⁵	0.865	1.15	1.520 × 10 ⁻³
240	3,344	813.7	16.73	1767	4760	3520	0.632	0.0487	0.111 × 10 ⁻³	1.712 × 10 ⁻⁵	0.836	1.24	1.720 × 10 ⁻³
260	4,688	783.7	23.69	1663	4970	4070	0.609	0.0540	0.102 × 10 ⁻³	1.788 × 10 ⁻⁵	0.832	1.35	2.000 × 10 ⁻³
280	6,412	750.8	33.15	1544	5280	4835	0.581	0.0605	0.094 × 10 ⁻³	1.870 × 10 ⁻⁵	0.854	1.49	2.380 × 10 ⁻³
300	8,581	713.8	46.15	1405	5750	5980	0.548	0.0695	0.086 × 10 ⁻³	1.965 × 10 ⁻⁵	0.902	1.69	2.950 × 10 ⁻³
320	11,274	667.1	64.57	1239	6540	7900	0.509	0.0836	0.078 × 10 ⁻³	2.084 × 10 ⁻⁵	1.00	1.97	
340	14,586	610.5	92.62	1028	8240	11,870	0.469	0.110	0.070 × 10 ⁻³	2.255 × 10 ⁻⁵	1.23	2.43	
360	18,651	528.3	144.0	720	14,690	25,800	0.427	0.178	0.060 × 10 ⁻³	2.571 × 10 ⁻⁵	2.06	3.73	
374.14	22,090	317.0	317.0	0	—	—	—	—	0.043 × 10 ⁻³	4.313 × 10 ⁻⁵			

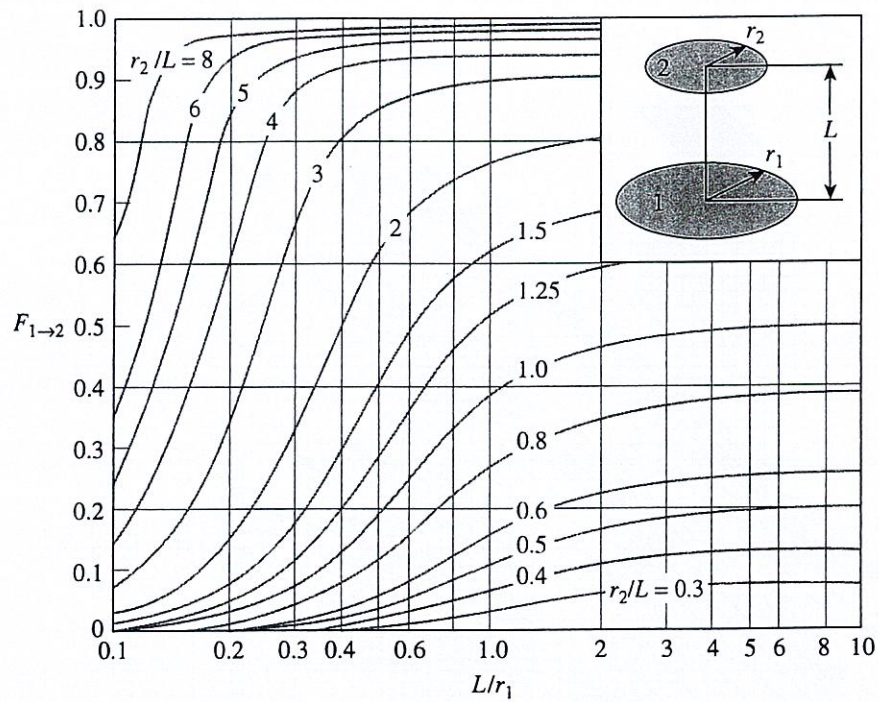
Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/Pr$. The temperatures 0.01°C, 100°C, and 374.14°C are the triple-, boiling-, and critical-point temperatures of water, respectively. The properties listed above (except the vapor density) can be used at any pressure with negligible error except at temperatures near the critical-point value.

Note 2: The unit kJ/kg·°C for specific heat is equivalent to kJ/kg·K, and the unit W/m·°C for thermal conductivity is equivalent to W/m·K.

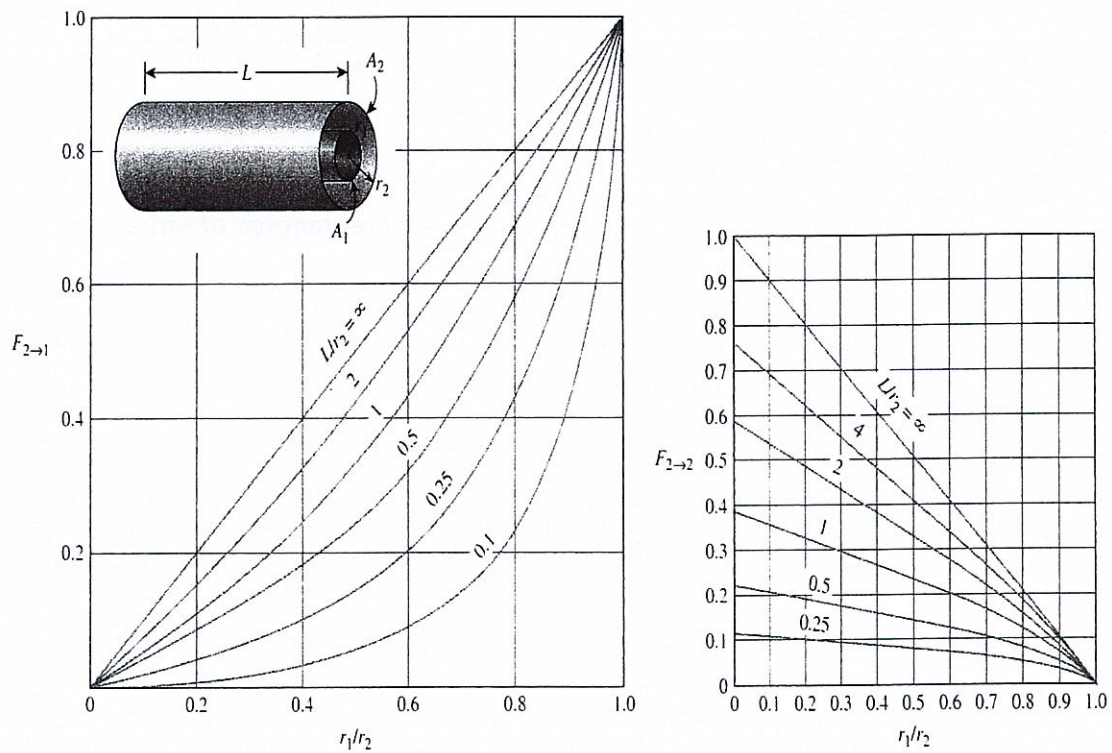
Source: Viscosity and thermal conductivity data are from J. V. Sengers and J. T. R. Watson, *Journal of Physical and Chemical Reference Data* 15 (1986), pp. 1291–1322. Other data are obtained from various sources or calculated.



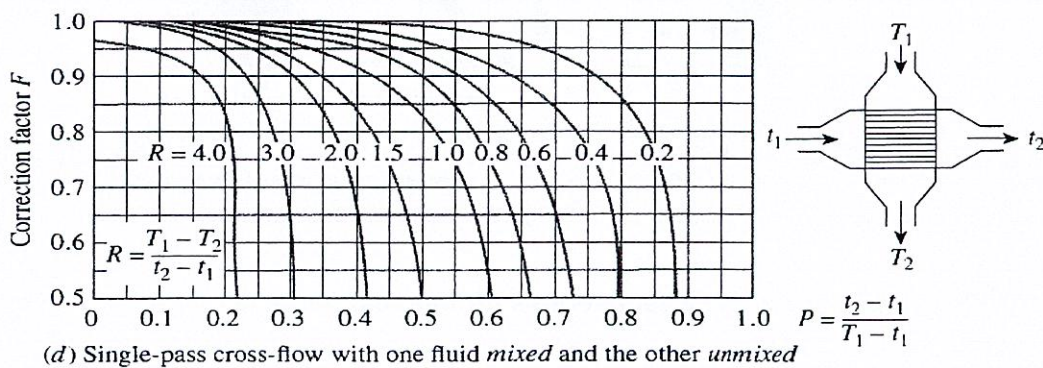
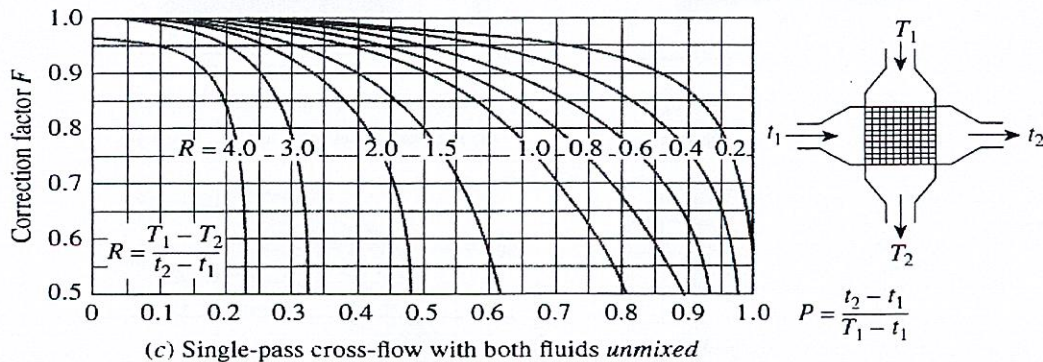
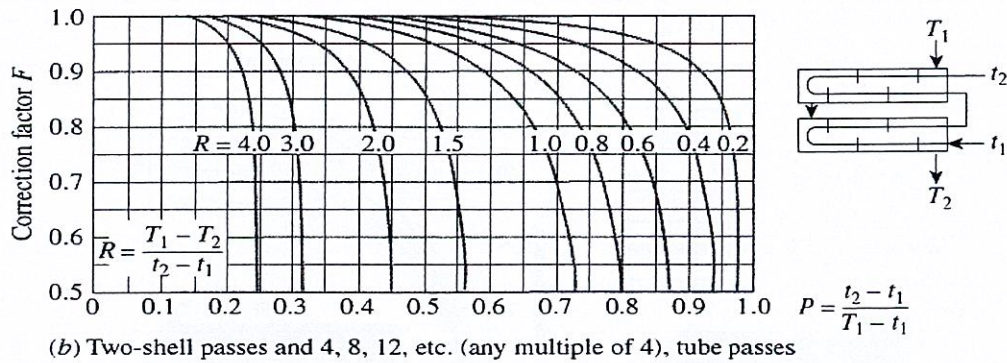
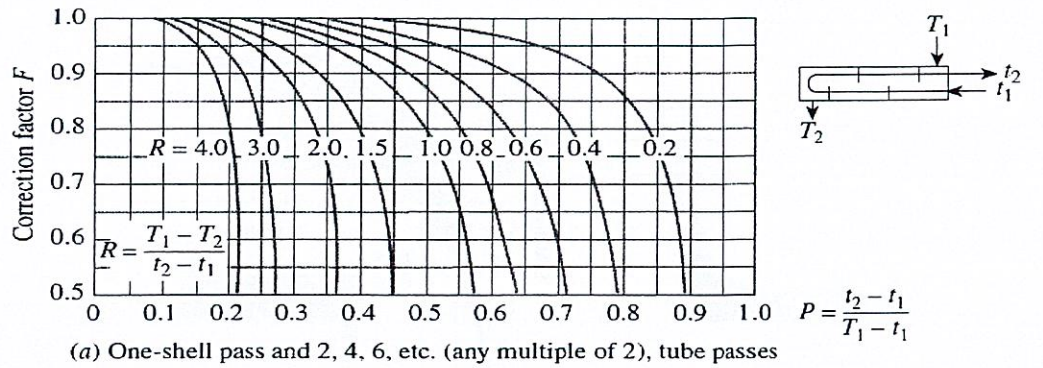
Appendix A3: View factor between two aligned parallel rectangles of equal size.



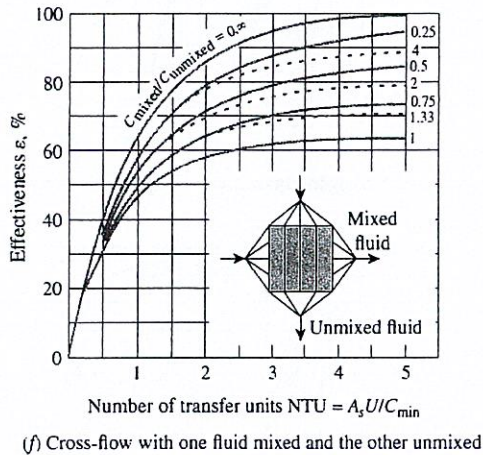
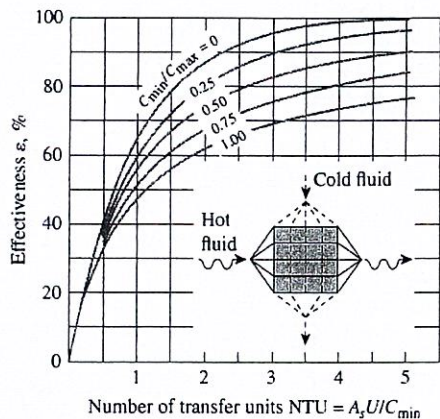
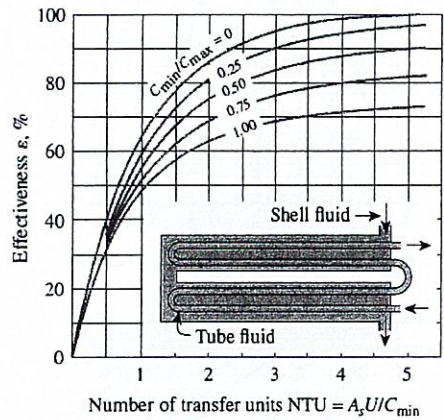
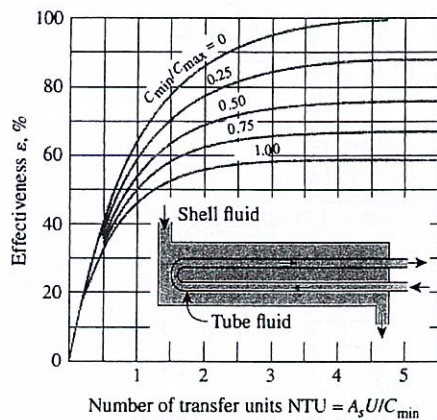
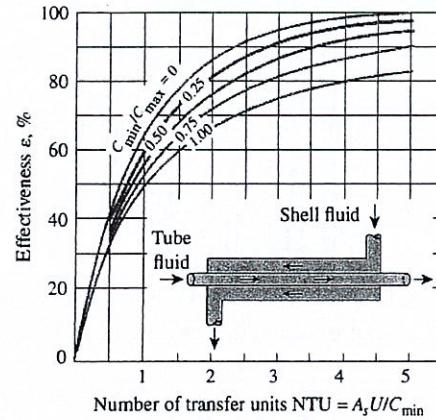
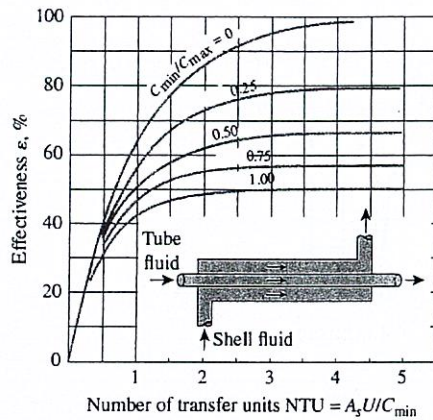
Appendix A4: View factor between two coaxial parallel disks.



Appendix A5: View factors for two concentric cylinders of finite length: (a) outer cylinder to inner cylinder; (b) outer cylinder to itself.



Appendix A6: Correction factor F charts for common shell-and-tube and cross-flow heat exchangers.



Appendix A7: Effectiveness for heat exchangers.