UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF CHEMICAL AND BIO-ENGINEERING TECHNOLOGY

FINAL EXAMINATION

OCTOBER 2025 SEMESTER

COURSE CODE	:	CLD20402
COURSE TITLE	:	TRANSPORT PROCESS
PROGRAMME NAME	:	DIPLOMA IN CHEMICAL ENGINEERING TECHNOLOGY (FOOD)
DATE	:	02 FEBRUARY 2026
TIME	:	2:00PM - 4:00PM
DURATION	:	2 HOURS

INSTRUCTIONS TO CANDIDATES

1. Please read the instructions given in the question paper CAREFULLY.
2. This question paper is printed on both sides of the paper.
3. This question paper consist of TWO sections.
4. Section A consist 25 MCQ or EMQ questions. Answer ALL questions.
5. Section B consist of four questions. Answer THREE (3) questions only.
6. Please write your answer on the answer booklet provided.
7. Please answer all questions in English only.
8. Please answer MCQ/EMQ questions using OMR sheet. ☑ *Tick if applicable*
9. Refer to the attached Formula/ Appendies ☑ *Tick if applicable*

THERE ARE 13 PAGES OF QUESTIONS INCLUDING THIS PAGE

SECTION A (Total: 25 marks)

Answer ALL questions.

Please use the objective answer sheet provided.

1. The effectiveness of heat exchanger depends on the following factors EXCEPT

   A. Weight of material

   B. Heat transfer area

   C. Flow arrangements

   D. Temperature differences

2. In a counter-flow heat exchanger, the hot and cold fluids flow _____.

   A. Randomly

   B. At right angles

   C. In the same direction

   D. In opposite directions

3. Identify a type of flow arrangement in heat exchangers.

   A. Laminar flow

   B. Parallel flow

   C. Turbulent flow

   D. Cross flow

4. Heat transfer in a heat exchanger mainly occurs by _____.

   A. Convection and conduction

   B. Conduction only

   C. Radiation and convection

   D. Radiation only

5. A heat exchanger is a device that _____.

   A. Transfers heat between two fluids without mixing

   B. Generates heat energy

   C. Converts heat to work

   D. Mix two fluids at different temperatures

6. Diffusion caused by a temperature gradient is known as _____.

   A. Molecular diffusion

   B. Thermal diffusion

   C. Forced diffusion

   D. Pressure diffusion

7. The following are the factors which directly caused diffusion EXCEPT _____.

   A. Activity gradients

   B. Pressure gradients

   C. Mass gradients

   D. Concentration gradients

8. Mass diffusion can be described by _____.

   A. Fick's Law

   B. Fourier's Law

   C. Newton's Law

   D. Boyle's Law

9. Diffusion is considered as _____.

   A. Chemical conversion

   B. Change of phase

   C. Flow of energy

   D. Flow of matter

10. Identify which statement is TRUE about diffusion

   A. It is driven by concentration gradients

   B. It occurs only in gases

   C. It stops when the temperature achieves equilibrium

   D. It requires mechanical stirring

11. Energy transfer by radiation travels at the speed of

   A. Sound

   B. Fluid flow

   C. Light

   D. Heat conduction

12. Radiation heat transfer is defined as energy transfer in the form of

   A. Electromagnetic waves

   B. Molecular collisions

   C. Sound waves

   D. Mechanical vibrations

13. LMTD stands for

    A. Local Mean Temperature Difference

    B. Log Mean Temperature Difference

    C. Large Mean Thermal Difference

    D. Linear Mean Temperature Difference

14. In a parallel flow heat exchanger,

    A. Fluids flow perpendicular to each other

    B. Fluid flow is stagnant

    C. Fluids flow in opposite direction

    D. Both fluids flow in the same direction

15. The correction factor, F, is used when

    A. Fouling is neglected

    B. Heat exchanger has multiple shell or tube passes

    C. NTU method is applied

    D. Fluids are mixed

16. The main function of baffles in a shell and tube heat exchanger is to _____.

    A. Prevent fouling

    B. Support the tubes only

    C. Reduce pressure drop

    D. Increase heat transfer by directing fluid flow

17. A black body is defined as a surface that

    A. Transmits all incident radiation

    B. Reflects all incident radiation

    C. Absorbs all incident radiation

    D. Emits no radiation

18. A black body is considered a perfect

    A. Absorber and emitter

    B. Insulator

    C. Conductor

    D. Reflector

19. The law that relates radiation heat transfer to the fourth power of absolute temperature is

    A. Fourier's Law

    B. Newton's Law of Cooling

    C. Stefan–Boltzmann Law

    D. Planck's Law

20. The value of emissivity (ε) for a perfect black body is

    A. 0

    B. 1

    C. 0.1

    D. 10

21. Emissivity (ε) is defined as the ratio of

A. Transmitted radiation to reflected radiation

B. Reflected radiation to absorbed radiation

C. Radiation emitted by a surface to that emitted by a black body at the same temperature.

D. Emitted radiation to absorbed radiation

22. Radiation heat transfer can occur

A. Only in solids

B. Only in liquids

C. In solids, liquids, and gases

D. Only in gases

23. Diffusion is defined as the movement of molecules from_____.

A. High temperature to low temperature

B. High pressure to low pressure

C. High density to low density

D. High concentration to low concentration

24. Select an example of diffusion

A. Pumping air into a tank

B. Stirring sugar in water

C. Heating water on a stove

D. Dye spreading in water

25. Fouling in a heat exchanger refers to

A. Increase in heat transfer

B. Accumulation of unwanted deposits

C. Leakage of fluid

D. Mixing of fluids

SECTION B (Total: 75 marks)

Answer THREE (3) questions only.

Please use the answer booklet provided.

Question 1

Answer all questions.

(a) A heated vertical wall 0.305 m high of an oven for baking food with the surface at 525 K is in contact with air at 275 K. Calculate the heat-transfer coefficient and the heat transfer if the width of the wall is 0.305m.

(10 marks)

(b) A thick-walled tube of stainless steel having a thermal conductivity, k = 21.63 W/m.K with dimensions of inside diameter of 0.0254 m and outside diameter of 0.0508 m, is covered with a 0.0254m thick layer of insulation (k = 0.2423 W/mK). The inside-wall temperature of the pipe is 811K and the outside surface of the insulation is at 310.8K. For a 0.305 m length of pipe,

i. Calculate the total resistance of the system.

(4 marks)

ii. Calculate the heat loss.

(4 marks)

iii. Calculate the temperature at the interface between the metal and the insulation.

(3 marks)

(c) The inner and outer surfaces of a 0.5 cm thick, 2 m x 2 m window glass in winter are 10°C and 3°C, respectively. If the thermal conductivity of the glass is 0.78 W/m.K. Determine the amount of heat loss through the glass over a period of 5 hours.

(4 marks)

Question 2

Answer all questions.

(a) Two very large concentric cylinders of diameters D_1 = 0.2 m and D_2 = 0.5m are maintained at uniform temperatures of T_1 = 950 K and T_2 = 500 K and have emissivity ε_1 = 0.3 and ε_2 = 0.7, respectively. The length of both pipes is 1.5m.

i. Determine the net rate of radiation heat transfer between two cylinders.

(4 marks)

ii. Determine the net rate of radiation heat transfer if both surfaces area blackbody.

(4 marks)

(b) A small oxidized horizontal metal tube with an outside diameter of 0.0254 m, 0.61 m long, and with a surface temperature at 588 K is in a very large furnace enclosure with firebrick walls and the surrounding air at 1088 K. The emissivity of the metal tube is 0.60 at 1088 K. Calculate the heat transfer to the tube by radiation.

(4 marks)

(c) A counter flow heat exchanger is used to heat a cold fluid from 37.8°C to 121.1°C by using a hot fluid entering at 315.6°C and leaving at 148.9°C. Calculate the log mean temperature difference (LMTD) for the heat exchanger.

(4 marks)

(d) A shell-and-tube heat exchanger with 2-shell passes and 12-tube passes is used to heat water (Cp = 4180 J/kg.°C) in the tubes from 20°C to 70°C at a rate of 4.5 kg/s. Heat is supplied by hot oil (Cp = 2300 J/kg.°C) that enters the shell side at 170°C at a rate of 10kg/s. For a tube-side overall heat transfer coefficient of 600 W/m^2.°C, determine the heat transfer surface area on the tube side.

(9 marks)

Question 3

Answer all questions.

(a) Water flows in a pipe of 0.0475 m inside diameter at a velocity of 1.5 m/s. The temperature of the water is 65°C and the wall temperature of the pipe is 35°C. Calculate the heat transfer coefficient.

(10 marks)

(b) A horizontal steel pipe with 2.5 mm diameter has an outside surface temperature of 80°C. The pipe is exposed to air at room temperature of 20°C.

i. Determine the heat transfer coefficient on the outside surface of the pipe.

(12 marks)

ii. Determine the total heat transfer from the surface of the pipe if the length is 3 m.

(3 marks)

Question 4

Answer all questions.

(a) Calculate the rate of heat transfer through a glass window with 3 m^2 surface area and 5 mm thickness if the temperature on the two sides of the glass is 14°C and 15°C, respectively and the thermal conductivity of the glass is 0.7 W/m.°C. The system is at steady state.

(4 marks)

(b) Hot water is transferred through a stainless steel pipe of 0.04 m inside diameter and 5 m length. The inside wall temperature is 90°C, the outside surface temperature is 88°C, the thermal conductivity of stainless steel is 16 W/m.°C and the wall thickness is 2 mm. Calculate the heat losses for the system at steady state.

(4 marks)

(c) The wall of an oven consists of two metal sheets with insulation in between. The temperature of the inner wall surface is 200°C and that of the outer surface is 50°C. The thickness of each metal sheet is 2 mm, the thickness of the insulation is 5 cm, and the thermal conductivity is 16 W/m.°C and 0.055 W/m.°C respectively.

i. Calculate the total resistance of the wall to heat transfer.

(4 marks)

ii. Calculate the heat transfer losses through the wall per m^2 of wall area.

(3 marks)

(d) A layer of fat 5 mm thick underneath the skin covers a part of the human body. If the temperature of the inner surface of the fat layer is 36.6°C and the body loses heat at a rate of 200 W/m^2, calculate the temperature at the surface of the skin. Assume that the thermal conductivity of fat is 0.2 W/m.°C.

(4 marks)

(e) The temperature of one side of copper block 5 cm thick is maintained at 260°C. The other side is covered with a layer of fiber glass 2.5 cm thick. The outside of the fiber glass is maintained at 38°C, and the total heat flow through the copper and fiber glass combination is 40 kW. Determine the area of the slab.

Given:

k_{copper} = 386 W/m.K

$k_{fiber\ glass}$ = 0.038 W/m.K

(6 marks)

END OF EXAMINATION PAPER

A. CONDUCTION

System	Equation
Flat slab or wall	$q = kA\frac{\Delta T}{\Delta X}$ $R_{TH} = \frac{\Delta x}{kA}$
Hollow cylinder	$q_r = 2\pi kL\ \frac{[T_1 - T_2]}{\ln\left(\frac{r_2}{r_1}\right)}$ $R_{TH} = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k L}$
Spherical	$q_r = 4\pi k\ \frac{[T_1 - T_2]}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}$ $R_{TH} = \frac{\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}{4\pi k} = \frac{r_2 - r_1}{4\pi r_2 r_1 k}$

B. CONVECTION

Free Convection	Force Convection
Vertical Plate/ Vertical Cylinder $Nu = \left\{ 0.825 + \frac{0.387\ Ra_L^{1/6}}{\left[1 + (0.492/\mathrm{Pr})^{9/16}\right]^{8/27}} \right\}^2$	**Flat Plate** **Laminar flow (Re < 5 x 10^5):** $Nu = \frac{hL}{k} = 0.664\,\mathrm{Re}^{0.5}\,\mathrm{Pr}^{1/3}$ **Turbulent flow (Re > 5 x 10^5):** $Nu = \frac{hL}{k} = 0.0366\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3}$
Horizontal Cylinder $Nu = \left\{ 0.6 + \frac{0.387\ Ra_D^{1/6}}{\left[1 + (0.559/\mathrm{Pr})^{9/16}\right]^{8/27}} \right\}^2$	**Cylinder** $Nu = \frac{hD}{k} = 0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}}{\left[1 + (0.4/\mathrm{Pr})^{2/3}\right]^{1/4}} \left[1 + (\mathrm{Re}/282000)^{5/8}\right]^{4/5}$
Sphere $Nu = 2 + \frac{0.589\ Ra_D^{1/4}}{\left[1 + (0.469/\mathrm{Pr})^{9/16}\right]^{4/9}}$	**Sphere** $Nu = \frac{hD}{k} = 2.0 + \left[0.4\,\mathrm{Re}^{1/2} + 0.06\,\mathrm{Re}^{2/3}\right]\mathrm{Pr}^{0.4} \left(\frac{\mu_\infty}{\mu_s}\right)^{1/4}$

$$Gr = \frac{L_c^3 \rho^2 g \beta \Delta T}{\mu^2}$$

$$Ra = Gr.Pr$$

$$q = hA(T_w - T_b)$$

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

$$Re = \frac{\rho v L_c}{\mu}$$

C. RADIATION

$$q = \varepsilon A \sigma T^4$$

$$q = \varepsilon A \sigma (T_1{}^4 - T_2{}^4)$$

$\sigma = 5.676 \times 10^{-8}\ W/m^2.K^4$

$$Q_{12} = \frac{A_s \sigma (T_1{}^4 - T_2{}^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$ for 2 parallel plates

$$Q_{12} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1-\varepsilon_2}{\varepsilon_2}\left(\frac{r_1}{r_2}\right)}$$ for 2 concentric cylinders

D. HEAT EXCHANGER

$$\Delta T_m = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

Parallel $\theta_2 = T_{ho} - T_{co}$ $\theta_1 = T_{hi} - T_{ci}$

Counter-flow $\theta_1 = T_{hi} - T_{co}$ $\theta_2 = T_{ho} - T_{ci}$

$$q = UA\Delta T_m$$
$$q = mC_p\Delta T$$
$$q = UFA\Delta T_m$$

E. INTERPOLATION

$$Y_{1(interpolated)} = Y_2 + \frac{(X_1 - X_2)(Y_3 - Y_2)}{(X_3 - X_2)}$$

TABLE A–15

Properties of air at 1 atm pressure

Temp. T, °C	Density ρ, kg/m^3	Specific Heat c_p, J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m^2/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m^2/s	Prandtl Number Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-5}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

TABLE A–9

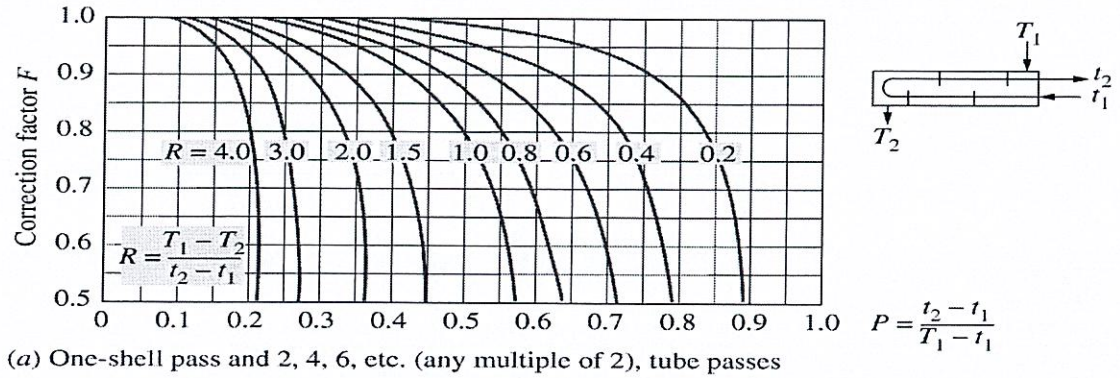
Properties of saturated water

Temp. T, °C	Saturation Pressure P_{sat}, kPa	Density ρ, kg/m³ Liquid	Density ρ, kg/m³ Vapor	Enthalpy of Vaporization h_{fg}, kJ/kg	Specific Heat c_p, J/kg·K Liquid	Specific Heat c_p, J/kg·K Vapor	Thermal Conductivity k, W/m·K Liquid	Thermal Conductivity k, W/m·K Vapor	Dynamic Viscosity μ, kg/m·s Liquid	Dynamic Viscosity μ, kg/m·s Vapor	Prandtl Number Pr Liquid	Prandtl Number Pr Vapor	Volume Expansion Coefficient β, 1/K Liquid
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	995.0	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	0.653×10^{-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}			

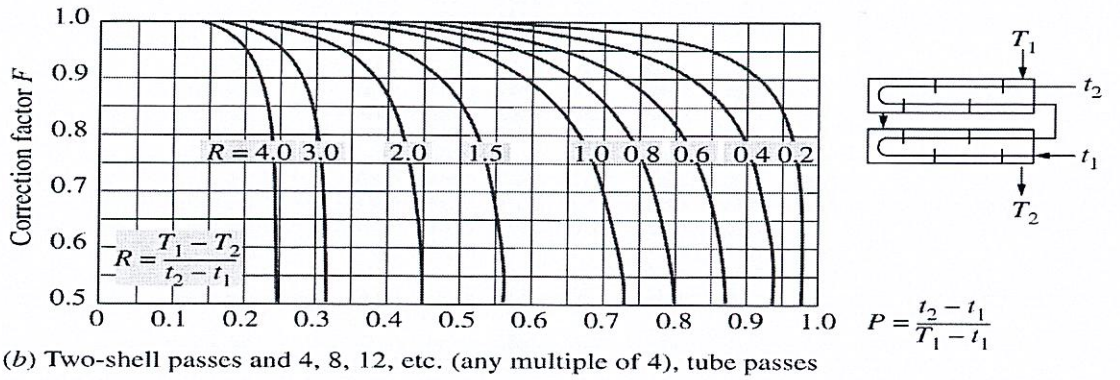
Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/\text{Pr}$. The temperatures 0.01°C, 100°C, and 374.14°C are the triple-, boiling-, and critical-point temperatures of water, respectively. The properties 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.

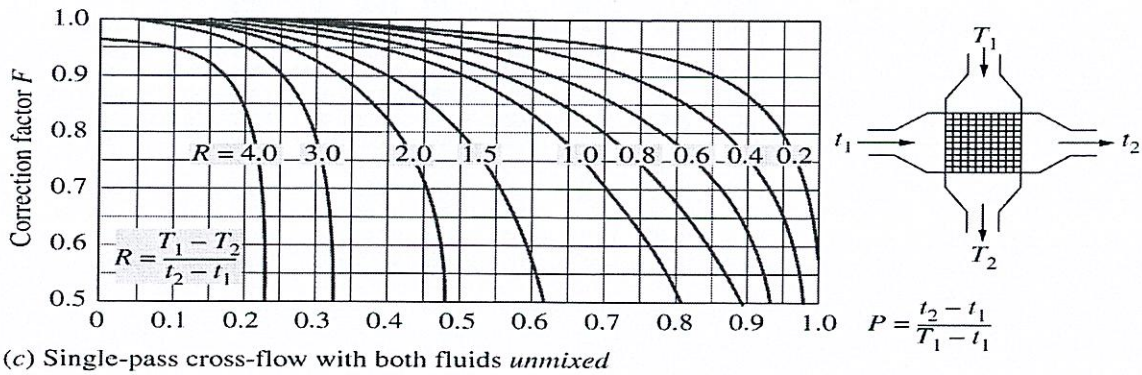
Source: Viscosity and thermal conductivity data are from J. V. Sengers and J. T. R. Watson, *Journal of Physical and Chemical Reference Data* 15 (1986), pp. 1291–1322. Other data are obtained from various sources or calculated.



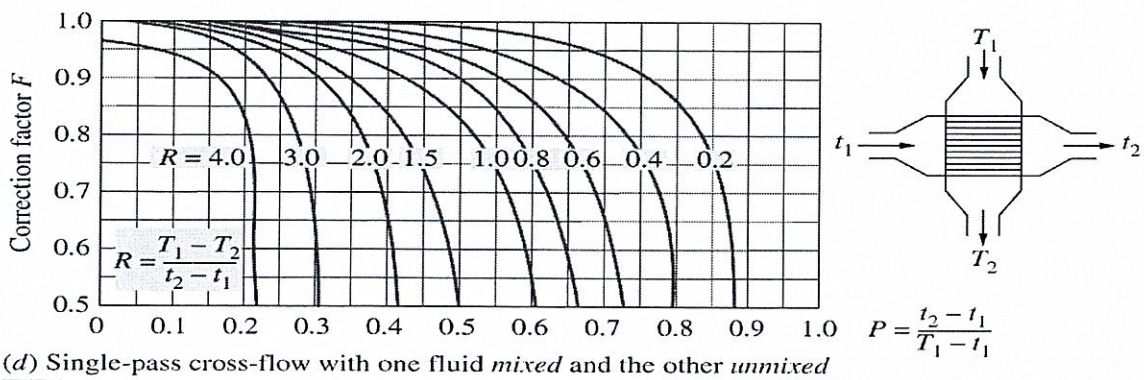
(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



(*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*