SULIT

BAHAGIAN PEPERIKSAAN DAN PENILAIAN
JABATAN PENDIDIKAN POLITEKNIK DAN KOLEJ KOMUNITI
KEMENTERIAN PENDIDIKAN MALAYSIA

JABATAN KEJURUTERAAN PETROKIMIA

PEPERIKSAAN AKHIR

SESI DISEMBER 2018

DGP3113: HEAT TRANSFER

TARIKH : 24 APRIL 2019
MASA : 11.15 PAGI – 1.15 PETANG (2 JAM)

Kertas ini mengandungi **LIMA BELAS (15)** halaman bercetak.

Struktur (4 soalan)

Dokumen sokongan yang disertakan : Formula dan Property Table

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JANGAN BUKA KERTAS SOALAN INI SEHINGGA DIARAHKAN

(CLO yang tertera hanya sebagai rujukan)

SULIT

INSTRUCTION:
This section consists of **FOUR (4)** structured questions. Answer **ALL** questions.

ARAHAN:
*Bahagian ini mengandungi **EMPAT (4)** soalan berstruktur. Jawab **SEMUA** soalan.*

QUESTION 1
SOALAN 1

CLO1
C1

a) Heat is the form of energy that can be transferred from one system to another system as a result of temperature difference.

Haba adalah satu bentuk tenaga yang boleh dipindahkan dari satu sistem ke.sistem lain akibat dari perbezaan suhu.

i) List **THREE (3)** types of heat transfer mode.
*Senaraikan **TIGA (3)** jenis mod pemindahan haba.*

[3 marks]
[3 Markah]

ii) Select **TWO (2)** types and write down its formula.
*Pilih **DUA (2)** jenis dan nyatakan formulanya.*

[2 marks]
[2 markah]

CLO1
C2

b) Consider a person standing in a breezy room at 20°C. This person exposed to surface area and the average outer surface temperature as much as 1.6 m^2 and 29°C, respectively, and the convection heat transfer coefficient is 6 W/$m^2 \cdot$ °C as shown in **Figure 1b** .

*Pertimbangkan seorang yang berdiri di dalam bilik yang berangin pada suhu 20 ° C. Orang ini terdedah kepada kawasan permukaan yang dan suhu rata permukaan luar sebanyak 1.6 m^2 dan 29 ° C, dan pekali pemindahan haba konveksi ialah 6 W / m^2 ° C seperti yang ditunjukkan dalam **Rajah 1b**.*

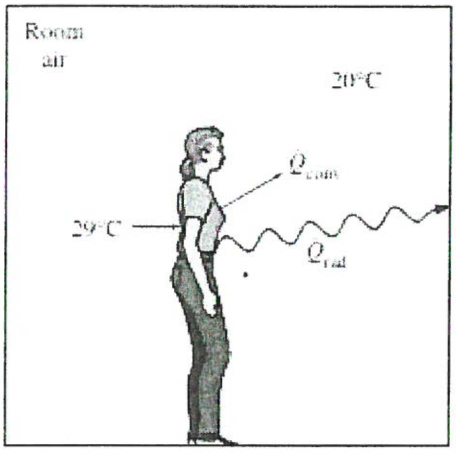

Figure 1b / *Rajah 1b*

i) Calculate the heat transfer rate for convection.
Kirakan kadar pemindahan haba bagi konduksi.

[3 marks]
[3 markah]

ii) Calculate the heat transfer rate for radiation.
Kirakan kadar pemindahan haba bagi sinaran.

[3 marks]
[3 markah]

iii) Determine the total rate of heat transfer from this person.
Tentukan jumlah pemindahan haba dari orang ini.

[2 marks]
[2 markah]

CLO2
C3

c) Consider a 0.8-m-high and 1.5-m-wide glass window with a thickness of 8 mm and a thermal conductivity of k = 0.78 W/m · °C as shown in **Figure 1c**. The room is maintained at 20°C while the temperature of the outdoors is -10°C. Take the heat transfer coefficients on the inner and outer surfaces of the window to be $h_1 = 10$ W/m^2 · °C and $h_2 = 40$ W/m^2 · °C.

Pertimbangkan jendela kaca mempunyai ketinggian 0.8-m dan kelebaran 1.5-m serta ketebalan 8 mm dan kekonduksian terma, k = 0.78 W / m. °C seperti yang ditunjukkan dalam ***Rajah 1c****. Bilik ini dikekalkan pada suhu 20°C manakala suhu di luar adalah -10°C. Ambil pekali pemindahan haba pada permukaan dalam dan luar jendela menjadi $h_1 = 10$ W/m^2·°C dan $h_2 = 40$ W/m^2·°C.*

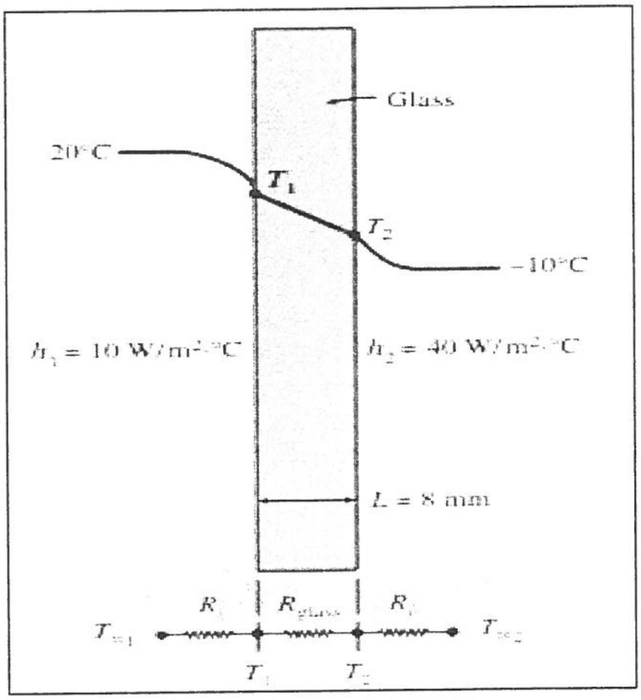

Figure 1c / *Rajah 1c*

i) Calculate the total resistance.

Hitung jumlah rintangan.

[10 marks]
[10 markah]

ii) Determine the steady rate of heat transfer through this glass window.

Tentukan kadar pemindahan haba melalui jendela kaca ini

[2 marks]
[2 markah]

QUESTION 2
SOALAN 2

CLO1 C2

a) Recognize the Velocity boundary layer with a proper diagram.
Kenalpasti lapisan sempadan halaju dengan bantuan gambarajah.

[5 marks]
[5 markah]

CLO2 C3

b) Mercury at 25°C flows over a 3-m-long and 2-m-wide flat plate maintained at 75°C with a velocity 0.8 m/s.

Mercuri pada 25°C mengalir di atas plat rata 3-m-panjang dan 2-m-lebar yang dikekalkan pada suhu 75°C dengan kelajuan 0.8m/s.

i) Calculate the heat transfer coefficient.
Kirakan pekali pemindahan haba.

[7 marks]
[7 markah]

ii) Calculate the rate of heat transfer from the entire plate.
Kirakan kadar pemindahan haba dari keseluruhan plat.

[3 marks]
[3 markah]

CLO2 C4

c) A long 10-cm- diameter steam pipe whose external surface temperature is 110°C passes through some open area that is not protected against the winds as shown in **Figure 3c**. Determine the rate of heat loss from the pipe per unit of its length when the air is at 1 atm pressure and 10° C and the wind is blowing across the pipe at a velocity of 8 m/s.

*Paip stim berdiameter 10 cm panjang dengan suhu permukaan luarannya 110°C melalui beberapa kawasan terbuka yang tidak dilindungi terhadap angin seperti yang ditunjukkan dalam **Rajah 3c**. Tentukan kadar kehilangan haba dari paip per unit panjang apabila udara berada pada tekanan 1 atm dan 10°C dan angin bertiup merentasi paip pada halaju 8 m / s.*

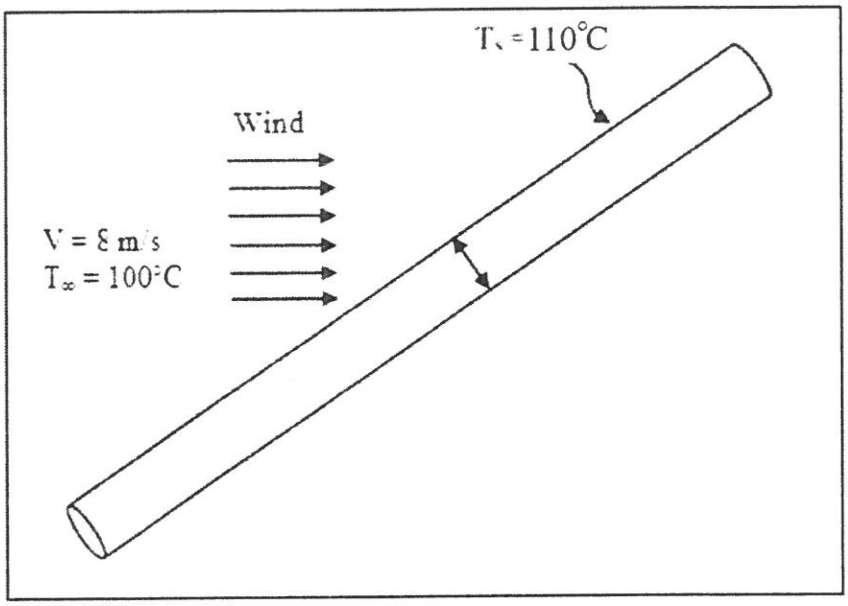

Figure 3c / *Rajah 3c*

[10 marks]
[10 markah]

QUESTION 3
SOALAN 3

CLO1 C2

a) Radiation is one of the mode in heat transfer.
Radiasi adalah salah satu mod pemindahan haba.

i) Explain the definition for radiation.
Terangkan definasi bagi radiasi.

[2 marks]
[2 markah]

ii) Identify **FIVE (5)** examples of radiation process application in daily life or industry.
*Kenalpasti **LIMA (5)** contoh aplikasi proses radiasi dalam kehidupan seharian atau industri.*

[5 marks]
[5 markah]

CLO2
C3

b) Everything around us constantly emits radiation, and the emissivity represents the emission characteristics of those bodies. Emissivity can divide into three components.

Segala di sekeliling kita sentiasa memancarkan sinaran, dan kadar pelepasannya mewakili ciri-ciri pelepasan bahan tersebut. Pelepasan boleh dibahagikan kepada tiga komponen.

i) Generalize the **THREE (3)** components with simple explanation.
Kenal pasti **TIGA (3)** *komponen tersebut dengan penjelasan ringkas.*

[6 marks]
[6 markah]

ii) Sketch a simple diagram that connects these three components.
Lakarkan gambarajah mudah yang menghubungkan ketiga-tiga komponen ini.

[2 marks]
[2 markah]

CLO2
C4

c) The spectral emissivity of an opaque surface at 1200K is approximated as:
Kadar pelepasan spektrum permukaan lega pada 1200K dianggarkan sebagai:

$$\varepsilon_1 = 0, \quad \lambda < 2\mu m$$
$$\varepsilon_2 = 0.85\,, \quad 2 \leq \lambda \leq 6\mu m$$
$$\varepsilon_3 = 0, \quad \lambda > 6\mu m$$

Determine :
Tentukan :

i) the total emissivity of the surface and
jumlah kadar pelepasan oleh permukaan

[7 marks]
[7 markah]

ii) the emissive flux from the surface, in W/m^2
kadar pelepasan fluks dari permukaan, dalam W/m^2

[3 marks]
[3 markah]

QUESTION 4
SOALAN 4

CLO1
C2

a) Heat exchangers are classified according to flow arrangement and type of construction.
Penukar haba diklasifikasikan mengikut susunan aliran dan jenis pembinaan.

i) Identify **THREE (3)** types of heat exchanger.
*Kenalpasti **TIGA (3)** jenis penukar haba.*

[3 marks]
[3 markah]

ii) Identify **TWO (2)** types of flow arrangement of cross flow in compact heat exchanger.
*Kenalpasti **DUA (2)** jenis susunan aliran di dalam aliran silang penukar haba padat.*

[2 marks]
[2 markah]

CLO2
C3

b) Water at an average temperature of 107°C and an average velocity of 3.5 m/s flows through a 5-m-long stainless steel tube (k = 14.2 W/m · °C) in a boiler. The inner and outer diameters of the tube are D_0 = 1.0 cm and D_1 = 1.4 cm, respectively. If the convection heat transfer coefficient at the outer surface of the tube where boiling is taking place is h_0 = 8400 W/m^2 · °C. Given $Nu = \frac{hD_h}{k} = 0.023\, Re^{0.8} Pr^{0.4}$ determine:

Air pada suhu purata 107 ° C dan halaju purata 3.5 m / s mengalir melalui tiub keluli tahan karat 5 m (k = 14.2 W / m . ° C) dalam dandang. Diameter dalam dan luar tiub adalah D_0 = 1.0 cm dan D_1 = 1.4 cm, masing-masing. Jika pekali pemindahan haba konveksi pada permukaan luar tiub di mana mendidih sedang berlaku ialah h_0 = 8400 W/m^2 · °C. Diberi $Nu = \frac{hD_h}{k} = 0.023\, Re^{0.8} Pr^{0.4}$ tentukan :

i) the thermal resistance.

kirakan rintangan haba.

[8 marks]
[8 markah]

ii) the overall heat transfer coefficient U_i of this boiler based on the inner surface area of the tube.

pekali pemindahan haba keseluruhan U_i dandang ini berdasarkan kawasan permukaan dalam tiub.

[2 marks]
[2 markah]

CLO2
C4

c) A long thin-walled double-pipe heat exchanger with tube and shell diameters of 1.0 cm and 2.5 cm, respectively, is used to condense refrigerant 134a by water at 20°C. The refrigerant flows through the tube, with a convection heat transfer coefficient of h_1 = 5000 W/m^2 · °C. Water flows through the shell at a rate of 0.3 kg/s, determine the overall heat transfer coefficient of this heat exchanger.

Penukar haba paip berganda yang panjang serta berdinding nipis dengan tiub dan diameter shell masing-masing 1.0 cm dan 2.5 cm digunakan untuk menyejukkan penyejuk 134a dengan air pada 20 °C. Penyejuk mengalir melalui tiub, dengan pekali pemindahan haba konveksi h_1 = 5000 W/m^2 · °C. Air mengalir melalui shell pada kadar 0.3 kg / s. Tentukan pekali pemindahan haba secara keseluruhan bagi penukar haba ini.

[10 marks]
[10 markah]

SOALAN TAMAT

Formula list / *Senarai formula*

CONDUCTION

The elementary thermal resistance relations:

Conduction resistance (plane wall): $R_{wall} = \frac{L}{kA}$

Conduction resistance (cylinder): $R_{cyl} = \frac{\ln(r_2/r_1)}{2\pi Lk}$

Conduction resistance (sphere): $R_{sph} = \frac{r_2 - r_1}{4\pi r_1 r_2 k}$

Convection resistance: $R_{conv} = \frac{1}{hA}$

CONVECTION

The average friction coefficient relations for flow over a flat plate:

Laminar: $C_f = \frac{1.328}{Re_L^{1/2}}$ $\quad Re_L < 5 \times 10^5$

Turbulent: $C_f = \frac{0.074}{Re_L^{1/5}}$ $\quad 5 \times 10^5 \le Re_L \le 10^7$

Combined: $C_f = \frac{0.074}{Re_L^{1/5}} - \frac{1742}{Re_L}$ $\quad 5 \times 10^5 \le Re_L \le 10^7$

Rough surface, turbulent: $C_f = \left(1.89 - 1.62 \log \frac{\varepsilon}{L}\right)^{-2.5}$

The average Nusselt number relations for flow over a flat plate:

Laminar: $Nu = \frac{hL}{k} = 0.664\, Re_L^{0.5}\, Pr^{1/3}$ $\quad Re_L < 5 \times 10^5$

Turbulent:

$$Nu = \frac{hL}{k} = 0.037\, Re_L^{0.8}\, Pr^{1/3} \qquad \begin{array}{l} 0.6 \le Pr \le 60 \\ 5 \times 10^5 \le Re_L \le 10^7 \end{array}$$

Combined:

$$Nu = \frac{hL}{k} = (0.037\, Re_L^{0.8} - 871)\, Pr^{1/3}, \qquad \begin{array}{l} 0.6 \le Pr \le 60 \\ 5 \times 10^5 \le Re_L \le 10^7 \end{array}$$

The average Nusselt number for cross flow over a cylinder and sphere:

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

which is valid for Re Pr > 0.2, and

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

which is valid for $3.5 \leq Re \leq 80{,}000$ and $0.7 \leq Pr \leq 380$

<u>RADIATION</u>

Stefan–Boltzmann law: $E_b(T) = \sigma T^4$; $\sigma = 5.670 \times 10^{-8}$ W/m²·K⁴

Spectral blackbody emmisive power;

$$E_{b\lambda}(\lambda, T) = \frac{C_1}{\lambda^5[\exp(C_2/\lambda T) - 1]} \qquad (W/m^2 \cdot \mu m)$$

where

$$C_1 = 2\pi h c_0^2 = 3.742 \times 10^8\ W \cdot \mu m^4/m^2$$
$$C_2 = hc_0/k = 1.439 \times 10^4\ \mu m \cdot K$$

Wien's displacement law:

$$(\lambda T)_{max\ power} = 2897.8\ \mu m \cdot K$$

<u>HEAT EXCHANGER</u>

Overall heat transfer coefficient U or a total thermal resistance R, expressed as:

$$\frac{1}{UA_s} = \frac{1}{U_iA_i} = \frac{1}{U_oA_o} = R = \frac{1}{h_iA_i} + R_{wall} + \frac{1}{h_oA_o}$$

The effects of fouling on both the inner and the outer surfaces of the tubes of a heat exchanger can be accounted for by:

$$\frac{1}{UA_s} = \frac{1}{U_iA_i} = \frac{1}{U_oA_o} = R$$
$$= \frac{1}{h_iA_i} + \frac{R_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{R_{f,o}}{A_o} + \frac{1}{h_oA_o}$$

LMTD method, the rate of heat transfer

$$\dot{Q} = UA_s\,\Delta T_{lm}$$

where

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$$

TABLE 11–2

Blackbody radiation functions f_λ

λT, $\mu m \cdot K$	f_λ	λT, $\mu m \cdot K$	f_λ
200	0.000000	6200	0.754140
400	0.000000	6400	0.769234
600	0.000000	6600	0.783199
800	0.000016	6800	0.796129
1000	0.000321	7000	0.808109
1200	0.002134	7200	0.819217
1400	0.007790	7400	0.829527
1600	0.019718	7600	0.839102
1800	0.039341	7800	0.848005
2000	0.066728	8000	0.856288
2200	0.100888	8500	0.874608
2400	0.140256	9000	0.890029
2600	0.183120	9500	0.903085
2800	0.227897	10,000	0.914199
3000	0.273232	10,500	0.923710
3200	0.318102	11,000	0.931890
3400	0.361735	11,500	0.939959
3600	0.403607	12,000	0.945098
3800	0.443382	13,000	0.955139
4000	0.480877	14,000	0.962898
4200	0.516014	15,000	0.969981
4400	0.548796	16,000	0.973814
4600	0.579280	18,000	0.980860
4800	0.607559	20,000	0.985602
5000	0.633747	25,000	0.992215
5200	0.658970	30,000	0.995340
5400	0.680360	40,000	0.997967
5600	0.701046	50,000	0.998953
5800	0.720158	75,000	0.999713
6000	0.737818	100,000	0.999905

TABLE A-2

Boiling and freezing point properties

Substance	Boiling Data at 1 atm: Normal Boiling Point, °C	Latent Heat of Vaporization h_{fg}, kJ/kg	Freezing Data: Freezing Point, °C	Latent Heat of Fusion h_{if}, kJ/kg	Liquid Properties: Temperature, °C	Density ρ, kg/m³	Specific Heat c_p, kJ/kg·K
Ammonia	−33.3	1357	−77.7	322.4	−33.3	682	4.43
					−20	665	4.52
					0	639	4.60
					25	602	4.80
Argon	−185.9	161.6	−189.3	28	−185.6	1394	1.14
Benzene	80.2	394	5.5	126	20	879	1.72
Brine (20% sodium chloride by mass)	103.9	—	−17.4	—	20	1150	3.11
n-Butane	−0.5	385.2	−138.5	80.3	−0.5	601	2.31
Carbon dioxide	−78.4*	230.5 (at 0°C)	−56.6		0	298	0.59
Ethanol	78.2	838.3	−114.2	109	25	783	2.46
Ethyl alcohol	78.6	855	−156	108	20	789	2.84
Ethylene glycol	198.1	800.1	−10.8	181.1	20	1109	2.84
Glycerine	179.9	974	18.9	200.6	20	1261	2.32
Helium	−268.9	22.8	—	—	−268.9	146.2	22.8
Hydrogen	−252.8	445.7	−259.2	59.5	−252.8	70.7	10.0
Isobutane	−11.7	367.1	−160	105.7	−11.7	593.8	2.28
Kerosene	204–293	251	−24.9	—	20	820	2.00
Mercury	356.7	294.7	−38.9	11.4	25	13,560	0.139
Methane	−161.5	510.4	−182.2	58.4	−161.5	423	3.49
					−100	301	5.79
Methanol	64.5	1100	−97.7	99.2	25	787	2.55
Nitrogen	−195.8	198.6	−210	25.3	−195.8	809	2.06
					−160	596	2.97
Octane	124.8	306.3	−57.5	180.7	20	703	2.10
Oil (light)					25	910	1.80
Oxygen	−183	212.7	−218.8	13.7	−183	1141	1.71
Petroleum	—	230–384			20	640	2.0
Propane	−42.1	427.8	−187.7	80.0	−42.1	581	2.25
					0	529	2.53
					50	449	3.13
Refrigerant-134a	−26.1	216.8	−96.6	—	−50	1443	1.23
					−26.1	1374	1.27
					0	1295	1.34
					25	1207	1.43
Water	100	2257	0.0	333.7	0	1000	4.22
					25	997	4.18
					50	988	4.18
					75	975	4.19
					100	958	4.22

* Sublimation temperature. (At pressures below the triple-point pressure of 518 kPa, carbon dioxide exists as a solid or gas. Also, the freezing-point temperature of carbon dioxide is the triple-point temperature of −56.5°C.)

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^{-4}
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	0.653×10^{-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 $\alpha = k/\rho c_p = \nu/Pr$. 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 1

TABLE A-15

Properties of air at 1 atm pressure

Temp T, °C	Density ρ, kg/m³	Specific Heat c_p, J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m²/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m²/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}	1.123×10^{-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	1254	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties c_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 1984; and Thermophysical Properties of Matter, Vol. 3: Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena; Vol. 11: Viscosity, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenum, NY, 1970, ISBN 0-306067020-8.