UNIVERSITI TUN HUSSEIN ONN MALAYSIA

PEPERIKSAAN AKHIR
SEMESTER II
SESI 2008/2009

NAMA MATAPELAJARAN : MEKANIK BENDALIR II

KOD MATAPELAJARAN : BDA3023

KURSUS : BDD/BDI

TARIKH PEPERIKSAAN : APRIL/MEI 2009

JANGKAMASA : 3 JAM

ARAHAN

1. JAWAB **EMPAT (4)** SOALAN SAHAJA DARIPADA ENAM (6) SOALAN
2. SIMBOL YANG DIGUNAKAN MEMPUNYAI TAKRIFAN YANG LAZIM KECUALI JIKA DINYATAKAN SEBALIKNYA
3. NYATAKAN ANDAIAN YANG DIBUAT BAGI SETIAP SOALAN

KERTAS SOALAN INI MENGANDUNGI DUA PULUH SATU (21) MUKA SURAT

S1 a) Terangkan secara ringkas beserta lakaran, bagaimana terjadinya pembentukan profil halaju setempat dan tegasan ricih bagi aliran laminar di dalam paip bulat.

(5 markah)

b) Profil halaju bagi satu aliran laminar di dalam paip bulat dinyatakan dalam sebutan halaju setempat u (r) sebagai:

$$u(r) = -\frac{1}{4\mu}\left(\frac{\partial p}{\partial x}\right)\left(R^2 - r^2\right)$$

dengan :

R	=	jejari keseluruhan paip
μ	=	kelikatan dinamik bendalir
$\left(\frac{\partial p}{\partial x}\right)$	=	kecerunan tekanan dalam arah aliran
r	=	jejari setempat

Dari profil halaju ini:

(i) Nyatakan tiga (3) anggapan yang penting dibuat untuk persamaan di atas; dan

(ii) Dapatkan pernyataan untuk halaju titik tengah, V_c atau halaju maksima, u_{mak} dalam sebutan halaju purata, V.

(10 markah)

c) Air mengalir dalam sebatang paip dengan diameter 50 mm. Kirakan kejatuhan tekanan per unit panjang, ($\Delta p / L$) dan tegasan ricih maksimum, τ_{max}, jika julat No Reynold untuk aliran lamina, $0 < Re \leq 2000$.

Anggapkan kelikatan dinamik air, $\mu = 1 \times 10^{-3}$ Pa.s dan ketumpatan air, $\rho = 1000$ kg/m^3.

(10 markah)

S2 a) Nyatakan kesan kekasaran permukaan terhadap kejatuhan tekanan bagi aliran gelora dalam paip. Berikan pendapat anda sekiranya aliran adalah laminar?

(5 Markah)

b) Sebatang paip air mendatar berdiameter 5 cm membesar sekata ke 10 cm sebagaimana ditunjukkan dalam **Rajah S2(b).** Sudut pembesaran adalah 35° dari paksi mendatar. Halaju purata dan tekanan sebelum pembesaran masing-masing adalah 8 m/s and 160 kPa. Tentukan kehilangan turus dalam seksyen pembesaran dan tekanan dalam paip besar.

Diberi: $\alpha_1 = \alpha_2 = 1.06$, $\rho_{air} = 1000$ kg/m^3 dan pekali kehilangan, K_L untuk paip membesar pada $\theta = 70$ adalah 0.075

(12 Markah)

c) Air pada 10°C mengalir dari takungan besar ke takungan kecil melalui sebatang paip besi tuangan berdiameter 10 cm sebagaimana ditunjukkan dalam **Rajah S2(c).** Tentukan paras Z_1 untuk kadar alir 15 l/s.

(8 Markah)

S3 a) Terangkan secara ringkas tiga (3) perbezaan utama antara medan aliran dalam bentuk rangkap arus dan rangkap upaya.

(6 markah)

b) Nyatakan ciri-ciri aliran bendalir yang diwakili oleh persamaan-persamaan berikut:

(i) $\vec{V} = 3(x^2 - y^2)\hat{i} - 6xy\hat{j}$

(ii) $\psi = -2x^2 + y$

(iii) Aliran vortek bebas

(contoh: mantap atau tak-mantap, 1-D, 2-D atau 3-D, aliran mampat atau tak-mampat, aliran berputar atau tak-berputar, aliran likat atau tak-likat dan sebagainya)

(9 markah)

c) Satu medan aliran diwakili oleh rangkap upaya $\phi = 2x^2 y - \left(\frac{2}{3}\right) y^3$. Untuk medan aliran ini:

(i) tentukan komponen-komponen halaju u dan v;

(ii) nyatakan ciri-ciri aliran ini dengan melalui pembuktian persamaan Laplace;

(iii) dapatkan pernyataan untuk rangkap arus, dan

(iv) lakarkan bentuk aliran ini dengan menunjukkan garis-garis arus atau upaya.

(10 markah)

S4 **a)** Terangkan secara ringkas dua (2) perbezaan ciri-ciri utama di antara lapisan sempadan laminar dengan lapisan sempadan gelora.

(5 markah)

b) Nyatakan dua (2) jenis daya hela (daya seret) utama. Terangkan pembentukannya pada sesuatu objek seperti kereta yang sedang bergerak di jalanraya.

(5 markah)

c) Satu ujikaji dibuat untuk mengkaji pembentukan lapisan sempadan di atas sekeping plat rata yang mewakili sayap kapalterbang. Plat tersebut yang mempunyai panjang 1.2 m dan lebar 3 m diletakkan secara melintang terhadap aliran di tengah-tengah ruang ujian. Kelajuan udara di dalam ruang ujian terowong angin adalah seragam pada 10 m/s. Tentukan:

(i) ketebalan lapisan sempadan di hujung plat;

(ii) daya seret; dan

(iii) daya seret jika kelajuan udara ditingkatkan kepada 40 m/s.

Diberi ketumpatan dan kelikatan dinamik udara masing-masing sebagai $\rho = 1.23$ kg/m^3 dan $\mu = 1.80 \times 10^{-5}$ Ns/m^2.

(15 markah)

S5 a) Tentukan suhu, tekanan dan ketumpatan genangan bagi aliran udara 'di hujung hadapan' sebuah kapal terbang yang bergerak dengan kelajuan 250 m/s pada altitud 2500m. Andaikan aliran isentropik mantap.

(10 Markah)

b) Berapakah ratio tekanan statik kepada tekanan genangan akibat pergerakan berikut didalam udara piawai (satndard):

i) Seorang pelari pecut berlari pada kadar 15 batu per jam.

ii) Seorang penunggang motorsikal bergerak pada kelajuan 40 batu per jam.

iii) Sebuah kereta bergerak pada kadar 100 batu sejam

iv) Sebuah kapalterbang sedang bergerak dengan kadar 600 batu per jam

Sila buat kesimpulan setelah menilai (i), (ii), (iii) dan (iv).

(15 Markah)

S6 a) Gambarkan bentuk umum graf kapasiti melawan tekanan hantaran untuk pam putar anjakan positif dan pam empar anjakan tak positif.

(5 Markah)

b) Sebuah pam empar dengan diameter 0.6 m beroperasi pada 1400 rpm. Air masuk selari dengan aci utama pam. Sudut bilah keluar, β_2 ad alah 25^0 seb agaimana ditunjukkan dalam rajah 4(b). Tentukan kuasa aci yang diperlukan untuk memusing bilah bila aliran melalui pam adalah 0.25 m^3/s. Ketinggian bilah adalah seragam iaitu 50 mm.

(20 Markah)

ENGLISH TRANSLATION

S1 a) Explain briefly with sketch, the development of local velocity profile and shear stress for laminar flow in a circular pipe.

(5 marks)

b) The velocity profile for a laminar flow in a circular pipe is given in terms of local velocity u_r as:

$$u(r) = -\frac{1}{4\mu}\left(\frac{\partial p}{\partial x}\right)\left(R^2 - r^2\right)$$

where :

R	=	overall radius
μ	=	dynamic viscosity
$\left(\frac{\partial p}{\partial x}\right)$	=	pressure gradient
r	=	local radius

From this velocity profile :

(i) state three (3) important point to obtain that equation; and

(ii) obtain an expression for centerline velocity or maximum velocity in terms of average velocity.

(10 marks)

c) The flow of water in a 50- mm diameter pipe. Determine the pressure drop per unit length, and maximum shear stress, if the range of Reynolds number for laminar flow, $0<Re<2000$.

Given: $\mu_{water} = 1 \times 10^{-3}$ Pa.s and $\rho_{water} = 1000$ kg/m^3.

(10 marks)

S2 a) How does surface roughness affect the pressure drop in a pipe if the flow is turbulent? What you opinion if the flow were laminar?

(5 Marks)

b) A 6 cm diameter horizontal water pipe expands gradually to a 10 cm diameter pipe as shown in **fig. rajah S2(b).** The wall of the expansion section are angled 35^o from the horizontal. The average velocity and pressure of water before the expansion section are 8 m/s and 160 kPa respectively. Determine the head loss in the expansion section and the pressure in the larger-diameter pipe.
Given: $\alpha_1 = \alpha_2 = 1.06$, $\rho_{water} = 1000$ kg/m^3, Loss Coefficient for pipe gradually expand if $\theta = 70$, $K_L = 0.075$.

(12 Marks)

c) Water at 10°C flows from a large reservoir to a smaller one through a 10 cm diameter cast iron piping system, as shown in **fig. rajah S2©.** Determine the elevation Z_1 for a flow rate of 15 L/s.

(8 Marks)

S3 a) Explain three (3) main differences between stream function and potential function in the flow field.

(6 marks)

b) State the characteristics of the flow which are represented by the following equations

(i) $\vec{V} = 3(x^2 - y^2)\hat{i} - 6xy\hat{j}$

(ii) $\psi = -2x^2 + y$

(iii) Free vortex

(eg. Steady or unsteady, 1-D, 2-D or 3-D, compressible or incompressible, rotational or irrotational, viscous or inviscid etc.):

(9 marks)

c) A flow field is given by the following velocity potential $\phi = 2x^2y - \left(\frac{2}{3}\right)y^3$. For this flow field:

(i) determine the velocity components u and v ;

(ii) state the flow characteristics through the Laplace equation;

(iii) obtain an expression for the stream function; and

(iv) sketch the flow showing streamlines or potential lines.

(10 marks)

S4 a) Explain two (2) main difference characterstics between laminar boundary layer and turbulent boundary layer.

(5 marks)

b) State two (2) types of drag force. Explain the development of this force when a car is moving on the road.

(5 marks)

c) The test on the flat plate is assumed on the wing of the aircraft. This flat plate is 1.2 m long and 3 m wide in the wind tunnel test section. The wind speed in the wind tunnel is 10 m/s. Determine ;

(i) the boundary layer thickness at the trailing edge;

(ii) the drag force ; and

(iii) the drag force if the wind speed is increased to 40 m/s

Given: $\mu_{air} = 1.80 \times 10^{-5}$ Pa.s and $\rho_{air} = 1.23$ kg/m^3.

(15 marks)

S5 a) Find the stagnation temperature, pressure and density of air at the nose of an airplane travelling at speed of 250 m/s and at altitude of 2500m. Assume steady isentropic flow.

(10 Marks)

b) What is the static pressure to stagnation pressure ratio associated with the following motion in standard air:

i) a runner moving at the rate of 15 mph

ii) a cyclist moving at the rate of 40 mph

iii) a car moving at the rate of 100 mph

iv) an airplane moving at the rate of 600 mph

Please make a conclusion after evaluate (i), (ii), (iii) dan (iv).

(15 Marks)

S6 a) Describe the general shape of the plot of capacity versus discharge pressure for a positive displacement rotary pump and non positive displacement pump.

(5 Marks)

b) A centrifugal water pump having an impeller diameter of 0.6 m operates at 1400 rpm. The water enters the pump parallel to the pump shaft. If the exit blade angle, β_2 is 25^0 as shown in fig 4(b). Determine the shaft power required to turn the impeller when the flow through the pump is 0.25 m^3/s. The uniform blade height is 50 mm.

(20 Marks)

Lampiran 1

PEPERIKSAAN AKHIR
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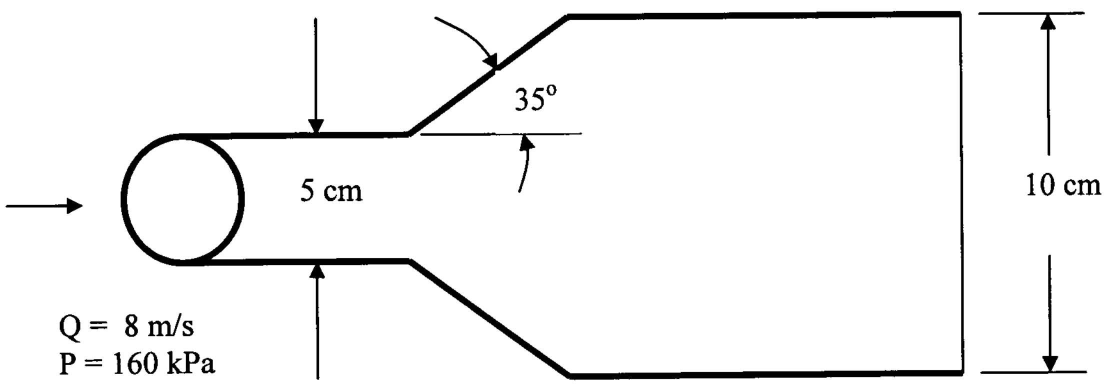

Rajah S2(b)

Lampiran 2

PEPERIKSAAN AKHIR

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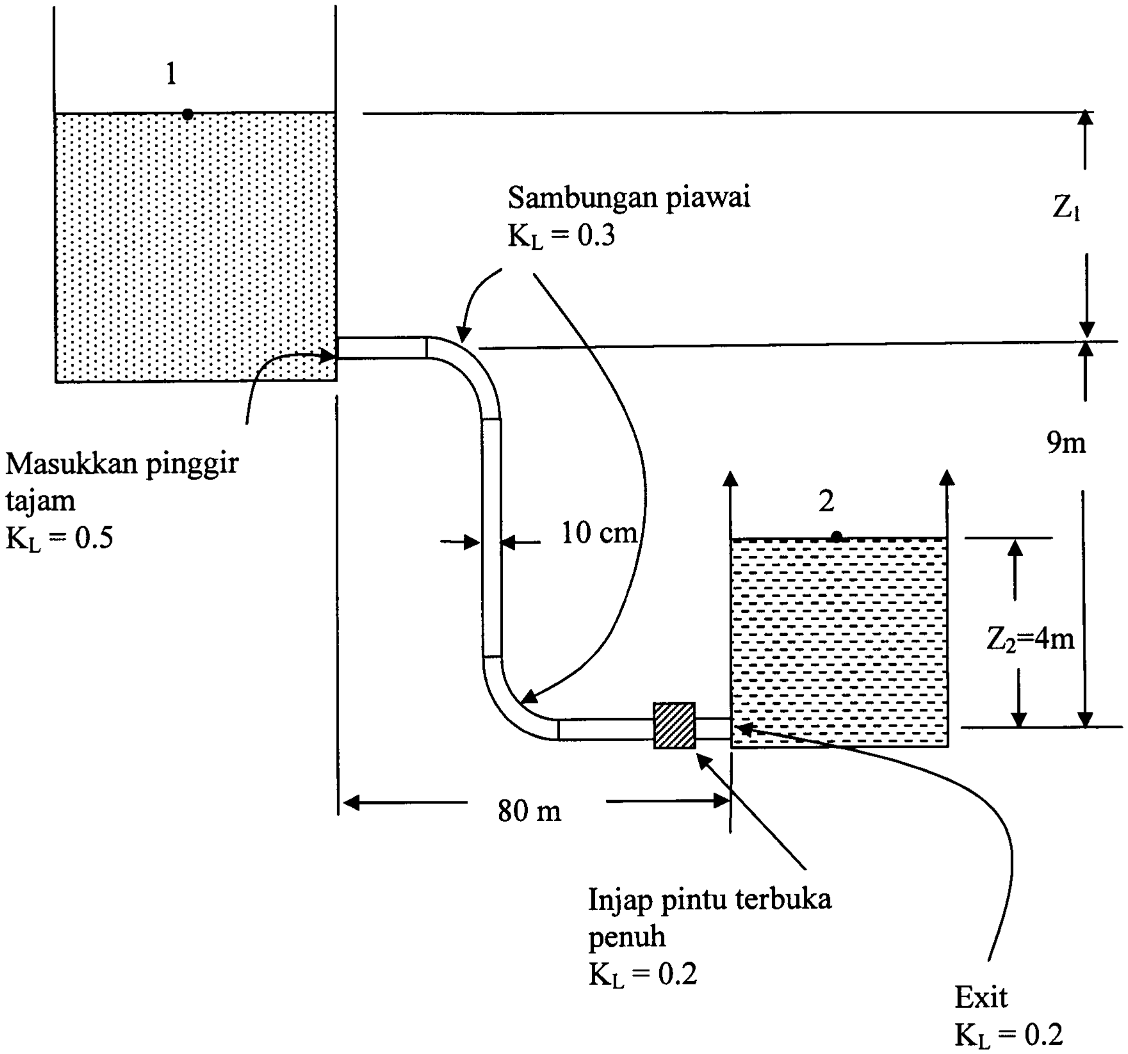
MATA PELAJARAN: MEKANIK BENDALIR 2 KOD MATA PELAJARAN: BDA3023



Rajah S2(c)

Lampiran 3

PEPERIKSAAN AKHIR

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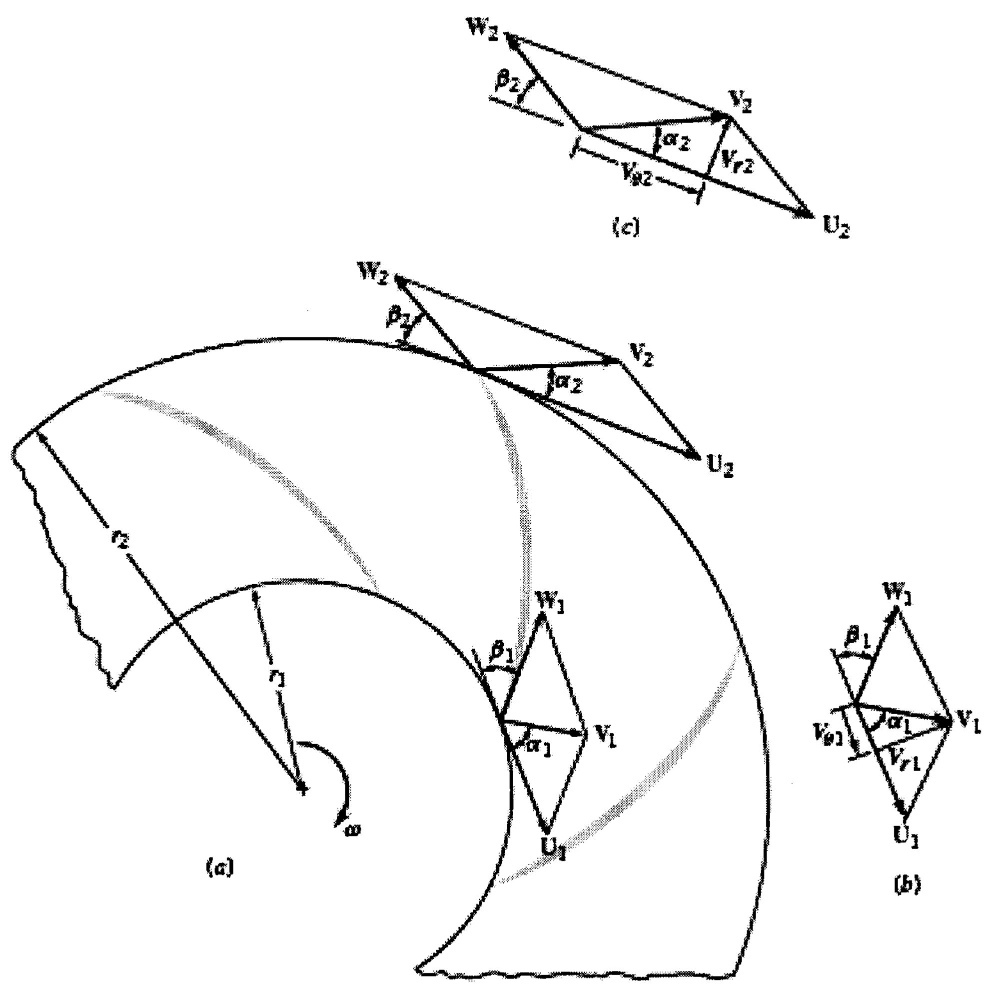
MATA PELAJARAN: MEKANIK BENDALIR 2 KOD MATA PELAJARAN: BDA3023



Rajah S4(b)

Lampiran 4

PEPERIKSAAN AKHIR
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MATA PELAJARAN: MEKANIK BENDALIR 2 KOD MATA PELAJARAN: BDA3023

Equivalent Roughness for New Pipes [From Moody (Ref. 7) and Colebrook (Ref. 8)]

	Equivalent Roughness, ε	
Pipe	**Feet**	**Millimeters**
Riveted steel	0.003–0.03	0.9–9.0
Concrete	0.001–0.01	0.3–3.0
Wood stave	0.0006–0.003	0.18–0.9
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Commercial steel or wrought iron	0.00015	0.045
Drawn tubing	0.000005	0.0015
Plastic, glass	0.0 (smooth)	0.0 (smooth)

Lampiran 5

PEPERIKSAAN AKHIR

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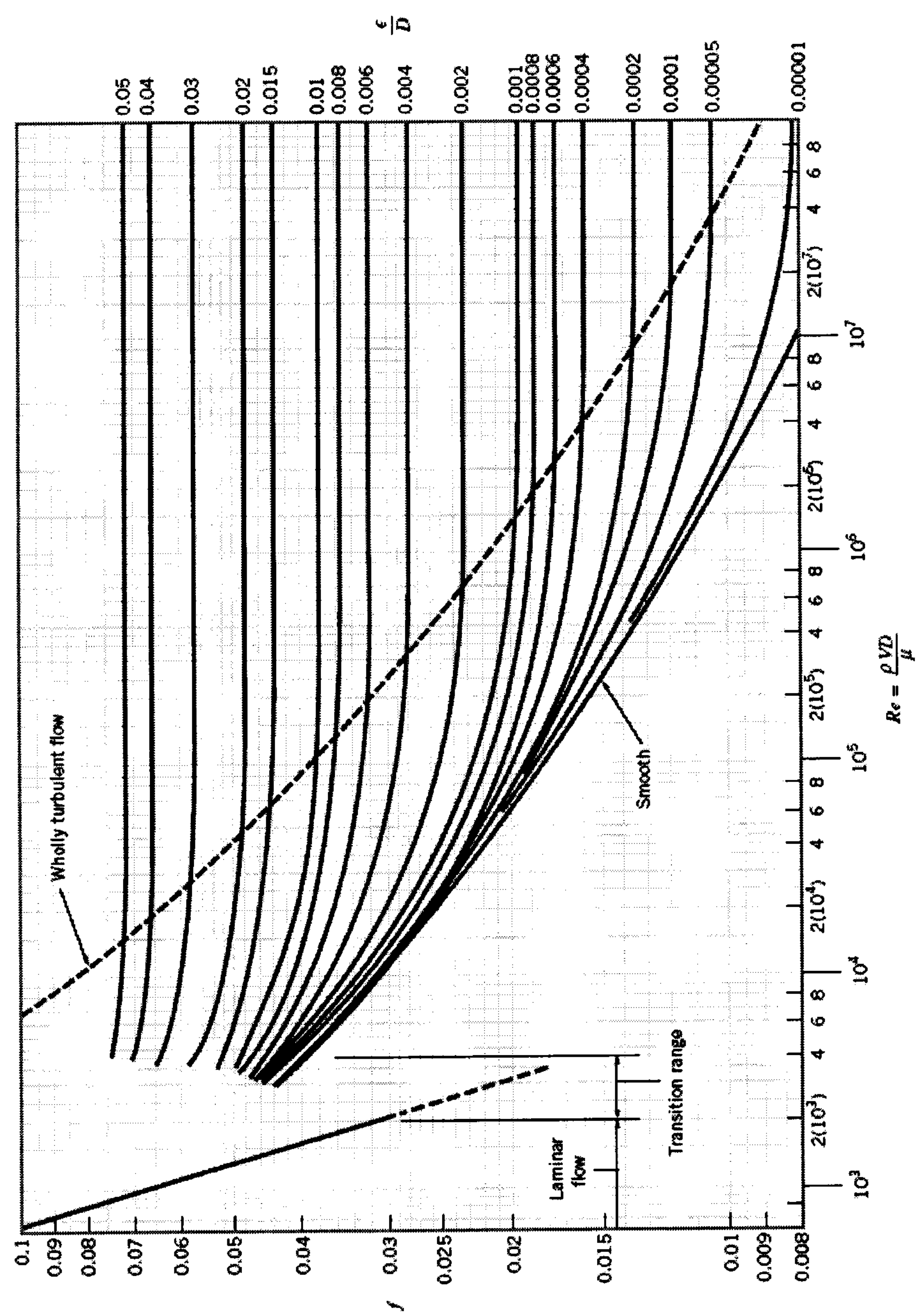
MATA PELAJARAN: MEKANIK BENDALIR 2 KOD MATA PELAJARAN: BDA3023



■ FIGURE 8.20 Friction factor as a function of Reynolds number and relative roughness for round pipes—the Moody chart. (Data from Ref. 7 with permission.)

Lampiran 6

PEPERIKSAAN AKHIR
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MATA PELAJARAN: MEKANIK BENDALIR 2 KOD MATA PELAJARAN: BDA3023

■ TABLE B.1
Physical Properties of Water (BG Units)[a]

Temperature (°F)	Density, ρ (slugs/ft³)	Specific Weight[b], γ (lb/ft³)	Dynamic Viscosity, μ (lb·s/ft²)	Kinematic Viscosity, ν (ft²/s)	Surface Tension[c], σ (lb/ft)	Vapor Pressure, p_v [lb/in²(abs)]	Speed of Sound[d], c (ft/s)
32	1.940	62.42	3.732 E − 5	1.924 E − 5	5.18 E − 3	8.854 E − 2	4603
40	1.940	62.43	3.228 E − 5	1.664 E − 5	5.13 E − 3	1.217 E − 1	4672
50	1.940	62.41	2.730 E − 5	1.407 E − 5	5.09 E − 3	1.781 E − 1	4748
60	1.938	62.37	2.344 E − 5	1.210 E − 5	5.03 E − 3	2.563 E − 1	4814
70	1.936	62.30	2.037 E − 5	1.052 E − 5	4.97 E − 3	3.631 E − 1	4871
80	1.934	62.22	1.791 E − 5	9.262 E − 6	4.91 E − 3	5.069 E − 1	4819
90	1.931	62.11	1.500 E − 5	8.233 E − 6	4.86 E − 3	6.979 E − 1	4960
100	1.927	62.00	1.423 E − 5	7.383 E − 6	4.79 E − 3	9.493 E − 1	4995
120	1.918	61.71	1.164 E − 5	6.067 E − 6	4.67 E − 3	1.692 E + 0	5049
140	1.908	61.38	9.743 E − 6	5.106 E − 6	4.53 E − 3	2.888 E + 0	5091
160	1.896	61.00	8.315 E − 6	4.385 E − 6	4.40 E − 3	4.736 E + 0	5101
180	1.883	60.58	7.207 E − 6	3.827 E − 6	4.26 E − 3	7.507 E + 0	5195
200	1.869	60.12	6.342 E − 6	3.393 E − 6	4.12 E − 3	1.152 E + 1	5089
212	1.860	59.83	5.886 E − 6	3.165 E − 6	4.04 E − 3	1.469 E + 1	5062

[a] Based on data from *Handbook of Chemistry and Physics*, 69th Ed., CRC Press, 1988. Where necessary, values obtained by interpolation.
[b] Density and specific weight are related through the equation $\gamma = \rho g$. For this table, $g = 32.174$ ft/s².
[c] In contact with air.
[d] From R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.

■ TABLE B.2
Physical Properties of Water (SI Units)[a]

Temperature (°C)	Density, ρ (kg/m³)	Specific Weight[b], γ (kN/m³)	Dynamic Viscosity, μ (N·s/m²)	Kinematic Viscosity, ν (m²/s)	Surface Tension[c], σ (N/m)	Vapor Pressure, p_v [N/m²(abs)]	Speed of Sound[d], c (m/s)
0	999.9	9.806	1.787 E − 3	1.787 E − 6	7.56 E − 2	6.105 E + 2	1403
5	1000.0	9.807	1.519 E − 3	1.519 E − 6	7.49 E − 2	8.722 E + 2	1427
10	999.7	9.804	1.307 E − 3	1.307 E − 6	7.42 E − 2	1.228 E + 3	1447
20	998.2	9.789	1.002 E − 3	1.004 E − 6	7.28 E − 2	2.338 E + 3	1481
30	995.7	9.765	7.975 E − 4	8.009 E − 7	7.12 E − 2	4.243 E + 3	1507
40	992.2	9.731	6.529 E − 4	6.580 E − 7	6.96 E − 2	7.376 E + 3	1526
50	988.1	9.690	5.468 E − 4	5.534 E − 7	6.79 E − 2	1.233 E + 4	1541
60	983.2	9.642	4.665 E − 4	4.745 E − 7	6.62 E − 2	1.992 E + 4	1552
70	977.8	9.589	4.042 E − 4	4.134 E − 7	6.44 E − 2	3.116 E + 4	1555
80	971.8	9.530	3.547 E − 4	3.650 E − 7	6.26 E − 2	4.734 E + 4	1555
90	965.3	9.467	3.147 E − 4	3.260 E − 7	6.08 E − 2	7.010 E + 4	1550
100	958.4	9.399	2.818 E − 4	2.940 E − 7	5.89 E − 2	1.013 E + 5	1543

[a] Based on data from *Handbook of Chemistry and Physics*, 69th Ed., CRC Press, 1988.
[b] Density and specific weight are related through the equation $\gamma = \rho g$. For this table, $g = 9.807$ m/s².
[c] In contact with air.
[d] From R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.

Lampiran 7

PEPERIKSAAN AKHIR
SEMESTER/SESI : SEMESTER 2/2008/2009 KURSUS : BDD / BDI
MATA PELAJARAN: MEKANIK BENDALIR 2 KOD MATA PELAJARAN: BDA3023

TABLE B.3
Physical Properties of Air at Standard Atmospheric Pressure (BG Units)[a]

Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight[b], γ (lb/ft^3)	Dynamic Viscosity, μ (lb·s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Specific Heat Ratio, k (—)	Speed of Sound, c (ft/s)
−40	2.939 E − 3	9.456 E − 2	3.29 E − 7	1.12 E − 4	1.401	1004
−20	2.805 E − 3	9.026 E − 2	3.34 E − 7	1.19 E − 4	1.401	1028
0	2.683 E − 3	8.633 E − 2	3.38 E − 7	1.26 E − 4	1.401	1051
10	2.626 E − 3	8.449 E − 2	3.44 E − 7	1.31 E − 4	1.401	1062
20	2.571 E − 3	8.273 E − 2	3.50 E − 7	1.36 E − 4	1.401	1074
30	2.519 E − 3	8.104 E − 2	3.58 E − 7	1.42 E − 4	1.401	1085
40	2.469 E − 3	7.942 E − 2	3.60 E − 7	1.46 E − 4	1.401	1096
50	2.420 E − 3	7.786 E − 2	3.68 E − 7	1.52 E − 4	1.401	1106
60	2.373 E − 3	7.636 E − 2	3.75 E − 7	1.58 E − 4	1.401	1117
70	2.329 E − 3	7.492 E − 2	3.82 E − 7	1.64 E − 4	1.401	1128
80	2.286 E − 3	7.353 E − 2	3.86 E − 7	1.69 E − 4	1.400	1138
90	2.244 E − 3	7.219 E − 2	3.90 E − 7	1.74 E − 4	1.400	1149
100	2.204 E − 3	7.090 E − 2	3.94 E − 7	1.79 E − 4	1.400	1159
120	2.128 E − 3	6.846 E − 2	4.02 E − 7	1.89 E − 4	1.400	1180
140	2.057 E − 3	6.617 E − 2	4.13 E − 7	2.01 E − 4	1.399	1200
160	1.990 E − 3	6.404 E − 2	4.22 E − 7	2.12 E − 4	1.399	1220
180	1.928 E − 3	6.204 E − 2	4.34 E − 7	2.25 E − 4	1.399	1239
200	1.870 E − 3	6.016 E − 2	4.49 E − 7	2.40 E − 4	1.398	1258
300	1.624 E − 3	5.224 E − 2	4.97 E − 7	3.06 E − 4	1.394	1348
400	1.435 E − 3	4.616 E − 2	5.24 E − 7	3.65 E − 4	1.389	1431
500	1.285 E − 3	4.135 E − 2	5.80 E − 7	4.51 E − 4	1.383	1509
750	1.020 E − 3	3.280 E − 2	6.81 E − 7	6.68 E − 4	1.367	1685
1000	8.445 E − 4	2.717 E − 2	7.85 E − 7	9.30 E − 4	1.351	1839
1500	6.291 E − 4	2.024 E − 2	9.50 E − 7	1.51 E − 3	1.329	2114

[a] Based on data from R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.
[b] Density and specific weights are related through the equation $\gamma = \rho g$. For this table $g = 32.174$ ft/s^2.

Lampiran 8

PEPERIKSAAN AKHIR
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MATA PELAJARAN: MEKANIK BENDALIR 2 KOD MATA PELAJARAN: BDA3023

TABLE B.4
Physical Properties of Air at Standard Atmospheric Pressure (SI Units)[a]

Temperature (°C)	Density, ρ (kg/m³)	Specific Weight[b], γ (N/m³)	Dynamic Viscosity, μ (N·s/m²)	Kinematic Viscosity, ν (m²/s)	Specific Heat Ratio, k (—)	Speed of Sound, c (m/s)
−40	1.514	14.85	1.57 E − 5	1.04 E − 5	1.401	306.2
−20	1.395	13.68	1.63 E − 5	1.17 E − 5	1.401	319.1
0	1.292	12.67	1.71 E − 5	1.32 E − 5	1.401	331.4
5	1.269	12.45	1.73 E − 5	1.36 E − 5	1.401	334.4
10	1.247	12.23	1.76 E − 5	1.41 E − 5	1.401	337.4
15	1.225	12.01	1.80 E − 5	1.47 E − 5	1.401	340.4
20	1.204	11.81	1.82 E − 5	1.51 E − 5	1.401	343.3
25	1.184	11.61	1.85 E − 5	1.56 E − 5	1.401	346.3
30	1.165	11.43	1.86 E − 5	1.60 E − 5	1.400	349.1
40	1.127	11.05	1.87 E − 5	1.66 E − 5	1.400	354.7
50	1.109	10.88	1.95 E − 5	1.76 E − 5	1.400	360.3
60	1.060	10.40	1.97 E − 5	1.86 E − 5	1.399	365.7
70	1.029	10.09	2.03 E − 5	1.97 E − 5	1.399	371.2
80	0.9996	9.803	2.07 E − 5	2.07 E − 5	1.399	376.6
90	0.9721	9.533	2.14 E − 5	2.20 E − 5	1.398	381.7
100	0.9461	9.278	2.17 E − 5	2.29 E − 5	1.397	386.9
200	0.7461	7.317	2.53 E − 5	3.39 E − 5	1.390	434.5
300	0.6159	6.040	2.98 E − 5	4.84 E − 5	1.379	476.3
400	0.5243	5.142	3.32 E − 5	6.34 E − 5	1.368	514.1
500	0.4565	4.477	3.64 E − 5	7.97 E − 5	1.357	548.8
1000	0.2772	2.719	5.04 E − 5	1.82 E − 4	1.321	694.8

[a]Based on data from R. D. Blevins, *Applied Fluid Dynamics Handbook*, Van Nostrand Reinhold Co., Inc., New York, 1984.
[b]Density and specific weight are related through the equation $\gamma = \rho g$. For this table $g = 9.807$ m/s².

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PEPERIKSAAN AKHIR
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TABLE C.1
Properties of the U.S. Standard Atmosphere (BG Units)[a]

Altitude (ft)	Temperature (°F)	Acceleration of Gravity, g (ft/s^2)	Pressure, p [lb/in.^{2}(abs)]	Density, ρ (slugs/ft^3)	Dynamic Viscosity, μ (lb·s/ft^2)
−5,000	76.84	32.189	17.554	2.745 E − 3	3.836 E − 7
0	59.00	32.174	14.696	2.377 E − 3	3.737 E − 7
5,000	41.17	32.159	12.228	2.048 E − 3	3.637 E − 7
10,000	23.36	32.143	10.108	1.756 E − 3	3.534 E − 7
15,000	5.55	32.128	8.297	1.496 E − 3	3.430 E − 7
20,000	−12.26	32.112	6.759	1.267 E − 3	3.324 E − 7
25,000	−30.05	32.097	5.461	1.066 E − 3	3.217 E − 7
30,000	−47.83	32.082	4.373	8.907 E − 4	3.107 E − 7
35,000	−65.61	32.066	3.468	7.382 E − 4	2.995 E − 7
40,000	−69.70	32.051	2.730	5.873 E − 4	2.969 E − 7
45,000	−69.70	32.036	2.149	4.623 E − 4	2.969 E − 7
50,000	−69.70	32.020	1.692	3.639 E − 4	2.969 E − 7
60,000	−69.70	31.990	1.049	2.256 E − 4	2.969 E − 7
70,000	−67.42	31.959	0.651	1.392 E − 4	2.984 E − 7
80,000	−61.98	31.929	0.406	8.571 E − 5	3.018 E − 7
90,000	−56.54	31.897	0.255	5.610 E − 5	3.052 E − 7
100,000	−51.10	31.868	0.162	3.318 E − 5	3.087 E − 7
150,000	19.40	31.717	0.020	3.658 E − 6	3.511 E − 7
200,000	−19.78	31.566	0.003	5.328 E − 7	3.279 E − 7
250,000	−88.77	31.415	0.000	6.458 E − 8	2.846 E − 7

[a]Data abridged from *U.S. Standard Atmosphere*, 1976, U.S. Government Printing Office, Washington, D.C.

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TABLE C.2
Properties of the U.S. Standard Atmosphere (SI Units)[a]

Altitude (m)	Temperature (°C)	Acceleration of Gravity, g (m/s^2)	Pressure, p [N/m^2(abs)]	Density, ρ (kg/m^3)	Dynamic Viscosity, μ ($N \cdot s/m^2$)
−1,000	21.50	9.810	1.139 E + 5	1.347 E + 0	1.821 E − 5
0	15.00	9.807	1.013 E + 5	1.225 E + 0	1.789 E − 5
1,000	8.50	9.804	8.988 E + 4	1.112 E + 0	1.758 E − 5
2,000	2.00	9.801	7.950 E + 4	1.007 E + 0	1.726 E − 5
3,000	−4.49	9.797	7.012 E + 4	9.093 E − 1	1.694 E − 5
4,000	−10.98	9.794	6.166 E + 4	8.194 E − 1	1.661 E − 5
5,000	−17.47	9.791	5.405 E + 4	7.364 E − 1	1.628 E − 5
6,000	−23.96	9.788	4.722 E + 4	6.601 E − 1	1.595 E − 5
7,000	−30.45	9.785	4.111 E + 4	5.900 E − 1	1.561 E − 5
8,000	−36.94	9.782	3.565 E + 4	5.258 E − 1	1.527 E − 5
9,000	−43.42	9.779	3.080 E + 4	4.671 E − 1	1.493 E − 5
10,000	−49.90	9.776	2.650 E + 4	4.135 E − 1	1.458 E − 5
15,000	−56.50	9.761	1.211 E + 4	1.948 E − 1	1.422 E − 5
20,000	−56.50	9.745	5.529 E + 3	8.891 E − 2	1.422 E − 5
25,000	−51.60	9.730	2.549 E + 3	4.008 E − 2	1.448 E − 5
30,000	−46.64	9.715	1.197 E + 3	1.841 E − 2	1.475 E − 5
40,000	−22.80	9.684	2.871 E + 2	3.996 E − 3	1.601 E − 5
50,000	−2.50	9.654	7.978 E + 1	1.027 E − 3	1.704 E − 5
60,000	−26.13	9.624	2.196 E + 1	3.097 E − 4	1.584 E − 5
70,000	−53.57	9.594	5.221 E + 0	8.283 E − 5	1.438 E − 5
80,000	−74.51	9.564	1.052 E + 0	1.846 E − 5	1.321 E − 5

[a]Data abridged from *U.S. Standard Atmosphere*, 1976, U.S. Government Printing Office, Washington, D.C.

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TABLE 1.5
Approximate Physical Properties of Some Common Liquids (BG Units)

Liquid	Temperature (°F)	Density, ρ (slugs/ft³)	Specific Weight, γ (lb/ft³)	Dynamic Viscosity, μ (lb · s/ft²)	Kinematic Viscosity, ν (ft²/s)	Surface Tension,[a] σ (lb/ft)	Vapor Pressure, p_v [lb/in.² (abs)]	Bulk Modulus,[b] E_v (lb/in.²)
Carbon tetrachloride	68	3.09	99.5	2.00 E − 5	6.47 E − 6	1.84 E − 3	1.9 E + 0	1.91 E + 5
Ethyl alcohol	68	1.53	49.3	2.49 E − 5	1.63 E − 5	1.56 E − 3	8.5 E − 1	1.54 E + 5
Gasoline[c]	60	1.32	42.5	6.5 E − 6	4.9 E − 6	1.5 E − 3	8.0 E + 0	1.9 E + 5
Glycerin	68	2.44	78.6	3.13 E − 2	1.28 E − 2	4.34 E − 3	2.0 E − 6	6.56 E + 5
Mercury	68	26.3	847	3.28 E − 5	1.25 E − 6	3.19 E − 2	2.3 E − 5	4.14 E + 6
SAE 30 oil[c]	60	1.77	57.0	8.0 E − 3	4.5 E − 3	2.5 E − 3	—	2.2 E + 5
Seawater	60	1.99	64.0	2.51 E − 5	1.26 E − 5	5.03 E − 3	2.26 E − 1	3.39 E + 5
Water	60	1.94	62.4	2.34 E − 5	1.21 E − 5	5.03 E − 3	2.26 E − 1	3.12 E + 5

[a]In contact with air.
[b]Isentropic bulk modulus calculated from speed of sound.
[c]Typical values. Properties of petroleum products vary.

TABLE 1.6
Approximate Physical Properties of Some Common Liquids (SI Units)

Liquid	Temperature (°C)	Density, ρ (kg/m³)	Specific Weight, γ (kN/m³)	Dynamic Viscosity, μ (N · s/m²)	Kinematic Viscosity, ν (m²/s)	Surface Tension,[a] σ (N/m)	Vapor Pressure, p_v [N/m² (abs)]	Bulk Modulus,[b] E_v (N/m²)
Carbon tetrachloride	20	1,590	15.6	9.58 E − 4	6.03 E − 7	2.69 E − 2	1.3 E + 4	1.31 E + 9
Ethyl alcohol	20	789	7.74	1.19 E − 3	1.51 E − 6	2.28 E − 2	5.9 E + 3	1.06 E + 9
Gasoline[c]	15.6	680	6.67	3.1 E − 4	4.6 E − 7	2.2 E − 2	5.5 E + 4	1.3 E + 9
Glycerin	20	1,260	12.4	1.50 E + 0	1.19 E − 3	6.33 E − 2	1.4 E − 2	4.52 E + 9
Mercury	20	13,600	133	1.57 E − 3	1.15 E − 7	4.66 E − 1	1.6 E − 1	2.85 E + 10
SAE 30 oil[c]	15.6	912	8.95	3.8 E − 1	4.2 E − 4	3.6 E − 2	—	1.5 E + 9
Seawater	15.6	1,030	10.1	1.20 E − 3	1.17 E − 6	7.34 E − 2	1.77 E + 3	2.34 E + 9
Water	15.6	999	9.80	1.12 E − 3	1.12 E − 6	7.34 E − 2	1.77 E + 3	2.15 E + 9

[a]In contact with air.
[b]Isentropic bulk modulus calculated from speed of sound.
[c]Typical values. Properties of petroleum products vary.

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■ TABLE 1.7
Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (BG Units)

Gas	Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight, γ (lb/ft^3)	Dynamic Viscosity, μ (lb · s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Gas Constant,[a] R (ft · lb/slug · °R)	Specific Heat Ratio,[b] k
Air (standard)	59	2.38 E − 3	7.65 E − 2	3.74 E − 7	1.57 E − 4	1.716 E + 3	1.40
Carbon dioxide	68	3.55 E − 3	1.14 E − 1	3.07 E − 7	8.65 E − 5	1.130 E + 3	1.30
Helium	68	3.23 E − 4	1.04 E − 2	4.09 E − 7	1.27 E − 3	1.242 E + 4	1.66
Hydrogen	68	1.63 E − 4	5.25 E − 3	1.85 E − 7	1.13 E − 3	2.466 E + 4	1.41
Methane (natural gas)	68	1.29 E − 3	4.15 E − 2	2.29 E − 7	1.78 E − 4	3.099 E + 3	1.31
Nitrogen	68	2.26 E − 3	7.28 E − 2	3.68 E − 7	1.63 E − 4	1.775 E + 3	1.40
Oxygen	68	2.58 E − 3	8.31 E − 2	4.25 E − 7	1.65 E − 4	1.554 E + 3	1.40

[a]Values of the gas constant are independent of temperature.
[b]Values of the specific heat ratio depend only slightly on temperature.

■ TABLE 1.8
Approximate Physical Properties of Some Common Gases at Standard Atmospheric Pressure (SI Units)

Gas	Temperature (°C)	Density, ρ (kg/m^3)	Specific Weight, γ (N/m^3)	Dynamic Viscosity, μ (N · s/m^2)	Kinematic Viscosity, ν (m^2/s)	Gas Constant,[a] R (J/kg · K)	Specific Heat Ratio,[b] k
Air (standard)	15	1.23 E + 0	1.20 E + 1	1.79 E − 5	1.46 E − 5	2.869 E + 2	1.40
Carbon dioxide	20	1.83 E + 0	1.80 E + 1	1.47 E − 5	8.03 E − 6	1.889 E + 2	1.30
Helium	20	1.66 E − 1	1.63 E + 0	1.94 E − 5	1.15 E − 4	2.077 E + 3	1.66
Hydrogen	20	8.38 E − 2	8.22 E − 1	8.84 E − 6	1.05 E − 4	4.124 E + 3	1.41
Methane (natural gas)	20	6.67 E − 1	6.54 E + 0	1.10 E − 5	1.65 E − 5	5.183 E + 2	1.31
Nitrogen	20	1.16 E + 0	1.14 E + 1	1.76 E − 5	1.52 E − 5	2.968 E + 2	1.40
Oxygen	20	1.33 E + 0	1.30 E + 1	2.04 E − 5	1.53 E − 5	2.598 E + 2	1.40

[a]Values of the gas constant are independent of temperature.
[b]Values of the specific heat ratio depend only slightly on temperature.