pressure

force

density

velocity

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Preface

This book is designed primarily to supplement standard textbooks in fluid mechanics and hydraulics. It is based on the authors' conviction that clarification and understanding of the basic principles of any branch of mechanics can be accomplished best by means of numerous illustrative problems.

Previous editions of this book have been very favorably received. This third edition contains two new chapters—one on fluid statics, the other on flow of compressible fluids. Additionally, many chapters have been revised and expanded to keep pace with the most recent concepts, methods, and terminology. Another very important feature of this new edition is the use of the International System of Units (SI). Precisely half of all problems that involve units of measure utilize SI units, the other half employing the British Engineering System.

The subject matter is divided into chapters covering duly recognized areas of theory and study. Each chapter begins with statements of pertinent definitions, principles, and theorems together with illustrative and descriptive material. This material is followed by graded sets of solved and supplementary problems. The solved problems illustrate and amplify the theory, present methods of analysis, provide practical examples, and bring into sharp focus those fine points which enable the student to apply the basic principles correctly and confidently. Free-body analysis, vector diagrams, the principles of work and energy and of impulse-momentum, and Newton's laws of motion are utilized throughout the book. Efforts have been made to present original problems developed by the authors during many years of teaching the subject. Numerous proofs of theorems and derivations of formulas are included among the solved problems. The large number of supplementary problems serve as a complete review of the material of each chapter.

In addition to its use by engineering students of fluid mechanics and hydraulics, this book should be of considerable value as a reference for practicing engineers. They will find well-detailed solutions to many practical problems and can refer to the summary of the theory when the need arises. Also, the book should serve individuals who must review the subject for licensing examinations or other reasons.

We hope you will enjoy using this book and that it will help a great deal in your study of fluid mechanics and hydraulics. We would be pleased to receive your comments, suggestions, and/or criticisms.

Jack B. Evett
Cheng Liu

Symbols and Abbreviations

The following tabulation lists the letter symbols used in this book. Because the alphabet is limited, it is impossible to avoid using the same letter to represent more than one concept, Since each symbol is defined when it is first used, no confusion should result.

a	acceleration, area
A	area
b	weir length, width of water surface, bed width of open channel
c	coefficient of discharge, celerity of pressure wave (acoustic velocity)
c_c	coefficient of contraction
c_v	coefficient of velocity
C	coefficient (Chezy), constant of integration
CB	center of buoyancy
CG	center of gravity
C_p	center of pressure, power coefficient for propellers
C_D	coefficient of drag
C_F	thrust coefficient for propellers
C_L	coefficient of lift
C_T	torque coefficient for propellers
C_1	Hazen-Williams coefficient
cfs	cubic feet per second
CP	center of pressure
d, D	diameter
D_1	unit diameter
e	efficiency
E	bulk modulus of elasticity, specific energy
f	friction factor (Darcy) for pipe flow
F	force, thrust
F_B	buoyant force
FE	pressure energy
Fr	Froude number
g	gravitational acceleration ($= 32.2$ ft/sec^2 $= 9.81$ m/s^2)
gpm	gallons per minute
h	head, height or depth, pressure head
H	total head (energy)
H_L, h_L	lost head (sometimes LH)
hp	horsepower $= 0.746$ kW
I	moment of inertia
I_{xy}	product of inertia
J	joule
k	ratio of specific heats, isentropic (adiabatic) exponent, von Karman constant
K	discharge factors for trapezoidal channels, lost head factor for enlargements, any constant
K_c	lost head factor for contractions
KE	kinetic energy
l	mixing length
L	length
L_E	equivalent length
m	roughness factor in Bazin formula, weir factor for dams
mc	metacenter
M	mass, molecular weight
$\overline{MB}$	distance from CB to mc
n	roughness coefficient, exponent, roughness factor in Kutter's and Manning's formulas
N	rotational speed
N_s	specific speed
N_u	unit speed
N_M	Mach number
p	pressure, wetted perimeter
p'	pressure
P	power
Pa	pascal
PE	potential energy
P_u	unit power
psf	lb/ft^2
psia	lb/in^2, absolute
psig	lb/in^2, gage
q	unit flow
Q	volume rate of flow
Q_u	unit discharge

r	any radius
r_o	radius of pipe
R	gas constant, hydraulic radius
Re	Reynolds number
S	slope of hydraulic grade line, slope of energy line
S_0	slope of channel bed
sp gr	specific gravity
t	time, thickness, viscosity in Saybolt seconds
T	temperature, torque, time
u	peripheral velocity of rotating element
u, v, w	components of velocity in X, Y, and Z directions
v	volume, local velocity, relative velocity in hydraulic machines
v_s	specific volume $(= 1/\gamma)$
v_*	shear velocity
V	average velocity
V_c	critical velocity
V_d	volume of fluid displaced
W	weight, weight flow
We	Weber number
x	distance
y	depth, distance
y_c	critical depth
y_N	normal depth
Y	expansion factor for compressible flow
z	elevation (head)
Z	height of weir crest above channel bottom

α (alpha)	angle, kinetic energy correction factor
β (beta)	angle, momentum correction factor
γ (gamma)	specific (or unit) weight
δ (delta)	boundary layer thickness
Δ (delta)	flow correction term
ϵ (epsilon)	surface roughness
η (eta)	eddy viscosity
θ (theta)	any angle
μ (mu)	absolute viscosity
ν (nu)	kinematic viscosity
π (pi)	dimensionless parameter
ρ (rho)	density
σ (sigma)	surface tension, intensity of tensile stress
τ (tau)	shear stress
ϕ (phi)	speed factor, velocity potential, ratio
ψ (psi)	stream function
ω (omega)	angular velocity

Conversion Factors

1 cubic foot = 7.48 U.S. gallons = 28.32 liters
1 U.S. gallon = 8.338 pounds of water at 60°F
1 cubic foot per second = 0.646 million gallons per day
= 448.8 gallons per minute
1 pound-second per square foot (μ) = 478.7 poises
1 square foot per second (ν) = 0.0929 square meter per second
1 horsepower = 550 foot-pounds per second = 0.746 kilowatt
30 inches of mercury = 34 feet of water = 14.7 pounds per square inch
762 millimeters of mercury = 10.4 meters of water = 101.3 kilopascals

Parameter	**British Engineering System to International System**	**International System to British Engineering System**
Length	1 in = 0.0254 m	1 m = 39.37 in
	1 ft = 0.3048 m	1 m = 3.281 ft
Mass	1 slug = 14.59 kg	1 kg = 0.06854 slug
Force	1 lb = 4.448 N	1 N = 0.2248 lb
Time	1 sec = 1 s	1 s = 1 sec
Specific (or unit) weight	1 lb/ft^3 = 157.1 N/m^3	1 N/m^3 = 0.006366 lb/ft^3
Mass density	1 slug/ft^3 = 515.2 kg/m^3	1 kg/m^3 = 0.001941 slug/ft^3
Specific gravity	Same dimensionless value in both systems	Same dimensionless value in both systems
Dynamic viscosity	1 lb-sec/ft^2 = 47.88 N·s/m^2	1 N·s/m^2 = 0.02089 lb-sec/ft^2
Kinematic viscosity	1 ft^2/sec = 0.09290 m^2/s	1 m^2/s = 10.76 ft^2/sec
Pressure	1 lb/ft^2 = 47.88 Pa	1 Pa = 0.02089 lb/ft^2
	1 lb/in^2 = 6.895 kPa	1 kPa = 0.1450 lb/in^2
Surface tension	1 lb/ft = 14.59 N/m	1 N/m = 0.06853 lb/ft

Contents

Chapter 1

Properties of Fluids

FLUID MECHANICS AND HYDRAULICS

Fluid mechanics and hydraulics represent that branch of applied mechanics that deals with the behavior of fluids at rest and in motion. In the development of the principles of fluid mechanics, some fluid properties play principal roles, others only minor roles or no roles at all. In fluid statics, specific weight (or unit weight) is the important property, whereas in fluid flow, density and viscosity are predominant properties. Where appreciable compressibility occurs, principles of thermodynamics must be considered. Vapor pressure becomes important when negative pressures (gage) are involved, and surface tension affects static and flow conditions in small passages.

DEFINITION OF A FLUID

Fluids are substances that are capable of flowing and conform to the shape of containing vessels. When in equilibrium, fluids cannot sustain tangential or shear forces. All fluids have some degree of compressibility and offer little resistance to change of form.

Fluids can be classified as liquids or gases. The chief differences between liquids and gases are (*a*) liquids are practically incompressible whereas gases are compressible and usually must be so treated and (*b*) liquids occupy definite volumes and have free surfaces whereas a given mass of gas expands until it occupies all portions of any containing vessel.

BRITISH ENGINEERING (OR FPS) SYSTEM OF UNITS

In this system the fundamental mechanical dimensions are *length*, *force*, and *time*. The corresponding fundamental units are the foot (ft) of length, pound (lb) of force (or pound weight), and second (sec) of time. All other units can be derived from these. Thus unit volume is the ft^3, unit acceleration is the ft/sec^2, unit work is the ft-lb, and unit pressure is the lb/ft^2.

The unit for mass in this system, the *slug*, is derived from the fundamental units as follows. For a freely falling body in vacuum, the acceleration is that of gravity $\left(g = 32.2\ \text{ft/sec}^2 \text{ at sea level}\right)$, and the only force acting is its weight. From Newton's second law,

$$\text{force in pounds} = \text{mass in slugs} \times \text{acceleration in ft/sec}^2$$

Then

$$\text{weight in pounds} = \text{mass in slugs} \times g\left(32.2\ \text{ft/sec}^2\right)$$

or

$$\text{mass } M \text{ in slugs} = \frac{\text{weight } W \text{ in pounds}}{g\left(32.2\ \text{ft/sec}^2\right)} \tag{1}$$

By equation (*1*), slug = $\text{lb-sec}^2\text{/ft}$.

The temperature unit of the British system is the degree Fahrenheit (°F) or, on the absolute scale, the degree Rankine (°R).

INTERNATIONAL SYSTEM OF UNITS (SI)

In the SI, the fundamental mechanical dimensions are *length*, *mass* (unlike the British system), and *time*. The corresponding fundamental units are meter (m), kilogram (kg), and second (s). In terms of these, unit volume is the m^3, unit acceleration the m/s^2, and unit (mass) density the kg/m^3.

The SI unit of force, the newton (N), is derived via Newton's second law:

$$\text{force in N} = (\text{mass in kg}) \times (\text{acceleration in m/s}^2) \tag{2}$$

Thus, $1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$. Along with the newton are derived the joule (J) of work, where $1\ \text{J} = 1\ \text{N} \cdot \text{m}$, and the pascal (Pa) of pressure or stress, where $1\ \text{Pa} = 1\ \text{N/m}^2$.

In the SI, temperatures are usually reported in degrees Celsius (°C); the unit of absolute temperature is the kelvin (K).

SPECIFIC OR UNIT WEIGHT

The specific (or unit) weight γ of a substance is the weight of a unit volume of the substance. For liquids, γ may be taken as constant for practical changes of pressure. The specific weight of water for ordinary temperature variations is 62.4 lb/ft^3, or 9.79 kN/m^3. See Appendix, Table 1, for additional values.

The specific weight of a gas can be calculated using its *equation of state*,

$$\frac{pv}{T} = R \tag{3}$$

where pressure p is absolute pressure, v is the volume per unit weight, temperature T is the absolute temperature, and R is the *gas constant* of that particular species:

$$R = \frac{R_0}{Mg} = \frac{\text{universal gas constant}}{\text{molar weight}} \tag{4}$$

Since $\gamma = 1/v$, equation (*3*) can be written

$$\gamma = \frac{p}{RT} \tag{5}$$

MASS DENSITY OF A BODY ρ (rho) = mass per unit volume = γ/g.

In the British Engineering system of units, the mass density of water is $62.4/32.2 = 1.94$ slugs/ft^3. In the International system, the density of water is 1000 kg/m^3 at 4°C. See Appendix, Table 1.

SPECIFIC GRAVITY OF A BODY

The specific gravity of a body is the dimensionless ratio of the weight of the body to the weight of an equal volume of a substance taken as a standard. Solids and liquids are referred to water (at 68°F = 20°C) as standard, while gases are often referred to air free of carbon dioxide or hydrogen (at 32°F = 0°C and 1 atmosphere = 14.7 lb/in^2 = 101.3 kPa pressure) as standard. For example,

$$\begin{aligned} \text{specific gravity of a substance} &= \frac{\text{weight of substance}}{\text{weight of equal volume of water}} \\ &= \frac{\text{specific weight of substance}}{\text{specific weight of water}} \\ &= \frac{\text{density of substance}}{\text{density of water}} \end{aligned} \tag{6}$$

Thus if the specific gravity of a given oil is 0.750, its specific weight is $(0.750)(62.4\ \text{lb/ft}^3) = 46.8\ \text{lb/ft}^3$, or $(0.750)(9.79\ \text{kN/m}^3) = 7.34\ \text{kN/m}^3$. Specific gravities are tabulated in the Appendix, Table 2.

VISCOSITY OF A FLUID

The viscosity of a fluid is that property which determines the amount of its resistance to a shearing force. Viscosity is due primarily to interaction between fluid molecules.

Referring to Fig. 1-1, consider two large, parallel plates a small distance y apart, the space between the plates being filled with a fluid. To keep the upper plate moving at constant velocity U, it is found that a constant force F must be applied. Thus there must exist a viscous interaction between plate and fluid, manifested as a drag on the former and a shear force on the latter. The fluid in contact with the upper plate will adhere to it and will move at velocity U, and the fluid in contact with the fixed plate will have velocity zero. If distance y and velocity U are not too great, the velocity profile will be a straight line. Experiments have shown that shear force F varies with the area of the plate A, with velocity U, and inversely with distance y. Since by similar triangles, $U/y = dV/dy$, we have

$$F \propto \left(\frac{AU}{y} = A\frac{dV}{dy}\right) \qquad \text{or} \qquad \left(\frac{F}{A} = \tau\right) \propto \frac{dV}{dy}$$

where $\tau = F/A =$ shear stress. If a proportionality constant μ (mu), called the *absolute (dynamic) viscosity*, is introduced,

$$\tau = \mu\frac{dV}{dy} \qquad \text{or} \qquad \mu = \frac{\tau}{dV/dy} = \frac{\text{shear stress}}{\text{rate of shear strain}} \tag{7}$$

It follows that the units of μ are Pa · s or $\frac{\text{lb-sec}}{\text{ft}^2}$. Fluids for which the proportionality of equation (*7*) holds are called *Newtonian fluids* (see Problem 1.10).

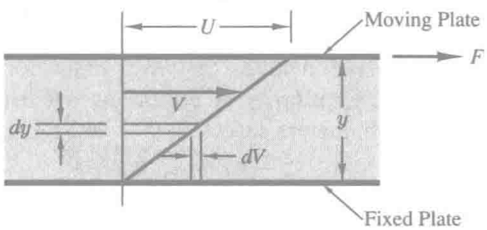


Fig. 1-1

Another viscosity coefficient, the *coefficient of kinematic viscosity*, is defined as

$$\text{kinematic viscosity } \nu \text{ (nu)} = \frac{\text{absolute viscosity } \mu}{\text{mass density } \rho}$$

or

$$\nu = \frac{\mu}{\rho} = \frac{\mu}{\gamma/g} = \frac{\mu g}{\gamma} \tag{8}$$

The units of ν are $\frac{\text{m}^2}{\text{s}}$ or $\frac{\text{ft}^2}{\text{sec}}$.

Viscosities are reported in older handbooks in poises or stokeses (cgs units) and on occasion in Saybolt seconds, from viscosimeter measurements. Conversions to the fps system are illustrated in Problems 1.7 through 1.9. A few values of viscosities are given in Tables 1 and 2 of the Appendix.

Viscosities of liquids decrease with temperature increases but are not affected appreciably by pressure changes. The absolute viscosity of gases increases with increase in temperature but is not appreciably changed by changes in pressure. Since the specific weight of gases changes with pressure changes (temperature constant), the kinematic viscosity varies inversely as the pressure.

VAPOR PRESSURE

When evaporation takes place within an enclosed space, the partial pressure created by the vapor molecules is called vapor pressure. Vapor pressures depend upon temperature and increase with it. See Table 1 in the Appendix for values for water.

SURFACE TENSION

A molecule in the interior of a liquid is under attractive forces in all directions, and the vector sum of these forces is zero. But a molecule at the surface of a liquid is acted on by a net inward cohesive force that is perpendicular to the surface. Hence it requires work to move molecules to the surface against this opposing force, and surface molecules have more energy than interior ones.

The surface tension σ (sigma) of a liquid is the work that must be done to bring enough molecules from inside the liquid to the surface to form one new unit area of that surface $\left(\mathrm{J/m^2} \text{ or } \mathrm{ft\text{-}lb/ft^2}\right)$. Equivalently, the energized surface molecules act as though they compose a stretched sheet, and

$$\sigma = \Delta F / \Delta L \tag{9}$$

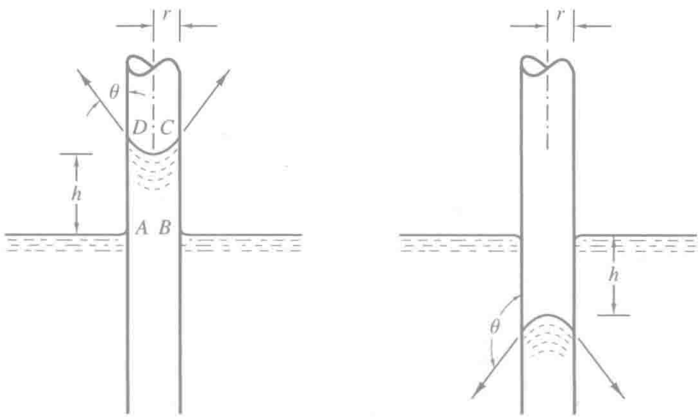
where ΔF is the elastic force transverse to any length element ΔL in the surface. Definition (*9*) gives the units N/m or lb/ft. The value of surface tension of water with air is 0.0756 N/m at 0°C, or 0.00518 lb/ft at 32°F. Table 1C gives values of surface tension for other temperatures.

CAPILLARITY

Rise or fall of liquid in a capillary tube (or in porous media) is caused by surface tension and depends on the relative magnitudes of the cohesion of the liquid and the adhesion of the liquid to the walls of the containing vessel. Liquids rise in tubes they wet (adhesion > cohesion) and fall in tubes they do not wet (cohesion > adhesion). Capillarity is important when using tubes smaller than about $\frac{3}{8}$ inch (10 mm) in diameter. For tube diameters larger than $\frac{1}{2}$ in (12 mm), capillary effects are negligible.

Figure 1-2 illustrates capillary rise (or depression) in a tube, which is given approximately by

$$h = \frac{2\sigma \cos\theta}{\gamma r} \tag{10}$$



(*a*) Water (*b*) Mercury

Fig. 1-2

where

h = height of capillary rise (or depression)
σ = surface tension
θ = wetting angle (see Fig. 1-2)
γ = specific weight of liquid
r = radius of tube

If the tube is clean, θ is 0° for water and about 140° for mercury.

BULK MODULUS OF ELASTICITY (E)

The bulk modulus of elasticity (E) expresses the compressibility of a fluid. It is the ratio of the change in unit pressure to the corresponding volume change per unit of volume.

$$E = \frac{dp}{-dv/v} \tag{11}$$

Because a pressure increase, dp, results in a decrease in fractional volume, dv/v, the minus is inserted to render E positive. Clearly, the units of E are those of pressure—Pa or lb/in^2.

ISOTHERMAL CONDITIONS

For a fixed temperature, the ideal gas law, equation (3) or (5), becomes

$$p_1 v_1 = p_2 v_2 \qquad \text{and} \qquad \frac{\gamma_1}{\gamma_2} = \frac{p_1}{p_2} = \text{constant} \tag{12}$$

Also,

$$\text{bulk modulus } E = p \tag{13}$$

ADIABATIC OR ISENTROPIC CONDITIONS

If no heat is exchanged between the gas and its container, equations (12) and (13) are replaced by

$$p_1 v_1^k = p_2 v_2^k \qquad \text{or} \qquad \left(\frac{\gamma_1}{\gamma_2}\right)^k = \frac{p_1}{p_2} = \text{constant} \tag{14}$$

Also,

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{(k-1)/k} \tag{15}$$

and

$$\text{bulk modulus } E = kp \tag{16}$$

Here k is the ratio of the specific heat at constant pressure to the specific heat at constant volume.

PRESSURE DISTURBANCES

Pressure disturbances imposed on a fluid move in waves, at speed

$$c = \sqrt{E/\rho} \tag{17}$$

For gases, the acoustic velocity is

$$c = \sqrt{kp/\rho} = \sqrt{kgRT} \tag{18}$$

Solved Problems

1.1. Calculate the specific weight γ, specific volume v_s, and density ρ of methane at 100°F and 120 psi absolute.

Solution:

From Table 1A in the Appendix, $R = 96.3$ ft/°R.

$$\text{specific weight } \gamma = \frac{p}{RT} = \frac{120 \times 144}{(96.3)(460 + 100)} = 0.320 \text{ lb/ft}^3$$

$$\text{density } \rho = \frac{\gamma}{g} = \frac{0.320}{32.2} = 0.00994 \text{ slug/ft}^3$$

$$\text{specific volume } v_s = \frac{1}{\rho} = \frac{1}{0.00994} = 101 \text{ ft}^3\text{/slug}$$

1.2. If 6 m^3 of oil weighs 47 kN, calculate its specific weight γ, density ρ, and specific gravity.

Solution:

$$\text{specific weight } \gamma = \frac{47 \text{ kN}}{6 \text{ m}^3} = 7.833 \text{ kN/m}^3$$

$$\text{density } \rho = \frac{\gamma}{g} = \frac{7833 \text{ N/m}^3}{9.81 \text{ m/s}^2} = 798 \text{ kg/m}^3$$

$$\text{specific gravity } = \frac{\gamma_{\text{oil}}}{\gamma_{\text{water}}} = \frac{7.833 \text{ kN/m}^3}{9.79 \text{ kN/m}^3} = 0.800$$

1.3. At 90°F and 30.0 psi absolute the volume per unit weight of a certain gas was 11.4 ft^3/lb. Determine its gas constant R and the density ρ.

Solution:

Since $\gamma = \dfrac{p}{RT}$,

$$R = \frac{p}{\gamma T} = \frac{pv}{T} = \frac{(30.0 \times 144)(11.4)}{460 + 90} = 89.5 \text{ ft/°R}$$

$$\text{density } \rho = \frac{\gamma}{g} = \frac{1/v}{g} = \frac{1}{vg} = \frac{1}{11.4 \times 32.2} = 0.00272 \text{ slug/ft}^3$$

1.4. (*a*) Find the change in volume of 1.00 ft^3 of water at 80°F when subjected to a pressure increase of 300 psi.

(*b*) From the following test data determine the bulk modulus of elasticity of water: at 500 psi the volume was 1.000 ft^3, and at 3500 psi the volume was 0.990 ft^3.

Solution:

(*a*) From Table 1C in the Appendix, E at 80°F is 325,000 psi. Using formula (*11*),

$$dv = -\frac{v\,dp}{E} = -\frac{1.00 \times 300}{325{,}000} = -0.00092 \text{ ft}^3$$

(*b*)

$$E = -\frac{dp}{dv/v} = -\frac{3500 - 500}{(0.990 - 1.000)/1.000} = 3 \times 10^5 \text{ psi}$$

1.5. At a great depth in the ocean, the pressure is 80 MPa. Assume that specific weight at the surface is 10 kN/m^3 and the average bulk modulus of elasticity is 2.340 GPa. Find: (*a*) the change in specific volume between the surface and that great depth, (*b*) the specific volume at that depth, and (*c*) the specific weight at that depth.

Solution:

(*a*)
$$(v_s)_1 = \frac{1}{\rho_1} = \frac{g}{\gamma_1} = \frac{9.81}{10 \times 10^3} = 9.81 \times 10^{-4}\ \text{m}^3/\text{kg}$$

$$E = \frac{dp}{-dv_s/v_s}$$

$$2.340 \times 10^9 = \frac{(80 \times 10^6) - 0}{dv_s/(9.81 \times 10^{-4})}$$

$$dv_s = -0.335 \times 10^{-4}\ \text{m}^3/\text{kg}$$

(*b*)
$$(v_s)_2 = (v_s)_1 + dv_s = (9.81 - 0.335) \times 10^{-4} = 9.475 \times 10^{-4}\ \text{m}^3/\text{kg}$$

(*c*)
$$\gamma_2 = g/(v_s)_2 = 9.81/(9.475 \times 10^{-4}) = 10.35\ \text{kN/m}^3$$

1.6. A cylinder contains 12.5 ft^3 of air at 120°F and 40 psi absolute. The air is compressed to 2.50 ft^3. (*a*) Assuming isothermal conditions, what is the pressure at the new volume, and what is the bulk modulus of elasticity? (*b*) Assuming adiabatic conditions, what is the final pressure and temperature, and what is the bulk modulus of elasticity?

Solution:

(*a*) For isothermal conditions, $p_1 v_1 = p_2 v_2$

Then $(40 \times 144)(12.5) = (p_2 \times 144)(2.50)$ and $p_2 = 200$ psi absolute

The bulk modulus $E = p = 200$ psi.

(*b*) For adiabatic conditions, $p_1 v_1^k = p_2 v_2^k$, and Table 1A in the Appendix gives $k = 1.40$.

Then $(40 \times 144)(12.5)^{1.40} = (p_2 \times 144)(2.50)^{1.40}$ and $p_2 = 381$ psi absolute

The final temperature is obtained by using equation (*15*):

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{(k-1)/k}, \qquad \frac{T_2}{460 + 120} = \left(\frac{381}{40}\right)^{0.40/1.40}, \qquad T_2 = 1104°R = 644°F$$

The bulk modulus $E = kp = 1.40 \times 381 = 533$ psi.

1.7. From the International Critical Tables, the viscosity of water at 20°C (68°F) is 1.008 cp (centipoises). (*a*) Compute the absolute viscosity in lb-sec/ft^2. (*b*) If the specific gravity at 20°C is 0.998, compute the kinematic viscosity in ft^2/sec.

Solution:

Using 1 poise = 1 dyne-sec/cm^2, 1 lb = 444,800 dynes, and 1 ft = 30.48 cm, we obtain

$$1\,\frac{\text{lb-sec}}{\text{ft}^2} = \frac{444{,}800\ \text{dyne-sec}}{(30.48\ \text{cm})^2} = 478.8\ \text{poises}$$

(*a*)
$$\mu = \frac{1.008 \times 10^{-2}\ \text{poise}}{(478.8\ \text{poise})/(\text{lb-sec/ft}^2)} = 2.11 \times 10^{-5}\,\frac{\text{lb-sec}}{\text{ft}^2}$$