SCHAUM'S SOLVED PROBLEMS SERIES

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FLUID MECHANICS AND HYDRAULICS

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by

Jack B. Evett, Ph.D

Cheng Liu, Ph.D

University of North Carolina at Charlotte

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Jack B. Evett, Ph.D., *Professor of Civil Engineering*, and Cheng Liu, M.S., *Associate Professor of Civil Engineering Technology*, both at the *University of North Carolina at Charlotte*.

Both authors have extensive teaching experience in the domain of fluid mechanics and hydraulics. They are coauthors of a textbook in fluid mechanics for the McGraw-Hill College Division.

Other Contributors to This Volume

Robert L. Daugherty, Ph.D., *California Institute of Technology*

E. John Finnemore, Ph.D., *University of Santa Clara*

Joseph B. Franzini, Ph.D., *Stanford University*

Ranald V. Giles, Ph.D., *Drexel Institute of Technology*

Max A. Kohler, Ph.D., *U.S. National Weather Service*

Ray K. Linsley, Ph.D., *Stanford University*

Alan Mironer, Ph.D., *University of Lowell*

Irving H. Shames, Ph.D., *State University of New York at Buffalo*

Victor L. Streeter, Ph.D., *University of Michigan*

Frank M. White, Ph.D., *University of Rhode Island*

E. Benjamin Wylie, Ph.D., *University of Michigan*

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To the Student

This book contains precisely 2500 completely solved problems in the areas of fluid mechanics and hydraulics. Virtually all types of problems ordinarily encountered in study and practice in these areas are covered. Not only you, but teachers, practitioners, and graduates reviewing for engineering licensing examinations should find these problems valuable.

To acquaint you with our "approach," particular steps taken in presenting the problems and their solutions are itemized below.

- First and most important of all, each problem and its solution are essentially independent and self-contained. That is to say, each contains all the data, equations, and computations necessary to find the answers. Thus, you should be able to pick a problem anywhere and follow its solution without having to review whatever precedes it. The exception to this is the occasional problem that specifically refers to, and carries over information from, a previous problem.
- In the solutions, our objective has been to present any needed equation first and then clearly to evaluate each term in the equation in order to find the answer. The terms may be evaluated separately or within the equation itself. For example, when solving an equation that has the parameter "area" as one of its terms, the area term (A) may be evaluated separately and its value substituted into the equation [as in Prob. 14.209], or it may be evaluated within the equation itself [as in Prob. 14.94].
- Virtually every number appearing in a solution is either "given" information (appearing as data in the statement of the problem or on an accompanying illustration), a previously computed value within the problem, a conversion factor (obtainable from the List of Conversion Factors), or a physical property (obtainable from a table or illustration in the Appendix). For example, in Prob. 1.77, the number 1.49, which does not appear elsewhere in the problem, is the dynamic viscosity (μ) of glycerin; it was obtained from Fig. A-3 in the Appendix.
- We have tried to include all but the most familiar items in the List of Abbreviations and Symbols. Hence, when an unknown sign is encountered in a problem or its solution, a scan of that list should prove helpful. Thus, the infrequently used symbol ψ is encountered in Prob. 25.6. According to the list, ψ represents the stream function, and you are quickly on your way to a solution.

Every problem solution in this book has been checked, but, with 2500 in all, it is inevitable that some mistakes will slip through. We would appreciate it if you would take the time to communicate any mistakes you find to us, so that they may be corrected in future printings. We wish to thank Bill Langley, of The University of North Carolina at Charlotte, who assisted us with some of the problem selection and preparation.

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Fundamentals of Fluid Mechanics, Jack B. Evett and Cheng Liu, 1987.
Fluid Mechanics, 2d ed., Frank M. White, 1986.
Fluid Mechanics with Engineering Applications, 8th ed., Robert L. Daugherty, Joseph B. Franzini, and E. John Finnemore, 1985.
Fluid Mechanics, 8th ed., Victor L. Streeter and E. Benjamin Wylie, 1985.
Mechanics of Fluids, 2d ed., Irving H. Shames, 1982.

Schaum's Outline Series: *Theory and Problems of Fluid Mechanics and Hydraulics,* 2d ed., Ranald V. Giles, 1962.

Water Resources Engineering, 3d ed., Ray K. Linsley and Joseph B. Franzini, 1979.

Engineering Fluid Mechanics, Alan Mironer, 1979.

Hydrology for Engineers, 3d ed., Ray K. Linsley, Max A. Kohler, and Joseph L. H. Paulhus, 1982.

Abbreviations and Symbols

a	acceleration or area
A	area
abs	absolute
α (alpha)	angle between absolute velocity of fluid in hydraulic machine and linear velocity of a point on a rotating body or coefficient of thermal expansion or dimensionless ratio of similitude
atm	atmosphere
atmos	atmospheric
β (beta)	angle between relative velocity in hydraulic machines and linear velocity of a point on a rotating body or coefficient of compressibility or ratio of obstruction diameter to duct diameter
b	surface width or other width
B	surface width or other width
bhp	brake horsepower
bp	brake power
Btu	British thermal unit
c	speed of sound or wave speed (celerity)
C	Celsius or discharge coefficient or speed of propagation
cal	calorie
c.b. or CB	center of buoyancy
C_c	coefficient of contraction
C_d	coefficient of discharge
C_D	drag coefficient
C_f	friction-drag coefficient
C_F	force coefficient
cfs	cubic foot per second
c.g. or CG	center of gravity
C_I	Pitot tube coefficient
C_L	lift coefficient
cm	centimeter (10^{-2} m)
cP	centipoise
c.p.	center of pressure
c_p	specific heat at constant pressure
c_v	specific heat at constant volume
C_v	coefficient of velocity
C_w	weir coefficient
d	depth or diameter
D	depth or diameter or drag force
δ (delta)	thickness of boundary layer
δ_1 (delta)	thickness of the viscous sublayer
Δ (Delta)	change in (or difference between)
d_c	critical depth
D_{eff}	effective diameter
D_h	hydraulic diameter
d_m	mean depth
d_n	normal depth
d_N	normal depth
E	modulus of elasticity or specific energy or velocity approach factor
e_h	hydraulic efficiency
el	elevation
η (eta)	pump or turbine efficiency
ϵ (epsilon)	height or surface roughness
E_p	pump energy
E_t	turbine energy
exp	exponential
f	frequency of oscillation (cycles per second) or friction factor

F	Fahrenheit or force
F_b	buoyant force
F_D	drag force
F_H	horizontal force
F_L	lift force
fps	foot per second
F.S.	factor of safety
ft	foot
F_U	uplift force on a dam
F_V	vertical force
g	acceleration due to gravity or gage height or gram
G_w	weight flow rate
gal	gallon
γ (gamma)	specific (or unit) weight
Γ (Gamma)	circulation
GN	giganewton (10^9 N)
GPa	gigapascal (10^9 Pa)
gpm	gallons per minute
h	enthalpy per unit mass or height or depth or pressure head or hour
$\bar{h}$	average height or depth or head
$\hat{h}$	enthalpy per unit weight
H	energy head or total energy head
h_1	unit head loss
h_{cg}	vertical depth to center of gravity
h_{cp}	vertical depth to center of pressure
h_f	head loss due to friction
Hg	mercury
HGL	hydraulic grade line
h_L	total head loss
h_m	head loss due to minor losses
hp	horsepower
Hz	hertz (cycles per second)
I	inflow or moment of inertia
ID	inside diameter
in	inch
∞ (infinity)	sometimes used as a subscript to indicate upstream
J	joule
K	bulk modulus of elasticity or Kelvin or minor loss coefficient
k	specific heat ratio
kcal	kilocalorie (10^3 cal)
kg	kilogram (10^3 g)
kJ	kilojoule (10^3 J)
km	kilometer (10^3 m)
kN	kilonewton (10^3 N)
kPa	kilopascal (10^3 Pa)
kW	kilowatt (10^3 W)
L	length or lift force or liter
λ (lambda)	model ratio or wave length
lb	pound
lb_m	pound mass
L_e	equivalent length
L_m	linear dimension in model
L_p	linear dimension in prototype
m	mass or meter
$\dot{m}$	mass flow rate
M	mass flow rate or molecular weight or moment or torque
$\overline{MB}$	distance from center of buoyancy to metacenter
mbar	millibar (10^{-3} bar)
mc	metacenter
mgd	million gallons per day

ml	milliliter (10^{-3} L)
min	minute
mm	millimeter (10^{-3} meter)
MN	meganewton (10^6 N)
MPa	megapascal (10^6 Pa)
mph	mile per hour
MR	manometer reading
μ (mu)	absolute or dynamic viscosity
MW	megawatt (10^6 W)
n	Manning roughness coefficient or number of moles
N	newton or rotational speed
N_B	Brinkman number
N_F	Froude number
N_M	Mach number
NPSH	net positive suction head
N_R	Reynolds number
N_s	specific speed of pump or turbine
ν (nu)	kinematic viscosity
N_W	Weber number
O	outflow
OD	outside diameter
Ω (ohm)	rotational rate
ω (omega)	angular velocity
p	pressure or poise
P	force (usually resulting from an applied pressure) or power
Pa	pascal
ϕ (phi)	peripheral-velocity factor
π (pi)	constant = 3.14159265
Π (pi)	dimensionless parameter
P_r	power ratio
p_s	stagnation pressure
psi	pound per square inch
ψ (psi)	stream function
psia	pound per square inch absolute
psig	pound per square inch gage
$p^{*\prime}$	pressure for condition at $N_M = 1/\sqrt{k}$
p_v	vapor pressure
p_w	wetted perimeter
q	flow rate per unit width or heat per unit mass
Q	discharge or heat or volume flow rate
Q_H	heat transferred per unit weight of fluid
Q/w	volume flow rate per unit width of channel
qt	quart
r	radius
R	gas constant or Rankine or resultant force
R'	manometer reading
rad	radian
R_c	critical hydraulic radius
R_h	hydraulic radius
ρ (rho)	mass density
r_i	inside radius
r_o	outside radius
rpm	revolutions per minute
R_u	universal gas constant
s	entropy of a substance or second or [illegible]
S	slope or storage
s_c	critical slope
s.g.	specific gravity
s.g.$_M$	specific gravity of manometer fluid
s.g.$_F$	specific gravity of flowing fluid

σ (sigma)	pump cavitation parameter or stress or surface tension
σ'	cavitation index
Σ (sigma)	summation
S	specific gravity of flowing fluid
S_0	specific gravity of manometer fluid
t	thickness or time
T	surface width or temperature or torque or tension
τ (tau)	shear stress
τ_0 (tau)	shear stress at the wall
T_s	stagnation temperature
u	velocity
$u_{\text{℄}}$	centerline velocity
U	velocity
v	velocity
v_c	critical velocity
V	velocity or volume
v_{av}	average velocity
$V_{\text{℄}}$	centerline velocity
V_d	volume of fluid displaced
V_m	velocity in model
V_p	velocity in prototype
V_s	specific volume
v_*	shear velocity
v_t	tangential velocity
v_T	terminal velocity
w	width
W	watt or weight or weight flow rate or work
x_{cp}	distance from center of gravity to center of pressure in x direction
ξ (xi)	vorticity
y	depth
y_c	critical depth
y_{cp}	distance from center of gravity to center of pressure in y direction
y_n	normal depth
y_N	normal depth
z_{cg}	inclined distance from liquid surface to center of gravity
z_{cp}	inclined distance from liquid surface to center of pressure

Conversion Factors

$0.00001667\ m^3/s = 1\ L/min$
$0.002228\ ft^3/s = 1\ gal/min$
$0.0145\ lb/in^2 = 1\ mbar$
$0.100\ kN/m^2 = 1\ mbar$
$0.3048\ m = 1\ ft$
$2.54\ cm = 1\ in$
$3.281\ ft = 1\ m$
$4\ qt = 1\ gal$
$4.187\ kJ = 1\ kcal$
$4.448\ N = 1\ lb$
$6.894\ kN/m^2 = 1\ lb/in^2$
$7.48\ gal = 1\ ft^3$
$12\ in = 1\ ft$
$14.59\ kg = 1\ slug$
$25.4\ mm = 1\ in$
$60\ min = 1\ h$
$60\ s = 1\ min$
$100\ cm = 1\ m$
$100\ N/m^2 = 1\ bar$
$101.3\ kPa = 1\ atm$
$144\ in^2 = 1\ ft^2$
$550\ ft\text{-}lb/s = 1\ hp$
$778\ ft\text{-}lb = 1\ Btu$
$1000\ N = 1\ kN$
$1000\ L = 1\ m^3$
$1000\ mm = 1\ m$
$1000\ Pa = 1\ kPa$
$1728\ in^3 = 1\ ft^3$
$2000\ lb = 1\ ton$
$3600\ s = 1\ h$
$4187\ J = 1\ kcal$
$5280\ ft = 1\ mile$
$86\,400\ s = 1\ day$
$1\,000\,000\ N = 1\ MN$
$1\,000\,000\ Pa = 1\ MPa$
$1\,000\,000\,000\ N = 1\ GN$
$1\,000\,000\,000\ Pa = 1\ GPa$

CONTENTS

CHAPTER 1
Properties of Fluids

Note: For many problems in this chapter, values of various physical properties of fluids are obtained from Tables A-1 through A-8 in the Appendix.

1.1 A reservoir of glycerin (glyc) has a mass of 1200 kg and a volume of 0.952 m³. Find the glycerin's weight (W), mass density (ρ), specific weight (γ), and specific gravity (s.g.).

$$F = W = ma = (1200)(9.81) = 11\,770\ \text{N} \quad \text{or} \quad 11.77\ \text{kN}$$
$$\rho = m/V = 1200/0.952 = 1261\ \text{kg/m}^3$$
$$\gamma = W/V = 11.77/0.952 = 12.36\ \text{kN/m}^3$$
$$\text{s.g.} = \gamma_{\text{glyc}}/\gamma_{\text{H}_2\text{O at 4}^\circ\text{C}} = 12.36/9.81 = 1.26$$

1.2 A body requires a force of 100 N to accelerate it at a rate of 0.20 m/s². Determine the mass of the body in kilograms and in slugs.

$$F = ma$$
$$100 = (m)(0.20)$$
$$m = 500\ \text{kg} = 500/14.59 = 34.3\ \text{slugs}$$

1.3 A reservoir of carbon tetrachloride (CCl_4) has a mass of 500 kg and a volume of 0.315 m³. Find the carbon tetrachloride's weight, mass density, specific weight, and specific gravity.

$$F = W = ma = (500)(9.81) = 4905\ \text{N} \quad \text{or} \quad 4.905\ \text{kN}$$
$$\rho = m/V = 500/0.315 = 1587\ \text{kg/m}^3$$
$$\gamma = W/V = 4.905/0.315 = 15.57\ \text{kN/m}^3$$
$$\text{s.g.} = \gamma_{\text{CCl}_4}/\gamma_{\text{H}_2\text{O at 4}^\circ\text{C}} = 15.57/9.81 = 1.59$$

1.4 The weight of a body is 100 lb. Determine **(a)** its weight in newtons, **(b)** its mass in kilograms, and **(c)** the rate of acceleration [in both feet per second per second (ft/s²) and meters per second per second (m/s²)] if a net force of 50 lb is applied to the body.

(a) $W = (100)(4.448) = 444.8\ \text{N}$

(b) $F = W = ma \qquad 444.8 = (m)(9.81) \qquad m = 45.34\ \text{kg}$

(c) $m = 45.34/14.59 = 3.108\ \text{slugs}$

$$F = ma \qquad 50 = 3.108a \qquad a = 16.09\ \text{ft/s}^2 = (16.09)(0.3048) = 4.904\ \text{m/s}^2$$

1.5 The specific gravity of ethyl alcohol is 0.79. Calculate its specific weight (in both pounds per cubic foot and kilonewtons per cubic meter) and mass density (in both slugs per cubic foot and kilograms per cubic meter).

$$\gamma = (0.79)(62.4) = 49.3\ \text{lb/ft}^3 \qquad \gamma = (0.79)(9.79) = 7.73\ \text{kN/m}^3$$
$$\rho = (0.79)(1.94) = 1.53\ \text{slugs/ft}^3 \qquad \rho = (0.79)(1000) = 790\ \text{kg/m}^3$$

1.6 A quart of water weights about 2.08 lb. Compute its mass in slugs and in kilograms.

$$F = W = ma \qquad 2.08 = (m)(32.2)$$
$$m = 0.0646\ \text{slug} \qquad m = (0.0646)(14.59) = 0.943\ \text{kg}$$

1.7 One cubic foot of glycerin has a mass of 2.44 slugs. Find its specific weight in both pounds per cubic foot and kilonewtons per cubic meter.

$F = W = ma = (2.44)(32.2) = 78.6\ \text{lb}$. Since the glycerin's volume is 1 ft³, $\gamma = 78.6\ \text{lb/ft}^3 = (78.6)(4.448)/(0.3048)^3 = 12\,350\ \text{N/m}^3$, or $12.35\ \text{kN/m}^3$.

1.8 A quart of SAE 30 oil at 68 °F weighs about 1.85 lb. Calculate the oil's specific weight, mass density, and specific gravity.

▮

$$V = 1/[(4)(7.48)] = 0.03342\ \text{ft}^3$$
$$\gamma = W/V = 1.85/0.03342 = 55.4\ \text{lb/ft}^3$$
$$\rho = \gamma/g = 55.4/32.2 = 1.72\ \text{slugs/ft}^3$$
$$\text{s.g.} = \gamma_{\text{oil}}/\gamma_{H_2O \text{ at } 4\,°C} = 55.4/62.4 = 0.888$$

1.9 The volume of a rock is found to be 0.00015 m³. If the rock's specific gravity is 2.60, what is its weight?

▮ $\gamma_{\text{rock}} = (2.60)(9.79) = 25.5\ \text{kN/m}^3$ $\quad W_{\text{rock}} = (25.5)(0.00015) = 0.00382\ \text{kN}$ or $3.82\ \text{N}$

1.10 A certain gasoline weighs 46.0 lb/ft³. What are its mass density, specific volume, and specific gravity?

▮ $\rho = \gamma/g = 46.0/32.2 = 1.43\ \text{slugs/ft}^3$ $\quad V_s = 1/\rho = 1/1.43 = 0.699\ \text{ft}^3/\text{slug}$

$\text{s.g.} = 1.43/1.94 = 0.737$

1.11 If the specific weight of a liquid is 8000 N/m³, what is its mass density?

▮

$$\rho = \gamma/g = 8000/9.81 = 815\ \text{kg/m}^3$$

1.12 An object at a certain location has a mass of 2.0 kg and weighs 19.0 N on a spring balance. What is the acceleration due to gravity at this location?

▮

$$F = W = ma \qquad 19.0 = 2.0a \qquad a = 9.50\ \text{m/s}^2$$

1.13 If an object has a mass of 2.0 slugs at sea level, what would its mass be at a location where the acceleration due to gravity is 30.00 ft/s²?

▮ Since the mass of an object does not change, its mass will be 2.0 slugs at that location.

1.14 What would be the weight of a 3-kg mass on a planet where the acceleration due to gravity is 10.00 m/s²?

▮

$$F = W = ma = (3)(10.00) = 30.00\ \text{N}$$

1.15 Determine the weight of a mass of 3 slugs at a place where the acceleration due to gravity is 31.7 ft/s².

▮

$$F = W = ma = (3)(31.7) = 95.1\ \text{lb}$$

1.16 If 200 ft³ of oil weighs 10 520 lb, calculate its specific weight, density, and specific gravity.

▮ $\gamma = W/V = 10\,520/200 = 52.6\ \text{lb/ft}^3$ $\quad \rho = \gamma/g = 52.6/32.2 = 1.63\ \text{slugs/ft}^3$

$\text{s.g.} = \gamma_{\text{oil}}/\gamma_{H_2O \text{ at } 4\,°C} = 52.6/62.4 = 0.843$

1.17 How high will the free surface be if 1 ft³ of water is poured into a container that is a right circular cone 18 in high with a base radius of 10 in? How much additional water is required to fill the container?

▮ $V_{\text{cone}} = \pi r^2 h/3 = \pi(10)^2(18)/3 = 1885\ \text{in}^3$ $\quad V_{H_2O} = 1\ \text{ft}^3 = 1728\ \text{in}^3$

Additional water to fill container $= 1885 - 1728 = 157\ \text{in}^3$. From Fig. 1-1, $r_o/10 = h_o/18$, or $r_o = h_o/1.8$; $V_{\text{empty (top) cone}} = \pi(h_o/1.8)^2 h_o/3 = 157$; $h_o = 7.86$ in. Free surface will be $18 - 7.86$, or 10.14 in above bottom of container.

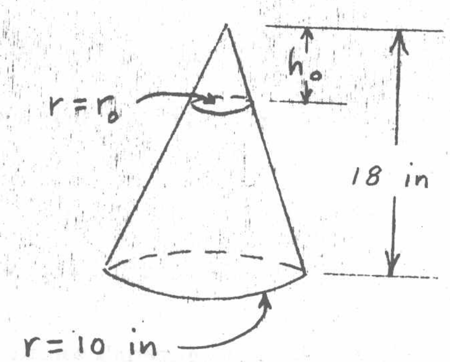

Fig. 1-1

1.18 If the conical container in Prob. 1.17 can be filled with 27.0 kg of a certain oil, what is the density of the oil?

$$V_{cone} = 1885\ \text{in}^3 \quad \text{(from Prob. 1.17)}$$
$$= \tfrac{1885}{1728}(0.3048)^3 = 0.03089\ \text{m}^3$$
$$\rho = m/V = 27.0/0.03089 = 874\ \text{kg/m}^3$$

1.19 A certain gas weights 0.10 lb/ft³ at a certain temperature and pressure. What are the values of its density, specific volume, and specific gravity relative to air weighing 0.075 lb/ft³?

$$\rho = \gamma/g = 0.10/32.2 = 0.00311\ \text{slug/ft}^3 \qquad V_s = 1/\rho = 1/0.00311 = 322\ \text{ft}^3/\text{slug}$$
$$\text{s.g.} = 0.10/0.075 = 1.333$$

1.20 If the specific volume of a gas is 350 ft³/slug, what is its specific weight?

$$\rho = 1/V_s = \tfrac{1}{350} = 0.002857\ \text{slug/ft}^3 \qquad \gamma = \rho g = (0.002857)(32.2) = 0.0920\ \text{lb/ft}^3$$

1.21 Initially, when 1000.00 ml of water at 10 °C is poured into a glass cylinder, the depth of the water column is 100.00 cm. The water and its container are heated to 80 °C. Assuming no evaporation, what will be the depth of the water column if the cofficient of thermal expansion (α) for the glass is 3.6×10^{-6} per °C?

Mass of water $= \rho V = \rho_{10}V_{10} = \rho_{80}V_{80}$ $\quad (1000)(1000.00/1000) = 971V_{80} \quad V_{80} = 1.030\ \text{m}^3$ or $1030\ \text{cm}^3$

$$A_{10} = V_{10}/h_{10} = 1000.00/100.00 = 10.000\ \text{cm}^2$$
$$A_{10} = \pi r_{10}^2 \qquad 10.000 = \pi r_{10}^2 \qquad r_{10} = 1.7841\ \text{cm}$$
$$r_{80} = r_{10}[1 + (\Delta T)(\alpha)] = (1.7841)[1 + (80-10)(3.6\times10^{-6})] = 1.7845\ \text{cm}$$
$$A_{80} = \pi r_{80}^2 = \pi(1.7845)^2 = 10.004\ \text{cm}^2 \qquad h_{80} = V_{80}/A_{80} = 1030/10.004 = 102.96\ \text{cm}$$

1.22 A vessel contains 3.000 ft³ of water at 50 °F and atmospheric pressure. If it is heated to 160 °F, what will be the percentage change in its volume? What weight of water must be removed to maintain the volume at the origin value?

$$\text{Weight of water} = \gamma V = \gamma_{50}V_{50} = \gamma_{160}V_{160} \qquad (62.4)(3.000) = 61.0V_{160} \qquad V_{160} = 3.0689\ \text{ft}^3$$

Change in volume = (3.0689 − 3.000)/3.000 = 0.023, or 2.3% (increase). Must remove (3.0689 − 3.000)(61.0), or 4.20 lb.

1.23 A vertical, cylindrical tank with a diameter of 10.00 m and a depth of 5.00 m contains water at 20 °C and is filled to the brim. If the water is heated to 50 °C, how must water will spill over the edge of the tank?

$$V_{tank} = (V_{H_2O})_{20} = \pi(10.00/2)^2(5.00) = 392.7\ \text{m}^3$$
$$W_{H_2O} = (9.79)(392.7) = 3845\ \text{kN} \qquad (V_{H_2O})_{50} = 3845/9.69 = 396.8\ \text{m}^3$$
$$\text{Amount of water spilled} = 396.8 - 392.7 = 4.1\ \text{m}^3$$

1.24 A closed heavy steel chamber is filled with water at 50 °F and atmospheric pressure. If the temperature of water and chamber is raised to 90 °F, what will be the new pressure of the water? Assume the chamber is unaffected by the water pressure. The coefficient of thermal expansion of steel (α) is 6.5×10^{-6} per °F.

The volume of water would attempt to expand proportional to the cube of the linear thermal expansion. Hence, $V_{90} = V_{50}[1 + (90-50)(6.5\times10^{-6})]^3 = 1.000780V_{50}$; weight of water $= \gamma V = \gamma_{50}V_{50} = \gamma_{90}V_{90}$, $62.4V_{50} = \gamma_{90}(1.000780V_{50})$, $\gamma_{90} = 62.35\ \text{lb/ft}^3$. From Fig. A-3, $p_{90} = 1300$ psia (approximately).

1.25 A liquid compressed in a cylinder has a volume of 1000 cm³ at 1 MN/m² and a volume of 995 cm³ at 2 MN/m². What is its bulk modulus of elasticity (K)?

$$K = -\frac{\Delta p}{\Delta V/V} = -\frac{2-1}{(995-1000)/1000} = 200\ \text{MPa}$$

1.26 Find the bulk modulus of elasticity of a liquid if a pressure of 150 psi applied to 10 ft³ of the liquid causes a volume reduction of 0.02 ft³.

$$K = -\frac{\Delta p}{\Delta V/V} = -\frac{(150-0)(144)}{-0.02/10} = 10\,800\,000\ \text{lb/ft}^2 \quad \text{or} \quad 75\,000\ \text{psi}$$

1.27 For $K = 2.2$ GPa for the bulk modulus of elasticity for water, what pressure is required to reduce its volume by 0.5 percent?

$$K = -\frac{\Delta p}{\Delta V/V} \qquad 2.2 = -\frac{p_2 - 0}{-0.005} \qquad p_2 = 0.0110 \text{ GPa} \quad \text{or} \quad 11.0 \text{ MPa}$$

1.28 Find the change in volume of 1.00000 ft³ of water at 80 °F when subjected to a pressure increase of 300 psi. Water's bulk modulus of elasticity at this temperature is 325 000 psi.

$$K = -\frac{\Delta p}{\Delta V/V} \qquad 325\,000 = -\frac{300 - 0}{\Delta V/1.00000} \qquad \Delta V = -0.00092 \text{ ft}^3$$

1.29 From the following test data, determine the bulk modulus of elasticity of water: at 500 psi the volume was 1.000 ft³, and at 3500 psi the volume was 0.990 ft³.

$$K = -\frac{\Delta p}{\Delta V/V} = -\frac{500 - 3500}{(1.000 - 0.990)/1.000} = 300\,000 \text{ psi}$$

1.30 A high-pressure steel container is partially full of a liquid at a pressure of 10 atm. The volume of the liquid is 1.23200 L. At a pressure of 25 atm, the volume of the liquid equals 1.23100 L. What is the average bulk modulus of elasticity of the liquid over the given range of pressure if the temperature after compression is allowed to return to the original temperature? What is the coefficient of compressibility (β)?

$$K = -\frac{\Delta p}{\Delta V/V} = -\frac{(25 - 10)(101.3)}{(1.23100 - 1.23200)/1.23200} = 1.872 \times 10^6 \text{ kN/m}^2 \quad \text{or} \quad 1872 \text{ MN/m}^2$$

$$\beta = 1/K = \tfrac{1}{1872} = 0.000534 \text{ m}^2/\text{MN}$$

1.31 A heavy tank contains oil (A) and water (B) over which air pressure is varied. The dimensions shown in Fig. 1-2 correspond to the atmospheric pressure of the air. If air is slowly added from a pump to bring pressure p up to 1 MPa gage, what will be the total downward movement of the free surface of oil and air? Take average values of bulk moduli of elasticity of the liquids to be, for the pressure range, 2050 MN/m² for oil and 2075 MN/m² for water. Assume the container does not change volume. Neglect hydrostatic pressures.

$$K = -\frac{\Delta p}{\Delta V/V} \qquad 2050 = -\frac{1 - 0}{\Delta V_{\text{oil}}/[\frac{500}{1000}\pi(\frac{300}{1000})^2/4]} \qquad \Delta V_{\text{oil}} = -0.00001724 \text{ m}^3$$

$$2075 = -\frac{1 - 0}{\Delta V_{H_2O}/[\frac{800}{1000}\pi(\frac{300}{1000})^2/4]} \qquad \Delta V_{H_2O} = -0.00002725 \text{ m}^3$$

$$\Delta V_{\text{total}} = -0.00001724 + (-0.00002725) = -0.00004449 \text{ m}^3$$

Let x = the distance the upper free surface moves. $-0.00004449 = -[\pi(\frac{300}{1000})^2/4]x$, $x = 0.000629$ m or 0.629 mm.

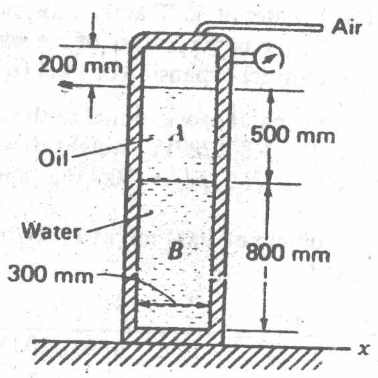

Fig. 1-2

1.32 Water at a pressure of 4442 psig is forced into a thin-walled spherical tank. If the water is then released from the tank, how much water will be collected at atmospheric pressure? The deformed inside volume in the tank is

800.4069 in^3 when the pressure is 4442 psig. Use a value of 305 000 psi for an average value of the bulk modulus of elasticity.

▌ $$K = -\frac{\Delta p}{\Delta V/V} \qquad 305\,000 = -\frac{0 - 4442}{(V_2 - 800.4069)/800.4069} \qquad V_2 = 812.06\ \text{in}^3$$

$$W = (62.4)(812.06/1728) = 29.3\ \text{lb}$$

1.33 Water in a hydraulic press is subjected to a pressure of 15 000 psia at 68 °F. If the initial pressure is 15 psia, what will be the percentage decrease in specific volume? Use an average bulk modulus of elasticity of 365 000 psi for this pressure range.

▌ $$K = -\frac{\Delta p}{\Delta V/V} \qquad 365\,000 = -\frac{15\,000 - 15}{\Delta V/V_1} \qquad \frac{\Delta V}{V_1} = -0.0411 \quad \text{or} \quad 4.11\%\ \text{decrease}$$

1.34 At a depth of 8 km in the ocean, the pressure is 81.8 MPa. Assume specific weight at the surface is 10 050 N/m^3 and the average bulk modulus of elasticity is $2.34 \times 10^9\ N/m^2$ for that pressure range. (*a*) What will be the change in specific volume between that at the surface and at that depth? (*b*) What will be the specific volume at that depth? (*c*) What will be the specific weight at that depth?

▌ (*a*) $$(V_s)_1 = 1/\rho_1 = g/\gamma_1 = 9.81/10\,050 = 0.0009761\ \text{m}^3/\text{kg}$$

$$K = -\frac{\Delta p}{\Delta V_s/V_s} \qquad 2.34 \times 10^9 = -\frac{81.8 \times 10^6 - 0}{\Delta V_s/0.0009761} \qquad \Delta V_s = -0.0000341\ \text{m}^3/\text{kg}$$

(*b*) $$(V_s)_2 = (V_s)_1 + \Delta V_s = 0.0009761 - 0.0000341 = 0.000942\ \text{m}^3/\text{kg}$$

(*c*) $$\gamma_2 = g/V_2 = 9.81/0.000942 = 10\,414\ \text{N/m}^3$$

1.35 Approximately what pressure must be applied to water at 60 °F to reduce its volume 2 percent?

▌ $$K = -\frac{\Delta p}{\Delta V/V} \qquad 311\,000 = -\frac{p_2 - 0}{0.02} \qquad p_2 = 6220\ \text{psi}$$

1.36 A gas at 20 °C and 0.2×10^6 Pa abs has a volume of 40 L and a gas constant (R) of 210 m · N/(kg · K). Determine the density and mass of the gas.

▌ $$\rho = p/RT = 0.2 \times 10^6/[(210)(20 + 273)] = 3.25\ \text{kg/m}^3 \qquad m = \rho V = (3.25)(\tfrac{40}{1000}) = 0.130\ \text{kg}$$

1.37 What is the specific weight of air at 60 psia and 90 °F?

▌ $\gamma = p/RT$. From Table A-6, $R = 53.3$ ft/°R; $\gamma = (60)(144)/[(53.3)(90 + 460)] = 0.295\ \text{lb/ft}^3$.

Note: p/RT gives ρ (Prob. 1.36) or γ (Prob. 1.37), depending on the value of R used. Corresponding values of R in Table A-6 differ by a factor of g.

1.38 What is the density of water vapor at 400 000 Pa abs and 15 °C? Its gas constant (R) is 462 m · N/(kg · K).

▌ $$\rho = p/RT = 400\,000/[(462)(15 + 273)] = 3.01\ \text{kg/m}^3$$

1.39 A gas with molecular weight 28 has a volume of 4.0 ft^3 and a pressure and temperature of 2000 lb/ft^2 abs and 600 °R, respectively. What are its specific volume and specific weight?

▌ $$R = R_u/M = 49\,709/28 = 1775\ \text{ft} \cdot \text{lb/(slug} \cdot {}^\circ\text{R)}$$

[where R_u, the universal gas constant, = 49 709 ft · lb/(slug · °R)]

$$\rho = 1/V_s = p/RT = 2000/[(1775)(600)] \qquad V_s = 532.5\ \text{ft}^3/\text{slug}$$

$$\gamma = \rho g = (1/V_s)(g) = (1/532.5)(32.2) = 0.0605\ \text{lb/ft}^3$$

1.40 One kilogram of hydrogen is confined in a volume of 150 L at −40 °C. What is the pressure if R is 4115 m · N/(kg · K)?

▌ $$p = \rho RT = (m/V)RT = (1/\tfrac{150}{1000})(4115)(-40 + 273) = 6.392 \times 10^6\ \text{N/m}^2 \quad \text{or} \quad 6392\ \text{kPa abs}$$

1.41 What is the specific weight of air at a temperature of 30 °C and a pressure of 470 kPa abs?

▌ $$\gamma = p/RT = 470/[(29.3)(30 + 273)] = 0.0529\ \text{kN/m}^3$$