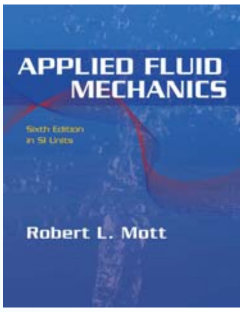
Applied Fluid Mechanics



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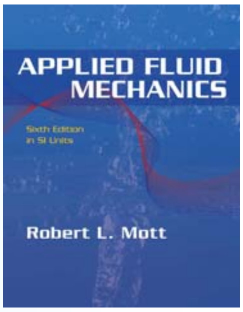

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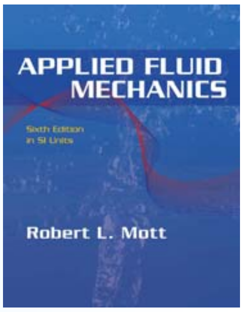

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1. The Nature of Fluid and the Study of Fluid Mechanics

Chapter Objectives

- Differentiate between a gas and a liquid.
- Define *pressure*.
- Identify the units for the basic quantities of time, length, force, and mass in the SI system (metric unit system).
- Identify the units for the basic quantities of time, length, force, and mass in the U.S. Customary System.
- Properly set up equations to ensure consistency of units.
- Define the relationship between force and mass.
- Define *density*, *specific weight*, and *specific gravity.*
- Identify the relationships between specific weight, specific gravity, and density, and solve problems using these relationships.
- Define *surface tension.*

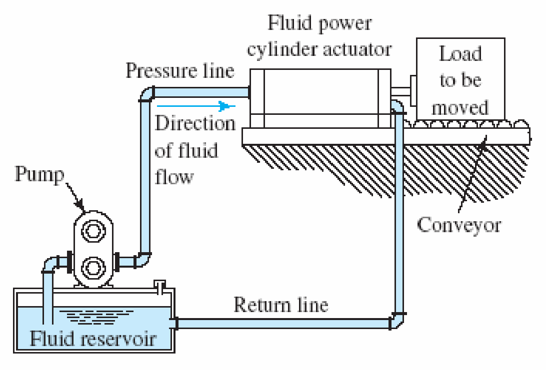
1. The Nature of Fluid and the Study of Fluid Mechanics

Chapter Outline

1. The Nature of Fluid and the Study of Fluid Mechanics

1.1 Basic Introductory Concepts

- Figure 1.1 shows the typical piping system for fluid power.



1. The Nature of Fluid and the Study of Fluid Mechanics

1.1 Basic Introductory Concepts

Pressure

- Pressure is defined as the amount of force exerted on a unit area of a substance or on a surface.
- This can be stated by the equation

$$p = \frac{F}{A} \qquad (1-1)$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.1 Basic Introductory Concepts

Liquid and Gases

- Fluids can be either liquids or gases.
- The following general descriptions of liquids and gases that we will use in this book:

1. Gases are readily compressible.
2. Liquids are only slightly compressible.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.1 Basic Introductory Concepts

Weight and Mass

- Mass is the property of a body of fluid that is a measure of its inertia or resistance to a change in motion. It is also a measure of the quantity of fluid.
- Weight is the amount that a body of fluid weighs, that is, the force with which the fluid is attracted toward Earth by gravitation.
- We use the symbol *m* for mass and *w* for weight in this book.

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1.1 Basic Introductory Concepts

Fluid Properties

- Other fluid properties are *specific weight*, *density*, *specific gravity*, *surface tension* and *viscosity*.
- It is also important in determining the character of the flow of fluids and the amount of energy that is lost from a fluid flowing in a system.

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1.2 The International System of Units (SI)

- The SI units for the basic quantities are

$$\begin{aligned} \text{length} &= \text{meter (m)} \\ \text{time} &= \text{second (s)} \\ \text{mass} &= \text{kilogram (kg) or N}\cdot\text{s}^2/\text{m} \\ \text{force} &= \text{newton (N) or kg}\cdot\text{m/s}^2 \end{aligned}$$

- An equivalent unit for force indicated above is derived from the relationship between force and mass,

$$F = ma$$

where *a* is the acceleration expressed (m/s^2)

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1.2 The International System of Units (SI)

- Therefore, the derived unit for force is

$$F = ma = \text{kg}\cdot\text{m/s}^2 = \text{N}$$

- Similarly

$$m = \frac{F}{a} = \frac{\text{N}}{\text{m/s}^2} = \frac{\text{N}\cdot\text{s}^2}{\text{m}}$$

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1.2.1 SI Unit Prefixes

- Table 1.1 shows the SI unit prefixes.

Prefix	SI symbol	Factor
giga	G	$10^9 = 1\,000\,000\,000$
mega	M	$10^6 = 1\,000\,000$
kilo	k	$10^3 = 1\,000$
milli	m	$10^{-3} = 0.001$
micro	μ	$10^{-6} = 0.000\,001$
nano	n	$10^{-9} = 0.000\,000\,001$

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1.2.1 SI Unit Prefixes

- Results of calculations should normally be adjusted so that the number is between 0.1 and 10 000 times some multiple of 10^3.
- Some examples follow.

Computed Result	Reported Result
0.004 23 m	4.23×10^{-3} m, or 4.23 mm (millimeters)
15 700 kg	15.7×10^{3} kg, or 15.7 Mg (megagrams)
86 330 N	86.33×10^{3} N, or 86.33 kN (kilonewtons)

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1.3 The US Customary System

- U.S. Customary System defines the basic quantities as follows:

$$\begin{aligned} \text{length} &= \text{foot (ft)} \\ \text{time} &= \text{second (s)} \\ \text{force} &= \text{pound (lb)} \\ \text{mass} &= \text{slug or lb-s}^2/\text{ft} \end{aligned}$$

- It may help to note the relationship between force and mass,

$$F = ma$$

$$m = \frac{F}{a} = \frac{\text{lb}}{\text{ft/s}^2} = \frac{\text{lb-s}^2}{\text{ft}} = \text{slug}$$

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1.4 Weight and Mass

- Weight is a force and mass is the quantity of a substance.
- We relate these two terms by applying Newton's law of gravitation stated as *force equals mass times acceleration*, or $F = ma$
- Weight and mass relationship becomes

$$w = mg \qquad (1-2)$$

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1.4.1 Weight and Mass in the SI Unit System

- For example, consider a rock with a mass of 5.60 kg suspended by a wire. To determine what force is exerted on the wire, we use Newton's law of gravitation

$$w = mg = \text{mass} \times \text{acceleration due to gravity}$$

$$w = 5.60\ \text{kg} \times 9.81\ \text{m/s}^2 = 54.9\ \text{kg·m/s}^2 = 54.9\ \text{N}$$

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1.4.1 Weight and Mass in the SI Unit System

- We can also compute the mass of an object if we know its weight. For example, assume that we have measured the weight of a valve to be 8.25 N. What is its mass?

$$w = mg$$

$$m = \frac{w}{g} = \frac{8.25\ \text{N}}{9.81\ \text{m/s}^2} = \frac{0.841\ \text{N·s}^2}{\text{m}} = 0.841\ \text{kg}$$

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1.4.2 Weight and Mass in the US Unit System

- For an example of the weight–mass relationship in the U.S. Customary System, assume that we have measured the weight of a container of oil to be 84.6 lb. What is its mass?
- We write

$$w = mg$$
$$m = w/g = 84.6\ \text{lb}/32.2\ \text{ft/s}^2 = 2.63\ \text{lb-s}^2/\text{ft} = 2.63\ \text{slugs}$$

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1.4.3 Mass expressed as lbm

- In the analysis of fluid systems, some professionals use the unit lbm (pounds-mass) for the unit of mass instead of the unit of slugs.
- When one tries to relate force and mass units using Newton's law, one obtains

$$F = ma = \text{lbm}(\text{ft/s}^2) = \text{lbm-ft/s}^2$$

- This is *not* the same as the lbf.
- In summary, because of the cumbersome nature of the relationship between lbm and lbf, we avoid the use of lbm in this book.
- Mass will be expressed in the unit of slugs when problems are in the U.S. Customary System of units.

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1.5 Temperature

- Temperature is most often indicated in (degrees Celsius) or (degrees Fahrenheit).
- The following values at sea level on Earth is as follow:

  Water freezes at 0°C and boils at 100°C.

  Water freezes at 32°F and boils at 212°F.

- Given the temperature in ˚F the temperature in ˚C is

$$T_C = (T_F - 32)/1.8$$

- Given the temperature in ˚C the temperature in ˚F is

$$T_F = 1.8T_C + 32$$

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1.5.1 Absolute Temperature

- The absolute temperature is defined so the zero point corresponds to the condition where all molecular motion stops.
- This is called *absolute zero*.
- In the SI unit system, the standard unit of temperature is the *kelvin*, for which the standard symbol is K and the reference (zero) point is absolute zero.
- We can then make the conversion from the Celsius to the *kelvin* scale by using

$$T_K = T_C + 273.15$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.6 Consistent Units in an Equation

- A simple straightforward procedure called *unit cancellation* will ensure proper units in any kind of calculation, not only in fluid mechanics, but also in virtually all your technical work.
- Table 1.2 shows the SI units for common quantities used in fluid mechanics.
- Table 1.3 shows the U.S. customary units for common quantities used in fluid mechanics.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.6 Consistent Units in an Equation

Quantity	Basic Definition	Standard SI Units	Other Units Often Used
Length	—	meter (m)	millimeter (mm); kilometer (km)
Time	—	second (s)	hour (h); minute (min)
Mass	Quantity of a substance	kilogram (kg)	$N \cdot s^2/m$
Force or weight	Push or pull on an object	newton (N)	$kg \cdot m/s^2$
Pressure	Force/area	N/m^2 or pascal (Pa)	kilopascals (kPa); bar
Energy	Force times distance	N·m or Joule (J)	$kg \cdot m^2/s^2$
Power	Energy/time	N·m/s or J/s	watt (W); kW
Volume	$(Length)^3$	m^3	liter (L)
Area	$(Length)^2$	m^2	mm^2
Volume flow rate	Volume/time	m^3/s	L/s; L/min; m^3/h
Weight flow rate	Weight/time	N/s	kN/s; kN/min
Mass flow rate	Mass/time	kg/s	kg/h
Specific weight	Weight/volume	N/m^3	$kg/m^2 \cdot s^2$
Density	Mass/volume	kg/m^3	$N \cdot s^2/m^4$

1.6 Consistent Units in an Equation

Quantity	Basic Definition	Standard U.S. Units	Other Units Often Used
Length	—	feet (ft)	inches (in); miles (mi)
Time	—	second (s)	hour (h); minute (min)
Mass	Quantity of a substance	slugs	lb·s^2/ft
Force or weight	Push or pull on an object	pound (lb)	kip (1000 lb)
Pressure	Force/area	lb/ft^2 or psf	lb/in^2 or psi; kip/in^2 or ksi
Energy	Force times distance	lb·ft	lb·in
Power	Energy/time	lb·ft/s	horsepower (hp)
Volume	(Length)^2	ft^3	gallon (gal)
Area	(Length)^3	ft^2	in^2
Volume flow rate	Volume/time	ft^3/s or cfs	gal/min (gpm); ft^3/min (cfm)
Weight flow rate	Weight/time	lb/s	lb/min; lb/h
Mass flow rate	Mass/time	slugs/s	slugs/min; slugs/h
Specific weight	Weight/volume	lb/ft^3	
Density	Mass/volume	slugs/ft^3	

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1.6 Consistent Units in an Equation

- The six steps of the procedure are listed below.

UNIT-CANCELLATION PROCEDURE

1) Solve the equation algebraically for the desired term.
2) Decide on the proper units for the result.
3) Substitute known values, including units.
4) Cancel units that appear in both the numerator and the denominator of any term.
5) Use conversion factors to eliminate unwanted units and obtain the proper units as decided in Step 2.
6) Perform the calculation.

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Example 1.1

Imagine you are traveling in a car at a constant speed of 80 kilometers per hour (km/h). How many seconds (s) would it take to travel 1.5 km?

For the solution, use the equation

$$s = vt$$

where *s* is the distance traveled, is the speed, and *t* is the time.

Using the unit-cancellation procedure outlined above, what is the first thing to do?

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.1

The first step is to solve for the desired term. Because you were asked to find time, you should have written

$$t = \frac{s}{v}$$

Step 2 is to decide on the proper units for the result, in this case time. From the problem statement the proper unit is seconds. If no specification had been given for units, you could choose any acceptable time unit such as hours. Proceed to Step 3. The result should look something like this:

$$t = \frac{s}{v} = \frac{1.5\,\text{km}}{80\,\text{km/h}}$$

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Example 1.1

For the purpose of cancellation it is not convenient to have the units in the form of a compound fraction as we have above. To clear this to a simple fraction, write it in the form

$$t = \frac{\frac{1.5\ \text{km}}{1}}{\frac{80\ \text{km}}{\text{h}}}$$

$$t = \frac{1.5\ \text{km}\cdot\text{h}}{80\ \text{km}}$$

After some practice, equations may be written in this form directly. Now perform Step 4 of the procedure.

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.1

The result should now look like this:

$$t = \frac{1.5\ \cancel{\text{km}}\cdot\cancel{\text{h}}}{80\ \cancel{\text{km}}} \times \frac{3600\ \text{s}}{1\ \cancel{\text{h}}}$$

The equation in the preceding panel showed the result for time in hours after kilometer units were cancelled. Although hours is an acceptable time unit, our desired unit is seconds as determined in Step 2. Thus the conversion factor 3600 s/1 h is required.

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.1

The units determine this. Our objective in using the conversion factor was to eliminate the hour unit and obtain the second unit. Because the unwanted hour unit was in the numerator of the original equation, the hour unit in the conversion factor must be in the denominator in order to cancel.

Now that we have the time unit of seconds we can proceed with Step 6.

The correct answer is t = 67.5 s.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.7 The Definition of Pressure

- *Pressure* is defined as the amount of force exerted on a unit area of a substance.
- This can be stated by the equation

$$p = \frac{F}{A} \qquad (1-3)$$

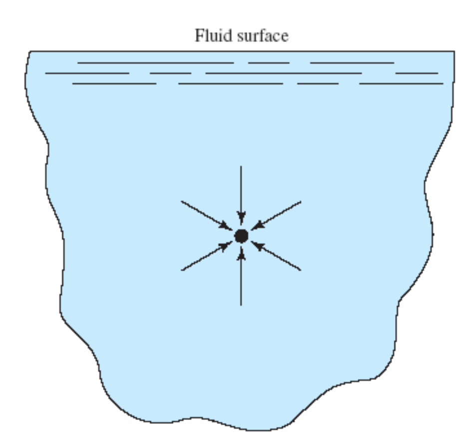
- Two important principles about pressure were described by Blaise Pascal, a seventeenth-century scientist:

1. Pressure acts uniformly in all directions on a small volume of a fluid.
2. In a fluid confined by solid boundaries, pressure acts perpendicular to the boundary.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.7 The Definition of Pressure

- Fig 1.2 shows the pressure acting uniformly in all directions on a small volume of fluid.



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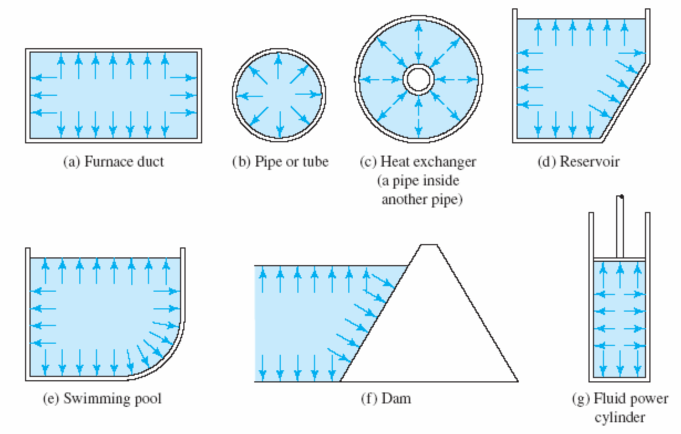
1.7 The Definition of Pressure

- Fig 1.3 shows the direction of fluid pressure on boundaries.



1. The Nature of Fluid and the Study of Fluid Mechanics

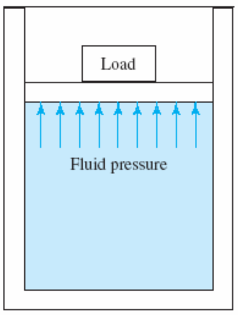
1.7 The Definition of Pressure

- The *bar* is another unit used by some people working in fluid mechanics and thermodynamics.
- The bar is defined as 10^5 Pa or 10^5 N/m^2.
- Another way of expressing the bar is 1 bar = 100 x 10^3 N/m^2, which is equivalent to 100 kPa.

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.2

Figure 1.4 shows a container of liquid with a movable piston supporting a load. Compute the magnitude of the pressure in the liquid under the piston if the total weight of the piston and the load is 500 N and the area of the piston is 2500 mm^2.



1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.2

It is reasonable to assume that the entire surface of the fluid under the piston is sharing in the task of supporting the load. The second of Pascal's laws states that the fluid pressure acts perpendicular to the piston. Then, using Eq. (1–3), we have

$$p = \frac{F}{A} = \frac{500\ \text{N}}{2500\ \text{mm}^2} = 0.20\ \text{N/mm}^2$$

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.2

The standard unit of pressure in the SI system is the N/m^2 called the *pascal* (Pa) in honor of Blaise Pascal. The conversion can be made by using the factor 10^3 mm = 1 m. We have

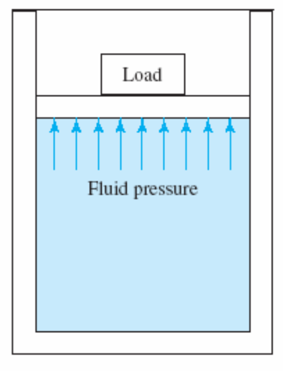
$$p = \frac{0.20\ \text{N}}{\text{mm}^2} \times \frac{(10^3\ \text{mm})^2}{\text{m}^2} = 0.20 \times 10^6\ \text{N/m}^2 = 0.20\ \text{MPa}$$

Note that the pressure in N/mm^2 is numerically equal to pressure in MPa. It is not unusual to encounter pressure in the range of several megapascals (MPa) or several hundred kilopascals (kPa).

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.3

A load of 200 pounds (lb) is exerted on a piston confining oil in a circular cylinder with an inside diameter of 2.50 inches (in). Compute the pressure in the oil at the piston.



1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.3

To use Eq. (1–3), we must compute the area of the piston

$$A = \pi D^2/4 = \pi(2.50\ \text{in})^2/4 = 4.91\ \text{in}^2$$

$$p = \frac{F}{A} = \frac{200\ \text{lb}}{4.91\ \text{in}^2} = 40.7\ \text{lb/in}^2$$

Example 1.3

Although the standard unit for pressure in the U.S. Customary System is pounds per square foot (lb/ft^2), it is not often used because it is inconvenient. Length measurements are more conveniently made in inches, and pounds per square inch (lb/in^2) abbreviated psi, is used most often for pressure in this system. The pressure in the oil is 40.7 psi. This is a fairly low pressure; it is not unusual to encounter pressures of several hundred or several thousand psi.

1.8 Compressibility

- *Compressibility* refers to the change in volume (*V*) of a substance that is subjected to a change in pressure on it.
- The usual quantity used to measure this phenomenon is the *bulk modulus of elasticity* or, simply, *bulk modulus*, *E*:

$$E = \frac{-\Delta p}{(\Delta V)/V} \qquad (1-4)$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.8 Compressibility

- Table 1.4 shows the Values for bulk modulus for selected liquids at atmospheric pressure and 68°F (20°C).

Liquid	Bulk Modulus (psi)	Bulk Modulus (MPa)
Ethyl alcohol	130 000	896
Benzene	154 000	1 062
Machine oil	189 000	1 303
Water	316 000	2 179
Glycerine	654 000	4 509
Mercury	3 590 000	24 750

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Example 1.4

Compute the change in pressure that must be applied to water to change its volume by 1.0 percent.

The 1.0-percent volume change indicates that $\Delta V/V = -0.01$. Then, the required change in pressure is

$$\Delta p = -E[(\Delta V)/V] = [-2179\text{ MPa}][-0.01] = 21.79\text{ MPa}$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9 Density, Specific Weight and Specific Gravity

- Density *is the amount of mass per unit volume of a substance.*
- Therefore, using the greek letter ρ (rho) for density, we write

$$E = m/V \qquad (1-5)$$

  where *V* is the volume of the substance having a mass *m*.
- The units for density are kilograms per cubic meter in the SI system and slugs per cubic foot in the U.S. Customary System.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9 Density, Specific Weight and Specific Gravity

- Specific weight *is the amount of weight per unit volume of a substance.*
- Using the Greek letter γ (gamma) for specific weight, we write

$$\gamma = w/V \qquad (1-6)$$

  where *V* is the volume of a substance having the weight *w*.
- The units for specific weight are newtons per cubic meter in the SI system and pounds per cubic foot in the U.S. Customary System.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9 Density, Specific Weight and Specific Gravity

- Specific gravity can be defined in either of two ways:

a. *Specific gravity* is the ratio of the density of a substance to the density of water at 4°C.

b. *Specific gravity* is the ratio of the specific weight of a substance to the specific weight of water at 4°C.

- These definitions for specific gravity (sg) can be shown mathematically as

$$\text{sg} = \frac{\gamma_s}{\gamma_w @ 4°\text{C}} = \frac{\rho_s}{\rho_w @ 4°\text{C}} \qquad (1-7)$$

where the subscript *s* refers to the substance whose specific gravity is being determined and the subscript *w* refers to water.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9.1 Relation Between Density and Specific Weight

- Quite often the specific weight of a substance must be found when its density is known and vice versa.
- The conversion from one to the other can be made using the following equation:

$$\gamma = \rho g \qquad (1-9)$$

- The definition of specific weight is $\gamma = \frac{w}{V}$
- By multiplying g on numerator and denominator, we reduced to $\gamma = \rho g$

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.5

Calculate the weight of a reservoir of oil if it has a mass of 825 kg.

We have

$$w = 825\ \text{kg} \times 9.81\ \text{m/s}^2 = 8093\ \text{kg}\cdot\text{m/s}^2$$

$$w = 8093\ \text{N} = 8.093 \times 10^3\ \text{N} = 8.093\ \text{kN}$$

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.6

If the reservoir from Example Problem 1.5 has a volume of 0.917m^3, compute the density, the specific weight, and the specific gravity of the oil.

Density:

$$\rho_o = \frac{m}{V} = \frac{825\ \text{kg}}{0.917\ \text{m}^3} = 900\ \text{kg/m}^3$$

Specific weight:

$$\gamma_o = \frac{w}{V} = \frac{8.093\ \text{kN}}{0.917\ \text{m}^3} = 8.83\ \text{kN/m}^3$$

Specific gravity:

$$\text{sg} = \frac{\rho_o}{\rho_w @ 4^\circ\text{C}} = \frac{900\ \text{kg/m}^3}{1000\ \text{kg/m}^3} = 0.90$$

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.7

Glycerine at 20°C has a specific gravity of 1.263. Compute its density and specific weight.

Density:

$$\rho_g = (sg)_g(1000\ \text{kg/m}^3) = (1.263)(1000\ \text{kg/m}^3) = 1263\ \text{kg/m}^3$$

Specific weight:

$$\gamma_g = (sg)_g(9.81\ \text{kN/m}^3) = (1.263)(9.81\ \text{kN/m}^3) = 12.39\ \text{kN/m}^3$$

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.8

A pint of water weighs 4.632 N. Find its mass.

Because w = mg, the mass is

$$m = \frac{w}{g} = \frac{4.632\ \text{N}}{9.81\ \text{m/s}^2}$$
$$= 0.472\ \text{N}\cdot\text{s}^2/\text{m}$$
$$= 0.472\ \text{kg}$$

Remember that the units of kg and Ns^2/m are the same.

1. The Nature of Fluid and the Study of Fluid Mechanics

Example 1.9

One gallon of mercury has a mass of 51.2 kg. Find its weight. Write

$$w = mg = 51.2\ \text{kg} \times 9.81\ \text{m/s}^2 = 502.27\ \text{kg}\cdot\text{m/s}^2$$

This is correct, but the units may seem confusing because weight is normally expressed in N. The units of mass may be rewritten as Ns^2/m, and we have

$$w = mg = 51.2\ \text{N}\cdot\text{s}^2/\text{m} \times 9.81\ \text{m/s}^2 = 502.27\ \text{N}$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9.2 Specific Gravity in Degrees Baume or Degree API

- The reference temperature for specific gravity measurements on the Baumé or American Petroleum Institute (API) scale is 60°F rather than 4°C as defined before.
- To emphasize this difference, the API or Baumé specific gravity is often reported as

$$\text{Specific gravity}\ \frac{60^\circ}{60^\circ}\text{F}$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9.2 Specific Gravity in Degrees Baume or Degree API

- For liquids heavier than water,

$$sg = \frac{145}{145 - \text{deg Baume}} \qquad (1-10)$$

$$\text{deg Baume} = 145 - \frac{145}{sg} \qquad (1-11)$$

- For liquids lighter than water,

$$sg = \frac{140}{130 + \text{deg Baume}} \qquad (1-12)$$

$$\text{deg Baume} = \frac{140}{sg} - 130 \qquad (1-13)$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9.2 Specific Gravity in Degrees Baume or Degree API

- The API has developed a scale that is slightly different from the Baumé scale for liquids lighter than water.
- The formulas are

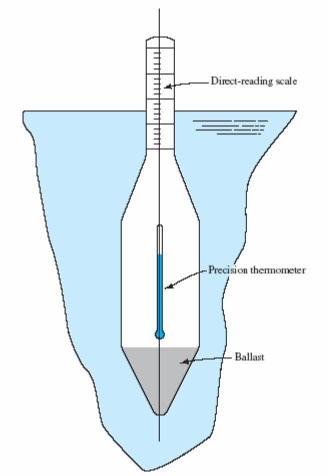
$$sg = \frac{141.5}{131.5 + \text{deg API}} \qquad (1-14)$$

$$\text{deg API} = \frac{141.5}{sg} - 131.5 \qquad (1-15)$$

1. The Nature of Fluid and the Study of Fluid Mechanics

1.9.2 Specific Gravity in Degrees Baume or Degree API

- Fig 1.5 shows the Hydrometer with built-in thermometer (thermohydrometer).



1. The Nature of Fluid and the Study of Fluid Mechanics

1.10 Surface Tension

- Surface tension acts somewhat like a film at the interface between the liquid water surface and the air above it.
- Surface tension is also the reason that water droplets assume a nearly spherical shape.
- The movement of liquids within small spaces depends on this capillary action.
- *Wicking* is the term often used to describe the rise of a fluid from a liquid surface into a woven material.

1. The Nature of Fluid and the Study of Fluid Mechanics

1.10 Surface Tension

- Table 1.5 shows the surface tension of water.

Temperature (°F)	Surface Tension (mlb/ft)	Temperature (°C)	Surface Tension (mN/m)
32	5.18	0	75.6
40	5.13	5	74.9
50	5.09	10	74.2
60	5.03	20	72.8
70	4.97	30	71.2
80	4.91	40	69.6
90	4.86	50	67.9
100	4.79	60	66.2
120	4.67	70	64.5
140	4.53	80	62.7
160	4.40	90	60.8
180	4.26	100	58.9
200	4.12		
212	4.04		

Source: Adapted with permission from data from *CRC Handbook of Chemistry and Physics*, CRC Press LLC, Boca Raton, FL.

Notes:
Values taken at atmospheric pressure
1.0 lb = 1000 mlb; 1.0 N = 1000 mN

1. The Nature of Fluid and the Study of Fluid Mechanics

1.10 Surface Tension

- Table 1.6 shows the surface tension of some common liquids.

Liquid	Surface Tension at Stated Temperature: 10°C (mN/m)	50°F (mlb/ft)	25°C (mN/m)	77°F (mlb/ft)	50°C (mN/m)	122°F (mlb/ft)	75°C (mN/m)	167°F (mlb/ft)	100°C (mN/m)	212°F (mlb/ft)
Water	74.2	5.08	72.0	4.93	67.9	4.65	63.6	4.36	58.9	4.04
Methanol	23.2	1.59	22.1	1.51	20.1	1.38				
Ethanol	23.2	1.59	22.0	1.51	19.9	1.36				
Ethylene glycol			48.0	3.29	45.8	3.14	43.5	2.98	41.3	2.83
Acetone	23.5	1.61	20.7	1.42						
Benzene			28.2	1.93	25.0	1.71	21.8	1.49		
Mercury	488	33.4	485	33.2	480	32.9	475	32.5	470	32.2

Source: Adapted with permission from data from *CRC Handbook of Chemistry and Physics*, CRC Press LLC, Boca Raton, FL.

Notes:
Values taken at atmospheric pressure
1.0 lb = 1000 mlb; 1.0 N = 1000 mN