Fluid Mechanics
(10626231)

Lectures 1+2: Introduction
Basic Concepts and Definitions

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FIGURE 1.1 Industrial and commercial fluid piping systems, like this one used in a chemical processing plant, involve complex arrangements requiring careful design and analysis.
(*Source*: Nikolay Kazachok/Fotolia)

FIGURE 1.2 Typical piping system for fluid power.

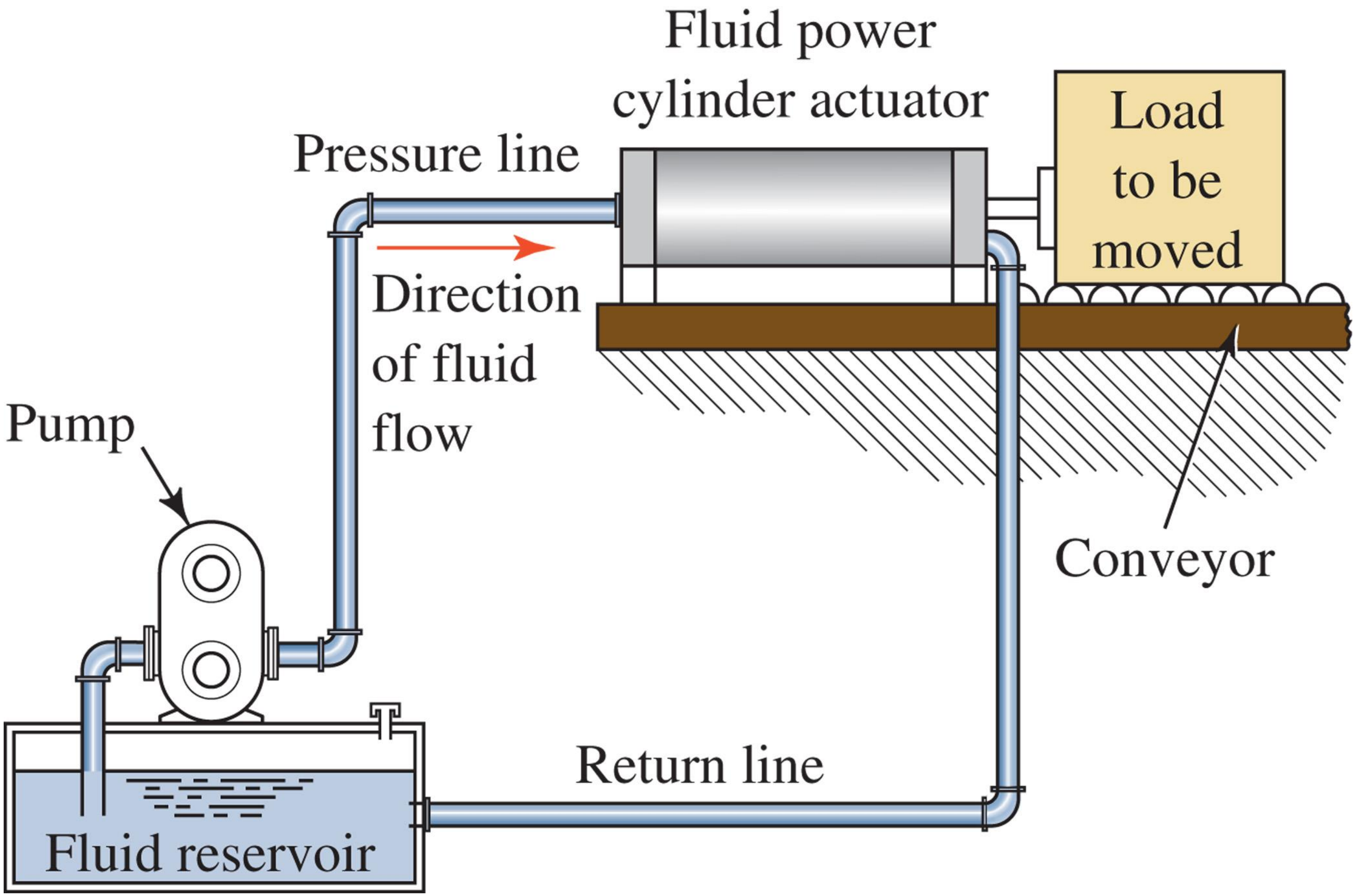

TABLE 1.1 SI unit prefixes

Prefix	SI symbol	Factor
terra	T	$10^{12} = 1\,000\,000\,000\,000$
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	$10^{-9} = 0.000\,000\,001$
pico	p	$10^{-12} = 0.000\,000\,000\,001$

TABLE1.2 Units for common quantities used in fluid mechanics in SI units and U.S. Customary units

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Quantity	Basic Definition	Standard SI Units	Other Metric Units Often Used	Standard U.S. Units	Other U.S. Units Often Used
Length (L)	—	meter (m)	millimeter (mm); kilometer (km)	foot (ft)	inch (in); mile (mi)
Time	—	second (s)	hour (h); minute (min)	second (s)	hour (h); minute (min)
Mass (m)	Quantity of a substance	kilogram (kg)	$N \cdot s^2/m$	slug	$lb \cdot s^2/ft$
Force (F) or weight (w)	Push or pull on an object	newton (N)	$kg \cdot m/s^2$	pound (lb)	kip (1000 lb)
Pressure (p)	Force/area	N/m^2 or pascal (Pa)	kilopascals (kPa); bar	lb/ft^2 or psf	lb/in^2 or psi; kip/in^2 or ksi
Energy	Force times distance	$N \cdot m$ or Joule (J)	$kg \cdot m^2/s^2$	$lb \cdot ft$	$lb \cdot in$
Power (P)	Energy/time	watt (W) or $N \cdot m/s$ or J/s	kilowatt (kW)	$lb \cdot ft/s$	horsepower (hp)
Volume (V)	L^3	m^3	liter (L)	ft^3	gallon (gal)
Area (A)	L^2	m^2	mm^2	ft^2	in^2
Volume flow rate (Q)	V/time	m^3/s	L/s; L/min; m^3/h	ft^3/s or cfs	gal/min (gpm); ft^3/min (cfm)
Weight flow rate (W)	w/time	N/s	kN/s; kN/min	lb/s	lb/min; lb/h
Mass flow rate (M)	M/time	kg/s	kg/hr	slugs/s	slugs/min; slugs/h
Specific weight (γ)	w/V	N/m^3 or $kg/m^2 \cdot s^2$		lb/ft^3	
Density (ρ)	M/V	kg/m^3 or $N \cdot s^2/m^4$		$slugs/ft^3$	

TABLE K.1:
Conversion factors

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Mass Standard SI unit: kilogram (kg). Equivalent unit: $N \cdot s^2/m$.

$\frac{14.59\ \text{kg}}{\text{slug}}$ $\frac{32.174\ \text{lb}_m}{\text{slug}}$ $\frac{2.205\ \text{lb}_m}{\text{kg}}$ $\frac{453.6\ \text{grams}}{\text{lb}_m}$ $\frac{2000\ \text{lb}_m}{\text{ton}_m}$ $\frac{1000\ \text{kg}}{\text{metric ton}_m}$

Force Standard SI unit: Newton (N). Equivalent unit: $kg \cdot m/s^2$.

$\frac{4.448\ \text{N}}{\text{lb}_f}$ $\frac{10^5\ \text{dynes}}{\text{N}}$ $\frac{4.448 \times 10^5\ \text{dynes}}{\text{lb}_f}$ $\frac{224.8\ \text{lb}_f}{\text{kN}}$

Length

$\frac{3.281\ \text{ft}}{\text{m}}$ $\frac{39.37\ \text{in}}{\text{m}}$ $\frac{12\ \text{in}}{\text{ft}}$ $\frac{1.609\ \text{km}}{\text{mi}}$ $\frac{5280\ \text{ft}}{\text{mi}}$ $\frac{6076\ \text{ft}}{\text{nautical mile}}$

Area

$\frac{144\ \text{in}^2}{\text{ft}^2}$ $\frac{10.76\ \text{ft}^2}{\text{m}^2}$ $\frac{645.2\ \text{mm}^2}{\text{in}^2}$ $\frac{10^6\ \text{mm}^2}{\text{m}^2}$ $\frac{43\,560\ \text{ft}^2}{\text{acre}}$ $\frac{10^4\ \text{m}^2}{\text{hectare}}$

Volume

$\frac{1728\ \text{in}^3}{\text{ft}^3}$ $\frac{231\ \text{in}^3}{\text{gal}}$ $\frac{7.48\ \text{gal}}{\text{ft}^3}$ $\frac{264.2\ \text{gal}}{\text{m}^3}$ $\frac{3.785\ \text{L}}{\text{gal}}$ $\frac{35.31\ \text{ft}^3}{\text{m}^3}$

$\frac{28.32\ \text{L}}{\text{ft}^3}$ $\frac{1000\ \text{L}}{\text{m}^3}$ $\frac{61.02\ \text{in}^3}{\text{L}}$ $\frac{1000\ \text{cm}^3}{\text{L}}$ $\frac{1.201\ \text{U.S. gal}}{\text{Imperial gallon}}$

Volume Flow Rate

$\frac{449\ \text{gal/min}}{\text{ft}^3\text{/s}}$ $\frac{35.31\ \text{ft}^3\text{/s}}{\text{m}^3\text{/s}}$ $\frac{15\,850\ \text{gal/min}}{\text{m}^3\text{/s}}$ $\frac{3.785\ \text{L/min}}{\text{gal/min}}$

$\frac{60\,000\ \text{L/min}}{\text{m}^3\text{/s}}$ $\frac{2119\ \text{ft}^3\text{/min}}{\text{m}^3\text{/s}}$ $\frac{16.67\ \text{L/min}}{\text{m}^3\text{/h}}$ $\frac{101.9\ \text{m}^3\text{/h}}{\text{ft}^3\text{/s}}$

Density **(mass/unit volume)**

$\frac{515.4\ \text{kg/m}^3}{\text{slug/ft}^3}$ $\frac{1000\ \text{kg/m}^3}{\text{gram/cm}^3}$ $\frac{32.17\ \text{lb}_m\text{/ft}^3}{\text{slug/ft}^3}$ $\frac{16.018\ \text{kg/m}^3}{\text{lb}_m\text{/ft}^3}$

Specific Weight **(weight/unit volume)**

$\frac{157.1\ \text{N/m}^3}{\text{lb}_f\text{/ft}^3}$ $\frac{1728\ \text{lb/ft}^3}{\text{lb/in}^3}$

Pressure Standard SI unit: pascal (Pa). Equivalent units: N/m^2 or $kg/m \cdot s^2$.

$\frac{144\ \text{lb/ft}^2}{\text{lb/in}^2}$ $\frac{47.88\ \text{Pa}}{\text{lb/ft}^2}$ $\frac{6895\ \text{Pa}}{\text{lb/in}^2}$ $\frac{1\ \text{Pa}}{\text{N/m}^2}$ $\frac{100\ \text{kPa}}{\text{bar}}$ $\frac{14.50\ \text{lb/in}^2}{\text{bar}}$

$\frac{27.68\ \text{inH}_2\text{O}}{\text{lb/in}^2}$ $\frac{249.1\ \text{Pa}}{\text{inH}_2\text{O}}$ $\frac{2.036\ \text{inHg}}{\text{lb/in}^2}$ $\frac{3386\ \text{Pa}}{\text{inHg}}$ $\frac{133.3\ \text{Pa}}{\text{mmHg}}$ $\frac{51.71\ \text{mmHg}}{\text{lb/in}^2}$

$\frac{14.696\ \text{lb/in}^2}{\text{Std. atmosphere}}$ $\frac{101.325\ \text{kPa}}{\text{Std. atmosphere}}$ $\frac{29.92\ \text{inHg}}{\text{Std. atmosphere}}$ $\frac{760.1\ \text{mmHg}}{\text{Std. atmosphere}}$

TABLE K.1 (continued): Conversion factors

TABLE K.1 Conversion factors (*continued*)

Note: Conversion factors based on the height of a column of liquid (e.g., inH_2O and mmHg) are based on a standard gravitational field ($g = 9.806\,65$ m/s^2), a density of water equal to 1000 kg/m^3, and a density of mercury equal to 13 595.1 kg/m^3, sometimes called ***conventional values*** for a temperature at or near 0°C. Actual measurements with such fluids may vary because of differences in local gravity and temperature.

Energy Standard SI unit: joule (J). Equivalent units: N·m or kg·m^2/s^2.

$$\frac{1.356\ \text{J}}{\text{lb-ft}} \quad \frac{1.0\ \text{J}}{\text{N·m}} \quad \frac{8.85\ \text{lb-in}}{\text{J}} \quad \frac{1.055\ \text{kJ}}{\text{Btu}} \quad \frac{3.600\ \text{kJ}}{\text{W·h}} \quad \frac{778.17\ \text{ft-lb}}{\text{Btu}}$$

Power Standard SI unit: watt (W). Equivalent unit: J/s or N·m/s.

$$\frac{745.7\ \text{W}}{\text{hp}} \quad \frac{1.0\ \text{W}}{\text{N·m/s}} \quad \frac{550\ \text{lb-ft/s}}{\text{hp}} \quad \frac{1.356\ \text{W}}{\text{lb-ft/s}} \quad \frac{3.412\ \text{Btu/hr}}{\text{W}} \quad \frac{1.341\ \text{hp}}{\text{kW}}$$

Dynamic Viscosity Standard SI unit: Pa·s or N·s/m^2 (cP = centipoise)

$$\frac{47.88\ \text{Pa·s}}{\text{lb-s/ft}^2} \quad \frac{10\ \text{poise}}{\text{Pa·s}} \quad \frac{1000\ \text{cP}}{\text{Pa·s}} \quad \frac{100\ \text{cP}}{\text{poise}} \quad \frac{1\ \text{cP}}{1\ \text{mPa·s}}$$

Kinematic Viscosity Standard SI unit: m^2/s (cSt = centistoke)

$$\frac{10.764\ \text{ft}^2/\text{s}}{\text{m}^2/\text{s}} \quad \frac{10^4\ \text{stoke}}{\text{m}^2/\text{s}} \quad \frac{10^6\ \text{cSt}}{\text{m}^2/\text{s}} \quad \frac{100\ \text{cSt}}{\text{stoke}} \quad \frac{1\ \text{cSt}}{1\ \text{mm}^2/\text{s}} \quad \frac{10^6\ \text{mm}^2/\text{s}}{\text{m}^2/\text{s}}$$

Refer to Section 2.6.5 for conversions involving Saybolt Universal seconds.

General Approach to Application of Conversion Factors. Arrange the conversion factor from the table in such a manner that when multiplied by the given quantity, the original units cancel out, leaving the desired units.

Example 1 Convert 0.24 m^3/s to the units of gal/min:

$$(0.24\ \text{m}^3/\text{s})\frac{15\,850\ \text{gal/min}}{\text{m}^3/\text{s}} = 3804\ \text{gal/min}$$

Example 2 Convert 150 gal/min to the units of m^3/s:

$$(150\ \text{gal/min})\frac{1\ \text{m}^3/\text{s}}{15\,850\ \text{gal/min}} = 9.46 \times 10^{-3}\ \text{m}^3/\text{s}$$

Temperature Conversions (Refer to Section 1.6)

Given the Fahrenheit temperature T_F in °F, the Celsius temperature T_C in °C is

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

Given the temperature T_C in °C, the Fahrenheit temperature T_F in °F is

$$T_F = 1.8T_C + 32$$

Given the temperature T_C in °C, the absolute temperature T_K in K (kelvin) is

$$T_K = T_C + 273.15$$

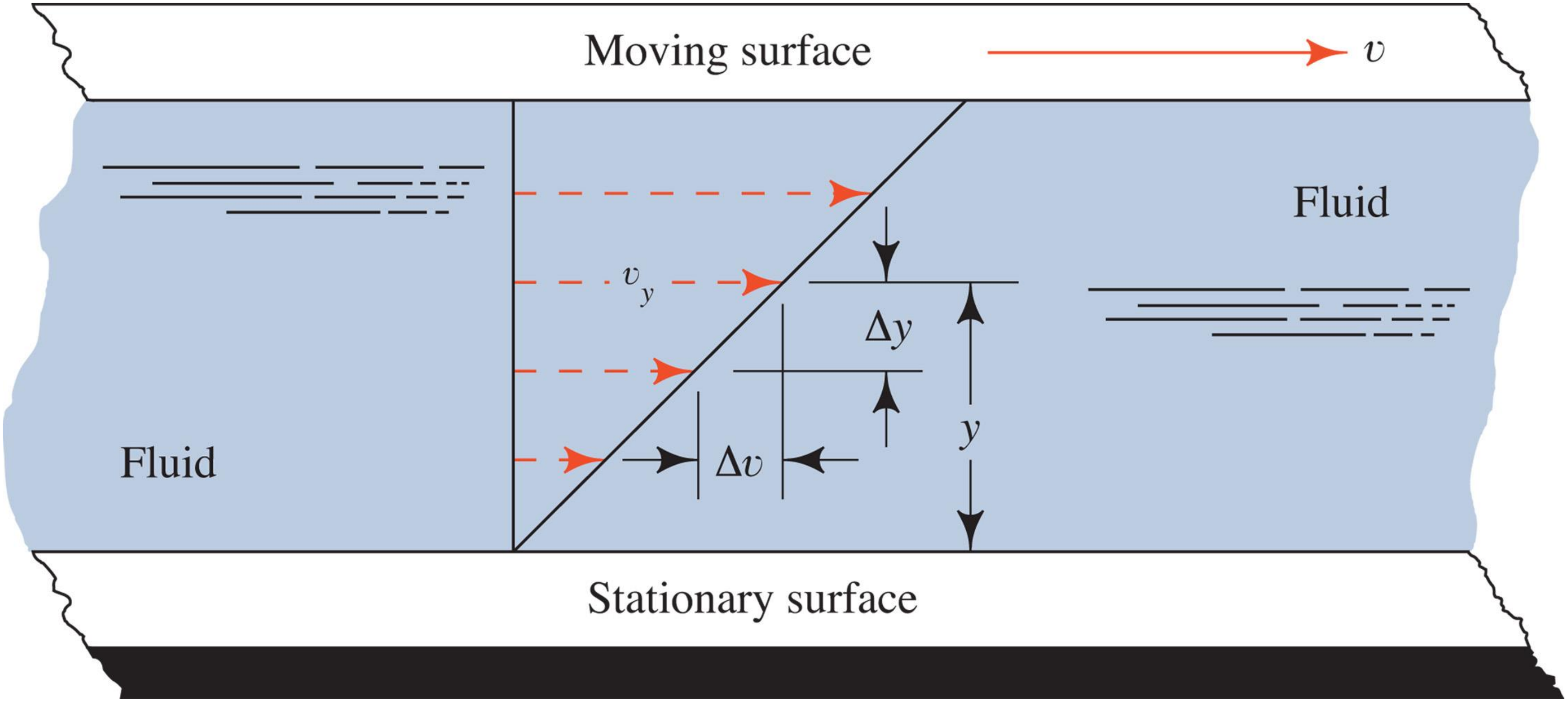
Given the temperature T_F in °F, the absolute temperature T_R in °R (degrees Rankine) is

$$T_R = T_F + 459.67$$

Given the temperature T_F in °F, the absolute temperature T_K in K is

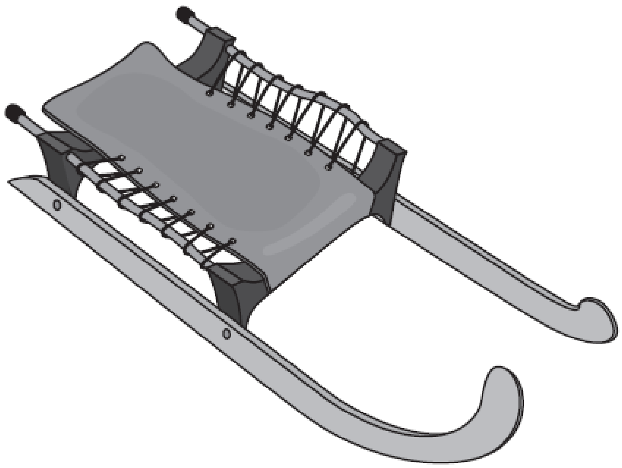
$$T_K = (T_F + 459.67)/1.8 = T_R/1.8$$

FIGURE 2.2 Velocity gradient in a moving fluid.



Example 1 – Viscosity

The sled shown in the figure slides along on a thin horizontal layer of water between the ice and the runners. The horizontal force that the water puts on the runners is equal to 1.2 lb when the sled's speed is 50 ft/s. The total area of both runners in contact with the water is 0.08 ft^2, and the viscosity of the water is 3.5×10^{-5} $lb.s/ft^2$. Determine the thickness of the water layer under the runners. Assume a linear velocity distribution in the water layer.



Example 2 – Viscosity

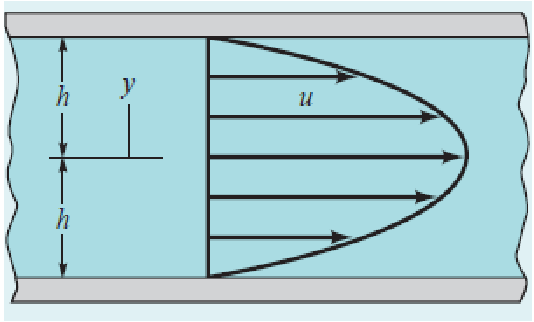
The velocity distribution for the flow of a Newtonian fluid between two wide parallel plates is given by the equation:

$$u = \frac{3v}{2}\left[1 - \left(\frac{y}{h}\right)^2\right]$$

where V is the mean velocity. The fluid has a viscosity of 0.04 lb.s/ft^2. Also, V = 2 ft/s and h = 0.2 in. Determine:

(a) the shearing stress acting on the bottom wall.

(b) the shearing stress acting on a plane parallel to the walls and passing through the centerline (midplane).



Example 3 – Viscosity and Dimensionless Quantity

A dimensionless combination of variables that is important in the study of viscous flow through pipes is called the Reynolds number (Re) defined as $\rho v D/\mu$, where, ρ is the fluid density, v is the mean fluid velocity, D is the pipe diameter, and μ is the fluid viscosity. A Newtonian fluid having a viscosity of 0.38 N.s/m^2 and a specific gravity of 0.91 flows through a 25 mm diameter pipe with a velocity of 2.6 m/s.

Determine the value of the Reynolds number using:

(a) SI units

(b) BG or US customary units.