Chapter 1 - INTRODUCTION

Prepared for CEE 3500 - *CEE Fluid Mechanics*

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Scope of Fluid Mechanics (1)

- Fluids: gases and liquids, water and air most prevalent in daily experience
- Examples:
  - Flow in pipes and channels -- air and blood in body
  - Air resistance or drag -- wind loading
  - Projectile motion -- jets, shock waves
  - Lubrication -- combustion
  - Irrigation -- sedimentation
  - Meteorology -- oceanography

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Scope of Fluid Mechanics (2)

- Used in the design of:
  - Water supply system -- waste water treatment
  - Dam spillways -- valves, flow meters
  - Shock absorbers, brakes -- automatic transmissions
  - ships, submarines -- breakwaters, marinas
  - Aircrafts, rockets -- computer disk drives
  - Windmills, turbines -- pumps, HVAC systems
  - Bearings -- artificial organs
  - Sport items:
    - Golf balls * Yatchs
    - Race cars * hang gliders
    - Surf boards

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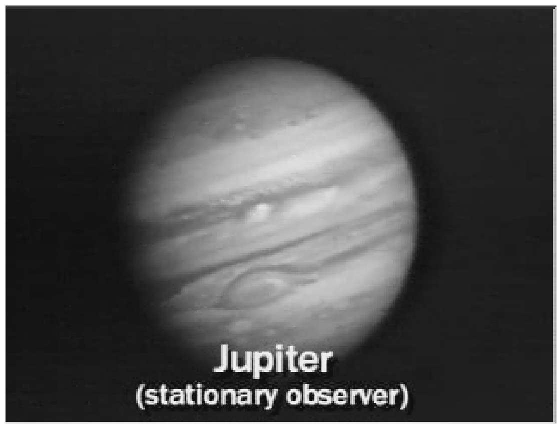
Fluids… fluids… everywhere



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As fish habitat…

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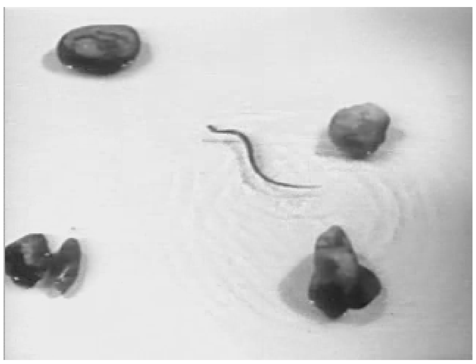
For reptile habitat…



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For mammals habitat…

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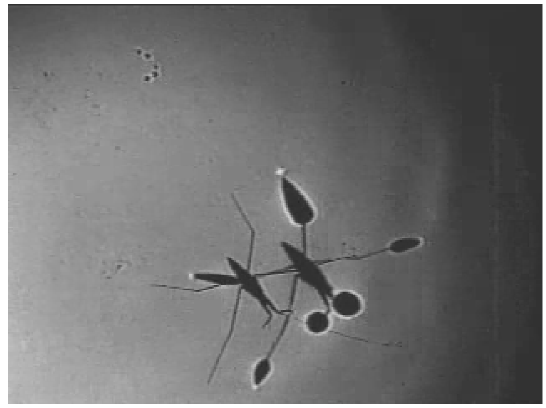
For insects to walk on a surface…



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In rivers and streams…

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A tornado… an atmospheric vortex

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Air to breathe…

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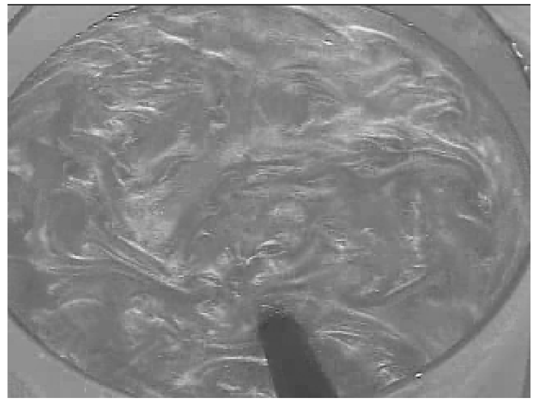
Mixing (as in soups)



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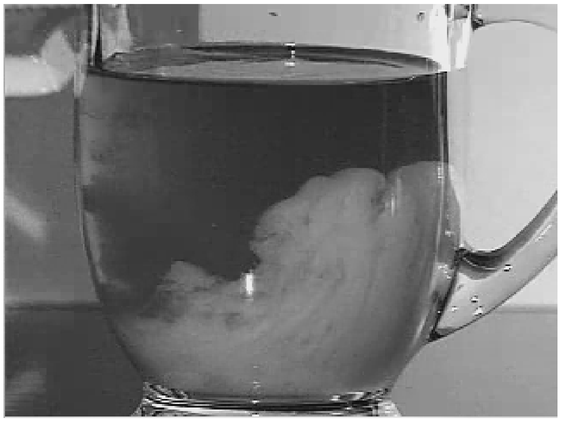
Mixing milk in coffee…



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Air as a transportation mean…

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Water surface for boating…

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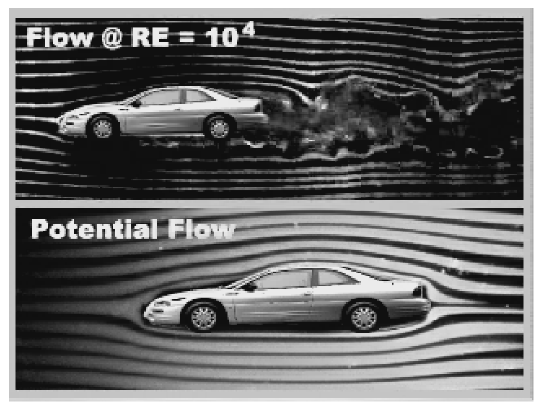
Flow of air around cars…



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Gases used as propulsion agents

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Air resistance to slow down a landing

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Smoke from homes…

Or industries…

Water or gas in conduits…

Pumps used to lift water…

Canals used for irrigation …

Hydroelectric dams…

Flood control dams...

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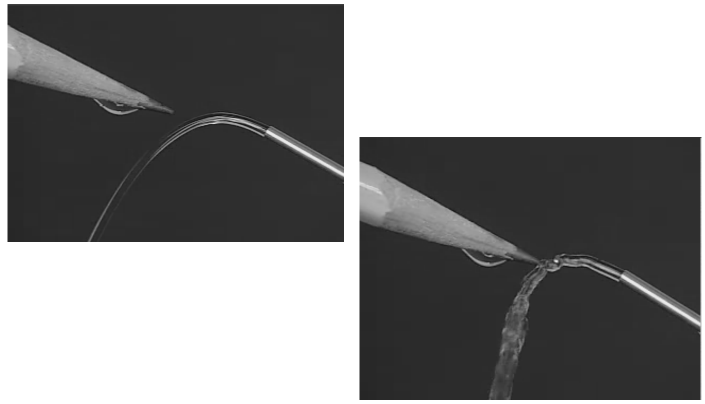
Fluid mechanics tries to explain fluids and their motions



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Scope of Fluid Mechanics (3)

- Science of the mechanics of liquids and gases
- Based on same fundamental principles as solid mechanics
- More complicated subject, however, since in fluids separate elements are more difficult to distinguish
- We'll solve problems of fluids on the surface of the Earth, within reasonable ranges of pressure and temperature.

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Scope of Fluid Mechanics (4)

- Branches:
  - Fluid statics: fluids at rest
  - Fluid kinematics: velocities and streamlines
  - Fluid dynamics: velocity & accelerations ↔ forces
- Classical hydrodynamics
  - Mathematical subject
  - Deals with ideal frictionless fluids
- Classical hydraulics:
  - Experimental science
  - Deals with real fluids

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Scope of Fluid Mechanics (5)

- Classical hydrodynamics and hydraulics are now combined into FLUID MECHANICS
- **Modern Fluid Mechanics**:
  - Combines mathematical principles with experimental data
  - Experimental data used to verify or complement theory or mathematical analysis
- **Computational Fluid Dynamics** (CDF)
  - Numerical solutions using computers
  - Methods:
    - Finite differences * finite elements
    - Boundary elements * analytic elements

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Historical development (1)

- Ancient civilizations: irrigation, ships
- Ancient Rome: aqueducts, baths (4^{th} century B.C.)
- Ancient Greece: Archimedes – buoyancy (3^{rd} century B.C.)
- Leonardo (1452-1519): experiments, research on waves, jets, eddies, streamlining, flying

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Historical development (2)

- Newton (1642-1727): laws of motion, law of viscosity, calculus
- 18th century mathematicians: solutions to frictionless fluid flows (hydrodynamics)
- 17th & 18th century engineers: empirical equations (hydraulics)
- Late 19th century: dimensionless numbers, turbulence

Historical development (3)

- Prandtl (1904): proposes idea of the boundary layer
-
  - Flow fields of low-viscosity fluids divided into two zones:
    - A thin, viscosity-dominated layer near solid surfaces
    - An effectively inviscid outer zone away from boundaries
  - Explains paradoxes
  - Allow analysis of more complex flows
- 20th century: hydraulic systems, oil explorations, structures, irrigation, computer applications

Historical development (4)

- Beginning of 21st century:
  - No complete theory for the nature of turbulence
  - Still a combination of theory and experimental data
- References:
  - Rouse & Ince: *History of Hydraulics*, Dover, NY 1963
  - Rouse: *History of Hydraulics in the United States (1776-1976)*, U of Iowa, 1976
  - Levy, E., *El Agua Segun la Ciencia*, CONACYT, Mexico, 1989

The Book (Finnerman & Franzini) - 1

- Inside covers: conversion factors, temperature tables, S.I. prefixes, important quantities
- Table of Contents
- Appendix A – data on material properties
- Appendix B – information on equations
- Appendix C – brief description of software
- Appendix D – examples of software solvers
- Appendix E – references on fluid mechanics
- Appendix F – answers to exercises in the book
- Alphabetical Index

The Book (Finnerman & Franzini) - 2

- Each chapter includes:
  - Concepts (“building blocks”)
  - Sample problems – applications of concepts
  - Exercises – reinforce understanding
  - Summary problems – real-world or examination problems
- Keys to mastering Fluid Mechanics
  - Learning the fundamentals: read and understand the text
  - Working many problems

The Book (Finnerman & Franzini) - 3

Only by working many problems can you truly understand the basic principles and how to apply them.

How to master assigned Material

- Study material to be covered *before* it is covered in class
- Study sample problems until you can solve them "closed book"
- Do enough of the drill Exercises, answer unseen
- Do the homework Problems you have been assigned

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Steps in solving problems (1)

a) Read and ponder problem statement, identify simplest approach

b) Summarize info to be used (given and obtained elsewhere), and quantities to be found

c) Draw neat figure(s), fully labelled

d) State all assumptions

e) Reference all principles, equations, tables, etc. to be used

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Steps in solving problems (2)

f) Solve as far as possible algebraically before inserting numbers

g) Check dimensions for consistency

h) Insert numerical values at last possible stage using consistent units. Evaluate to appropriate precision.

i) Check answer for reasonableness and accuracy.

j) Check that assumptions used are satisfied or appropriate. Note limitations that apply.

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Precision in numerical answers (see step h*, above)*

- Should not be more precise (as %) than that of the least precise inserted value
- Common rule is to report results to 3 significant figures, or four figures if they begin with a "1", which yields a maximum error of 5%
- Do not round off values in your calculator, only do so when presenting your answer

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More on problem solving (1)

- Master simpler problems, then tackle advanced ones.
- Practice working problems "closed book" with time limits
- Form a study group early on in the course – quiz each other about
  - Category a problem falls into
  - Procedures that should be used in solution
- Know how and when to use the material learned
- Seek and build understanding of applications of your knowledge

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More on problem solving (2)

- Techniques to be used:
  - For most problems: algebra, trial-and-error methods, graphical methods, calculus methods
  - Also: computer and experimental techniques
- Repetitive numerical evaluations using computers
- Programmable calculators for root solving

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Real-world problem solving

- Many real-world problem are not like in the textbook
- Develop ability to *recognize* problems and to clearly *define* (or formulate) them, before analysis
- Experience helps in determining best method of solution among many available
- In real world problems:
  - Numerical results not the ultimate goal
  - Results need to be interpreted in terms of physical problem
  - Recommendations must be made for action

Dimensions and units (1)

- Units needed to properly express a physical quantity
- Systems to be used:
  - S.I. (Systeme Internationale d'Unites)
    - Adopted in 1960
    - Used by nearly every major country, except the U.S.
    - Likely to be adopted by the U.S. in the near future
  - B.G. (British Gravitational system)
    - Used in the technical literature for years
    - Preferred system in the U.S.

Dimensions and units (2)

- Basic dimensions used in fluid mechanics:
  - Length (L)
  - Mass (M)
  - Time (T)
  - Temperature (θ)
- Dimensions of acceleration: $[a] = LT^{-2}$
- Newton's 2nd law: $F = [m][a] = MLT^{-2}$
- Only 3 of the four basic units can be assigned arbitrarily, the fourth becoming a *derived* unit

Dimensions and units (3)

Commonly used units in SI and BG

Dimension	BG unit	SI unit
Length (L)	foot (ft)	meter, metre (m)
Mass (M)	slug (=lb sec^2 /ft)	kilogram (kg)
Time (T)	second (sec)	second (s)
Force (F)	pound (lb)	newton (n) (=kg m/s^2)
Temperature (θ)		
Absolute	Rankine (°R)	Kelvin (K)
Ordinary	Fahrenheit (°F)	Celsius (°C)

See other dimensions and units in page 8

Dimensions and units (4)

- Weight,

$$W = mg$$

- g = gravitational acceleration
- On the surface of Earth

$$g = 32.2\ ft/s^2 = 9.81\ m/s^2$$

- Weights of unit mass
  - BG units: $W = mg = (1\ slug)(32.2\ ft/s^2) = 32.2\ lb$
  - SI units: $W = mg = (1\ kg)(9.81\ m/s^2) = 9.81\ N$

Example P1.1 – Weight calculation

Gravity on the surface of the moon (g_m) is 1/6 that of Earth, i.e., $g_m = g/6$. What is the weight, in *newtons*, of $m = 2.5\ kg$ of water on Earth, and on the surface of the moon?

On Earth,

$$W = mg = (2.5\ kg)(9.81\ m/s^2) = 24.53\ N$$

On the moon,

$$W_m = mg_m = mg/6 = (2.5\ kg)(9.81\ m/s^2)/6 = 4.087\ N$$

Dimensions and units (5)

Other systems of units used:

- English Engineering (EE) - inconsistent
  - M (pound mass, *lbm*), F (pound force, *lbf*)
- MKS (m-kg-s) metric - inconsistent
  - M (kg mass, *kgm*), F (kg force, *kgf*)
- Cgs (cm-g-s) metric – consistent
  - M (*g*), F(*dyne* = $g\ cm/s^2$)
  - $1\ dyne = 10^{-5}\ N$, a very small quantity

Dimensions and units (6)

Popular usage in Europe and other countries

- A "kilo" of sugar or other produce, represents a mass of 1 kg
- A "kilo", therefore, represents a weight of 9.81 N
- A pound of weight has a mass of about 0.4536 kg
- Thus, the conversion factor for popular usage is

$$1.00/0.4536 = 2.205 \text{ lb/kgf}$$

- In engineering, reserve *kg* for mass only, and *N* for force only

Unit abbreviations (1)

- Abbreviations
  - *kg* = kilogram
  - *lb* = pound(s), not *lbs*
  - Time units:
    - *s, min, h, d, y* (S.I.)
    - *Sec, min, hr, day, yr* (B.G.)
- Non-standard abbreviations
  - *fps* = feet per second
  - *gpm* = gallons per minute
  - *cfs*, or *cusecs* = cubic feet per second
  - *cumecs* = cubic meters per second

Unit abbreviations (2)

- Abbreviations
  - *Acres, tons, slugs* abbreviated [Although, *Ac* = acres]
  - Units named after people:
    - Upper case when abbreviated: *N, J, Pa*
    - Lower case when spelled out: *newton, joule, pascal*
  - Use *L* for liter (to avoid confusing *l* with *1*)
  - S.I. absolute temperature is in *K* (*kelvin*) not ^oK
- 1 British or imperial gallon = 1.2 U.S. Gallon (±0.1%)
- When not specified, assume *U.S. gallons*

Derived quantities (1)

Basic dimensions: *mass (M), length (L), time (T)*

- *Velocity = Length / Time*
- *Acceleration = Velocity / Time = Length / Time*^{2}
- *Discharge = Volume / Time*
- *Force = Mass × Acceleration*
- *Pressure = Force / Area* (also *Stress*)
- *Work = Force × Length* (also *Energy, Torque*)
- *Power = Work / Time = Force × Velocity*
- *Angular Velocity = Angle / Time*
- *Angular Acceleration = Angular Velocity / Time*

Derived quantities (2)

Basic dimensions: *force (M), length (L), time (T)*

- *Velocity = Length / Time*
- *Acceleration = Velocity / Time = Length / Time*^{2}
- *Discharge = Volume / Time*
- *Mass = Force / Acceleration*
- *Pressure = Force / Area* (also *Stress*)
- *Work = Force × Length* (also *Energy, Torque*)
- *Power = Work / Time = Force × Velocity*
- *Angular Velocity = Angle / Time*
- *Angular Acceleration = Angular Velocity / Time*

Basic units for derived quantities

Derived quantity	B.G.	S.I.
Velocity	*ft/sec = fps*	*m/s*
Acceleration	*ft/sec²*	*m/s²*
Discharge	*ft³/s = cfs*	*m³/s*
Mass	slug = lb sec² / ft	*kg*
Force	*lb*	*N = kg m/s²*
Pressure	*lb/ft² = psf*	*Pa = N/m²*
Work	*lb ft*	*J = N m*
Power	*lb ft/sec*	*W = J/s*
Angular velocity	*rad/sec*	*rad/s*
Angular acceleration	*rad/sec²*	*rad/s²*

Example P1.2 – Mass, force, pressure

- A mass $m = 2.5\ kg$ is subject to an acceleration of $a = 4\ m/s^2$. What is the force applied to the mass?

$$F = ma = (2.5\ kg)(4\ m/s^2) = 10\ N$$

- A force $F = 20\ lb$ produces an acceleration of $a = 2\ ft/s^2$, determine the mass m?

$$m = F/a = (20\ lb)/(2\ ft/s^2) = 10\ slugs$$

- Determine the pressure p produced by a force $F = 10\ lb$ on an area $A = 5\ ft^2$:

$$P = F/A = (10\ lb)/(5\ ft^2) = 2\ psf$$

Example P1.3 – Pressure, Work, Power

- A force $F = 40\ N$ is applied on an area of $A = 2\ m^2$, what is the average pressure p on the area?

$$p = F/A = (40\ N)/(2\ m^2) = 80\ Pa$$

- If the force $F = 40\ N$ moves a mass a distance $x = 2\ m$ in a time $t = 10\ s$, what is the work developed and the corresponding power?

$$W = F\cdot x = (40\ N)(2\ m) = 80\ J$$
$$P = W/t = (80\ J)/(10\ s) = 8\ W$$

Unit prefixes in S.I.

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n

Example P1.4 – Pressure, work, power

- A force $F = 4000\ N$ is applied on an area of $A = 20\ m^2$, what is the average pressure p on the area?

$$p = F/A = (4000\ N)/(20\ m^2) = 80000\ Pa = 80\ kPa$$

- If the force $F = 4000\ N$ moves a mass a distance $x = 2000\ m$ in a time $t = 10\ s$, what is the work developed and the corresponding power?

$$W = F\cdot x = (4000\ N)(2000\ m) = 8\ 000\ 000\ J = 8\ MJ$$
$$P = W/t = (8\ 000\ 000\ J)/(10\ s) = 800\ 000\ W$$
$$= 800\ kW = 0.8\ MW$$

Other units (B.G.)

- Length: *1 in = 1/12 ft, 1 mi = 5280 ft, 1 yd = 3 ft*
- Area: *1 Acre = 43 560.17 ft²*
- Volume: *1 gallon (U.S.) = 0.1337 ft³*
  1 acre-ft = 43 560.17 ft³
- Velocity: *1 mph = 1.467 fps*
- Pressure: *1 psi [lb/in²] = 144 psf, 1 in Hg = 70.73 psf,*
  1 ft H_20 = 62.37 psf
- Energy: *1 BTU = 778.17 lb×ft*
- Power: *1 hp = 550 lb×ft / s*

Example P1.5 – Various B.G. Units (1)

- A steel pipe has a diameter *D = 6 in*. What is the diameter in ft?

$$D = 6\ in = (6\ in)(1/12\ ft/in) = 0.5\ ft$$

- The area of a reservoir is given as A = 2.5 acres. What is the area in ft2?

$$A = 2.5\ acres = (2.5\ acres)(43560.17\ ft^2/acres) = 108\ 900.43\ ft^2$$

Example P1.5 – Various B.G. Units (2)

- What is the volume of a *5-gallon* container in ft^3?

$$V = 5\ gal = (5\ gal)(0.1337\ ft^3/gal) = 0.669\ ft^3$$

- The volume of a reservoir is given as *V = 1.2 acre-ft*. What is the reservoir volume in ft^3?

$$V = 1.2\ acre\text{-}ft = (1.2\ acre\text{-}ft)(43\ 560.17\ ft^3/acre\text{-}ft) = 52272.20\ ft^3$$

Example P1.5 – Various B.G. Units (3)

- A tire manometer reads 40 psi of pressure. What is the pressure in pounds per square foot (psf)?

$$p = 40\ psi = (40\ psi)(144\ psf/psi) = 5760\ psf$$

- A barometer reads an atmospheric pressure of *28 inches of mercury* (*28 inHg*). What is the atmospheric pressure in psf?

$$p = 28\ inHg = (28\ inHg)(70.73\ psf/inHg) = 1980.44\ psf$$

Example P1.5 – Various B.G. Units (4)

- A piezometric tube shows a pressure of *20 meters of water* ($p = 20\ ftH_20$). What is the pressure in psf?

$$p = 20\ ftH_20 = (20\ ftH_20)(62.37\ psf/ftH_20) = 1247.4\ psf$$

- During a short period of operation a heater produces an output of *300 BTU*s (*British thermal unit*). What is the heat produced in lb ft?

$$W = 300\ BTU = (300\ BTU)(778.17\ lb\ ft/BTU) = 233\ 451\ lb\ ft$$

Example P1.5 – Various B.G. Units (5)

- A machine is able to develop a power of *500 hp* (*horse power*). What is the power of this machine in *lb ft/s*?

$$P = 500\ hp = (500\ hp)(550\ lb{\cdot}ft/(s{\cdot}hp))$$

$$= 275\ 000\ lb\ ft/s$$

Other units (S.I.)

- Area: $1\ ha = 10^{4}\ m^2$
- Volume: $1\ L = 10^{-3}\ m^3 = 10^{3}\ cc$
- Mass: $1\ g = 10^{-3}\ kg$
- Pressure: $1\ atm = 101.325\ kPa$, $1\ bar = 10^{5}\ Pa$, $1\ mmHg = 133.32\ Pa$, $1\ mH_20 = 9.810\ kPa$
- Energy: $1\ cal = 4.186\ J$, $1\ erg = 1\ dyne \times cm = 10^{-7}\ J$, $1\ kW \times h = 3.6 \times 10^{6}\ J$
- Angular velocity: *1 rpm = 0.1047 rad/s* (both systems)

Example P1.6 – Various S.I. units (1)

- The area of a small basin is reported to be $A = 0.5\ ha$. What is the area in m^2?

$$A = 0.5\ ha = (0.5\ ha)(104\ m^2/ha) = 5\ 103\ m^2$$

- The volume of a tank is $V = 40000\ L$. What is the tank's volume in m^3?

$$V = 40000\ L = (40000\ L)(10^{-3}\ m^3/L) = 40\ m^3$$

Example P1.6 – Various S.I. units (2)

- he volume of a small container is V = 0.3 L. What is the volume in cc (cubic centimeters)?

$$V = 0.3\ L = (0.3\ L)(103\ cc/L) = 300\ cc$$

- Convert the following pressures to Pa or kPa:

$$p_1 = 0.6\ atm = (0.6\ atm)(101.325\ kPa/atm) = 60.80\ kPa$$

$$p_2 = 0.02\ bar = (0.02\ bar)(105\ Pa/bar) = 2.1\ Pa$$

Example P1.6 – Various S.I. units (3)

- Convert the following pressures to Pa or kPa:

$$p_3 = 100\ mmHg = (100\ mmHg)(133.32\ Pa/mmHg)$$

$$= 133\ 320\ Pa = 133.32\ kPa = 0.133\ MPa$$

$$p_4 = 2.5\ mH20 = (2.5\ mH20)(9.810\ kPa)$$

$$= 24.525\ kPa$$

Example P1.6 – Various S.I. units (4)

- Determine the energy in Joules contained in *2000 calories.*

$$E = 2000\ cal = (2000\ cal)(4.186\ J/cal) = 8372\ J$$

- If a refrigerator uses *0.05 kW-h* during a period of operation, what is the energy consumed in *joules*?

$$E = 0.05\ kW\text{-}h = (0.05\ kW\text{-}h)(3.6\ 106\ J) = 180\ 000\ J = 180\ kJ = 0.18\ MJ$$

Example P1.6 – Various S.I. units (5)

- If a pump operates at 400 rpm, what is the equivalent angular velocity in rad/s?
-

$$\omega = 400\ rpm = (400\ rpm)(0.1047\ rad/(s\ rpm))$$

$$= 41.88\ rad/s$$

Selected conversion factors (BG-SI)

- Length: *1 ft = 0.3048 m, 1 mi = 1.609 km*
- Area: *1 acre = 0.4047 ha*
- Volume: *1 gal = 3.786 L,*
  1 acre-ft = 1233.49 m^3
- Discharge: *1 gpm =* $6.309\times10^{-5}\ m^3/s$
- Mass: *1 slug = 14.594 kg*
- Force: *1 lb = 4.448 N*
- Work: *1 lb ft = 1.356 J, 1 BTU = 1055.06 J,*
  1 BTU = 252 cal
- Power: *1 lb ft/s = 1.356 W, 1 hp = 745.70 W*

Example P1.7 – BG to SI conversions (1)

- A pipeline is measured to be *300 ft* in length. What is the pipe length in m?

$$L = 300\ ft = (300\ ft)(0.3048\ m/ft) = 91.44\ m$$

- The area of a small pond is measured to be *2.3 acres*. What is the pond area in hectares?

$$A = 2.3\ acres = (2.3\ acres)(0.4047\ ha/acre) = 0.9381\ ha$$

Example P1.7 – BG to SI conversions (2)

- The volume of a small container is $V = 12.5\ gal$. What is the container's volume in liters?

$$V = 12.5\ gal = (12.5\ gal)(3.786\ L/gal) = 47.33\ L$$

- The volume of a reservoir is *3.5 acre-ft*. What is the reservoir volume in cubic meters?

$$V = 3.5\ acre\text{-}ft = (3.5\ acre\text{-}ft)(1233.49\ m^3/acre\text{-}ft) = 4317.49\ m^3$$

Example P1.7 – BG to SI conversions (3)

- A pipeline carries a discharge $Q = 5\ gpm$. What is the pipeline discharge in *m3/s?*

$$Q = 5\ gpm = (5\ gpm)(6.309\times 10^{-5}\ m^3/(s\ gpm)) = 0.0003155\ m^3/s$$

- The mass of a given volume of water is measured to be $m = 4.5\ slugs$. What will this mass be in *kg*?

$$m = 4.5\ slugs = (4.5\ slugs)(14.594\ kg/slug) = 65.673\ kg$$

Example P1.7 – BG to SI conversions (4)

- The force applied by water flowing under a sluice gate on the gate is measured to be $F = 145\ lb$. What is the force on the gate in *newtons*?

$$F = 145\ lb = (145\ lb)(4.448\ N/lb) = 644.96\ N$$

- The potential energy of a water mass is measured to be $E = 236\ lb\ ft$. What is this energy in *J?*

$$E = 236\ lb\ ft = (236\ lb\ ft)(1.356\ J/(lb\ ft)) = 320.02\ J$$

Example P1.7 – BG to SI conversions (5)

- The heat transferred through an industrial process is measured to be $q = 2000\ BTU$. What is the amount of heat in *J*?

$$q = 2000\ BTU = (2000\ BTU)(1055.06\ J/BTU) = 2\ 110\ 120\ J = 2\ 110.12\ kJ = 2.11\ MJ$$

- How many calories are there in *2000 BTU*?

$$q = 2000\ BTU = (2000\ BTU)(252\ cal/BTU) = 504\ 000\ cal = 504\ kcal$$

Example P1.7 – BG to SI conversions (6)

- The power developed by a pump is $P = 150\ lb\ ft/s$. What is the pump's power in *watts*?

$$P = 150\ lb\ ft/s = (150\ lb\ ft/s)(1.356\ W\ s/(lb\ ft)) = 203.4\ W = 0.203\ kW$$

- If a turbine's power is rated to be $P = 500\ hp$, what is the turbine's power in *watts*?

$$P = 500\ hp = (500\ hp)(745.7\ W/hp) = 372\ 850\ W = 372.85\ kW = 0.373\ MW$$

Selected conversion factors (SI-BG)

- Length: *1 m = 3.28 ft, 1 km = 0.621 mi*
- Area: *1 ha = 2.47 acre*
- Volume: *1 L = 0.264 gallon,*
  $1\ m^3 = 9.107\times10^{-4}$ *acre-ft*
- Discharge: $1\ m^3/s$ = *15 850.32 gpm*
- Mass: $1\ kg = 6.852\times10^{-2}$ *slug*
- Force: *1 N = 0.225 lb*
- Work: $1\ J = 0.738$ *lb-ft* $= 9.478\times10^{-4}$ *BTU ,*
  $1\ cal = 3.968\times10^{-3}$ *BTU, 1 kW-h = 3412.14 BTU*
- Power: *1 W = 0.7375 lb ft/s,* $1\ W = 1.34\times10^{-3}$ *hp*

Example P1.8 – SI to BG conversions (1)

- A large aqueduct is built with a length of *3.5 km*. What is this length in miles?

L = 3.5 km = (3.5 km)(0.621 mi/km) = 2.1735 mi

- A crop area A = 2.5 ha is to be irrigated. What is the area in acres?

A = 2.5 ha = (2.5 ha)(2.47 acre/ha) = 6.175 acre

Example P1.8 – SI to BG conversions (2)

- You collect a volume of *25 L* for a test. What is this volume in *gallons?*

V = 25 L = (25 L)(0.264 gal/L) = 6.6 gal

- A canal carries a flow $Q = 0.02\ m^3/s$. What is this flow in *gallons per minute?*

$Q = 5.6\ m^3/s = (0.02\ m^3/s)(15\ 850.32\ gpm\cdot s/m^3)$
$= 317.00$ *gpm*

Example P1.8 – SI to BG conversions (3)

- How many slugs are there in a mass of *18 kg?*

$m = 18\ kg = (18\ kg)(6.852\times10^{-2}\ slug/kg)$
$= 1.233$ *slug*

- The shear force on a segment of a channel is measured to be *250 N*. What is this force in *pounds?*

F = 250 N = (250 N)(0.225 lb/N) = 56.25 lb

Example P1.8 – SI to BG conversions (4)

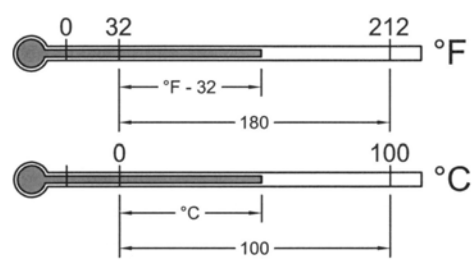
- If you use *0.5 KW-h* of energy, how much energy did you use in *BTU?*

W = 0.5 kW-h = (0.5 Kw-h)(3412.14 BTU/KW-h)
= 1706.7 BTU

- If a turbine is rated for a power *P = 1.5 kW,* how many *hp*s is the rating power?

$P = 1.5\ kW = (1500\ W)(1.34\times10^{-3}\ hp) = 2.01\ hp$

Common temperature scales



$$\frac{°F - 32}{°C} = \frac{180}{100} = \frac{5}{9}$$

Example P1.9 – Common temperature scales

- Determine the value for which both the Celsius (centigrade) and Fahrenheit scales have the same reading.

We try to find x such that $^oF = x$ and $^oC = x$ in

$$(^oF\text{-}32)/^oC = 9/5, \text{ i.e., } (x\text{-}32)/x = 9/5, \text{ thus}$$

$$5x - 160 = 9x \;\Rightarrow\; -4x = 160 \;\Rightarrow\; x = -40$$

Thus, -40^{o}F = -40^{o}C is the point where both scales read the same value.

More temperature relations

$$^oC = (5/9)(^oF\text{-}32)$$

$$^oF = (9/5)(^oC) + 32$$

$$K = {}^oC + 273$$

$$^oR = {}^oF + 460$$

$$K = (5/9)(^oR)$$

$$^oR = (9/5)\ K$$

Example P1.10 – Temperature conversions

$$T = 68^oF \;\Rightarrow\; {}^oC = (5/9)(^oF\text{-}32) = (5/9)(68\text{-}32) = 20^oC$$

$$T = 25^oC \;\Rightarrow\; {}^oF = (9/5)(^oC) + 32 = (9/5)(25)+32 = 77\ {}^oF$$

$$T = -20\ oC \;\Rightarrow\; K = {}^oC + 273 = -20 + 273 = 253\ K$$

$$T = -250\ {}^oF \;\Rightarrow\; {}^oR = {}^oF + 460 = -250 + 460 = 210\ {}^oR$$

$$T = 495\ {}^oR \;\Rightarrow\; K = (5/9)(^oR) = (5/9)(495) = 275\ K$$

$$T = 360\ K \;\Rightarrow\; {}^oR = (9/5)\ K = (9/5)(360) = 648\ {}^oR$$

Unit conversions HP calculators(1)

- Convert *350 hp* to *W*:
[↱][UNITS][NXT][POWR][3][5][0][hp][1][W]
[↱][UNITS][TOOLS][CONVE]

$$350\ hp = 260994.96\ W$$

- Convert *25 acre-ft* to m^3:
[↱][UNITS][AREA][NXT][2][5][acre][NXT]
[UNITS][LENG][1][ft][×][↱][UNITS][VOL]
[1][m^3] [↱][UNITS][TOOLS][CONVE]

$$25\ acre\text{-}ft = 30837.17\ m^3$$

Unit conversions HP calculators(2)

- Convert *150 kW-h* to *lb×ft*:
[↱][UNITS][NXT][POWR][1][5][0][↱][-]
[ALPHA][↰][K][W][ENTER][UNITS][TIME]
[1][h][×][NXT][UNITS][NXT][ENRG][1][ft×lb]
[NXT][UNITS][TOOLS][CONVE]

$$150\ kW\text{-}h = 398283560.61\ ft{\cdot}lbf$$

<u>NOTES</u>: (1) Use of prefixes, e.g., *k* = kilo:
[↱][-][ALPHA][↰][K]
(2) The answer is given using *lbf* (pound-force), note that *lbf* (EE) = *lb* (BG).

Unit conversions TI 89 (1)

- Convert *350 hp* to *W*:
[HOME][3][5][0][2nd][UNITS]
Press [▼] 13 times to highlight *Power .... _hp*
[Enter] (selects *_hp*) [Enter] (auto convert to *_W*)

$$350\ hp = 260995\ W$$

- Convert *25 acre-ft* to m^3:
[HOME][2][5][2nd][UNITS][▼][▼][Enter][×][1]
[2nd][UNITS][▼][▶][▼][▼][▼][▼][▼][Enter]

$$25\ acre\text{-}ft = 30837.\ m^3$$

Unit conversions TI 89 (2)

- Convert *150 kW-h* to *lb×ft*:

[HOME][1][5][0][2nd][UNITS]
Press [▼] 12 times to highlight *Energy* .... [▶]
Press [▼] 7 times to highlight *_kWh* [Enter][2nd][▸]
[2nd][UNITS]
Press [▼] 12 times to highlight *Energy* .... [▶]
Press [▼] 7 times to highlight *_ftlb* [Enter]

150 kW-h = 3.98284E8_ftlb = 3.98284×10^{8} *lb·ft*

Note: the symbol [2nd][▸] is the *conversion operator*

Quantities, dimensions, and units

	Dimensions		Preferred units	
Quantity	(M,L,T)	(F,L,T)	S.I.	E.S.
Length (L)	L	L	*m*	*ft*
Time (T)	T	T	*s*	*s*
Mass (M)	M	FT^2L^{-1}	*kg*	*slug*
Area (A)	L^2	L^2	m^2	ft^2
Volume (Vol)	L^3	L^3	m^3	ft^3
Velocity (V)	LT^{-1}	LT^{-1}	*m/s*	*ft/s or fps*
Acceleration (a)	LT^{-2}	LT^{-2}	m/s^2	ft/s^2
Discharge (Q)	L^3T^{-1}	L^3T^{-1}	m^3/s	ft^3/s or cfs
Kinematic viscosity (ν)	L^2T^{-1}	L^2T^{-1}	m^2/s	ft^2/s
Force (F)	MLT^{-2}	F	*N*	*lb*
Pressure (p)	$ML^{-1}T^{-2}$	FL^{-2}	*Pa*	lb/ft^2
Shear stress (τ)	$ML^{-1}T^{-2}$	FL^{-2}	*Pa*	lb/ft^2
Density (ρ)	ML^{-3}	FT^2L^{-4}	kg/m^3	$slug/ft^3$
Specific weight (γ)	$ML^{-2}T^{-2}$	FL^{-3}	N/m^3	lb/ft^3
Energy/Work/Heat (E)	ML^2T^{-2}	FL	*J*	*lb ft*
Power (P)	ML^2T^{-3}	FLT^{-1}	*W*	*lb ft/s*
Dynamic viscosity (μ)	$ML^{-1}T^{-1}$	FTL^{-2}	$N\ s/m^2$	$lb\ s/ft^2$

Example P1.11 - Dimensions

- Let *P* = pressure, *ρ* = density, V = velocity. Determine the dimensions of the quantity

$$C_p = \frac{P}{\frac{1}{2}\rho V^2}$$

$$[C_p] = [P]/([\rho][V]^2) = ML^{-1}\,T^{-2}/(ML^{-3}\,(LT^{-1})^2)$$

$$= M^{1-1}\,L^{-1+3-2}\,T^{-2+2} = M^0\,L^0\,T^0 = \textit{dimensionless}$$

Example P1.12 – Dimensional homogeneity

- The theoretical equation for the discharge *Q* over a sharp-crested weir is given by

$$Q = (2/3)\cdot(2g)^{1/2}\cdot L\cdot H^{3/2},$$

where *g* = gravity, *L* = length, *H* = weir head. Check the equation for dimensional homogeneity.

With $[g] = LT^{-2}$, $[L] = L$, $[H] = L$, we find

$$[Q] = 1\cdot(1\cdot L\cdot T^{-2})^{1/2}\cdot L\cdot L^{3/2} = L^{1/2+1+3/2}\,T^{(-2)(1/2)} = L^3T^{-1}$$