

CHEE 201: Introduction to Chemical Engineering Calculations

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Textbook: Hammelblau D. M. and Riggs J. B., Basic Principles and Calculations in Chemical Engineering, 8th Edition Prentice Hall; (2012).

Reference: Ritchard M. Felder, Ronald W. Rousseau, Elementary Principles of Chemical Processes, 3rd Edition, John Wiley & Sons; (2005)

CHAPTER (1): DIMENSIONS, UNITS, AND THEIR CONVERSION

1.1 Units and Dimensions

- **Dimensions** are our basic concepts of measurement such as length, time, mass, temperature, and so on.
- **Units** are the means of expressing the dimension such as feet or centimeters for length and seconds or hours for time

DIMENSIONS, UNITS, AND THEIR CONVERSION

- The two most commonly used systems of units:
 - SI system of units.
 - AE, or American Engineering system of units
- Dimensions and their respective units are classified as:
 - Fundamental (or basic) dimensions /units are those that can be measured independently and are sufficient to describe essential physical quantities.
 - Derived dimensions /units are those that can be developed in terms of the fundamental dimensions /units.

Physical Quantity	Name of Unit	Symbol for Unit*	Definition of Unit
<i>Basic SI units</i>			
Length	metre, meter	m	
Mass	kilogramme, kilogram	kg	
Time	second	s	
Temperature	kelvin	K	
Amount of substance	mole	mol	
<i>Derived SI units</i>			
Force	newton	N	$(\text{kg})(\text{m})(\text{s}^{-2}) \rightarrow (\text{J})(\text{m}^{-1})$
Energy	joule	J	$(\text{kg})(\text{m}^2)(\text{s}^{-2})$
Power	watt	W	$(\text{kg})(\text{m}^2)(\text{s}^{-3}) \rightarrow (\text{J})(\text{s}^{-1})$
Density	kilogram per cubic meter		$(\text{kg})(\text{m}^{-3})$
Velocity	meter per second		$(\text{m})(\text{s}^{-1})$
Acceleration	meter per second squared		$(\text{m})(\text{s}^{-2})$
Pressure	newton per square meter, pascal		$(\text{N})(\text{m}^{-2}), \text{Pa}$
Heat capacity	joule per (kilogram $\times$ kelvin)		$(\text{J})(\text{kg}^{-1})(\text{K}^{-1})$
<i>Alternative units</i>			
Time	minute, hour, day, year	min, h, d, y	
Temperature	degree Celsius	$^{\circ}\text{C}$	
Volume	litre, liter (dm^3)	L	
Mass	tonne, ton (Mg), gram	t, g	

*Symbols for units do not take a plural form, but plural forms are used for the unabbreviated names. Non-SI units such as day (d), liter or litre (L), and ton or tonne (t) are legally recognized for use with SI.

Physical Quantity	Name of Unit	Symbol
<i>Some basic units</i>		
Length	foot or inch	ft or in.
Mass	pound (mass)	lb _m
Time	second, hour	s, hr
Temperature	degree Rankine or degree Fahrenheit	°R or °F
Amount of substance	pound mole	lb mol
<i>Derived units</i>		
Force	pound (force)	lb _f
Energy	British thermal unit, foot pound (force)	Btu, (ft)(lb _f)
Power	horsepower	hp
Density	pound (mass) per cubic foot	lb _m /ft ³
Velocity	feet per second	ft/s
Acceleration	feet per second squared	ft/s ²
Pressure	pound (force) per square inch	lb _f /in. ²
Heat capacity	Btu per pound (mass) per degree F	Btu/[(lb _m)(°F)]
Volume	cubic feet	ft ³

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- SI Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^9	giga	G	10^{-1}	deci	d
10^6	mega	M	10^{-2}	centi	c
10^3	Kilo	K	10^{-3}	milli	m
10^2	hekta	h	10^{-6}	micro	μ
10^1	deka	da	10^{-9}	nano	n

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1.2 Operations with Units

- Addition, Subtraction, Equality

You can add, subtract, or equate numerical quantities only if the associated units of the quantities are the same. Thus, the operation

- 5 kilograms + 3 joules $\rightarrow$ cannot be carried out
- 10 pounds + 5 grams $\rightarrow$ can be performed only after the units are transformed to be the same

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- Multiplication and Division

You can multiply or divide unlike units at will such as

$$3 \text{ N} \times 2 \text{ m} = 6(\text{N})(\text{m})$$

but you cannot cancel or merge units unless they are identical.

EXAMPLE: Add the following:

- (a) 1 foot + 3 seconds
- (b) 1horse power + 300 watts

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1.3 Conversion of Units and Conversion Factors

Example: If a plane travels at the speed of sound (assume that the speed of sound is 1100 ft/s), how fast is it going in miles per hour?

Solution:

$$\frac{1100 \cancel{ft}}{\cancel{s}} \left| \frac{mi}{5280 \cancel{ft}} \right| \frac{3600 \cancel{s}}{h} = \frac{1100 \times 3600}{5280} mi/h = 750 mi/h$$

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Example: Conversion of Units

- (a) Convert 2 km to miles.
- (b) Convert 400 in³/day to cm³/min.

Solution:

$$a) \frac{2 \cancel{\text{km}}}{1} \left| \frac{1 \text{ mile}}{1.61 \cancel{\text{km}}} \right| = 1.24 \text{ mile}$$

$$b) \frac{400 \cancel{\text{in}^3}}{\cancel{\text{day}}} \left| \left(\frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in}}} \right)^3 \right| \left| \frac{1 \cancel{\text{day}}}{24 \cancel{\text{hr}}} \right| \frac{1 \cancel{\text{hr}}}{60 \text{ min}} = 4.65 \text{ cm}^3/\text{min}$$

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Example: a semiconductor (ZnS) with a particle diameter of 1.8 nanometers.
Convert this value to:

(a) dm (decimeters)

(b) inches.

Solution:

$$a) \frac{1.8 \cancel{\text{nm}}}{1 \cancel{\text{nm}}} \left| \frac{10^{-9} \cancel{\text{m}}}{1 \cancel{\text{m}}} \right| \frac{10 \text{ dm}}{1 \cancel{\text{m}}} = 1.8 \times 10^{-8} \text{ dm}$$

$$b) \frac{1.8 \cancel{\text{nm}}}{1 \cancel{\text{nm}}} \left| \frac{10^{-9} \cancel{\text{m}}}{1 \cancel{\text{m}}} \right| \frac{39.37 \text{ in}}{1 \cancel{\text{m}}} = 7.09 \times 10^{-8} \text{ in}$$

DIMENSIONS, UNITS, AND THEIR CONVERSION

$$F = Cma$$

Where F = force

C= a constant whose numerical value and units depend on those selected for F, m, and a

m = mass

a = acceleration

- In the SI system the unit of force is defined to be the Newton (N) when 1 kg is accelerated at 1 m/s², a conversion factor C= 1 N/(Kg)(m)/s² must be introduced to have the force be 1 N:

$$F = \underbrace{\frac{1 \text{ N}}{(\text{kg})(\text{m})}}_C \underbrace{\frac{1 \text{ kg}}{}}_m \underbrace{\frac{1 \text{ m}}{\text{s}^2}}_a = 1 \text{ N}$$

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$$F = \frac{1 \text{ N}}{\frac{(\text{kg})(\text{m})}{\text{s}^2}} \left| \frac{1 \text{ kg}}{1 \text{ kg}} \right| \left| \frac{1 \text{ m}}{1 \text{ m}} \right| \frac{1 \text{ s}^2}{1 \text{ s}^2} = 1 \text{ N}$$

$C \qquad m \qquad a$

- Because the numerical value associated with the conversion factor is 1, the conversion factor seems simple, even nonexistent and the units are normally ignore
- In AE system, if a mass of 1 lb_m is accelerated at gft/s^2 , where g is the acceleration that would be caused by gravity (about 32.2 ft/s^2 depending on the location of the mass), we can make the force be 1 lb_f by choosing the proper numerical value and units for the conversion factor C :

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$$F = \left(\frac{1(\text{lb}_f)(\text{s}^2)}{32.174(\text{lb}_m)(\text{ft})} \right) \left(\frac{1 \text{ lb}_m}{m} \left| \frac{g \text{ ft}}{s^2} \right. \right) = 1 \text{ lb}_f$$

C_{AE} m g

- A numerical value of 1/32.174 has been chosen for the numerical value in the conversion factor because 32.174 is the numerical value of the average acceleration of gravity (g) (9.80665 m/s²) at sea level at 45° latitude when g is expressed in ft/s².

- $g_c = 32.174 \frac{(\text{ft})(\text{lb}_m)}{(\text{s}^2)(\text{lb}_f)}$ Where g_c is the inverse of the conversion factor

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- What is the difference between mass and weight?
- The weight of an object is the force exerted on the object by gravitational attraction.

$$W = mg$$

Where (g) is gravitational acceleration and (m) is the mass of an object.

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Example: What is the potential energy in $(\text{ft})(\text{lb}_f)$ of a 100 lb drum hanging 10 ft above the surface of the Earth with reference to the surface of the Earth?

Solution:

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Example: Experiments show that 1 $\mu\text{g mol}$ of glucoamylase in a 4% starch solution results in a production rate of glucose of $0.6 \mu\text{g mol}/(\text{mL})(\text{min})$. Determine the production rate of glucose for this system in the units of $\text{lb mol}/(\text{ft}^3)(\text{day})$

Solution:

$$\frac{0.6 \mu\text{g mol glucose}}{(\text{mL})(\text{min})} \left| \frac{1 \text{ g mol}}{10^6 \mu\text{g mol}} \right| \left| \frac{1 \text{ lb mol}}{454 \text{ g mol}} \right| \left| \frac{1 \text{ L}}{3.531 \times 10^{-2} \text{ ft}^3} \right|$$
$$\frac{60 \text{ min}}{1 \text{ hr}} \left| \frac{24 \text{ hr}}{1 \text{ day}} \right| = 0.0539 \frac{\text{lb mol}}{(\text{ft}^3)(\text{day})}$$

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1.4 Dimensional Consistency (Homogeneity)

A basic principle states that equations must be dimensionally consistent which means each term in an equation must have the same net dimensions and units as every other term to which it is added, subtracted, or equated.

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Example: Your handbook shows that microchip etching roughly follows the relation:

$$d = 16.2 - 16.2 e^{-0.021t} \quad t < 200$$

where d is the depth of the etch in microns (micrometers, μm) and t is the time of the etch in seconds. What are the units associated with the numbers 16.2 and 0.021? Convert the relation so that d becomes expressed in inches and t can be used in minutes

Solution:

- Both values of 16.2 must have the associated units of microns (μm).
- The exponential must be dimensionless so that 0.021 must have the associated units of s^{-1} .

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Solution (cont.):

$$d(\text{in.}) = \frac{16.2 \mu\text{m}}{10^6 \mu\text{m}} \left| \frac{1 \text{ m}}{10^6 \mu\text{m}} \right| \frac{39.37 \text{ in.}}{1 \text{ m}} \left[1 - \exp \frac{-0.021}{\text{s}} \left| \frac{60 \text{ s}}{1 \text{ min}} \right| \frac{t(\text{min})}{1} \right]$$
$$d(\text{in.}) = 6.38 \times 10^{-4} (1 - e^{-1.26t(\text{min})})$$

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- A groups of symbols, may be put together, have no net units. Such collections of variables or parameters are called dimensionless groups.
- One example is the Reynolds number (group) arising in fluid mechanics

$$\text{Reynolds number, } Re = \frac{Dv\rho}{\mu}$$

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1.5 Significant Figures

- To determine the number of significant figures in a number use the following 3 rules:
 1. All non-zero digits are significant.
 2. Any zeros between two significant digits are significant.
 3. A final zero or trailing zeros in the decimal portion only are significant.

Example:

.500 or .632000 the zeros are significant.

.006 or .000968 the zeros are NOT significant.

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- When you add or subtract numbers, keep the same number of decimal places as the factor with the least amount.

Example: $1.234 + 5.67 = 6.90$ Not 6.904

- When you multiply or divide numbers, keep the same number of significant figures as the factor with the least number of significant figures.

Example: $1.2 \times 4.56 = 5.5$ Not 5.472

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1.6 Validation of Problem Solutions

1. Repeat the calculations, possibly in a different order.
2. Start with the answer and perform the calculations in reverse order.
3. Review your assumptions and procedures. Make sure two errors do not cancel each other.
4. Compare numerical values with experimental data or data in a database (handbooks, the Internet, textbooks).
5. Examine the behavior of the calculation procedure. For example, use another starting value and check that the result changed appropriately.
6. Assess whether the answer is reasonable given what you know about the problem and its background