بسم الله الرحمن الرحيم

CHE 201: Introduction to Chemical Engineering Calculations

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Text Book: Basic Principles and Calculations in Chemical Engineering, *by David M. Himmelblau and James B Riggs, seventh Edition, 2004*

Reference: Elementary Principles of Chemical Engineering, *by Richard Felder and Ronald Rousseau, Third Edition, 2000*

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David M. Himmelblau / James B. Riggs

Basic Principles and Calculations in Chemical Engineering

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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.

TABLE 1.1 SI Units Encountered in This Book

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

TABLE 1.2 American Engineering (AE) System Units Encountered in This Book

Physical Quantity	Name of Unit	Symbol
	Some Basic Units	
Length	foot	ft
Mass	pound (mass)	lb_m
Time	second, minute, hour, day	s, min, h (hr), day
Temperature	degree Rankine or degree Fahrenheit	°R or °F
Molar amount	pound mole	lb mol
	Derived Units	
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	$lb_f/in.^2$, psi
Heat capacity	Btu per pound (mass) per degree F	Btu/(lb_m)(°F)

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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

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 ⟶ cannot be carried out

  - 10 pounds + *5* grams ⟶ 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

$$50(\text{kg})(\text{m})/(\text{s})$$

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

EXAMPLE: Add the following:

(a) 1 foot + *3* seconds

(b) 1 horse power + *300* watts

1.3 Conversion of Units and Conversion Factors

Example: If a plane travels at twice the speed of sound (assume that the speed of sound is1100 ft/s), how fast is it going in miles per hour?

Solution:

$$\frac{2 \times 1100\ \text{ft}}{\text{s}} \left| \frac{1\ \text{mi}}{5280\ \text{ft}} \right| \frac{60\ \text{s}}{1\ \text{min}} \left| \frac{60\ \text{min}}{1\ \text{hr}} \right.$$

$$\frac{\text{ft}}{\text{s}} \qquad \frac{\text{mi}}{\text{s}} \qquad \frac{\text{mi}}{\text{min}}$$

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EXAMPLE: Conversion of Units

(a) Convert 2 **km** to miles.

(b) Convert 400 in^3/day to cm^3/min.

Solution:

(a)

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

(b)

$$\text{(b)}\quad \frac{400\ \text{in.}^3}{\text{day}} \left| \left(\frac{2.54\ \text{cm}}{1\ \text{in.}}\right)^3 \right| \frac{1\ \text{day}}{24\ \text{hr}} \left| \frac{1\ \text{hr}}{60\ \text{min}} \right. = 4.55\,\frac{\text{cm}^3}{\text{min}}$$

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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)

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

(b)

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

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/s^2, a conversion factor *C* = 1 $N/(Kg)(m)/s^2$ must be introduced to have the force be 1 N:

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

$$\tilde{C} \qquad \tilde{m} \qquad \tilde{a}$$

- Because the numerical value associated with the conversion factor is 1, the conversion factor seems simple, even nonexistent and the units are normally ignored
- In AE system, if a mass of 1 lb_m is accelerated at *g* ft/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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$$F = \left(\frac{1(\text{lb}_f)(s^2)}{32.174(\text{lb}_m)(\text{ft})}\right)\left(\frac{1\ \text{lb}_m}{} \middle| \frac{g\ \text{ft}}{s^2}\right) = 1\ \text{lb}_f$$

$$\tilde{C} \qquad \tilde{m} \qquad \tilde{g}$$

- 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/s^2) at sea level at 45^o latitude when *g* is expressed in ft/s^2.

$$g_c = 32.174 \frac{(\text{ft})(\text{lb}_m)}{(\text{s}^2)(\text{lb}_f)}$$

Where g_c Is the inverse of the conversion factor.

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 (*g*) and (*m*) is the mass of an object.

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Example : water has a density of 62.4 lb_m/ft^3. How much does 2.000 ft^3 of water weigh at sea level and 45^o latitude?

Solution:

The mass of water $m = \left(62.4 \frac{lb_m}{ft^3}\right)(2\ ft^3) = 124.8\ lb_m$

The weight of water $W = (124.8\ lb_m) g \left(\frac{ft}{s^2}\right)\left(\frac{1\ lb_f}{32.174\ lb_m \cdot ft/s^2}\right)$

At sea level $g = 32.174\ ft/s^2$, so that $W = 124.8\ lb_f$.

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Example: What is the potential energy in (ft)(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:

Potential Energy= *mgh*

$$P = \frac{100\ \text{lb}_m}{} \left| \frac{32.2\ \text{ft}}{\text{s}^2} \right| \frac{10\ \text{ft}}{} \left| \frac{(\text{s}^2)(\text{lb}_f)}{32.174(\text{ft})(\text{lb}_m)} \right. = 1000\ (\text{ft})(\text{lb}_f)$$

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Example: Experiments show that I μg mol of glucoamylase in a 4% starch solution results in a production rate of glucose of 0.6 μg mol/(mL)(min). Determine the production rate of glucose for this system in the units of lb mol/(ft^3)(day).

Solution:

Basis: 1 min

$$\frac{0.6\ \mu\text{g mol}}{(\text{mL})(\text{min})}\left|\frac{1\ \text{g mol}}{10^6\ \mu\text{g mol}}\right|\frac{1\ \text{lb mol}}{454\ \text{g mol}}\left|\frac{1000\ \text{mL}}{1\ \text{L}}\right|\frac{1\ \text{L}}{3.531\times 10^{-2}\ \text{ft}^3}\left|\frac{60\ \text{min}}{\text{hr}}\right|\frac{24\ \text{hr}}{\text{day}}$$

$$= 0.0539\frac{\text{lb mol}}{(\text{ft}^3)(\text{day})}$$

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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.

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

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

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}.

$$d_{in} = \frac{16.2\ \mu m}{} \bigg| \frac{1\ m}{10^6\ \mu m} \bigg| \frac{39.27\ in.}{1\ m} \left[1 - \exp \frac{-0.021}{s} \bigg| \frac{60 s}{1\ min} \bigg| \frac{t_{min}}{} \right]$$

$$= 6.38 \times 10^{-4} (1 - e^{-1.26 t_{min}})\ \text{inches}$$

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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.

$$\text{Reynolds number} = \frac{Dv\rho}{\mu} = N_{RE}$$

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:

.5<u>00</u> or .632<u>000</u> the zeros are significant.

.<u>00</u>6 or .<u>000</u>968 the zeros are NOT significant.

1.5 Significant Figures

- 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 x 4.56 = 5.5 Not 5.472

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.