Introduction

Chemical principles in chemical engineering form the foundation for designing, analyzing, and optimizing industrial processes. These principles include the study of mass and energy balances, which ensure that material inputs and outputs are accounted for in any chemical process. Thermodynamics plays a crucial role in understanding energy transformations, phase equilibria, and reaction feasibility, which are essential for process efficiency. Reaction kinetics helps determine the speed of chemical reactions, influencing reactor design and operational conditions. Transport phenomena, including heat, mass, and momentum transfer, are fundamental in the design of equipment such as heat exchangers, reactors, and separation units. Additionally, phase equilibria guide separation processes like distillation and absorption, ensuring the effective purification of products. Process control and safety principles ensure the stability and reliability of operations, preventing hazards in chemical plants. Together, these chemical principles enable the development of sustainable and efficient industrial processes in various sectors, including pharmaceuticals, petrochemicals, and environmental engineering.

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	
Amount of substance	mole	mol	
	Derived SI units		
Force	newton	N	$(kg)(m)(s^{-2}) \rightarrow (J)(m^{-1})$
Energy	joule	J	$(kg)(m^2)(s^{-2})$
Power	watt	W	$(kg)(m^2)(s^{-3}) \rightarrow (J)(s^{-1})$
Density	kilogram per cubic meter		$(kg)(m^{-3})$
Velocity	meter per second		$(m)(s^{-1})$
Acceleration	meter per second squared		$(m)(s^{-2})$
Pressure	newton per square meter, pascal		$(N)(m^{-2})$, Pa
Heat capacity	joule per (kilogram × kelvin)		$(J)(kg^{-1})(K^{-1})$
	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	

Physical Quantity	Name of Unit	Symbol
	Some basic units	
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
	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	$lb_f/in.^2$
Heat capacity	Btu per pound (mass) per degree F	$Btu/[(lb_m)(°F)]$
Volume	cubic feet	ft^3

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	hecto	h	10^{-6}	micro	μ
10^1	deka	da	10^{-9}	nano	n

Relationship	Conversion Factor
1 ft = 12 in.	$\frac{1\text{ ft}}{12\text{ in.}}$
1 in. = 2.54 cm	$\frac{1\text{ in.}}{2.54\text{ cm}}$
1 m = 100 cm	$\frac{1\text{ m}}{100\text{ cm}}$

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?

Sol/

$$\frac{1100\text{ ft}}{\text{s}}\left|\frac{\text{mi}}{5280\text{ ft}}\right. = \frac{1100}{5280}\text{ mi/s} = 0.2083\text{ mi/s}$$

Email (Zainab.Hassan.Ali@uomus.edu.iq)

Example/Convert from seconds to hours to obtain an answer with the desired units?

Sol/

$$\frac{0.2083\ \text{mi}}{\cancel{\text{s}}}\Bigg|\frac{3600\ \cancel{\text{s}}}{\text{hr}} = (0.2083)(3600)\ \text{mi/hr} = 750\ \text{mi/hr}$$

Activity :

$$\frac{1100\ \cancel{\text{ft}}}{\cancel{\text{s}}}\Bigg|\frac{\text{mi}}{5280\ \cancel{\text{ft}}}\Bigg|\frac{3600\ \cancel{\text{s}}}{\text{hr}} = \frac{(110)(3600)}{5280}\ \text{mi/hr} = 750\ \text{mi/hr}$$

Example 2.1 Use of Conversion Factors

Change 400 in^3/day to cm^3/min.

Solution

$$\frac{400\ \cancel{\text{in}^3}}{\cancel{\text{day}}}\Bigg|\left(\frac{2.54\ \text{cm}}{1\ \cancel{\text{in}}}\right)^3\Bigg|\frac{1\ \cancel{\text{day}}}{24\ \cancel{\text{hr}}}\Bigg|\frac{1\ \cancel{\text{hr}}}{60\ \text{min}} = 4.56\ \frac{\text{cm}^3}{\text{min}}$$

In this example note that not only are the numbers raised to a power, but the units also are raised to the same power.

Example 2.2 Nanotechnology

Nanosize materials have become the subject of intensive investigation in the last decade because of their potential use in semiconductors, drugs, protein detectors, and electron transport. **Nanotechnology** is the generic term that refers to the synthesis and application of such small particles. An example of a semiconductor is ZnS with a particle diameter of 1.8 nm. Convert this value to (a) decimeters (dm) and (b) inches (in.).

Solution

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

(b) $$\frac{1.8\text{ nm}}{}\left|\frac{10^{-9}\text{ m}}{1\text{ nm}}\right|\frac{39.37\text{ in.}}{1\text{ m}} = 7.1 \times 10^{-8}\text{ in.}$$

Example 2.3 Conversion of Units Associated with Biological Materials

In biological systems, enzymes are used to accelerate the rates of certain biological reactions. Glucoamylase is an enzyme that aids in the conversion of starch to glucose (a sugar that cells use for energy). Experiments show that 1 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 units of lb mol/(ft^3)(day).

Solution

The production rate of glucose is stated in the problem as 0.6 μg mol/(mL)(min). Therefore, to solve this problem, you just have to convert this quantity into the specified units:

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

$$\frac{60\text{ min}}{1\text{ hr}}\left|\frac{24\text{ hr}}{1\text{ day}} = 0.0539\,\frac{\text{lb mol}}{(\text{ft}^3)(\text{day})}\right.$$

Email (Zainab.Hassan.Ali@uomus.edu.iq)

In the AE system the conversion of terms involving pound mass and pound force deserve special attention. Let us start the discussion with Newton's law, which states that force (F) is proportional to the product of mass (m) and acceleration (a), that is:

$$F = Cma \qquad (2.1)$$

where C is a constant whose numerical values and units depend on the units selected for F, m, and a. In the SI system, the unit of force is defined to be the newton (N), which corresponds to 1 kg accelerated at 1 m/s2. Therefore, the conversion factor C=1 N/(kg)(m)/S^2 results so that the force is expressed in newtons (N):

$$F = \underbrace{\frac{1\ \text{N}}{\frac{(\text{kg})(\text{m})}{\text{s}^2}}}_{C}\ \Bigg|\ \underbrace{1\ \text{kg}}_{m}\ \Bigg|\ \underbrace{\frac{1\ \text{m}}{\text{s}^2}}_{a} = 1\ \text{N} \qquad (2.2)$$

Note that in this case C has the numerical value of 1; hence the conversion factor seems simple, even nonexistent, and the units are usually ignored.

In the American Engineering system an analogous conversion factor is required. In the AE system, **one pound force** ($1\ \text{lb}_f$) corresponds to the action of the Earth's gravitational field on **one pound mass** ($1\ \text{lb}_m$):

$$F = \underbrace{\left(\frac{1(\text{lb}_f)(\text{s}^2)}{32.174(\text{lb}_m)(\text{ft})}\right)}_{C_{AE}}\left(\underbrace{\frac{1\ \text{lb}_m}{}}_{m}\Bigg|\underbrace{\frac{g\ \text{ft}}{\text{s}^2}}_{g}\right) = 1\ \text{lb}_f \qquad (2.3)$$

Email (Zainab.Hassan.Ali@uomus.edu.iq)

-Where g is the acceleration of gravity has the following value:

$$g = 32.174\,\frac{\text{ft}}{\text{s}^2} = 9.80665\,\frac{\text{m}}{\text{s}^2}$$

Example 2.4 A Conversion Involving Both lb_m and lb_f

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

The first thing to do is read the problem carefully. What are the unknown quantities? The potential energy (*PE*) is unknown. What are the known quantities? The mass and the height of the drum are known. How are they related? You have to look up the relation unless you recall it from physics:

$$\text{Potential energy} = PE = mgh$$

The 100 lb means 100 lb mass; let g = acceleration of gravity = 32.2 ft/s^2. Figure E2.4 is a sketch of the system.

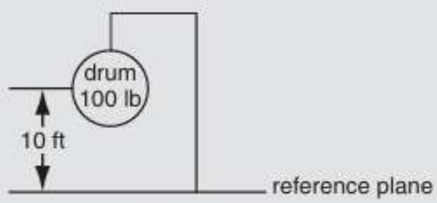

Figure E2.4

Now substitute the numerical values of the variables into the equation and perform the necessary unit conversions.

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

Notice that in the ratio of 32.2 ft/s^2 divided by $32.174[(\text{ft})(\text{lb}_m)]/[(\text{s}^2)(\text{lb}_f)]$, the numerical values are essentially equal. A good many engineers would solve the problem by saying that 100 lb × 10 ft = 1000 (ft)(lb) without realizing that in effect they are canceling out the numbers in the g/g_c ratio, and that the lb in the solution means lb_f.

HOME WORK/

Convert the following from AE to SI units:
a. 4 lb_m/ft to kg/m
b. 1.00 $lb_m/(ft^3)(s)$ to $kg/(m^3)(s)$

Conversion Factors

VOLUME EQUIVALENTS

	in.^{3}	ft^3	U.S. gal	liters	m^3
in.^{3}	1	5.787×10^{-4}	4.329×10^{-3}	1.639×10^{-2}	1.639×10^{-5}
ft^3	1.728×10^{3}	1	7.481	28.32	2.832×10^{-2}
U.S. gal	2.31×10^{2}	0.1337	1	3.785	3.785×10^{-3}
liters	61.03	3.531×10^{-2}	0.2642	1	1.000×10^{-3}
m^3	6.102×10^{4}	35.31	264.2	1000	1

MASS EQUIVALENTS

	avoir oz	pounds	grains	grams
avoir oz	1	6.25×10^{-2}	4.375×10^{2}	28.35
pounds	16	1	7×10^{3}	4.536×10^{2}
grains	2.286×10^{-3}	1.429×10^{-4}	1	6.48×10^{-2}
grams	3.527×10^{-2}	2.20×10^{-3}	15.432	1

Email (Zainab.Hassan.Ali@uomus.edu.iq)

Linear Measure Equivalents

	meter	inch	foot	mile
meter	1	39.37	3.2808	6.214×10^{-4}
inch	2.54×10^{-2}	1	8.333×10^{-2}	1.58×10^{-5}
foot	0.3048	12	1	1.8939×10^{-4}
mile	1.61×10^{3}	6.336×10^{4}	5280	1

Power Equivalents

	hp	kW	$(ft)(lb_f)/s$	Btu/s	J/s
hp	1	0.7457	550	0.7068	7.457×10^{2}
kW	1.341	1	737.56	0.9478	1.000×10^{3}
$(ft)(lb_f)/s$	1.818×10^{-3}	1.356×10^{-3}	1	1.285×10^{-3}	1.356
Btu/s	1.415	1.055	778.16	1	1.055×10^{3}
J/s	1.341×10^{-3}	1.000×10^{-3}	0.7376	9.478×10^{-4}	1

Email (Zainab.Hassan.Ali@uomus.edu.iq)

Heat, Energy, or Work Equivalents

	(ft)(lb$_f$)	kWh	(hp)(hr)	Btu	calorie*	joule
(ft)(lb$_f$)	1	3.766×10^{-7}	5.0505×10^{-7}	1.285×10^{-3}	0.3241	1.356
kWh	2.655×10^{6}	1	1.341	3.4128×10^{3}	8.6057×10^{5}	3.6×10^{6}
(hp)(hr)	1.98×10^{6}	0.7455	1	2.545×10^{3}	6.4162×10^{5}	2.6845×10^{6}
Btu	7.7816×10^{2}	2.930×10^{-4}	3.930×10^{-4}	1	2.52×10^{2}	1.055×10^{3}
calorie*	3.086	1.162×10^{-6}	1.558×10^{-6}	3.97×10^{-3}	1	4.184
joule	0.7376	2.773×10^{-7}	3.725×10^{-7}	9.484×10^{-4}	0.2390	1

*The thermochemical calorie = 4.184 J.

Pressure Equivalents

	mm Hg	in. Hg	bar	atm	kPa	psia
mm Hg	1	3.937×10^{-2}	1.333×10^{-3}	1.316×10^{-3}	0.1333	1.934×10^{-2}
in. Hg	25.40	1	3.386×10^{1}	3.342×10^{-2}	3.386	0.4912
bar	750.06	29.53	1	0.9869	100.0	14.51
atm	760.0	29.92	1.013	1	101.3	14.696
kPa	7.502	0.2954	1.000×10^{-2}	9.872×10^{-3}	1	0.1451
psia	51.71	2.036	6.893×10^{-2}	6.805×10^{-2}	6.893	1

Ideal Gas Constant R

1.987 cal/(g mol)(K)
1.987 Btu/(lb mol)(°R)
10.73 (psia)(ft^3)/(lb mol)(°R)
8.314 (kPa)(m^3)/(kg mol)(K) = 8.314 J/(g mol)(K)
82.06 (cm^3)(atm)/(g mol)(K)
0.08206 (L)(atm)/(g mol)(K)
21.9 (in Hg)(ft^3)/(lb mol)(°R)
0.7302 (ft^3)(atm)/(lb mol)(°R)

MISCELLANEOUS CONVERSION FACTORS

To convert from	To	Multiply by
angstrom	meter	1.000×10^{-10}
barrel (petroleum)	gal	42
centipoise	(newton)(s)/m^2	1.000×10^{-3}
torr (mm Hg, 0°C)	newton/meter^2	1.333×10^2
fluid oz	cm^3	29.57