## Chemical Engineering Principles


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## References

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- David M. Himmelblue and James B. Riggs, Basic Principles and Calculations in Chemical Engineering.
$\square$ Ron Darby, Chemical Engineering Fluid Mechanics.



## Introduction

Students of chemical engineering soon discover that the data used are expressed in a great variety of different units, so that quantities must be converted into a common system before proceeding with calculations. Standardization has been largely achieved with the introduction of the System International Units (SI Unit).

This system is now in general use in Europe and is rapidly being adopted throughout the rest of the world, including the USA where the initial inertia is now being overcome. Most of the physical properties determined in the laboratory will originally have been expressed in the (centimeter, gram, second "cgs") system.

The magnitude of any physical quantity is expressed as the product of two quantities; one is the magnitude of the unit and the other is the number of those units. Thus the distance between two points may be expressed as 1 m or as 100 cm or as 3.28 ft .

The meter, centimeter, and foot are respectively the size of the units, and 1,100, and 3,28 are the corresponding numbers of units. Since the physical properties of a system are interconnected by a series of mechanical and physical laws, it is convenient to regard certain quantities as basic and other quantities as derived.

## DIMENSIONS AND UNITS

Dimensions
The dimensions of a quantity identify the physical character of that quantity, e.g., force $(\mathrm{F})$, mass $(\mathrm{M})$, length ( L ), time ( t ), temperature (T), electric charge (e), etc. On the other hand, " units" identify the reference scale by which the magnitude of the respective physical quantity is measured.

Many different reference scales (units) can be defined for a given dimension; for example, the dimension of length can be measured in units of miles, centimeters, inches, meters, yards, angstroms, furlongs, light years, kilometers, etc.

There are two systems of fundamental dimensions in use (with their associated units), which are referred to as scientific and engineering systems. These systems differ basically in the manner in which the dimensions of force is defined. In both systems, mass, length, and time are fundamental dimensions.

Dimensions can be classified as either fundamental or derived. Fundamental dimensions cannot be expressed in terms of other dimensions and include length (L), time ( t ), temperature ( T ), mass ( M ), and/or force ( F ) (depending upon the system of dimensions used). Derived dimensions can be expressed in terms of fundamental dimensions, for example,

- Area $=L^{2}$
$\square$ Volume $=\mathrm{L}^{3}$


## Units

Several different sets of units are used in both scientific and engineering systems of dimensions. These can be classified as either metric (SI and cgs) or English (fps). Although the internationally accepted standard is the SI scientific system, English engineering units are still very common and will probably remain so for the foreseeable future

Therefore, the reader should at least master these two
systems and become adept at converting between them. These systems are illustrated in Table (1). Note
that there are two different English scientific systems,
one in which $\mathrm{M}, \mathrm{L}$, and t are fundamental and F is
derived, and another in which $\mathrm{F}, \mathrm{L}$, and t are
fundamental and M is derived.

In one system, mass (with the unit 'slug'') is fundamental; in the other, force (with the unit 'poundal'") is fundamental. However, these systems are archaic and rarely used in practice.

|  | Scienitic |  |  |  | Engineering |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | L | M | F | go | L | M | F | $g{ }_{c}$ |
| English | H | $1 \mathrm{~b}_{\mathrm{m}}$ | poundal | 1 | H | $1 b_{m}$ | $\mathrm{lb}_{\mathrm{i}}$ | 32.2 |
|  | H | slug | $\mathrm{lb}_{\mathrm{f}}$ | 1 |  |  |  |  |
| Metric (SI) (cgs) | m | kg | N | 1 | m | $\mathrm{kg}_{\mathrm{m}}$ | $\mathrm{kg}_{\mathrm{f}}$ | 9.8 |
|  | cm | g | dyn | 1 | cm | $g_{m}$ | $g_{i}$ | 980 |

## The Mole Unit

What is a mole? The best answer is that a mole is a certain number of molecules, atoms, electrons, or other specified types of particles. ${ }^{4}$ In particular, the 1969 International Committee on Weights and Measures approved the mole (symbol mol in the SI system) as being "the amount of a substance that contains as many elementary entities as there are atoms in 0.012 kg of carbon 12." Thus in the SI system the mole contains a different number of molecules than it does in the American engineering system. In the SI system a mole has about $6.023 \times 10^{23}$ molecules; we shall call this a gram mole (symbol g mol ) to avoid confusion even though in the SI system of units the official designation is simply mole (abbreviated mol). We can thereby hope to avoid the confusion that could occur with the American engineering system pound mole (abbreviated $l \mathrm{lb} \mathrm{mol}$ ), which has $6.023 \times 10^{23} \times 453.6$ molecules. Thus a pound mole of a substance has more mass than does a gram mole of the substance.

Here is another way to look at the mole unit. To convert the number of moles to mass, we make use of the molecular weight-the mass per mole:

$$
\begin{align*}
& \text { the } \mathrm{g} \mathrm{~mol}=\frac{\text { mass in } \mathrm{g}}{\text { molecular weight }}  \tag{1.4}\\
& \text { the } \mathrm{lb} \mathrm{~mol}=\frac{\text { mass in } \mathrm{lb}}{\text { molecular weight }} \tag{1.5}
\end{align*}
$$

or

$$
\begin{align*}
\text { mass in } \mathrm{g} & =(\mathrm{mol} . \mathrm{wt} .)(\mathrm{g} \mathrm{~mol})  \tag{1.6}\\
\text { mass in } \mathrm{lb} & =(\text { mol. wt. })(\mathrm{lb} \mathrm{~mol}) \tag{1.7}
\end{align*}
$$

Furthermore, there is no reason why you cannot carry out computations in terms of ton moles, kilogram moles, or any corresponding units if they are defined analogously to Eqs. (1.4) and (1.5) even if they are not standard units. If you read about a unit such as a kilomole (kmol) without an associated mass specification, or a kg mol , assume that it refers to the SI system and $10^{3} \mathrm{~g}$ mol.

## 1.3-1 Density

Density is the ratio of mass per unit volume, as, for example, $\mathrm{kg} / \mathrm{m}^{3}$ or $\mathrm{lb} / \mathrm{ft}^{3}$. It has both a numerical value and units. To determine the density of a substance, you must find both its volume and its mass. If the substance is a solid, a common method to determine its volume is to displace a measured quantity of inert liquid. For example, a known weight of a material can be placed into a container of liquid of known weight and volume, and the final weight and volume of the combination measured. The density (or specific gravity) of a liquid is commonly measured with a hydrometer (a known weight and volume is dropped into the liquid and the depth to which it penetrates into the liquid is noted) or a Westphal balance (the weight of a known slug is compared in the unknown liquid with that in water). Gas densities are quite difficult to measure; one device used is the Edwards balance, which compares the weight of a bulb filled with air to the same bulb when filled with the unknown gas.

In most of your work using liquids and solids, density will not change very much with pressure, but for precise measurements for common substances you can always look up in a handbook the variation of density with pressure. The change in density with temperature is illustrated in Fig. 1.1 for liquid water and liquid ammo-


Figure 1.1 Densities of liquid $\mathrm{H}_{2} \mathrm{O}$ and $\mathrm{NH}_{3}$ as a function of temperature.


Figure 1.2 Density of a mixture of ethyl alcohol and water as a function of composition.
nia. Figure 1.2 illustrates how density also varies with composition. In the winter you may put antifreeze in your car radiator. The service station attendant checks the concentration of antifreeze by measuring the specific gravity and, in effect, the density of the radiator solution after it is mixed thoroughly. He has a little thermometer in his hydrometer kit in order to be able to read the density corrected for temperature.

## 1.3-2 Specific Gravity

Specific gravity is commonly thought of as a dimensionless ratio. Actually, it should be considered as the ratio of two densities-that of the substance of interest, $A$, to that of a reference substance. In symbols:

$$
\begin{equation*}
\text { sp gr }=\text { specific gravity }=\frac{\left(\mathrm{lb} / \mathrm{ft}^{\mathrm{s}}\right)_{A}}{\left(\mathrm{lb} / \mathrm{ft}^{3}\right)_{\mathrm{ref}}}=\frac{\left(\mathrm{g} / \mathrm{cm}^{3}\right)_{A}}{\left(\mathrm{~g} / \mathrm{cm}^{3}\right)_{\mathrm{ref}}}=\frac{\left(\mathrm{kg} / \mathrm{m}^{3}\right)_{A}}{\left(\mathrm{~kg} / \mathrm{m}^{3}\right)_{\mathrm{ref}}} \tag{1.8}
\end{equation*}
$$

The reference substance for liquids and solids is normally water. Thus the specific gravity is the ratio of the density of the substance in question to the density of water. The specific gravity of gases frequently is referred to air, but may be referred to other gases, as discussed in more detail in Chap. 3. Liquid density can be considered to be nearly independent of pressure for most common calculations, but, as indicated in Fig. 1.1 it varies somewhat with temperature; therefore, to be very precise when referring to specific gravity, state the temperature at which each density is chosen. Thus

$$
\operatorname{spgr}=0.73 \frac{20^{\circ}}{4^{\circ}}
$$

$$
\mathrm{sp} \mathrm{gr}=0.73 \frac{20^{\circ}}{4^{\circ}}
$$

can be interpreted as follows: the specific gravity when the solution is at $20^{\circ} \mathrm{C}$ and the reference substance (water) is at $4^{\circ} \mathrm{C}$ is 0.73 . Since the density of water at $4^{\circ} \mathrm{C}$ is
very close to $1.0000 \mathrm{~g} / \mathrm{cm}^{3}$ in the SI system, the numerical values of the specific gravity and density in this system are essentially equal. Since densities in the American engineering system are expressed in $\mathrm{lb} / \mathrm{ft}^{3}$ and the density of water is about 62.4 $\mathrm{lb} / \mathrm{ft}^{3}$, it can be seen that the specific gravity and density values are not numerically equal in the American engineering system.

In the petroleum industry the specific gravity of petroleum products is usually reported in terms of a hydrometer scale called ${ }^{\circ} \mathrm{API}$. The equation for the API scale is

$$
\begin{equation*}
{ }^{\circ} \mathrm{API}=\frac{141.5}{\operatorname{sp~gr} \frac{60^{\circ}}{60^{\circ}}}-131.5 \tag{1.9}
\end{equation*}
$$

or

$$
\begin{equation*}
\operatorname{spgr} \frac{60^{\circ}}{60^{\circ}}=\frac{141.5}{{ }^{\circ} \mathrm{API}+131.5} \tag{1.10}
\end{equation*}
$$

The volume and therefore the density of petroleum products vary with temperature, and the petroleum industry has established $60^{\circ} \mathrm{F}$ as the standard temperature for volume and API gravity. The ${ }^{\circ} \mathrm{API}$ is being phased out as SI units are accepted for densities.

There are many other systems of measuring density and specific gravity that are somewhat specialized; for example, the Baumé ( ${ }^{\circ} \mathrm{Be}$ ) and the Twaddell ( ${ }^{\circ} \mathrm{Tw}$ ) systems. Relationships among the various systems of density may be found in standard reference books.

## 1.3-3 Specific Volume $=\frac{1}{p}$.

The specific volume of any compound is the inverse of the density, that is, the volume per unit mass or unit amount of material. Units of specific volume might be $\mathrm{ft}^{3} /$ $\mathrm{lb}_{\mathrm{m}}, \mathrm{ft}^{3} / \mathrm{lb}$ mole, $\mathrm{cm}^{3} / \mathrm{g}, \mathrm{bbl} / \mathrm{lb}_{\mathrm{m}}, \mathrm{m}^{3} / \mathrm{kg}$, or similar ratios.

## 1.3-4 Mole Fraction and Mass (Weight) Fraction

Mole fraction is simply the moles of a particular substance divided by the total number of moles present. This definition holds for gases, liquids, and solids. Similarly, the mass (weight) fraction is nothing more than the mass (weight) of the substance divided by the total mass (weight) of all substances present. Although the mass fraction is what is intended to be expressed, ordinary engineering usage employs the term weight fraction. Mathematically, these ideas can be expressed as

$$
\begin{align*}
\text { mole fraction of } A & =\frac{\text { moles of } A}{\text { total moles }}  \tag{1.11}\\
\text { mass (weight) fraction of } A & =\frac{\text { mass (weight) of } A}{\text { total mass (weight) }} \tag{1.12}
\end{align*}
$$

Mole percent and weight percent are the respective fractions times 100 .

## Heat and Temperature

There are many different forms of energy like heat, light, sound, electrical, kinetic, potential. All of these forms of energy have the ability to do work. One form of energy may be transformed into another.

For example; potential (stored chemical) energy is converted to heat energy during combustion. Kinetic energy (as a result of friction) and electrical energy may also be converted to heat.

## Heat

Is a measure of the total kinetic energy of the atoms or molecules in a body.

Is a measurement of the average kinetic energy of the molecules in an object or system and can be measured with a thermometer or a calorimeter. It is a means of determining the internal energy contained within the system. The units of heat is measured in Joules (J), kilo Joules (kJ), Btu.

The heat content of a body will depend on its temperature, its mass, and the nature of material. Heat energy is always transferred from an object at high temperature to one at lower temperature. Temperature is not the same as heat. Temperature measures the degree of hotness of a body.

It doesn't depend on the mass or the material of an object. It can be thought of as a measure of the average kinetic energy of the atoms or molecules in a body. Temperature is measured using a variety of temperature scales. The most commonly used are described in the following :-

- The Celsius Scale $\left({ }^{\circ} \mathrm{C}\right)$ :- This scale puts the freezing point of water at $0{ }^{\circ} \mathrm{C}$ and the boiling point of water at $100{ }^{\circ} \mathrm{C}$. The temperatures in between are divided up into 100 units (degrees).
- The Kelvin Scale ( ${ }^{\circ} \mathrm{K}$ ) :- This scale has absolute zero as the zero point on it's scale. The size of the degree is the same as a Celsius degree. There are no negative temperatures in this scale and absolute zero is 273 degrees below 0 ${ }^{\circ} \mathrm{C}$.

Fahrenheit scale ( ${ }^{\circ} \mathrm{F}$ ) :- Is a scale based on 32 for the freezing point of water and 212 for the boiling point of water, the interval between the two being divided into 180 parts.

## Rankine scale ( ${ }^{\circ}$ R) :- Absolute zero,

or $0^{\circ} R$, is the temperature at which molecular energy is a minimum, and it corresponds to a temperature of 459.67º .

There are many different types of thermometer used for measuring temperature e.g. mercury, alcohol, bimetallic strip, thermocouple, electrical resistance, brightness thermometer etc.

| 212 | 672 | Boiling point of | 373 | 100 |
| :---: | :---: | :---: | :---: | :---: |
| $\uparrow$ |  | water of 760 mm Hg |  | / |
| 180 |  |  |  | 100 |
| $\checkmark 32$ | 492 | Freezing point of water | 273 | 0 |
| 0 | 460 |  | 255 | -18 |
| -40 | 420 | ${ }^{\circ} \mathrm{C}={ }^{\circ} \mathrm{F}$ | 233 | $-40$ |
|  |  |  |  |  |
| $\begin{array}{\|c} 0 \\ 0 \\ 0 \\ 0.0 \\ 0.0 \\ 0 \\ \hline 0 \end{array}$ |  | - . .. . ... .- |  |  |
| -460 |  | . Absolute zero |  | -273 |

## $\Delta^{\circ} \mathrm{C}$ $\frac{\Delta^{\circ} \mathrm{C}}{\Delta^{\circ} \mathrm{F}}=1.8 \quad$ or $\quad \Delta^{\circ} \mathrm{C}=1.8 \Delta^{\circ} \mathrm{F}$

$$
\frac{\Delta \mathrm{K}}{\mathrm{~A}^{\circ} \mathrm{R}}=1.8 \quad \text { or } \quad \Delta \mathrm{K}=1.8 \Delta^{\circ} \mathrm{R}
$$

EXAMPLE 1.18 Temperature Conversion
Convert $100^{\circ} \mathrm{C}$ to (a) K , (b) ${ }^{\circ} \mathrm{F}$, and (c) ${ }^{\circ} \mathrm{R}$.
Solution
(a)

$$
(100+273)^{\circ} \mathrm{C} \frac{1 \Delta \mathrm{~K}}{1 \Delta^{\circ} \mathrm{C}}=373 \mathrm{~K}
$$

or with suppression of the $\Delta$ symbol,

$$
(100+273)^{\circ} \mathrm{C} \frac{1 \mathrm{~K}}{1^{\circ} \mathrm{C}}=373 \mathrm{~K}
$$

(b)

$$
\left(100^{\circ} \mathrm{C}\right) \frac{1.8^{\circ} \mathrm{F}}{1^{\circ} \mathrm{C}}+32^{\circ} \mathrm{F}=212^{\circ} \mathrm{F}
$$

(c)

$$
(212+460)^{\circ} \mathrm{F} \frac{1^{\circ} \mathrm{R}}{1^{\circ} \mathrm{F}}=672^{\circ} \mathrm{R}
$$

or

$$
(373 \mathrm{~K}) \frac{1.8^{\circ} \mathrm{R}}{1 \mathrm{~K}}=672^{\circ} \mathrm{R}
$$

## EXAMPLE 1.19 Temperature Conversion

The thermal conductivity of aluminum at $32^{\circ} \mathrm{F}$ is $117 \mathrm{Btu} /(\mathrm{hr})\left(\mathrm{ft}^{2}\right)\left({ }^{( } \mathrm{F} / \mathrm{ft}\right)$. Find the equivalent value at $0^{\circ} \mathrm{C}$ in terms of $\mathrm{Btu} /(\mathrm{hr})\left(\left(\mathrm{ft}^{2}\right)(\mathrm{K} / \mathrm{ft})\right.$.

Solution
Since $32^{\circ} \mathrm{F}$ is identical to $0^{\circ} \mathrm{C}$, the value is already at the proper temperature. The " ${ }^{\circ} \mathrm{F}$ " in the denominator of the thermal conductivity actually stands for $\Delta^{\circ} \mathrm{F}$, so that the equivalent value is

$$
\begin{array}{c|c|c}
117(\mathrm{Btu})(\mathrm{ft}) & 1.8 \Delta^{\circ} \mathrm{F} & 1 \Delta^{\circ} \mathrm{C} \\
\hline(\mathrm{hr})\left(\mathrm{ft} \mathrm{t}^{2}\right)\left(\Delta^{\circ} \mathrm{F}\right) & 1 \Delta^{\circ} \mathrm{C} & 1 \Delta \mathrm{~K}
\end{array}=211(\mathrm{Btu}) /(\mathrm{hr})\left(\mathrm{ft}^{2}\right)(\mathrm{K} / \mathrm{ft})
$$

or with the $\Delta$ symbol suppressed,

$$
\begin{array}{l|c|c}
117(\mathrm{Btu})(\mathrm{ft}) & 1.8^{\circ} \mathrm{F} & 1^{\circ} \mathrm{C} \\
\hline(\mathrm{hr})\left(\mathrm{ft}^{2}\right)\left({ }^{( } \mathrm{F}\right) & 1^{\circ} \mathrm{C} & 1 \mathrm{~K}
\end{array}=211(\mathrm{Btu}) /(\mathrm{hr})\left(\mathrm{ft}^{2}\right)(\mathrm{K} / \mathrm{ft})
$$

## Pressure

Pressure can be defined as the measure of force per unit area. The standard SI unit for pressure measurement is the Pascal (Pa) which is equivalent to one Newton per square meter ( $\mathrm{N} / \mathrm{m}^{2}$ ) or the Kilo Pascal ( kPa ) where 1 $\mathbf{k P a}=1000$ Pa. In the English system, pressure is usually expressed in pounds per square inch (psi).
$\square$ Pressure can be expressed in many different units including in terms of a height of a column of liquid.
$\square$ Pressure measurements can be divided into three different categories :-

- Absolute pressure :- It is the pressure referred to zero pressure under complete vacuum.
- Degree vacuum :- It is quantity of pressure below the atmospheric pressure.

Gauge pressure is the measurement of the difference between the absolute pressure and the local atmospheric pressure. The U.S. standard atmospheric pressure at sea level and $59^{\circ} \mathrm{F}\left(20^{\circ} \mathrm{C}\right)$ is $\mathbf{1 4 . 6 9 6}$ pounds per square inchabsolute (psia) or 101.325 kPa absolute (abs).

## Pressure Terms Relationship



Absolute pressure = Gauge pressure + Atmospheric pressure

Degree Vacuum = Atmospheric pressure - Absolute pressure

## Hydrostatic Pressure

Hydrostatic Pressure :- Is the pressure at the base of fluid column, hydrostatic pressure is also called head of fluid it can be calculated as follow :-

$$
P=F / A=m g / A=\rho V g / A=\rho A h g / A=\rho g h
$$

## Pressure Measuring Devices

$\square$ Atmospheric pressure is usually measured by a barometer hence this pressure called as the barometric pressure.

- At sea-level standard, with pa = 101,350 Pa and $\rho \mathrm{g}=133,100 \mathrm{~N} / \mathrm{m}^{3}$, the barometric height is $h=101,350 / 133,100=0.761 \mathrm{~m}$ or 761 mm.
$\square$ Mercury is used because it is the
heaviest common liquid. A water barometer would be 34 ft high.
$\square$ Several devices are used for the measurement of fluid pressure these devices are classified into two types :-


## Mechanical Gauge

The most common type of this class is a Bourdon gauge which normally measure fluid pressure from nearly perfect vacuum to about 7000 atm. The pressure sensing device is a thin metal tube.

## Bourdon gauge



## Manometers

In general, pressure below 3 atm can be measured by manometer. A manometer is a U-shaped tube partially filled with a liquid of known density. Manometers are of three types :-

Open end manometer which is used to measure the gauge pressure or degree vacuum. Mercury (Hg) is commonly used as a manometer fluid due to its higher density. The following relation can be used to complete the pressure in ( $\mathbf{m m H g}$ ) if other fluid is used:-

$$
\rho_{\mathrm{m}} \mathbf{h}_{\mathrm{m}}=\boldsymbol{\rho}_{\mathrm{Hg}} \mathbf{h}_{\mathrm{Hg}}
$$

where :- $\rho_{m}$ and $h_{m}$ are the density and height of the
fluid manometer.

## Open End Manometer



## Closed end manometer which is used to

 measure the absolute pressure

Differential manometer which is used to measure the difference of pressure between two points in a process line. The general differential manometer equation is :-
$P_{1}-P_{2}=\left(\rho_{m}-\rho\right) g h / g_{c}$

## Example :-

The pressure gauge on the steam condenser reads 26.2 in Hg of vacuum. The barometer reading is 30.4 in $\mathbf{H g}$. Calculate the pressure in the condenser in psig.

Answer :-
Abs. press. = atm press - degree vacuum = 30.4 - 26.2 = 4.2 in Hg * (14.7 psi / 29.92 in Hg)
$=2.06$ psia

## Example :-

Convert the pressure of 340 mm Hg to :-- in $\mathrm{H}_{2} \mathrm{O}$.
$\square \mathrm{kPa}$.

- psi.


## Answer :-

P = 340 mm Hg * (34 ft H20/760 mm Hg) * $(12 \mathrm{in} / 1 \mathrm{ft})=182.5$ in $\mathrm{H}_{2} \mathrm{O}$

P = 340 mm Hg * (101.3 kPa / 760 mm Hg )
$=45.3 \mathrm{kPa}$
P = 340 mm Hg * (14.7 psi / 760 mm Hg ) =
6.58 psi

## Basis of Calculations

It is necessary to choice and state a basis of calculations as the starting point of solutions of any problem. The following points must be considered in choosing the suitable basis :-

- The basis must be fitted the available data for example if mole fractions are known choose a total number of moles.
- It is usually most convenient to choose the stream that contains most of substances involve in the process or the stream about which most information are known (i.e composition, flow rates, ..... etc.)
- The amount of material chosen as the basis must be not very small or very large numbers. A convenient basis is often 1 or 100 since the weight or mole fraction and percent automatically equal the masses or moles of the constituent respectively.
- A suitable unit time (i.e hr, day, year, .........etc.) must be selected as the basis for continues process.


## Chemical Equation and Stoichiometry

Stoichiometry :- Is the subjects deals with the combining quantities of the elements or compounds involved in any chemical reaction.

Chemical reaction can be generally expressed by the chemical equation which must be balanced i.e the number of atoms of each clement must be the same in the both sides of the equation. Such equation provides qualitative and quantitative information essential for stoichiometric calculation.

Stoichiometric coefficients are the numbers that precede the compounds in the chemical equation such coefficients represent the quantity of any reactant theoretically required for complete conversion of other reactants.

## Stoichiometric ratio is the ratio

 between the stoichiometriccoefficients in the balanced chemical equation.

The reactants involved in industrial processes are rarely input to the reactor in stoichiometric ratios due to the economic considerations. The following definition must be understood from such point of view.

## Limiting reaction :- is the reactant that present in the smallest stoichiometric

 quantity.Excess reaction :- is the reactant that present in excess amount over the stoichiometric requirement equivalent to the limiting reaction.

Percentage excess :- is the true excess expressed as a percentage of the amount theoretically required to react completely with the limiting reaction according to the chemical equation.

$$
\% \text { excess }=\frac{\text { excess quantity }}{\text { theoretical quantity required }} \times 100
$$

$$
=\frac{\text { in put quantity - theoretical quantity required }}{\text { theoretical quantity required }} \times 100
$$

Conversion is the percent or fraction of some reactant materials that is actually converted into products.
\% conversion
$=\frac{\text { quantity of the substance that reacts }}{\text { quntity of the substance input to the reactor }} x 100$

Degree completion of reaction :- is the percentage or fraction of the limiting reactant that is actually converted into products.
fraction degree of completion
$=\frac{\text { quantity of the limiting reactant that reacts }}{\text { quantity of the limiting reactant input to the reactı }}$

Selectivity :- is the ratio of the moles of the desired product to the moles of the undesired product formed in the same reaction, or it can be expressed as the percentage between the quantity of the limiting reactant that is converted to the desired product to the total quantity of the limiting reactant that is converted.

Tield :- is the ratio between the quantity (mass or moles) of a specified final product to that specified initial product reactant either fed or consumed.

$$
\text { yield }=\frac{\text { quantity of final product }}{\text { quantity of intial product }}
$$

## \% selectivity

$=\frac{\text { number of moles of desired product }}{\text { number of moles of undesired product }}$

Thanks I

