FOOD TECHNOLOGY

GATE (XE) (XL)

ENGG. SCIENCE / LIFE SCIENCE

CAREER AVENUES

A book by Career Avenues

Chapter-1
Principles of Food Engineering

1.1 Introduction

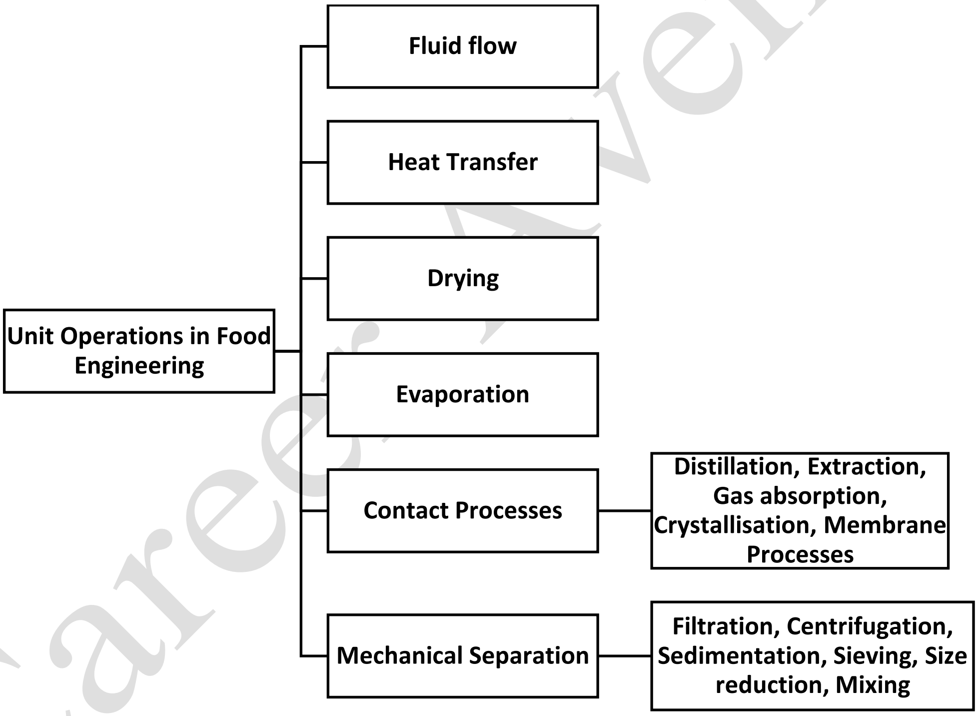
Food Engineering is a multi-disciplinary field of applied physical sciences which combines science, microbiology and engineering education for food and related industries.

The study of applied sciences helps us to understand the principles and group them into basic operations termed as 'UNIT OPERATIONS'

Example: Heating and Cooling

- To design any food process that revolves around heating and cooling, one must be aware of the basic principles of 'Heat Transfer' (a unit operation).
- There are many examples of Heating and Cooling applications in Food Engineering
- Examples: Baking of bread, freezing of peas, Tempering of Oils

Important Unit Operations in Food Engineering are:



NOTE:
All the unit operations in Food Engineering obeys the laws of Conservation of Energy and Mass.

1.2 <u>Law of Conservation of Mass and Energy</u>

Law of Conservation of Mass

Law of Conservation of Energy

The law of conse... mass can neith... destroyed.

For example: Th... entering the centr...

This means that t... entrance of the c... the mass of butt... centrifuge.

... Energy states that ... nor be destroyed, ... *form to another.*

..., the mechanical ... converted to heat

...d is converted by ... energy.

Consider the pasteu... xchanger and is first heated and then coo... s it affects the milk.

For total plant energ... energy to kinetic and heat energy, the kin... nd the various kinds of energy in the he... potential energies. To the food technologist, the energies affecting the product are the most important. In the case of the pasteurizer, the energy affecting the product is the heat energy in the milk. Heat energy is added to the milk by the pump and by the hot water passing through the heat exchanger. Cooling water then removes part of the heat energy and some of the heat energy is also lost to the surroundings.

The heat energy leaving in the milk must equal the heat energy in the milk entering the pasteurizer plus or minus any heat added or taken away in the plant.

Heat energy leaving in milk = Initial heat energy + heat energy added by pump + heat energy added in heating section - heat energy taken out in cooling section - heat energy lost to surroundings.

<u>NOTE:</u> From these laws of conservation of mass and energy, a balance sheet for materials and for energy can be drawn up at all times for a unit operation. These are called material balances and energy balances.

1.3 Overall view of an Engineering Process

A food engineering process can be viewed overall or as a series of units by applying Material and Energy balance.

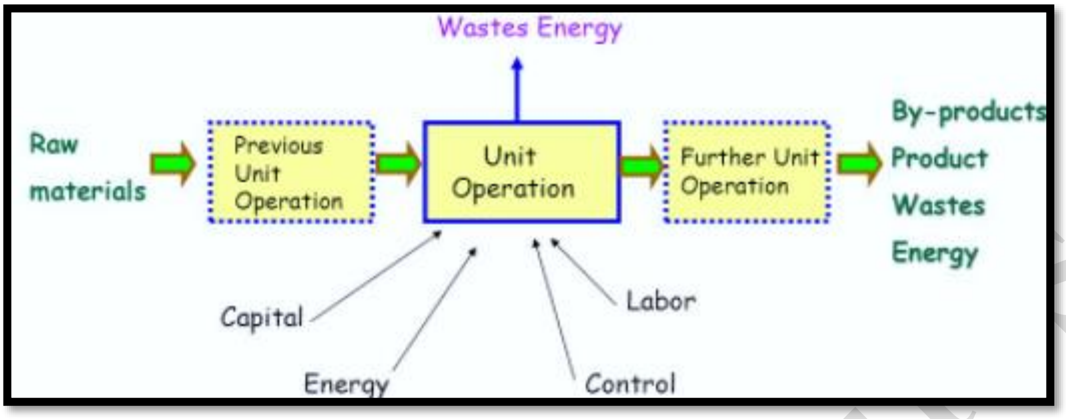


Figure 1: Overall view of an Engineering Process

1.4 Dimensions

A physical entity, which can be observed and/or measured is defined qualitatively by a dimension.

Example: Time, length, temperature, area, volume, mass, force, energy.

1.4.1 Engineering Units

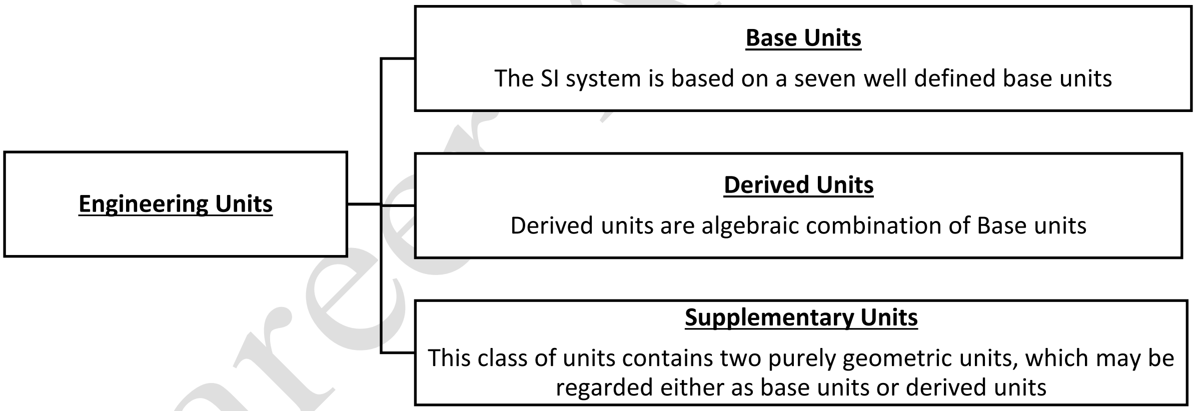


Table 1: SI Base units

Measurable attribute of phenomena or matter	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Table 2: SI derived units expressed in terms of Base units

	SI Unit	
Quantity	**Name**	**Symbol**
Area	square meter	m^2
Volume	cubic meter	m^3
Speed, velocity	meter per second	m/s
Acceleration	meter per second squared	m/s^2

SAMPLE

Table 3: SI derive

Quantity				**sion in terms se units**
Frequency				
Force				
Pressure, stress				$^{-2}$
Energy, work, qu				$^{-2}$
Power, radiant fl				$^{-3}$
Quantity of elec				
Electric potentia electromotive fo				$^{-3}$ A^{-1}
Capacitance				$^{-1}$ s^4 A^2
Electric resistance	ohm	Ω	V/A	m^2 kg s^{-3} A^{-2}
Conductance	siemens	S	A/V	m^{-2} kg^{-1} s^3 A^2
Celsius temperature	degree Celsius	°C		K
Luminous flux	lumen	lm		cd sr
Illuminance	lux	lx	lm/m^2	m^{-2} cd sr

Table 4: SI derived units expressed by means of special names

Quantity	SI Unit		Expression in terms of SI base units
	Name	Symbol	
Dynamic viscosity	pascal second	Pa s	m^{-1} kg s^{-1}
Moment of force	newton meter	N m	m^2 kg s^{-2}
Surface tension	newton per meter	N/m	kg s^{-2}
Power density, heat flux density, irradiance	watt per square meter	W/m^2	kg s^{-3}
Heat capacity, entropy	joule per kelvin	J/K	m^2 kg s^{-2} K^{-1}
Specific heat capacity	joule per kilogram kelvin	J/(kg K)	m^2 s^{-2} K^{-1}
Specific energy	joule per kilogram	J/kg	m^2 s^{-2}
Thermal conductivity	watt per meter kelvin	W/(m K)	m kg s^{-3} K^{-1}
Energy density	joule per cubic meter	J/m^3	m^{-1} kg s^{-2}
Electric field strength	volt per meter	V/m	m kg s^{-3} A^{-1}
Electric charge density	coulomb per cubic meter	C/m^3	m^{-3} s A
Electric flux density	coulomb per square meter	C/m^2	m^{-2} s A

Table 5: SI Supplementary units

Quantity	SI Unit	
	Name	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

1.5 System and Surroundings

System is that part of the universe which is under investigation or under the study of observer.

- Properties of the system are observed when the exchange of energy i.e., work or heat, takes place.
- There is no arbitrary rule for selection of system but proper selections make the calculations easy.

Surroundings

- The remaining portion of universe which is external to the system is called as surrounding.
- The exchange of energy takes place between system and surroundings; hence surroundings may be influenced by the changes taking place in system.

Universe

- System and surroundings together constitute Universe i.e.

  System + Surroundings = Universe.

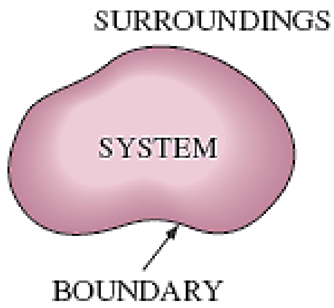


Figure 2: Thermodynamic system and surroundings

System Boundary

- System and surroundings in the universe are separated by System boundary.
- A system boundary has **zero thickness**.
- Boundary may be real or hypothetical and fixed or moving.
- It is a surface, and since a surface is a two-dimensional object, it has zero volume. Thus, **it attains neither mass nor volume**.

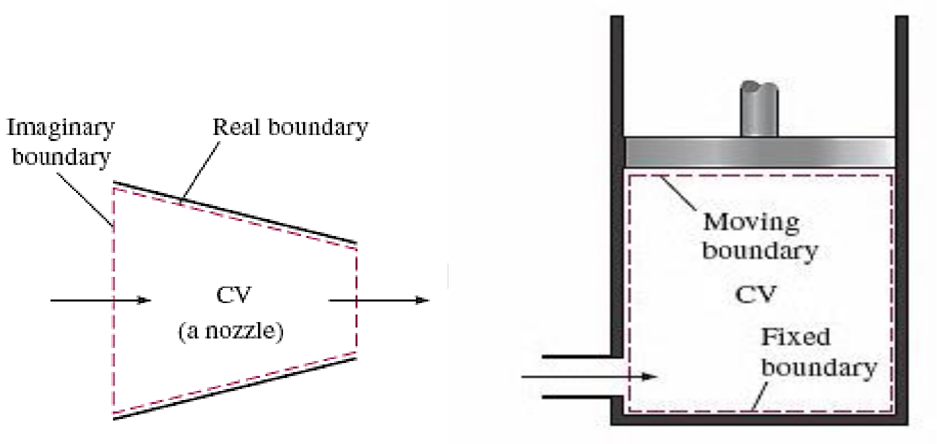


Figure 3

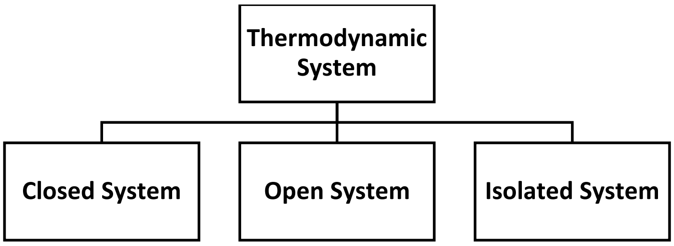
If heat (energy) exchange doesn't take place across body it is called adiabatic boundary otherwise it will be diathermic boundary.

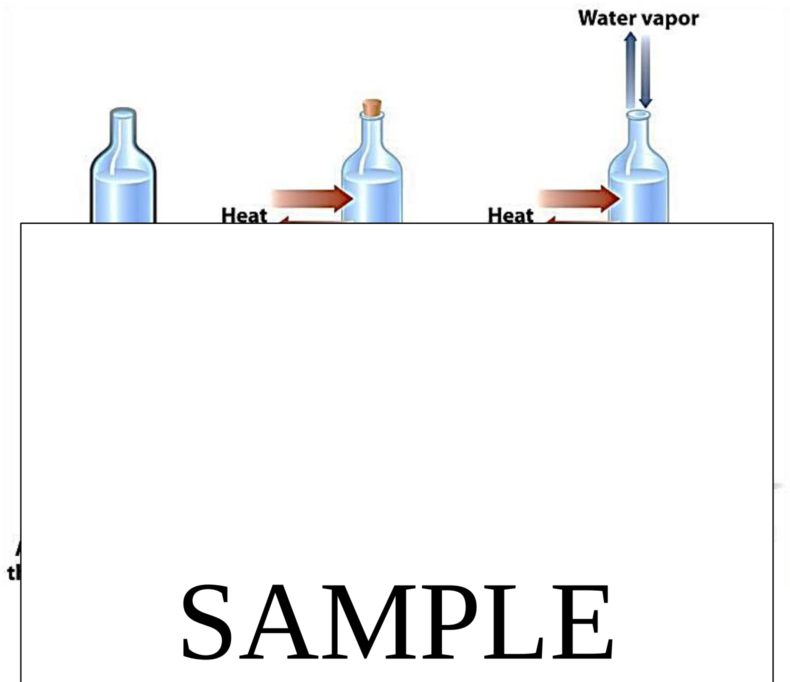
Difference between surroundings, immediate surroundings and environment

- **Surroundings** are everything outside the system boundaries.
- The **immediate surroundings** refer to the portion of the surroundings that is affected by the process, and
- **Environment** refers to the region beyond the immediate surroundings whose properties are not affected by the process at any point.

1.6 Classification of Thermodynamics System

On the basis of mass and energy transfer across/through the system boundaries, a thermodynamic system can be classified as follows:





Type of System			…mples
Open System			…m generator or …er
Closed System			…on cylinder …angement, gas …g compressed … piston in a …ed cylinder.
Isolated System	x	x	…hermos bottle with a lid screwed on tight

1.6.1 Closed System

The system which can exchange energy with surroundings but which cannot transfer matter across the boundaries are known as ***Closed System.***

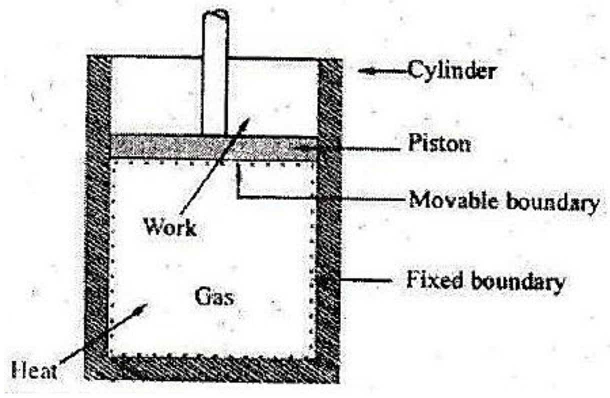


Figure 5: Closed System

<u>In a Closed System,</u>

- Heat and work (energy) crosses the boundary.
- No mass transfer takes place i.e., mass of system is fixed; hence it is also called as **NON-FLOW SYSTEM**.
- Due to fixed mass, closed system is also known as control mass.
- The boundary of closed system is not fixed but arbitrarily selected.
- Since boundary may change, volume of the system is not necessarily being fixed.
- Energy transfer can be experienced only at boundaries.
- **<u>Example:</u>** Piston cylinder arrangement, gas being compressed by a piston in a closed cylinder.
- The fluid contained in the cylinder can receive or reject heat, can expand or contract, hence changing the volume, but no matter (fluid) can flow out or into the cylinder, i.e., mass remains fixed.

1.6.2 <u>Open System</u>

- The system that can exchange both energy and matter with their environment.

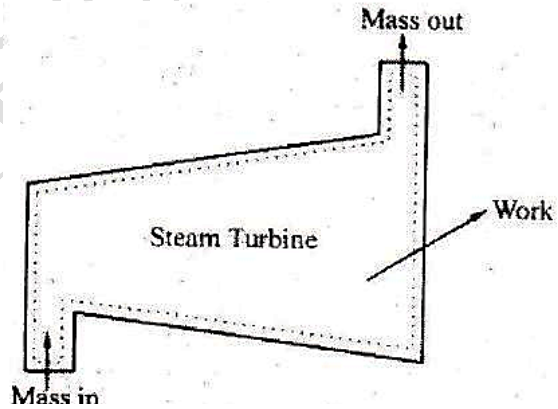


Figure 6: Open System

<u>In an Open System,</u>

- Heat and work cross the boundary.
- Mass transfer also takes place i.e., mass of system is not fixed; hence it is also called as **FLOW SYSTEM.**
- System boundary is known as **CONTROL SURFACE** which always remains fixed.
- Volume of the system does not change; hence open system is also defined as **CONTROL VOLUME**.

- **Example:** Steam generator or boiler
- A steam generator converts water into steam by gaining heat from furnace. Hence water flows into the system and steam flows out of the system; hence matter is crossing the boundary of system.

1.6.3 Isolated System

An isolated system exchanges neither matter nor energy with its surroundings.

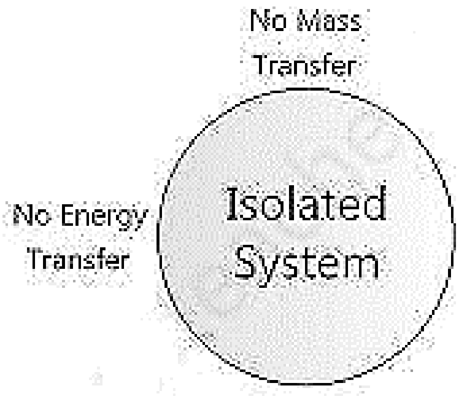


Figure 7: Isolated system

In an Isolated System,

- Heat and work do NOT cross the boundary.
- Mass of the system remains fixed i.e. No mass transfer takes place.
- **Example:** Thermos flask.
- Neither heat flows into/out of the system nor the matter flows.

Thus, a special type of closed system that does not interact with its surroundings is called an Isolated System.

1.7 Basic Terminologies

There are some basic terms one should know for the good study of thermodynamics:

1.7.1 Homogeneous and heterogeneous system

- **Phase:**
  A **phase** is defined as the quantity of matter which is homogeneous throughout in chemical composition i.e., chemical composition does not vary within system; and physical structure i.e., solid, liquid or gas.
- **Homogeneous system:**
  The system consisting of single phase is called a ***homogeneous system***. Example: air, mixture of water and sugar etc.
- **Heterogeneous system:**
  The system which consists of more than one phase is called ***heterogeneous system***. Example: mixture of water and oil etc.

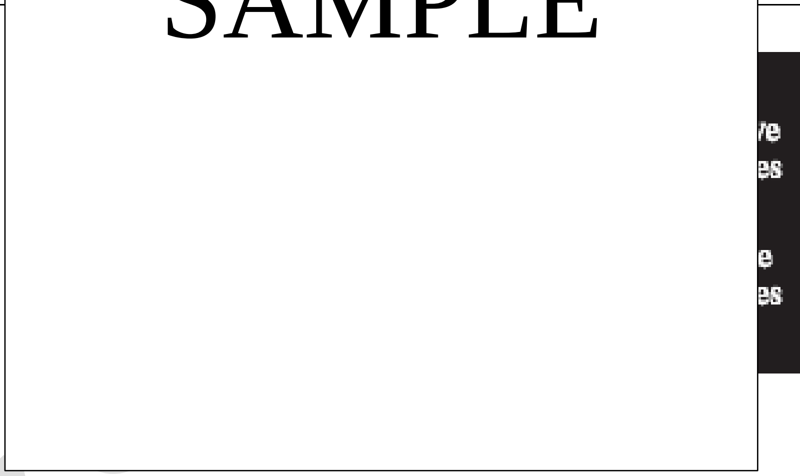
1.8 Intensive and Extensive properties

Properties of system can be classified as

(i) Intensive properties

(ii) Extensive properties

Intensive Properties	Extensive Properties
• Intensive Properties are those which are independent of mass of system. • Property of small portion of the system defines the ... system. • Intensive p... lower case ... temperature... • All the spe... properties. • Example: P... density(ρ) ...	• **Extensive Properties** are mass dependent. Hence their value depends upon the size of the system. ... when expressed ...es an intensive ...**erty**). ...e expressed in ...mass. ...gy (E), enthalpy



1.9 Fundamental properties to describe the state of the system

There are following fundamental properties which are used to describe the state of a system. Such as

1.9.1 Volume

Space occupied by the system in three dimensions is called *volume* of the system.

Unit: m^3, litre, c.c.

and $1\ m^3 = 10^3$ litre $= 10^6$ c.c.

1.9.2 Pressure

- Force exerted by the gaseous system perpendicular to the unit surface area.

  Mathematically,

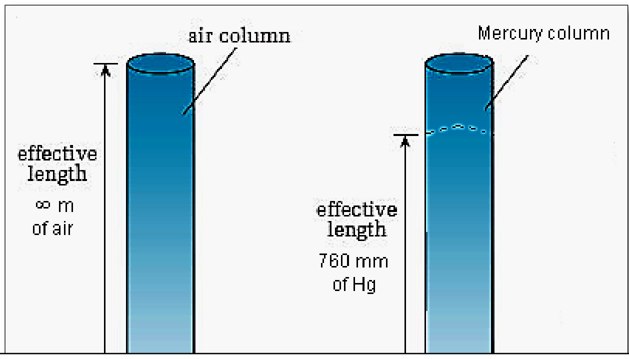
$$Pressure = \frac{Normal\ Component\ of\ Force}{Area}$$

Units: Pa, N / m^2, atm…

$$\text{And } 1 \text{ atm} = 101.325 \text{ KPa} = 101325 \text{ N} / \text{m}^2$$

- **<u>Standard Atmospheric Pressure</u>**

Weight of air column per 1 m^2 area is called standard atmospheric pressure.



SAMPLE

Since it is not practic … hus, we take an equivalent column of … m height.

Hence, we can say tha …

Hence,

From Hydrostatic law …

$P = \rho g h$

Therefore,

1.9.3 <u>Force</u>

- *Force* is which may change or tends to change the state of the system.

$$\text{Force} \propto \text{Rate of change of momentum}$$

$$F \propto \frac{d(mv)}{dt}$$

$$F \propto \left(m\frac{dv}{dt} + v\frac{dm}{dt} \right)$$

Since, m is the mass (i.e. matter contained by the body) of the body which is independent of the time and place.

Thus, equation becomes:

$$F \propto m\frac{dv}{dt}$$
$$F \propto ma$$
$$\boxed{F = k.ma}$$

Where k is the proportionality constant

- According to Force law:

$$1\,kg_f = k \times 1\,kg_m \times 9.81\tfrac{m}{s^2}$$
$$\Rightarrow\ k = \frac{1}{9.81} = \frac{1}{g_c}(say)$$

$g_c \rightarrow$ constant value of g everywhere

$$F = \frac{1}{g_c}ma$$
$$\Rightarrow 1kg_f = \frac{1}{g_c} \times 1kg_m \times 9.81\frac{m}{s^2}$$
$$\Rightarrow \boxed{g_c = 9.81\frac{kg_m.m}{kg_f.s^2}}$$

- **Relationship between kgf and N**

$$F = 70kg_m \times 5\left(\frac{m}{s^2}\right) = 350\frac{kg_m.m}{s^2} = 350N$$

hence, Mathematically

$$F = W$$
$$\Rightarrow 350N = 36.67788kg_f$$
$$\Rightarrow \boxed{1kg_f = 9.81N}$$

1.9.4 Velocity

Velocity may be defined as the distance travelled by the body per unit time.

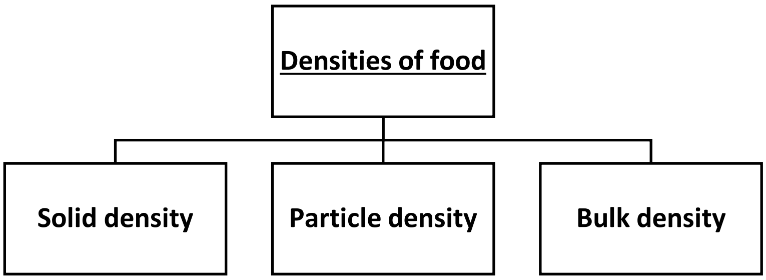
$$\boxed{v = \frac{\text{Distance travelled by the body}}{\text{Time taken by the body to travel that distance}} = \frac{d}{t}}$$

1.9.5 Temperature

- *Temperature* may be defined as the thermal potential of a system responsible for energy transfer (i.e., heat transfer).
- According to science, *temperature* is the measure of average kinetic energy of gases.

1.10 Density

- Density is defined as mass per unit volume.
- Dimensions of density are: $\frac{mass}{(length)^3}$
- It indicates how compact the material is.
- The material with more compact molecular arrangements have high densities.



> **NOTE:**
> The values of these three type of densities depends on how the pore spaces are present in the food material.

(1) Particle density:

- The presence of internal pores in a food material determines the particle density.
- It is defined as the ratio of the actual mass of the particle to its actual volume.

(2) Bulk density:

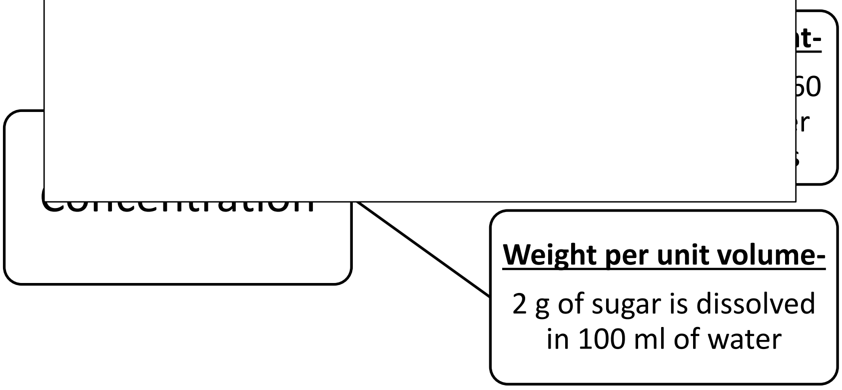
- It is defined as the mass of particles per unit volume of bed.
- Bulk densit
- The void sp

> **NOTE:**
> If the pore spaces ... 600 kg/m^3,
> except for high-fat

1.11 Concentration

It is a measure of th

Concentration can b



- **<u>Molarity:</u>** The concentration of solution in grams per litre divided by the molecular weight of the solute.
- **<u>Mole fraction:</u>** Ratio of the number of moles of a substance divided by the total number of moles in the system.
- For a solution containing two components, A and B, with number of moles n_A and n_B, respectively, the mole fraction of A, X_A, is

$$X_A = \frac{n_A}{n_A + n_B}$$

1.12 <u>Moisture content:</u>

The moisture content expresses the amount of water present in a moist sample

<table>
<tr>
<td rowspan="2"><u>Basis used to express moisture content</u></td>
<td><u>Wet basis:</u>
The moisture content on the wet basis is the amount of water per unit mass of moist or wet sample.
It is obtained by dividing the weight of water present in the material by the total weight of material.
Moisture content (wet basis) % = $\frac{w_W}{w_W+w_d} \times 100$
where W_W= weight of water in the material
W_d= weight of dry matter in the material</td>
</tr>
<tr>
<td><u>Dry basis:</u>
The moisture content on the dry basis is the amount of water per unit mass of dry solids present in the sample.
It is obtained by dividing the weight of water present in the material by the total weight of dry mater of material.
Moisture content (dry basis) % = $\frac{w_W}{w_d} \times 100$
where W_W= weight of water in the material
W_d= weight of dry matter in the material</td>
</tr>
</table>

<u>Relation between Dry basis and Wet basis moisture content</u>

Moisture content (dry basis) %= $\frac{M.C(wet\,basis),\%}{100 - M.C.(wet\,basis),\%} \times 100$

Moisture content (wet basis) %= $\frac{M.C(dry\,basis),\%}{100 + M.C.(dry\,basis),\%} \times 100$

NOTE: The value of dry basis moisture content is more than the wet basis moisture content.

Example 1: **Convert a moisture content of 70% wet basis to moisture content dry basis.**

Explanation:

Moisture content (dry basis) %= $\frac{M.C(wet\,basis),\%}{100-M.C.(wet\,basis),\%}\times 100$

➔ Moisture content (dry basis) %= $\frac{70}{100-70}\times 100=\frac{70}{30}\times 100=233.34\%$

Example 2: **A food product has a moisture content of 90% (dry weight basis). The moisture content of wet dry basis is ____ %.**

Explanation:

Moisture content (dry basis) %= $\frac{M.C(wet\,basis),\%}{100-M.C.(wet\,basis),\%}\times 100$

Moisture content (wet basis) %= $\frac{90}{100+90}\times 100=\frac{90}{190}\times 100=47.36\%$

Example 3: A 10-kg batch of a food product has a moisture content of 175% dry basis. Calculate the amount of water to be removed from the product to reduce the moisture content to 15% wet basis.

Explanation:

The food is 10 kg of raw product
The moisture content is 175% dry basis which is to be reduced to 15% wet basis
The percentage change of dry basis to wet basis can be calculated as follows:

$$MC_{wb}\% = \frac{MC_{db}}{1+MC_{db}} = \frac{1.75}{1+1.75} = 0.63636\%$$
$$= 63.64\%$$

Now, the food has 63.64% of water and remaining percentage of solid
So, in 10 kg batch, 6.3636 kg is water and 3.6363kg is solid
In the drying process, the final product has 15% moisture (wet basis)
Also.
Mass of total product = A kg of water + 3.6363kg
So,

$$0.15 = \frac{A}{A+3.6363}$$
$$A = 0.6417\text{kg of water}$$

Now,

$$F = P + W$$
$$6.3636 = 0.6417 + W$$
$$W = 5.722\text{kg}$$