

Code: ABE 512 *Title:* Processing & Storage of Agricultural Products Credit: 3

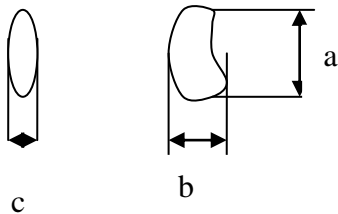
Properties and characteristics of agricultural materials in relation to their Processing and handling methods. Physical, mechanical, rheological, thermal, electrical and chemical properties. Introduction to agricultural product processing, Ambient temperature processing Materials cleaning, sorting and grading techniques. Size reduction and mixing, Processing by application of heat. Handling methods. Storage requirement of agricultural products.

Properties and Characteristics of Agricultural Materials

Physical Properties of Agricultural Products:

Shape size, volume, surface area, density, porosity, colour and appearance are some of the physical characteristics which are important in many problems associated with design of specific machine or analysis of the behavior of the product in handling of the material. When studying physical properties of Agricultural products by considering either bulk or individual units of the material it is important to have an accurate estimate of these properties which may be considered as engineering parameters for that product.

Shape and size: In a physical object shape and size are inseparable and both are generally necessary if the object is to be satisfactorily described. In defining the size the three principal dimensions namely the *length*, *width* and *thickness* (*major*, *minor intermediate diameter*) are measured to a given accuracy.



The principal dimensions are measured using different methods such as photographic enlarger, millimeter scale, a shadow graph, tracing of projected area or by the use of micrometer.

The major minor and intermediate diameter of an object can be measured by projection of each sample using photographic enlarger. The object is placed on the plane where the negative is positioned, turned so that its shadow covers the largest area. Then the enlarger is focused to give a sharp image.

Determination of Geometric Mean Diameter: The geometric mean diameter (D_g) of agricultural material is evaluated using the relationship given below.

$$\text{geometric mean diameter } D_g = (a \times b \times c)^{\frac{1}{3}}$$

Determination of Arithmetic Mean Diameter: the arithmetic mean diameter (D_a) is evaluated using the following relationship *Arithmetic mean diameter* $D_a = \frac{a+b+c}{3}$

Aspect Ratio: Aspect ratio is computed as *Aspect ratio* $= \frac{\text{Intermediate diameter}}{\text{major diameter}}$ it is also given as the ratio of width to length

Frontal Area: frontal area is computed as *frontal area* $= \frac{\pi}{4} (D_g)^2$

Slenderness Ratio is the *ratio* of the effective length to the least radius of a particle. It is calculated as *slenderness ratio* $= \frac{\text{minor diameter}}{\text{major diameter}}$

Thousand Seed Mass: This is the mass of thousand seeds of the particular crop (mainly for grain, pulses and seeds). Thousand seed weight was obtained by using the digital weighing balance of a given accuracy.

Description of some shape:

In defining the shape some dimensional parameters of the object must be measured. These parameters include Major minor and intermediate diameters and projected area. In this method tracings of longitudinal and lateral cross sections of the material can be compared with the shapes listed on a charted standard. Description of some shape and its measurement is given below:

Roundness of an object is a measure of the sharpness of the corners of the solid. Several methods have been proposed for estimating roundness. Roundness is calculated as

$$\text{Roundness} = \frac{A_p}{A_c} \text{ where}$$

A_p = Largest projected area of object in natural rest position

A_c = Area of smallest circumscribing circle

Roundness can also be computed as:

$$\text{Roundness} = \frac{\sum r}{NR} \text{ where}$$

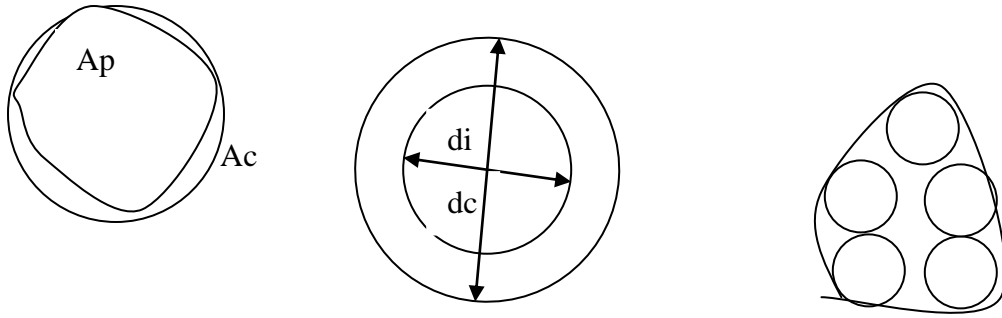
r = radius of curvature

R = radius of the largest inscribed circle

N = Total number of corners summed in numerator

Then roundness ratio is computed as

Roundness ratio $= \frac{r}{R}$ where: r is the radius of the curvature of the sharpest corner.



Sphericity concept rests upon the isoperimetric property of a sphere which is a round solid figure similar in shape to a ball. Sphericity expresses the shape character of the solid relative to that of a sphere of the same volume. Sphericity of an object is defined using the following relationship:

$sphericity = \frac{d_i}{d_c}$ where: d_i is the diameter of the largest inscribed circle

d_c is diameter of the smallest circumscribed circle

Sphericity is also defined based on axial dimensions as follows:

$$sphericity = \frac{\text{geometric mean diameter}}{\text{major diameter}} = \frac{(abc)^{\frac{1}{3}}}{a}$$

Where a,b and c are the major, intermediate and minor diameter of the object.

Density, specific gravity and volume:

Density and specific gravity of food material play an important role in design of storage bins, conveying equipments, separation equipments etc.. Density can be bulk density or unit density. *Bulk density* (kg/m^3) is obtained by weighing a known volume of the product. While a *unit density* is obtained by measuring the volume and weight of a unit product. *Specific gravity* also known as relative density is the ratio of density of a substance to the density of a standard substance at the same temperature and pressure. For liquids and solids the standard substance is water while for gasses it is air. Specific gravity of a product is obtained by the use of a specific gravity balance. Using this balance the product is weighed in air and in water. Then the specific gravity is computed as follows:

If the solid is heavier than water:

$$specific\ gravity = \left[\frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}} \right]$$

If the solid is lighter than water a sinker of a known weight is attached to the product and specific gravity is determined as:

$$specific\ gravity = \left[\frac{(W_a)_{object}}{(W_a - W_w)_{both} - (W_a - W_w)_{sinker}} \right]$$

Where W_a is weight in air and W_w is weight in water.

Specific gravity can also be determine using specific gravity gradient tube: this technique is based on observing the level at which a test specimen sinks in a liquid column exhibiting a

density gradient. The specimen must be impervious to the liquid in the column until the liquid and test specimen have reached equilibrium and a reading is obtained.

Pycno-meter method (which is a standardized vessel for determining specific gravity). It involves a standard container of accurately defined volume used to determine the specific gravity of solids and liquids.

Radiation method: This method uses a radioactive source. A radiation detector measured the amount of radiation coming through the product. The radiation decreases with increase in product density.

Volume (m^3) of larger objects such as fruits and root crops can be determined using the platform scale. Using this method the product is first weighed in air and submerged in to water and the weight of displaced water and the weight of the product in water is determined then the volume is measured as follows:

$$Volume(m^3) = \frac{Weight\ of\ displaced\ water(g)}{Weight\ density\ of\ water(\frac{g}{m^3})}$$

Or

$$Volume = \frac{Weight\ in\ air - Weight\ in\ water}{Weight\ density\ of\ water}$$

For some agricultural products volume can be calculated using the geometrical measurements as given below:

$$Volume = \frac{4}{3}(\pi ab^2)$$

Surface Area:

The knowledge of surface area (m^2) of some parts of plant such as leaf area, surface area of fruits is important to plant scientists as well as engineers. Surface area of a product is important in designing a conveying equipment, cleaning and separation equipment. Some of the methods used for measuring surface area are:

- contact printing the surface on a light sensitive paper and measuring the area by a planimeter
- tracing the area on a graph paper and counting the squares
- use of a photographic projector
- light interception method and
- use of an air flow planimeter which measure the area as a function of the surface obstruction to flow of air. This is a fast and reliable method.

Fruit surface area can be measured by peeling the fruit in a narrow strips and using a planimeter to measure the area and sum of the stripes is taken as accurate surface area.

The following relationship can also be used to determine surface area of spheroid bodies using the geometrical measurements.

$$S = 2\pi b^2 + 2\pi \frac{ab}{e} \sin^{-1} e \quad \text{where } e = \left[1 - \left(\frac{b}{a}\right)^2\right]^{\frac{1}{2}}$$

Porosity: Porosity is the percent void space in a product. This property is needed in air flow and heat flow studies. Porosity of granular and unconsolidated materials is measured using a devices which is specifically designed for that purpose. However, porosity which is also referred to as packing factor PF may be calculated from the following relationship:

$$PF = \frac{\text{Solid density of particle} - \text{density of packing}}{\text{Solid density of particles}}$$

Density of packing may be found by weighing a given volume of packed particles

Moisture content: Moisture content of a product is the amount of water present in that product. When studying engineering properties of agricultural products it is important to indicate the moisture content at which it is being studied. Moisture content affects other engineering properties. Moisture content of agricultural products can be measured using different methods. However, the oven method of determining moisture content is used very frequently. Using this method a known weight the product is dried in an oven for a given period of time and given temperature and weighed. The moisture content is then computed as follows:

$$\text{Moisture content on wet basis } MC_{wb} = \frac{W_i - W_f}{W_i} (\%)$$

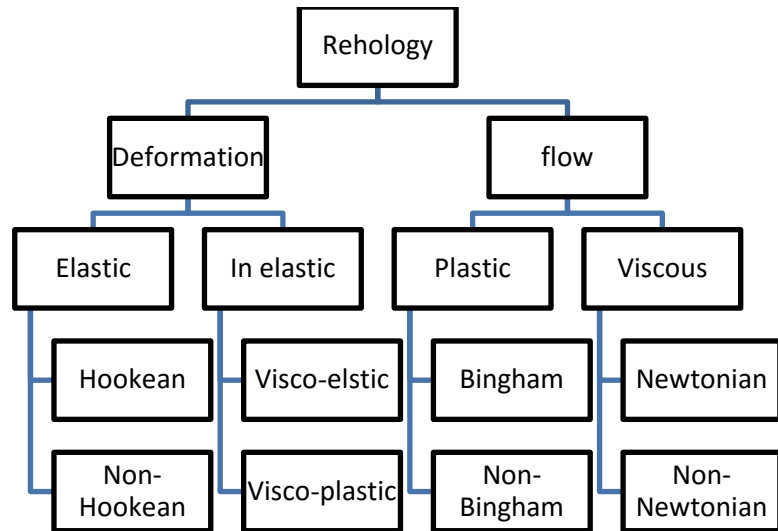
Moisture content on dry basis $MC_{db} = \frac{W_i - W_f}{W_f}$ where: W_i is the initial weight of the product before drying while W_f is the final weight of the product after drying. The wet base and dry base moisture content are related by the following equations:

$$MC_{wb} = \frac{MC_{db}}{(1 + MC_{db})}$$

$$MC_{db} = \frac{MC_{wb}}{(1 - MC_{wb})}$$

Mechanical Properties of Agricultural Products:

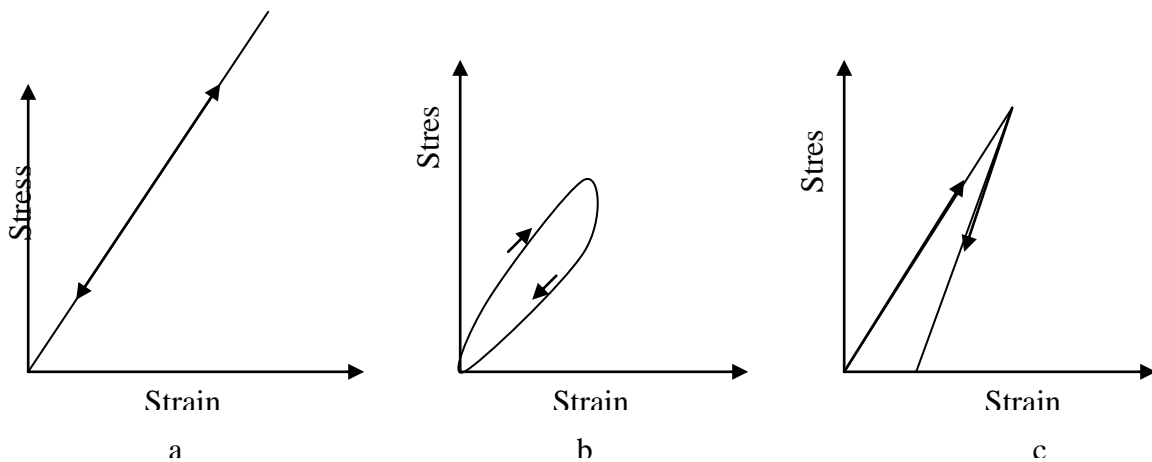
Mechanical property of agricultural product may be defined as those properties having to do with the behavior of the material under applied forces. Such properties include stress – strain behavior of material under static and dynamic loading, flow characteristics of material in air or in water. When the action of forces result in *deformation* and *flow* in the material the mechanical property is referred to as **rheological property**. Moreover rheology considers the *time* effect during the loading of the body. Rheologically, mechanical behavior of a material is expressed in terms of the three parameters *force*, *deformation/flow* and *time*. Examples of rheological properties are time dependant stress and strain behavior, stress relaxation, and viscosity.



Rheological properties

Agricultural materials are living things, constantly undergoing changes in shape, size, respiration and other aspects of life processes. During developments and storage, the cells are sensitive to such external influences such as humidity, temperature, oxygen, food supply energy consumption as well as the interplay of internal factors which are difficult to control. In Biological solids elasticity varies with age and physiological conditions. As a result of these complex conditions, in studying the rheology of a biological system only an empirical approach is possible.

In an ideal elastic behavior stress is directly proportional to strain as illustrated below fig a. This relationship is known as Hookean behavior. The behavior of a non linear elasticity such as in rubber is shown in the figure b below. In agricultural materials some residual deformation upon unloading is typical fig c. Thus agricultural materials are inelastic. Visco elastic behavior of materials combines liquid like and solid like characteristics.



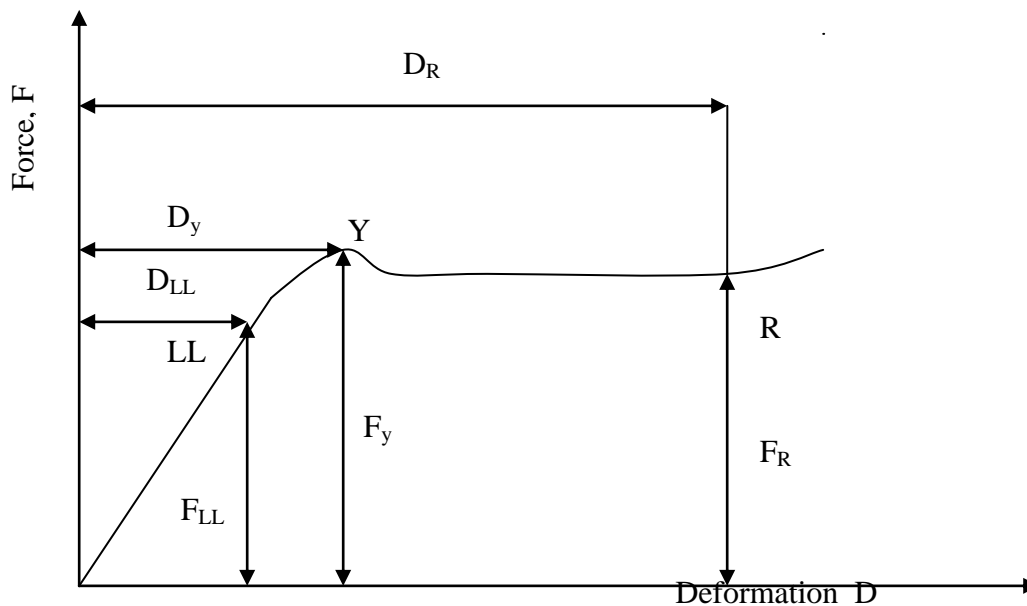
a, An ideal elastic behavior linear elasticity b, non linear elasticity c, inelasticity in agricultural material

Physical state of material: The state of various materials depend at any instant on load and deformation history to which it is subjected to as well as environmental factors such as temperature and moisture content. Under applied force a material may flow or be deformed. Deformation may be elastic or in-elastic while flow can be plastic or viscous. Rheological behavior of material can be described using elasticity, plasticity and viscosity.

In ideal elastic body stress is directly proportional to strain. Compression test of food and feed material indicate that even at a very small strain ideal elasticity does not apply in biological materials. Some residual deformation upon unloading is typical for most of food material.

Stress - Strain Characteristics of agricultural materials

Understanding the stress – strain (force - deformation) characteristics of agricultural materials is important in designing processing and handling equipments and also in understanding the behavior of the material under applied force. There are a number of test used to determine the behavior of material for a given type of deformation and given type of loading pattern. The Universal Testing Machine (UTM) and the triaxial machines are some of the machines used to test the mechanical properties of materials. The figure below shows a possible force deformation (stress-strain) curve for an agricultural product.



Force – Deformation curve for an agricultural product LL- Linear Limit; y - Bioyield point; R – rapture point

Some definitions of rheological properties (stress-strain relationship) are given below:

Strain: The unit change, due to force, in the size or shape of a body referred to its original size or shape. Strain is a non-dimensional quantity, but it is frequently expressed in centimeter per centimeter. Strain can be linear (strain or compressive) axial strain or shear strain.

Stress is the intensity at a point in a body of the internal forces or components of forces that act on a given plane through the point. Stress is expressed in force per unit of area (kilogram force per square millimeter).

Compressive strength: Is the maximum compressive stress which a material is capable of sustaining. Compressive strength is calculated from the maximum load during a compression test and the original cross-sectional area of the specimen.

Shear strength is the maximum shear stress which a material is capable of sustaining. It is calculated from the maximum load during a shear or torsion test and is based on the original dimension of the cross-section of the specimen.

Tensile strength is the maximum tensile stress which a material is capable of sustaining. It is calculated from the maximum load during a tension test carried to rupture and the original cross-sectional area of the specimen.

Pressure is a measure of the mean normal stress on a point of a body (kg/m^2)

Deformation or distortion is the relative displacement of points within a body. Deformation like a stress is a vector quantity. In general deformation is accompanied either by change of volume or by change of shape.

Bio-yield point is a point on the stress-strain or force-deformation curve at which there occurs an increase in deformation with a decrease or no change of force. In some agricultural products the presence of this bioyield point is an indication of initial cell rupture in the cellular structure of the material. Bioyield point may occur at any point beyond the linear limit point. Bioyield point may correspond to a failure in the microstructure of the specimen.

Rapture point is a point on the stress-strain or force-deformation curve at which the axially loaded specimen ruptures under a load. In biological material rupture may cause puncture of shell or skin, cracking or fracture planes. Rapture point may correspond to a failure in the macrostructure of the specimen. Rapture of the specimen may occur at any point on the curve beyond the bioyield point. In a brittle material rupture may occur in the early portion of the curve, while in a tough material rupture may take place after considerable plastic flow.

Elastic limit is the maximum stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress.

Modulus of elasticity or young's modulus the ratio of stress to corresponding strain below the proportional limit.

For tensile or compressive stress the modulus of elasticity or young's modulus is calculated as:

$$E = \frac{\text{Tensile or compressive stress } \sigma}{\text{tensile or compressive strain } \epsilon} \text{ where } \sigma = \frac{F}{A} \quad \epsilon = \frac{\Delta l}{l}$$

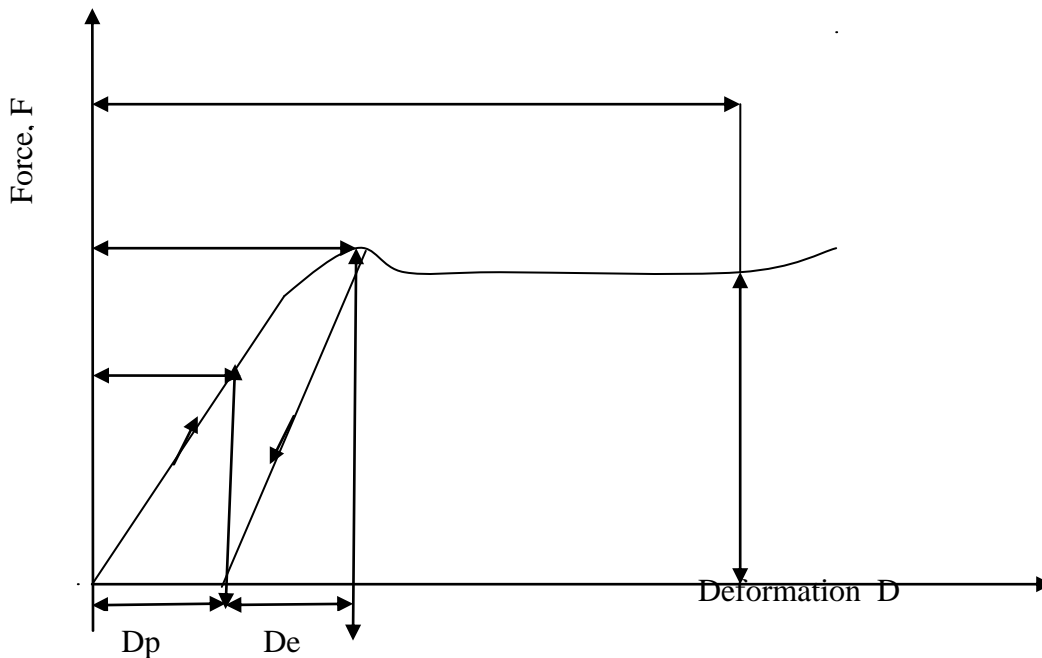
Where F is the force A the cross-section area of the body, Δl is the deformation and l is the original length of the body.

Yield point is the first stress in a material less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress.

Yield strength is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain.

Stiffness or rigidity is indicated by the slope of the initial straight line portion of the curve. The ratio of stress to strain in this elastic region of the curve may be referred to as the modulus of elasticity or young's modulus kg/m².

Elasticity is the capacity of a material for taking elastic or recoverable deformation. It is the point below the linear limit. Deformation from the bioyield point to the point of rapture is not all recoverable. The unrecoverable part can be taken as a measure of plastic deformation.



Degree of elasticity for loading – unloading curve D_e elastic or recoverable deformation; D_p plastic or residual deformation

Degree of elasticity is the ratio of elastic deformation to the sum of elastic and plastic deformation when a material is loaded to a certain load and then unloaded to zero load.

Degree of elasticity is given as $\frac{D_e}{(D_p + D_e)}$

Bioyield strength is the stress corresponding to the bioyield point. If the curve does not show a well defined bioyield point, the stress corresponding to an arbitrary strain similar to off set strain may be taken.

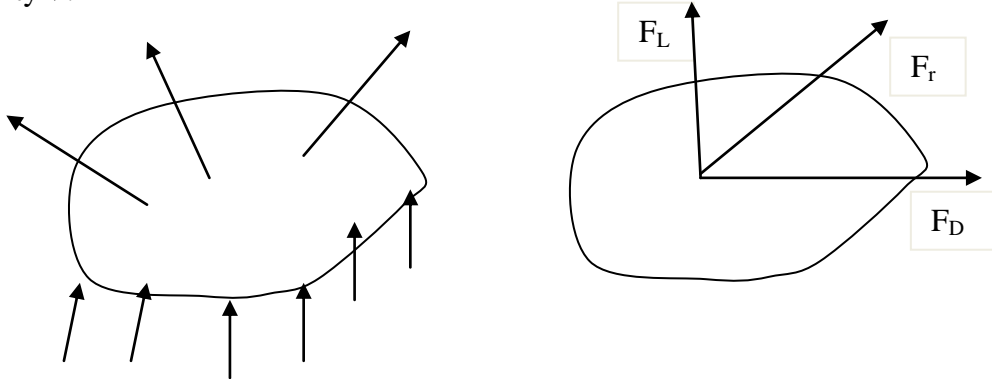
Toughness is the work required to cause rapture in a material

Aero and Hydrodynamic Properties of Agricultural Materials:

In handling and processing of agricultural products often air and water is used as a carrier for transport or for separating the desired product from the unwanted material. In this case fluid flow occurs around the solids and the problem involves the action of the forces exerted by the fluids on these solids. The pneumatic separation and conveying has been in use in agricultural machinery and food processing equipment for many years. Use of water, however as a carrier for more economical transport or less injury to such products as fruits and vegetables is a new concept in agricultural industry.

The main properties which affect the aerodynamic behavior of agricultural products are the drag coefficient and the terminal velocity.

Drag coefficient: when fluid flow about immersed objects the action of the forces involved include F_r the force acting on the body which is resolved in to components F_D drag and F_L the lift. These forces depend on the area A_p moving through, fluid density ρ_f , viscosity η and velocity V .



Flow about immersed object

The following equations have been developed for drag and lift:

$$F_D = C_D A_p \frac{\rho_f V^2}{2}$$

$$F_L = C_L A_p \frac{\rho_f V^2}{2}$$

Where C_D and C_L are the drag coefficient and the lift coefficient respectively. The net resistance force F_r is given in terms of an overall drag coefficient C as follows:

$$F_r = \frac{1}{2} C A_p \rho_f V^2 \quad \text{Where: } F_r \text{ is resistance or drag force}$$

C overall drag coefficient

A_p projected area normal to the direction of motion m^2

ρ_f is mass density of fluid

V is relative velocity between main body of fluid and object.

A number of relationships depending on the geometry of the body exist to compute the drag coefficient of agricultural materials. However, for laminar flow the drag coefficient can be estimated as: $C = \frac{1.328}{(Re)^{0.5}}$ while for turbulent flow it can be estimated as: $C = \frac{0.455}{(\log Re)^{2.58}}$ Where

Re is Reynolds Number and it is given as: $Re = \frac{vd\rho_f}{\eta}$ where

d is the effective dimension of the object (length, diameter etc..) and η is the viscosity of the fluid.

Terminal velocity: In free fall an object will attain a constant terminal velocity V_t at which the net gravitational accelerating force F_a equals the resistance upward the drag force F_r . It is the final constant speed of a falling object. Under the steady state condition where terminal velocity has been achieved if the particle density is greater than the fluid density the particle will move down word. If the particle density is smaller than the fluid density the particle will rise. When air stream is used to separate grain

From associated foreign materials such as straw and chaff, the knowledge of terminal velocity of all particle involved will define the range of air velocities affecting good separation of the grain from foreign materials. Thus terminal velocity is an important aerodynamic property of material in such application as pneumatic conveying and separation. The terminal velocity of a material is computed as follows:

$$V_t = \left[\frac{2mg(\rho_p - \rho_f)}{\rho_p \rho_f A_p C} \right]^{\frac{1}{2}}$$

Where m is mass of the particle

g is acceleration due to gravity

ρ_p is density of the particle

ρ_f is density of the fluid

A_c Projected area of the particle normal to the motion

C is drag coefficient

Flow of Fluids: The manner in which a fluid flows through a system is dependant upon the characteristics of the fluid, the size the shape and condition of the inside surface of the pipe or tube, and the fluid velocity. Generally, in fluides two types of flow are identified i.e. *Laminar (streamline) and turbulent flow:* In laminar flow the fluid moves in parallel elements, the direction of motion of each element being parallel to that of any other element. The velocity of any element is constant but not necessary the same as of an adjacent element. In turbulent flow the fluid moves in elemental swirls or eddies, both velocity and direction of each element change with time. In turbulent flow violent mixing results, whereas there is no significant mixing in laminar flow.

A velocity traverse of a fluid (liquid or gas) flowing in a pipe will show that the velocity is highest at the center and decreases towards the surface of the container, the velocity at the surface being zero. This characteristic holds both for laminar and turbulent flow. The velocity profile for laminar flow in a long circular conduit is parabolic in shape and the average velocity is one half the maximum which is at the center. For turbulent flow, the profile flattens and the relationship between the maximum and average velocity changes, its exact value being a function of a number of conditions under which flow results. A mathematical relationship defining the conditions under which flow changes from laminar to turbulent was defined by Reynolds number. The velocity at which transition results is called

the critical velocity. Reynolds identified four factors that affect the critical velocity. The factors and their mathematical relationship is: $Re = dV\rho/\eta$ where Re is Reynolds number

d diameter of pipe (m)

V average velocity of fluid (m/s)

ρ fluid density (kg/m³)

η dynamic viscosity of fluid (Pa s)

For straight circular pipe with isothermal flow, if Re is less than 2130 the flow will be laminar and if Re is over 4000 the flow will be turbulent. For values between 2130 to 4000 the characteristics of flow will depend upon the details of the structure and any defined prediction.

Viscosity: Viscosity is the internal resistance of fluid to shear. It may be considered as the coefficient of friction of fluid in fluid. Assuming two layers of fluid y meters apart, the inner space being filled with fluid, because of the resistance to motion offered by the fluid, a pressure P is required to maintain a constant velocity V of the top layer relative to the lower layer. For most fluids the required force is directly proportional to the velocity gradients within the fluid, dV/dy thus:

$$P = \eta A \left(\frac{dV}{dy} \right) \text{ then}$$

$$P/A = \eta \left(\frac{dV}{dy} \right)$$

Where η is the viscosity of the fluid (Ns/m²) or (Pas)

Assignment (CA 1) to be submitted on 16/09/2016 before 3 pm

- 1) The following values were determined for mango using a platform scale.

Weight of mango in air	---	0.36kg
Weight of container and water	---	1.4kg
Weight of container + water + mango	---	1.68kg

Assuming specific gravity of 1 and density of 1000 kg/m³ for water compute the volume density and specific gravity for mango
- 2) Milk is flowing at 0.12m³/min in a 2.5 cm diameter pipe. If the temperature of the milk is 21°C is the flow turbulent or streamline? Viscosity of milk at 21°C is 2.1x10⁻³ Pas and density is 1029kg/m³
- 3) The average values for major, minor and intermediate diameter for 50 pieces castor seed and its weight is given below. Calculate the arithmetic mean diameter, geometric mean diameter, volume, sphericity, density, frontal area, aspect ratio and surface area for the seed. Major diameter = 17,2mm; intermediate diameter =13.1mm; minor diameter = 7.9mm
Weight = 0.97g
- 4) If the above given seed is to be conveyed using pneumatic conveyor at the rate of 0.2m³/s through a 20 cm diameter pipe compute the drag coefficient and the terminal velocity. Density and viscosity of air is 1.29 kg/m³ and 1.91 x 10⁻⁵ Ns/m⁻²
- 5) 100 g of grain was dried at 50°C for 24 hours. After drying its weight was 40 g. Compute the moisture content in wet and dry basis.

Thermal Properties of Agricultural Materials

Thermal properties of agricultural materials are important to predict the heat transfer rates in thermal processing of foods and feed products. Thermal processing may include heating, cooling, drying and freezing. Products are heated or cooled to extend the shelf life, to soften the structure, to change the form or increase extraction. Thermal properties are generally non-uniform, changing with time, temperature, constituent of food and location as food product is cooled or heated.

In heat treatment of biological materials, time and temperature are equally important if the viability, nutrient and quality of the material are to be preserved. Thermal properties that are important in food engineering are: specific heat, thermal conductivity, thermal diffusivity, enthalpy, surface heat transfer coefficient and latent heat. Knowledge of these properties is essential when designing for heating or cooling of foods. Other thermal properties include melting/freezing point, heat of respiration, heat of adsorption, coefficient of thermal expansion and emissivity.

Specific Heat (kJ/kg°C): This is the amount of heat required to change the temperature of material. The heat required to heat a material of mass M from an initial temperature T_1 to final temperature T_2 is equal to the product of the mass \times specific heat $\times (T_2 - T_1)$. A heat balance for heating or cooling a material can not be attempted without knowledge of the heat capacity of the material. Specific heat is given in kJ/kg°C and it is measured using a calorimeter. Specific heat of frozen foods is much lower than that of not frozen foods. This is because specific heat of ice is only half of that of water.

Thermal Conductivity ($\text{Jm}^{-1}\text{s}^{-1}\text{C}^{-1}$): This is the measure of material's ability to conduct heat. In foods the thermal conductivity depends mostly on composition, but also on any factor that affects the heat flow paths through the material, such as percentage void space (porosity) moisture content, shape, size, arrangement of void spaces, homogeneity, orientation of fibers and chemical composition. The amount of heat Q that flows through a slab of material of thickness x having a thermal conductivity k is calculated as $Q = \frac{kA(T_2 - T_1)}{x}$ where A is the surface area of the material normal to direction of heat flow and T_1 and T_2 are the surface temperature of the material. Thermal conductivity of agricultural materials is measured using the thermal conductivity probe. Line heat source probes are used frequently for agricultural materials.

Thermal Diffusivity (m^2/s): Thermal diffusivity is used in the determination of heat transfer rate in solid foods of any shape. Physically it relates the ability of a material to conduct heat to its ability to store heat. It may be calculated as thermal conductivity divided by the product of specific heat and mass density or it may also be measured by transient heating technique. Thermal diffusivity generally tends to vary in a similar manner as thermal conductivity.

Enthalpy (kJ/kg): Enthalpy is the heat content or energy level of a material. The amount of heat energy required to heat a material from temperature T_1 to temperature T_2 is simply $M \times (h_2 - h_1)$. Where M is the mass of the material and h_2 and h_1 are the enthalpy at temperature

T_2 and T_1 respectively. Enthalpy has been used more for quantifying energy in steam than in foods. However it is convenient for frozen foods which often contain unfrozen water.

Surface heat transfer coefficient ($W/m^2\text{ }^\circ C$): The surface heat transfer coefficient is used to quantify the rate of heat convection to or away from the surface of an object. It is used to quantify heat transfer in food heating or cooling application. The surface heat transfer coefficient is equal to the heat flux through a surface divided by the difference between the surface temperature and the convecting medium temperature or the amount of heat transferred per meter square of the surface is given as: $Q = h_s A(T_2 - T_1)$ Where h_s is the surface heat transfer coefficient. The surface heat transfer coefficient can be regarded as the conductance of a hypothetical surface film of the cooling medium of thickness x_f then $h_s = \frac{k_f}{x_f}$ where k_f is the thermal conductivity of the cooling medium.

Latent heat (kJ/kg): This is the amount of heat energy that is absorbed or emitted when a substance undergoes a physical phase change. It could be latent heat of vaporization if heat is used to vaporize liquid and latent heat of sublimation if it is vaporized from solid.

Electrical Properties of Food

The electrical properties of foods are of engineering interest because they determine the coupling and distribution of energy and, therefore the products heating characteristics in high frequencies food processes involving conductive or irradiative energy transfer from electromagnetic field. The main electrical properties are the dielectric properties, transmission properties and electromagnetic field properties.

Agricultural Product Processing

Agricultural processing is any activity that maintains, raises the quality or changes the form or characteristics of an agricultural product. Processing activities are undertaken to provide a greater yield from a raw farm product by either increasing the amount of the finished product, the number of finished products or both and to improve the net economical value of a product. Many processes are involved in converting a raw product to the final product that is consumed by the end users. Each of these processes is referred to as a unit operation. In a processing factory the raw material arrives in different forms. The transformation of this to finished product involves a series of unit operations performed in a logical sequence.

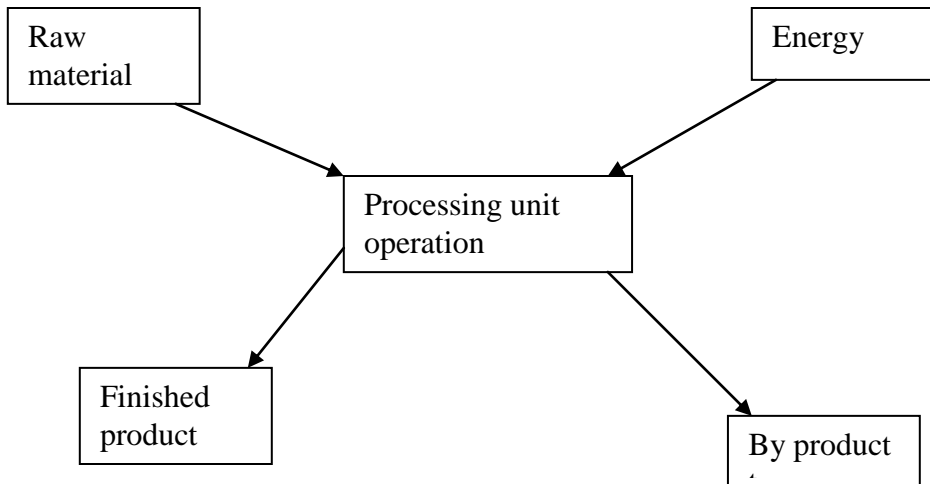


Figure 1. Processing of a raw material

Processing operations can be divided in to number different unit operations. Based on heat requirement it can be:

- ◇ Ambient temperature processing this include: raw material preparation (cleaning, grading, sorting, peeling), size reduction (cutting, milling, grinding), mixing and forming, mechanical separation (centrifugation, filtration, and expression), membrane concentration, irradiation
- ◇ Processing by application of heat this is divided in to:
 - heat processing using steam or water which include: Blanching, pasteurization, sterilization, Evaporation, extrusion,
 - heat processing using hot air which include: dehydration, drying, baking and roasting,
 - heat processing using hot oil which include: fraying and
 - heat processing by irradiated energy microwave and infrared energy
- ◇ Processing by removal of heat chilling and freezing

Based on the effect of the unit operation on the food it can be:

- ◇ Preliminary operations this include raw material preparation (cleaning; grading; sorting; peeling)
- ◇ Conversion operations this include size reduction, mixing filtration centrifugation, expression crystallization food conversion by heat processing baking, extrusion etc..
- ◇ Preservation operations preservation by heat processing (sterilization, pasteurization, evaporation, drying) fermentation, chilling and freezing irradiation

Ambient Temperature Processing

In this part, methods used to prepare freshly harvested or slaughtered foods, to alter the size of foods, to mix ingredients or to separate components of food are studied. Each of these operations is used either to aid subsequent processing or to alter the eating quality of food.

Raw Material Preparation

At the time harvest or slaughter, most foods are likely to contain contaminants, to have components which are inedible or to have variable physical characteristics such as shape, size and colour. It is therefore necessary to perform one or more of the unit operations of cleaning, sorting, grading and peeling to ensure that foods with a uniform high quality are prepared for subsequent processing. These are mechanical separation procedures which are applied near the beginning of a process to upgrade the quality of food material.

Cleaning: Cleaning is the unit operation, in which contaminating materials are removed from the food in a suitable condition for further processing. This contaminants could be soil, plant debris, metals, chemical residues, oil etc.. Cleaning should take place at the earliest opportunity in a food process both to prevent damage to subsequent processing equipment, and to prevent time and money from being spent on processing contaminants which is then discarded. Equipment for cleaning can be categorised in to:

- **Wet cleaning:** Wet cleaning is more effective than dry methods for removing soil from root crops or dust and pesticide residues from fruits and vegetables. It is also dust less and causes less damage to foods and equipments than dry methods. Different combination of detergent and sterilant at different temperatures allow flexibility in wet cleaning operations. However the use of warm cleaning water may accelerate chemical and microbiological spoilage. Furthermore wet procedures produce large volumes of effluent, with high concentration of dissolved and suspended solids. Thus it is require to purchase clean water and pay for the disposal of the effluent. To reduce cost, re-circulated, filtered and treated water is used whenever it is possible. Wet cleaning equipment include spray washers, drum washers, brush washers and flotation tank.
- **Dry Cleaning:** Dry cleaning procedures are used for products that are smaller, have greater mechanical strength and possess lower moisture content (grains and nuts). After cleaning the surface are dry. Separation by Dry procedures generally involve smaller cheaper equipments than wet procedures and produce a concentrated dry affluent which may be disposed off more cheaply. Generally cleaning is simpler and chemical and microbial deterioration if the food is reduced. The main groups of equipment used for dry cleaning are air classifiers, magnetic and electrostatic separators physical separators and separators based on the screening of foods and imaging machines.

Air classifiers use a fast moving stream of air to separate contaminants from foods using the difference in the densities and the projected areas of particle. Air classifiers have very wide application for removing solids from lighter solids and air or liquids from vapour. Air classifiers are widely used in harvesting machines to separate heavy contaminants and light contaminants from grain. Winnowers, aspirators are examples of air classifiers. . The air velocity required is calculated:

$$V_c = \sqrt{\left[\frac{4d(\rho_s - \rho)}{3C_d\rho} \right]}$$
 Where: V_c (ms^{-1}) is the minimum velocity, C_d is the drag coefficient ρ_s density of the solid and ρ density of the fluid.

- **Magnetic and Electrostatic Separators:** Contamination by metal fragments is a potential hazard in processing operations. Magnetic cleaning involves cascading the contaminated product over one or more magnates, the use magnetic drums and

magnetised conveyor belts or magnets located above conveyors. Both permanent and electrical magnet can be used. Electrical magnets are easier to clean (by simply switching the power off). However, permanent magnet cleaners are cheaper.

- Screening: screens are size separators which separate contaminants of different size from that of the raw material. Industrial screens can be rotary drum screens, flat bed screens and reciprocating screens.
- Physical separators: Separation of contaminants from food is possible when the food has a regular well defined shape such as peas and blackcurrant seeds. Such seeds are separated from contaminants by exploiting their ability to roll down on an inclined conveyor belt. A disk separator consists of a series of vertical metal discs with precisely engineered indentations in the sides. It is used to separate grain seed from weed seeds. The indentation match the shape of the grain and as the disc rotate the grain is lifted out and removed

Sorting: Sorting is separation of foods into categories on the basis of a measurable physical property. It should be employed as early as possible to ensure a uniform product for subsequent processing. Sorted foods have the following desirable attributes:

- ◇ They are better suited to mechanical operations such as peeling, blanching, and coring
- ◇ High uniformity of heat transfer rate (during sterilization and pasteurization)
- ◇ Better control of weight specially in filling and sealing
- ◇ At sales point they are more attractive to the eye and allow the serving of uniform portion.

The physical properties used for sorting are size and shape, colour, weight and density. The effectiveness of sorting procedure is calculated using:

$$effectiveness = \frac{PX_p R(1-X_r)}{FX_1 F(1-X_f)}$$

Where P (kgs-1) the product flow rate, F (kgs-1) the feed flow rate, R (kgs-1) the rejected food flow rate, X_p the mass fraction desired in product, X_f the mass fraction of desired material in the feed and X_r the mass fraction of desired material in the rejected food

Shape and size sorting is the separation of food items into two or more fractions on the basis of differences in size and shape it is particularly important if the food is to be cooled or heated as the rate of heat transfer is in part determined by the size of the individual piece and variation on the individual pieces will cause over processing or under processing. Shape and size sorting is achieved by belt and roller sorter for fruits & tubers, by disk sorter and screen sorters such as drum screen sorter.

Colour sorting (Photometric sorting) foods may be sorted at a very high rate using microprocessor controlled colour sorting equipment. Products, as they are passing through an illumination a photo-detector measure the reflected colour of each piece and compare it with a

preset standard. Foods are separated by a short blast of compressed air. In another system, arrays of pulsed laser beams are used to illuminate products as they are discharged from a conveyor. Reflected light is measured by a microprocessor, which operates an automatic reject system.

Weight sorting this method is more accurate than other method and it is used for more valuable foods (eggs, meat and fruits). A typical weight sorter consists of a slated conveyor which transports the product over a series of counterbalanced arms. The conveyor operates intermittently and while stationary, the arms rise and weigh the eggs. Heavy eggs are discharged into the padded chute and light eggs are replaced on the conveyor to travel to the next weigher.

Aspiration and flotation sorter use differences in density. Grains pulses and nuts are sorted by aspiration. Green beans and peas are sorted by flotation in brine. The dense mature pieces sink whereas the younger pieces float.

Grading or quality separation is the assessment of a number of attributes to obtain an indication of overall quality of food. Sorting on the basis of one characteristic may be used as part of grading operations but not vice versa. Generally the property of a food which determine its quality can be grouped into:

- ◇ Process suitability
- ◇ Consumer safety
- ◇ Conformity with legal requirements
- ◇ Consumer acceptance

Some grading standards include: size and shape, maturity, texture, flavour and aroma, freedom from blemish and contamination. Grading is carried out by trained operators who are able to asses a number of factors simultaneously. The grader forms a balance judgment of the overall quality and physically separates the food into quality categories.

Peeling it is a necessary operation in the processing of many fruits and vegetables to remove unwanted or inedible material, and to improve the appearance of the final product. The main consideration is to minimize cost by removing as little of the underlying food as possible and reducing energy, labour and material costs to a minimum. There are different mechanical peeling methods. Such as:

- **Flash steam peeling:** Foods (eg root crops) are fed into a pressure vessel which is rotated at 4-6rev/min. High pressure steam (1500kpa) is introduced and all food surfaces are exposed to the steam by rotation of the vessel for predetermined time, which differs according to the type of food. The high temperature causes the rapid heating of the surface layer within 10-15 s. The low thermal conductivity of the food prevents further heat penetration and cooking of the product. Texture and colour of the product is preserved. The pressure is then instantly released and the surface of the food is flashes off and discharged with the steam. Water sprays are used to remove the remaining traces. The system has minimum water consumption, minimum product loss, good appearance of the peeled surface, high throughput (up to 4500 kg/h) with full automatic control of the cycle and the production of easily disposable waste.
- **Knife peeling:** stationary blades are pressed against the surface of a rotating fruits or vegetable to remove the skin. Alternatively the blade may be rotating against

stationary foods. This method is particularly suitable for citrus fruits where the skin is easily removed and there is little damage or loss of fruit.

- **Abrasion peeling:** Food is fed into carborundum rollers or placed into a rotating bowl which is lined with carborundum. The abrasive surface removes the skin and it is washed away by water. The method has a low energy costs and good surface appearance of the food. However irregular surfaces may cause problem of peeling more so the method has high product loss, produces large volume of diluted waste and relatively low through put.
- **Caustic peeling:** A chemical solution (sodium hydroxide) is heated to 100 – 120°C and food is passed through it. The solution softens the skin of the product which is removed by high pressure of water spray. This method is used for root crops. It causes change in the colour of the product and incurs high cost.
- **Flame peeling:** Mostly used for onions, the peeler consists of a conveyor belt which carries and rotates the food through a furnace heated to higher than 1000°C. The outer paper shell and hairs are burned off and the charred skin is removed by high pressure of water sprays.

Size Reduction

Size reduction is the breakdown of solid material in to smaller particle by application of mechanical energy; it is a frequent requirement in many food processing operations. Size reduction has the following benefit in food processing:

- ◇ Size reduction may aid the extraction of a desired constituent from a composite structure
- ◇ Reduction to a definite size may be a product specific requirement
- ◇ Mixing and blending is usually easier with smaller size ranges of particles eg. Animal feed.
- ◇ Reduce cost of packaging and transportation.
- ◇ A decrease in particle size leads to an increase in surface area. This enhances rate of heat transfer (drying, cooling)

Nature of forces used in size reduction: Size reduction machines can be classified according to the nature of forces used in the process. The types of forces in size reduction are summarized below:

Force	Principle	Machine
Compressive	Compression	Crushing rolls, jaw crushers
Impact	Impact	Hammer mill
Shear	Attrition	Disc attrition mill, plate mill, burr mill
Cutting	Slicing, chopping	Blenders, digesters, slicers

In most size reduction operations all the forces are present, but often one type force is more important than others.

Energy requirement in size reduction: It is sometimes necessary to quantify the energy spent in size reduction operations. This can be used for sizing of such machines or for comparing

two or more processes of size reduction. Theoretically the energy dE required to produce a small change dx in the size of a product can be expressed as:

$$\frac{dE}{dx} = \frac{k}{x^n}$$

Where k is constant and n is an exponent

Depending on the value of the exponent different laws can be obtained which are relevant to specific application.

Rittinger's law ($n = 2$) then

$$\frac{dE}{dx} = \frac{k}{x^2}$$

Separating variables and integrating

$$\int_0^1 dE = k_1 \int_{x_1}^{x_2} \frac{dx}{x^2}$$

$$E = k_1 \left[\frac{1}{x_2} - \frac{1}{x_1} \right]$$

Where x_1 = average initial size of the material

x_2 = average final size of the material

E = energy per unit mass

k_1 = Rittingers constant

Rittingers law applies more to situations where fine grinding is required, where there is a much larger increase in surface area per unit mass of the material.

Kicks law ($n = 1$) if we set $n = 1$ then

$$\frac{dE}{dx} = \frac{k_2}{x}$$

Rearranging and integrating

$$\int_0^e dE = k_2 \int_{x_1}^{x_2} \frac{dx}{x}$$

Where K_2 is kicks constant, kicks law applies mostly to coarse grinding of solids, where there is a relatively small increase in surface area per unit mass of the material.

$$E = k_2 \ln \left(\frac{x_1}{x_2} \right)$$

Bonds law ($n = 3/2$) If n is set to $3/2$

$$\frac{dE}{dx} = \frac{k_3}{x^{3/2}}$$

Rearranging and integrating

$$\int_0^E dE = k_3 \int_{x_1}^{x_2} \frac{dx}{x^{\frac{3}{2}}}$$

$$E = 2k_3 \left[\frac{1}{\sqrt{x_2}} - \frac{1}{\sqrt{x_1}} \right]$$

Where k_3 is bonds constant, Bonds law applies to coarse, medium and fine grinding material

Moisture content and heat sensitivity of the food affect the extent of size reduction, the energy required and type of equipment to be selected. Moisture content significantly affects the degree of size reduction and the mechanism of breakdown of the food. Size reduction ratio can be used to estimate the extent of size reduction, it is computed as:

$$RR = \frac{\text{averagesize of feed}}{\text{averagesize of product}}$$

where RR is reduction ratio

Selection of Size Reduction Machines: In selection of size reduction machines the following factors must be considered:

Hardness of feed: Some products are harder than others. In selecting a size reduction machines it is important to know the mechanical strength of the product or feed. Such strength can be determined as the bio-yield strength or rupture strength of the product in either compression or impact. Once the strength is known it is possible to recommend high energy machines such as hammer mills for hard products and low strength machines such as burr mill for relatively soft product. Alternatively, the size reduction can be in the recycling mode, in which the size reduction is done many times.

Mechanical structure of feed: Every product has a mechanical structure which can be seen when the product is sectioned. Depending on how the grains or fibre are arranged, the product may be weak in impact but strong in compression. Such a product will be better reduced using an impact machine such as a hammer mill. On the other hand some products are weak in shear and therefore, shear machines should be used.

Moisture content: The hardness of any product increases as the moisture content decreases. In fact, in some cases the product has to be soaked for some hours to increase the moisture content before size reduction, in order to decrease the hardness.

Cost: Above all considerations is the cost of the equipment (both initial and running cost). The machine must be economically feasible for the user.

Temperature sensitivity of feed: for most size reduction machine there is temperature rise in the action zone. Products that contain oil will began to release oil at these points and also degradation of the product could occur. Thus the machine should be such that the temperature rise is not too high.

Size Reduction Equipments

Crushing rolls: Two heavy steel or wooden cylinders revolve towards each other. The materials to be crushed are nipped and pulled through the rolls, experiencing a compressive force which crushes them. The machines is powered by the tractor pto or an electric motor which drives the roll. The final size of the product is determined by the feed rate and clearance between the rolls, which is adjustable. The advantages of the machine include low power requirement, high throughput capacity, little flouring and dusting. However it can break down if foreign material enters the mill and it is not suitable for pulverizing feed. The theoretical capacity of the machine is estimated as

$$Q_{th} = 60\pi ND_r D_p L \quad \text{which is equal to} \quad Q_{th} = 60\pi ND_r D_p L \rho$$

Where Q_{th} = theoretical capacity m³/hr, kg/hr

N = is revolution per minute of rolls (rpm)

D_r = diameter of rolls

D_p = desired diameter of product

ρ = density of product kg/m³

L = length of rolls

The actual capacity is obtained by multiplying with an efficiency η which is usually between 65 and 75%.

Hammer mill: The hammer mill consists of a rotor carrying a collar that bears a number of hammers around its periphery which rotates inside a circular or rectangular rotor. A breaker plate is used to enhance comminution, while a screen is used to recycle material bigger than the required size of product. Size reduction is mainly due to impact force. The size of final product can be varied by varying rotor speed, feed rate, clearance between hammers and grinding plate, number and size of hammers and the size of the screen. The mill is good for hard crystalline solids, fibrous materials and is used extensively for poultry feed manufacture. The advantages include versatility and freedom from damage by foreign materials. However, the disadvantages of the mill are high power requirement and non uniform grinding.

Disc attrition mills: This consists of a set of two hard surfaced circular plates pressed together and rotating with relative motion. The material is reduced as it passes between the two plates. different size of feed is accomplished by varying the pressure on the plates using spring. Disc mills can be single disc, double disc and burr mills. In single disc mill feed passes between a high speed rotating grooved disc and the stationary casing of the mill. Intense shearing action result in comminution of the feed. In double disc mill the casing contain two rotating discs, rotating in opposite directions giving a greater degree of shear. Such attrition mills are widely used in cereal preparation, corn and rice milling. The burr mill is an older type of attrition mill, originally used in floor milling. Two circular stones are mounted on a vertical axis. The upper stone which is often fixed has a feed entry port while the lower stone rotates. Feed material passes to the gap between the upper and the lower stone. In some modes both stones rotate in opposite direction. Such mills are still in use in food industry and different variations of the mill exist.

Tumbling mills: it is extensively used for fine grinding and can be ball and roll mill. In the ball mill both shearing and impact forces are utilized in size reduction. The unit consists of a horizontal slow speed rotating cylinder containing a charge of steel balls. As the cylinder

rotates balls are lifted up the side of the cylinder and drop on the material being comminuted, which fills the void space between the balls. The balls also tumble over each other, exerting a shearing action on the feed material. This combination of impact and shearing forces brings about a very effective size reduction. Ball sizes are usually in the range of 25 to 150mm. Small balls give more point contact while larger balls give greater impact.

Sieve analysis: When grinding products to fine flour, the effectiveness of the size reduction can be evaluated using sieve analysis. Sieve analysis is carried out using a laboratory sieve. This is a set of sieves with successively decreasing opening in a standard screen series. Each sieve in the set has a mesh number which is the number of the apparatus per linear inch. The grinded material is loaded on the top most sieve and sieves are shaken using sieve shaker. The material retained on each successive sieve is collected and weighed. Then Fineness Modulus (FM), Uniformity Index (UI) and average size of the particle is calculated as shown below:

Fineness modulus is calculated as:

$$\text{fineness modulus (FM)} = \sum \frac{\text{weight of material retained on each sieve} \times \text{mesh}}{100}$$

Uniformity Index gives the relative proportion of coarse, medium and fine grinding. It is calculated by adding the % material retained in each region and dividing by ten.

Average Size of particle d is calculated as:

$$d = \sum \frac{\text{weight of material retained on each sieve} \times \text{mesh size}}{\text{Total weight of material}}$$

Mixing

Mixing is an operation in which two or more components are interspersed in space with one another or an operation which tends to remove non-uniformity in the properties (colour, temperature, composition etc..) of a material in bulk. Mixing operations in the food industry involves solid, liquid and gaseous phases and mixers are frequently classified on the basis of the nature of the phase involved.

Theory of Solid Mixing: In contrast with liquid and viscous mixing it is not possible to achieve a completely uniform mixture of dry powders or particulate solids. The degree of mixing that is achieved depends on:

- ◇ The relative particle size, shape, and density of each component
- ◇ The efficiency of a particular mixer for those components
- ◇ The tendency of the material to aggregate and
- ◇ The moisture content, surface characteristics and flow characteristics of each component

During mixing operation, differences in the properties of the component cause un-mixing of the component parts. The uniformity of the final product achieved depends on the

equilibrium achieved between the mechanism of mixing and un-mixing. If a two component mixture is sampled at the start of mixing, most samples will consist entirely of one of the components. As mixing proceeds, the components of each sample becomes more uniform and approach the average composition of the mixture. The change in composition can be determined by calculating the standard deviation of the each fraction in successive samples:

$$\sigma_m = \sqrt{\frac{1}{n-1} \sum (x - \bar{x})^2}$$
 Where σ_m is the standard deviation, n the number of samples, x the concentration of the component in each sample and \bar{x} the mean concentration of samples. Low standard deviations are found as the uniformity of the mixture is increases.

A number of mixing indices are available to monitor the extent of mixing and compare alternative types of equipment.

$$M_1 = \frac{\sigma_m - \sigma_\infty}{\sigma_0 - \sigma_\infty}$$

$$M_2 = \frac{\log \sigma_m - \log \sigma_\infty}{\log \sigma_0 - \log \sigma_\infty}$$
 where σ_∞ is the SD of the perfectly mixed sample, σ_0 is the SD the sample at the start of the mixing

$$M_3 = \frac{\sigma_m^2 - \sigma_\infty^2}{\sigma_0^2 - \sigma_\infty^2}$$

σ_0 is computed using:

$$\sigma_0 = \sqrt{V_1(1-V_1)}$$
 where V_1 is the average fractional volume or mass of a component in the mixture

The mixing index is related to the mixing time using:

$$\ln M = -Kt_m$$
 where K is the mixing rate constant which varies with the type of mixer and the nature of component and t_m is mixing time.

Equipment

Mixers are classified into types that are suitable for

- ◇ Low and medium viscosity liquids
- ◇ High viscosity liquids
- ◇ Dry powders and particulate solids

Low and medium viscosity liquids: examples of low and medium viscosity mixing are blending of oils in the manufacture of margarine, cooking fats, diluting concentrated solutions of fruit squashes etc.. The most commonly used mixer is the mechanically agitated impeller mixer. It consists of one or more impellers fixed to a rotating shaft which creates currents within the liquid. Three types of agitators are generally used, these are:

- ◇ *Paddle agitator:* consists of a flat blade fixed to a rotating shaft. The shaft is usually mounted centrally in the vessel and rotates at a speed of 20 – 150 rpm

- ◇ *Turbine agitator* consists of an impeller with more than four blades on the same base and fixed to a rotating shaft. Generally smaller than the paddle agitator, measuring 30 – 50 % of the vessel diameter. It rotates at a speed of 30 – 50 rpm
- ◇ *Propeller agitator* consists of short bladed impellers usually measuring less than ¼ of the vessel diameter rotating at high speed. More than 500 rpm

High viscosity liquids: the mixing of materials of high consistency is a common practice in food industry. Some examples are dough and batter mixing in bread cake and biscuits, meat and fish pastes, creams and dairy products, chocolate products etc.. The objective here is not just to obtain a uniform mixture however to subject the material to a particular type of mechanical action to obtain a product with a particular physical characteristic. In many cases during the mixing change occur in the properties of the product. Mixers for high viscosity liquids can be:

- ◇ *Pan mixers* it could be stationary or rotating pan. In a stationary pan mixer, mixing elements move in a plenary path. Visiting all parts of the stationary mixing pan. In a rotating pan type, the mixing vessel is mounted on a rotating turntable. The mixing element also rotate but in one position and are located near the pan wall. Mixing element vary in design depending on the duty.
- ◇ *Horizontal through mixers:* These consists of a pair of heavy blades rotating on horizontal axis in a through. The blades rotate at different speed, towards each other at the top of their cycle and may follow tangential or interlocking path. The material is drawn down, kneaded and sheared between the blades.
- ◇ *Continuous Paste Mixers:* Wide varieties of devices are used to mix and knead viscous materials continuously. A common principal is to force the material through a series of obstruction by means of single or twin screw conveyors. The material is kneaded and sheared between the screws and the walls and further acted on mechanically by being forced through the obstructions.

Dry powders and particulate solids: solid mixing is generally arises from one or more of the three mechanisms of convection, diffusion and shear.

- ◇ Convection is transfer of masses or groups of particles from one location in the mixer to another
- ◇ Diffusion is the transfer of individual particles from one location to another arising from the distribution of particles over a freshly developed surface
- ◇ Shear is setting up of a slipping planes within the mass, also resulting in mixing of groups of particles

All the three mechanism may be employed in the mixing mechanism; a particular type may predominate in a specific type of mixer. Examples of dry mixing include; blending of grains prior to mixing, blending of flours and incorporation of additives, dry soup mixes, dry cake mixes, incorporation of additives in dry products, coffee mixes. Some examples are:

- ◇ *Tumbler mixers:* It operates by tumbling the mass of solids inside a revolving vessel. These vessels take various forms. They may be filled with baffles or stays to reputedly redirect the movement of groups of the particle and so improve the

performance of the mixer. Some have separately driven internal rotating devices to help break up agglomerates. The shells rotate at speeds up to 100rpm i.e. about half the critical speed of the mixer. Its capacity is normally 50 – 60 % of the internal volume.

- ◇ *Horizontal through mixers:* Consists of semi-cylindrical horizontal vessels (open or close) in which one or more rotating devices are located. For simple operations single or twine screw conveyors are adequate and one passage through such a system may suffice. For more demanding duties a ribbon mixer may be used. In a ribbon mixer, two counteracting ribbons are mounted on the same shaft. One moves the solids slowly in one direction while the other moves it quickly in the opposite direction. There is a resultant movement of the solids in one direction and so the system can be used as a continuous mixer.
- ◇ *Vertical screw mixers:* A rotating screw located in a cylindrical cone shaped vessel fixed either centrally in the vessel or it may rotate or orbit around the central axis of the vessel near the wall. The latter arrangement is more effective and stagnant layers near the wall are eliminated. Vertical screw mixers are quick and quite efficient and particularly useful for mixing small quantities of additives into large masses of material

Mechanical Separation

There are basically three unit operations for the mechanical or physical separation of food components. These are centrifugation, filtration and expression.

Centrifugation: is the separation of immiscible liquids or solids from liquids by the application of centrifugal force. Centrifugal force is generated when materials are rotated, the size of the force depends on the radius and speed of rotation and the mass (or density) of the centrifuged material. In the separation of two liquids the denser liquid moves to the bowl wall and the lighter liquid is displaced to the inner wall. The thickness of the layers is determined by the density of the liquids, the pressure difference across the layers and the speed of rotation. The boundary region between the liquids at a given centrifuge speed forms at a radius r_n where the hydrostatic pressure of the two layers is equal. This is termed the neutral zone, and is important in determining the position of the feed and discharge pipes. It is found using:

$$r_n^2 = \frac{\rho_A r_A^2 - \rho_B r_B^2}{\rho_A - \rho_B}$$

Where ρ (kg/m^{-3}) is the density and r (m) the radius. The subscript A and B refer to the dense and light liquid respectively.

If the purpose is to remove light liquid from a mass of heavier liquid (separation of cream from milk), the residence time in the outer layer exceeds that in the inner layer. This is achieved by reducing the radius of the outer layer, and hence by reducing the radius of the

neutral zone. If a dense liquid is to be separated from mass of lighter liquid (separation of water from oil), the radius of the outer layer (and the neutral zone) is increased.

Centrifuge can be used for:

- ◇ Separation of immiscible liquids
- ◇ Clarification of liquids by removal of small amount of solids (centrifugal clarification)
- ◇ Removal of solids (de-sludging or dewatering centrifuges)

Filtration: is used to clarify liquids by removal of small amounts of solid particles (beverages, oils, syrup) or to separate liquids from the solid part of a food (fruit juice).

The rate of filtration is expressed as:

$$\text{Rate of filtration} = \frac{\text{driving force}}{\text{resistance to flow}}$$

Driving force is usually the pressure difference across the filter while resistance to flow is the filter medium and the cake accumulated on the filter medium.

Filtration equipment can be:

- Gravity filtration
- Pressure filtration
- Vacuum filtration

Expression: the main applications of expression are in the extraction of oils and juices. It is frequently combined with size reduction to maximize yield. Components are extracted from plant materials either for direct consumption (fruit Juice) or for use in subsequent processing (sugar and vegetable oils). These materials are located within the cell structure of the plant and it is necessary to disrupt the cells in order to release them. Factors that influence the yield of liquid from a press includes:

1. the maturity and growth condition of the raw material
2. the extent of disruption of the cell structure
3. the resistance of the solid to mechanical deformation
4. the rate of increase in pressure
5. the time of pressing
6. the maximum pressure applied
7. the thickness of the pressed solids
8. the temperature of solids and liquid and
9. the viscosity of the expressed liquid

Press can be a batch press and continuous press. Batch press can be:

The tank press and

The hydraulic ram press

While continuous press can be

Screw press and (fruit processing and oil extraction)

Roller press (sugar cane processing)

Processing by Application of Heat

Heat treatment is one of the most important methods used in food processing, not only because of the desired effects on eating quality (many foods are consumed in cooked form) but also because of the preservative effects on foods by the destruction of enzyme and microbiological activity, insects and parasites. Other advantages of heat processing are:

- destruction of anti nutritional components of foods (eg. trypsin inhibitors in legumes)
- improvement in availability of some nutrients (improve digestibility of proteins, gelatinization of starch etc)
- relatively simple control of processing conditions

Generally high temperature and longer periods of heating produce greater destruction of micro organism and enzymes. High temperature and low time result in extension of shelf life and greater retention of sensory and nutritive properties of foods.

Heat processing using steam or water.

Blanching: It is used to destroy enzyme activities in vegetable and some fruits, prior to further processing. As such it is not intended as the sole method of preservation but a pre treatment which is normally carried out between the preparation of the material and later operation. Blanching reduces the numbers of contaminating micro organisms on the surface of foods and hence assists in subsequent preservation operations. It also softens vegetable tissues to facilitate filling into containers.

Blanching is usually combined with peeling and cleaning of food. Blanching is a process in which food is heated rapidly to a preset temperature, held for a preset time and then cooled rapidly to near ambient temperature. The blanching time depend on

- the type of fruit or vegetable
- the size of the piece of food
- the blanching temperature and
- method of heating

The major problem in blanching is ensuring uniform heat treatment and controlling blanching lossess

Equipment

The two most widespread commercial methods of blanching involve passing food through an atmosphere of saturated steam or a bath of hot water.

Steam blencher consists of a mesh conveyor belt that carries food through a steam atmosphere of low pressure (150kNm^{-2}). The residence time of the food is controlled by the speed of the conveyor. Steam blanching results in higher nutrient retention provided that cooling is by cold air or cold water spray. Cooling with running water substantially increases leaching losses.

In hot water blanching (immersion blanching) food is suspended in hot water ($75 - 100^{\circ}\text{C}$) for a specified time and is removed to dewatering and cooling section). Large losses of water soluble components including vitamins occur in hot water blanching. However, it has a lower capital cost and better energy efficiency compare to steam blanching.

Pasteurisation: It is a relatively mild heat treatment, usually performed below 100°C which is used to extend the shelf life of foods for several days (milk) or several months (bottled fruit). It preserves foods by inactivation of enzymes and by destruction of relatively heat

sensitive micro organisms but causes minimal changes in the sensory characteristics or nutritive value of food.

The amount of heat requires to raise the temperature of liquid during pasteurisation is computed as: $Q = mc (\theta_A - \theta_B)$

Where Q (W) rate of heat transfer, m (kg/s) the mass flow rate, c (kJ/kg^oC) the specific heat capacity and θ_A & θ_B is the temperature change.

Equipment:

Pasteurization can be of packaged foods or unpackaged liquids. Some liquid foods (beers, fruit juice) are pasteurised after filling in to containers. Hot water is normally used if the food is packaged in glass to reduce the risk of thermal shock to the container. Metal or plastic containers are processed using steam air mixture or hot water. After pasteurisation the food is cooled to about 40°C. Hot water pasteurisation can be batch or continuous in operation. In batch operation crates of packaged foods are heated to a preset temperature and held for a required length of time and then cooled in a bath of cold water. The continuous pasteurizer consists of a long narrow trough fitted with a conveyor belt to carry containers through heating and cooling stages.

Unpackaged liquids are pasteurised using heat exchangers, such as plate heat exchanger. Plate heat exchanger consists of thin vertical stainless steel plates held tightly together in a metal frame. The plates form parallel channels, and liquid food and heating medium are pumped through alternate channels, usually in counter current flow pattern open.

Heat Sterilization: is the unit operation in which foods are heated at a sufficiently high temperature and held for a sufficiently long time to destroy microbial and enzyme activity. As a result sterilized foods have a shelf life in excess of six months. The severe heat treatment during sterilization produces substantial changes in nutritional and sensory qualities of foods. Damage to nutrient and sensory components by either reducing the time of processing in containers or processing foods before packaging (aseptic processing). In aseptic processing both processing and packaging food takes place in a sterile environment. Sterilization can be in container sterilization or ultrahigh-temperature processes (UHT).

In container sterilization: in this case the food is packaged in to a container before it is sterilized. The length of time required to sterilize a packaged food is influenced by

- The heat resistance of micro organisms or enzymes likely to be present in the food,
- The heating condition
- The pH of the food, in low acid foods (pH>4.5) the main purpose is destruction of photogenic bacteria while in high acid foods the purpose is destruction of spoilage micro-organism or enzyme inactivation
- The size of the container
- The physical state of the food

In in-container sterilization heat is transferred from steam or pressured water through the container and into the food. Factors that influence the rate of heat penetration into the food are:

- Type of product: liquid foods (peas in brine) in which natural convection current established heat faster than solid foods (meat paste, corned beef) in which heat is

transferred by conduction. The low thermal conductivity of foods is the major limitation to heat transfer in conduction heating foods

- Size of container: Heat penetration to the centre is faster in small containers
- Agitation of the container: end over end agitation or axial agitation increases the effectiveness of natural convection currents in liquid and semi solid foods
- Temperature of the retort: high temperature differences between the food and the heating medium causes faster heat penetration
- Shape of the container: tall containers promote convection currents in convection heating
- Type of the container: heat penetration is faster through metal than through glass or plastics owing to differences in thermal conductivity.

Drying

When the moisture content of a product is reduced below a certain limit, all metabolic activities cease and micro-organisms cannot survive. Such a product then can be stored. The process of moisture removal to the safe limit is known as drying. Drying is essentially a heat and mass transfer process.

Drying Methods:

Depending on the mode of heat transfer there are four major methods of drying: conduction, convection radiation and freeze drying.

Conduction: Some dryers operate by subjecting the product to heat by direct contact with a heated surface. In this case, the dryer can be a pan or some other container in which the product is kept. Heat is supplied below the pan. To avoid burning, such dryers are equipped with stirrer for turning the product.

Convection: air is heated and forced through the product which is usually enclosed in a container such as a storage bin, silo, drying chamber, conventional oven

Radiation: Drying is achieved by the application of energy from a radiating source to the product. Microwave ovens and solar energy dryers fall in this category.

Freeze dryers: In this method, moisture in the product is frozen by refrigeration. It is then sublimed into vapour by the application of heat under low pressure.

In practice the four methods are combined in the design of dryers. The different types of dryers available can be grouped into three: namely batch dryer, deep dryers and continuous dryers.

Batch dryer:

In batch drying system, the material is dried in a relatively shallow container or in trays and the drying air is allowed to pass through the product. The air which has collected some moisture is then allowed to escape through an exhaust. The drying is continued until the batch is dried and is removed to give way for another batch.

Deep bed dryer: Material is stalked into a relatively deep bed such as a silo. At the base are located a fan a blower a heater and a perforated floor. Heated air is forced through the product and is allowed to escape from the top. Because of the relatively high depth involved, drying is not uniform. Rather at any point in time there is a dry zone, a drying zone and a wet zone. This is caused by moisture migration as air moves through the drying system. The air could be introduced from the false floor below or it could a cross flow system.

Continuous flow dryer: For more uniform drying, the continuous flow dryer is used. Here both the drying air and grain are in motion. It could a counter flow or concurrent flow system. In concurrent flow both the grain and air flow in the same direction. In counter flow they move in opposite direction.

Operation of dryers

Beside the structure used in holding the grain, the machinery used in drying includes fans, heaters loading and unloading equipment and conveyors. Fans are used to force the heated air through the column of material to be dried. Two types of fans are generally used, centrifugal and axial flow fans. In centrifugal fan air is drawn into the centre of the fan and then forced out by the centrifugal action. They are relatively quiet, have high efficiency and consume very low power. Axial flow fans pass air parallel to their drive shaft. They are less expensive, more compact and noisier than centrifugal fans.

The efficiency of a fan can be estimated as follows;

$$\eta = \frac{P_{out}}{P_{in}} \quad \text{where } \eta = \text{efficiency (\%)} \quad P_{in} = \text{input power, } P_{out} = \text{output power in watts}$$

The power output can be obtained by using the flow rate of the drying air as: $P_{out} = V\rho H$

Where V is air flow rate, m³/s

H is pressure head, m of water

ρ is density of air kg/m³

Control are very important in using drying machinery, such controls are accomplished by the use of thermostat, humidistat and moisture meters. Thermostats are used for measuring temperature and can be used to turn off the heater. Humidistat are used to for relative humidity measurement and moisture meters are used for control of moisture content. The performance of drying machines is expressed in terms of rate of drying. The rate of moisture removal is estimated as

$$R = \frac{h_c A}{\lambda} (\theta_a - \theta_s) \quad \text{where R is rate of moisture removal (kg/s), } h_c \text{ (w/m}^2\text{°K) the surface heat transfer coefficient for convective heating, A (m}^2\text{) the surface area available for drying, } \theta_a \text{ average dry bulb temperature of drying } \theta_s \text{ average wet bulb temperature of drying air, } \lambda \text{ (J/kg) latent heat of evaporation at the wet bulb temperature.}$$

The most important control parameter in drying is the moisture of the product dried. In a typical drying operation a target is normally set. At intervals during drying the moisture can

be determined. The drying goes on until the set moisture content is reached. Moisture meters can be used for this purpose however they must be calibrated using the gravimetric method of moisture determination. This involves the drying of a sample of material in an oven at 105 °C (for grain) for 24 hours and determining the mc as follows

$$MC_{wb} = \left[\frac{M_1 - M_2}{M_1} \right] \times 100$$

$$MC_{db} = \left[\frac{M_1 - M_2}{M_2} \right] \times 100$$

where M_1 mass of wet sample; M_2 mass of dry sample; MC_{wb} moisture content wet basis; MC_{db} moisture content dry basis.

The mass of water to be removed from a product to be dried corresponds to the initial and final moisture content of the product. If a product is to be dried from initial moisture content of m_i to final moisture content of m_f the amount of water to be removed is computed as:

$$M_w = \frac{(m_i - m_f)M_i}{(100 - m_f)} \quad \text{or} \quad M_w = \frac{(m_i - m_f)M_f}{(100 - m_i)}$$

where M_w is the amount of water to be removed and M_i and M_f is the initial and final weight of the product.

The moisture pickup rate is computed as:

$$V_{ap} = \frac{M_w}{T_d}$$

where T_d is ideal drying time for a given product and V_{ap} is the moisture pickup rate.

Psychrometry and Psychrometric chart:

In the analysis of drying systems, where air is used, it is a frequent requirement to determine the thermodynamic properties of the air or mixture of air used in the drying process. This process is referred as Psychometrics. Some of the important properties are defined below:

Enthalpy: This is the heat content of moist air per unit weight of dry air at a certain temperature

Vapour pressure: this is the partial pressure exerted by water vapour molecules in moist air

Relative humidity: This is the ratio of the vapour pressure of water in to the vapour pressure in saturated air at the same temperature (%).

Specific volume: this is the volume per unit weight of dry air the unit is m³/kg

Humidity ratio: this is the weight of water vapour per unit weight of dry air in g/kg or kg/kg

Dew point temperature: this is the temperature at which condensation occurs when air is cooled at constant atmospheric pressure °C

Wet bulb temperature: This is the temperature of moist air indicated by a thermosometer whose sensing bulb is covered by a wet wick over which air is passed at a certain reference speed.

Psychrometric chart: The relationship between these properties are complex and are at best empirical in nature. To simplify analysis psychrometric chart has been developed to show the relationships graphically. Thus once any two properties are known the third one can be found from the graph. The application of psychrometric chart is:

- For any situation once the values of two properties are given values of the rest can be found from the chart.

- In heating and cooling the values of the heated or cooled air can be found from the chart
- When moist air is used for drying the properties of the air after drying can be obtained from the chart
- The drying potential of any moist air can be obtained from the chart
- When two air systems of different properties are mixed the property of the mixed air can be obtained from the chart.

When two air with different properties mix, the heat balance of the system is:

$$m_{a1}h_1 + m_{a2}h_2 = m_{a3}h_3$$

The mass balance of the dry air gives: $m_{a1} + m_{a2} = m_{a3}$

The mass balance for moisture is : $m_{a1}w_1 + m_{a2}w_2 = m_{a3}w_3$

From the above equation:

$$\frac{m_{a1}}{m_{a2}} = \frac{h_2 - h_3}{h_3 - h_1} = \frac{w_2 - w_3}{w_3 - w_1}$$

$$h = cT$$

substituting for h

$$\frac{C_a T_2 - C_a T_3}{C_a T_3 - C_a T_1} = \frac{w_2 - w_3}{w_3 - w_1} \quad \text{Then the resulting mixture can be calculated as:}$$

$$T_3 = \frac{T_2(w_3 - w_1) + (w_2 - w_3)}{w_2 - w_1} \quad \text{Where: } T \text{ is temperature, } C_a \text{ is specific heat of air; } w$$

humidity ratio; h is enthalpy, m_a is mass of air;

When heated air is used for drying the amount of moisture extracted by a cubic meter of air can be computed as follows:

$$q_w = \rho_{air}(h_a - h_e)\eta_d \quad \text{where: } h_a \text{ is average absolute humidity of out coming air over the total drying period time in g/kg of drying air, } h_e \text{ is absolute humidity of air entering the drying chamber in g/kg of drying air, } \eta_d \text{ is the drying efficiency, } \rho_{air} \text{ density of air}$$

Freeze drying: In hot air or contact drying the drying heat causes a loss of sensory and nutritional qualities. In freeze drying and freeze concentration a similar preservation effect is achieved by reduction in water activity without heating the food. Nutritional and sensory qualities are consequently better retained. However, freeze drying and concentration operations are slower than dehydration and drying. Energy cost of refrigeration and production of partial vacuum make the operation very expensive. Freeze drying is used to dry for expensive foods which have delicate aromas or textures (coffee, herbs, spices, fruit juices, meat, seafood's and vegetables). Freeze drying is achieved by drying frozen food at a low temperature and pressure. The first stage in freeze drying is to freeze the food. The type of freezing equipment depends on the nature of the food. Small pieces of foods are frozen rapidly to produce small ice crystals and to reduce damage to the cell structure of the food. In liquid foods, slow freezing is used to form an ice crystal.

If water vapour pressure of food is held below 610.5 Pa and the water is frozen, when the food is heated the solid ice sublimates directly to vapour without melting. Water vapour is continuously removed from food by keeping the pressure in the freeze drier cabinet below the vapour pressure at the surface of the ice, removing vapour with a vacuum pump and condensing it on refrigeration coils. The latent heat of sublimation is conducted through the food to the sublimation front. Water vapour travels out of the food through channels formed by the sublimed ice and is removed. Foods are dried in two stages; first by sublimation to approximately 15% mcwb and then by evaporative drying of unfrozen water to 2% mcwb. Freeze dried products are generally porous with lower density than the original food. Advantages of freeze drying include: minimal solute movement, minimal structural change or shrinkage, rapid complete dehydration, retention of nutrient, odour, flavour and colour and it is successful for most foods. Freeze drying generally costs approximately four times the conventional drying.

Mechanism, Types, Detection and Evaluation of Product Damage

One by product of mechanization in production and handling of agricultural products is mechanical damage to the product during harvesting and handling as well as on farm and off farm processing. Some varieties of crops are more susceptible to mechanical damage than others. This offers an opportunity to plant breeders to develop new varieties of products which would withstand the mechanical forces imposed on during mechanical handling. Eg. New tomato varieties.

Product damage on seeds and grain: In mechanical handling of seeds and grains most of the damage occurs in the threshing as well as mechanical conveying by screw conveyors and other equipments. Damage to grain would affect their milling quality, result in greater losses in sifting and would lower the germination capacity and seeding development. The damage resulting from impact forces is referred as cracking which may vary from complete splitting of the kernels to small hairline cracks invisible to naked eye. Even small cracks in the seed coat may allow soil bacteria to enter the seed and destroy the food supply before a plant is established. Factors affecting grain damage are crop variety, stage of maturity, storage and drying condition and moisture content of the seed. In addition design and operating characteristics of the machine which subjects the kernels to certain impact forces at certain rates for certain duration also influence grain damage.

Product damage in Fruits and vegetables: In fruits and vegetables the mechanical damage occurs during mechanical harvesting, handling and transportation. The major damage is bruising of tissues due to impact forces. This generally reduces the market quality of the product and allows entry point to pathogens. Transit losses in fruits due to vibration have been reported to be above 10 percent. Internal bruising of fruits due to impact and vibration does not extend to the surface. After a period of storage the bruised flesh begins to dry out and becomes corky. Not been visible the damaged fruits cannot be sorted out before processing, this reduces the quality of processed product.

Causes of mechanical damage: mechanical causes in agricultural products are due to either external forces under static and dynamic conditions or internal forces. Example of mechanical damage due to external forces are mechanical injuries in fruit and vegetables, seeds and grain, egg shell etc.. Mechanical damage due to internal forces can be the result of physical changes such as variations in temperature and moisture content or chemical or biological changes. Examples are stress cracks in corn and rice; thermal chocking of egg shells, skin cracks in fruits and vegetables (tomato, sweet potato) in intact agricultural products failure is usually manifested through rupture in the internal or external cellular structure of the material.

Biological and chemical reactions following mechanical damage: The course of all infectious diseases consists of infection, incubation, and then healing and rehabilitation if the infected part is survived. In the absence of a wound (puncture or crack) successful infection of the host organism seldom occurs. There are certain types of fungi which secrete toxins that penetrate, disrupt and kill the host cells opening the way for penetration of the fungus. Therefore, it is important to prevent injuries that expose the susceptible internal tissues of a plant or animal material. The degree of infection of mechanically damaged products depends on the nature of the attacking fungi present and the resistance of the product to the invading organism after infection has occurred. In grains and fruits and vegetables breakages which are not necessarily visible externally provides a point of entry to pathogens. Mechanical injuries in the form of cutting, peeling and bruising which result in crushing of tissue in fresh fruit and vegetables under load produce a darkening of tissue called browning. There are two types of browning: Enzymatic browning which occurs when injured tissue is exposed to air and non enzymatic browning occurs in processed foods such as dried fruits.

Types of product damage: The following types of external damages are identified in Agricultural materials

- ◇ *Abrasion:* abrasive injury, usually occur in tubers. It may vary in severity from separation of the periderm or skin to removal of part or all of the pericyclic cortex. Skin abrasions are difficult to detect at time of harvest, but can readily be observed after storage for a week or long at low humidity's.
- ◇ *Bruising:* damage to plant tissue by external forces causing physical change in texture and/or eventual chemical alteration of color, flavor and texture. Bruising does not break the skin
- ◇ *Distortion:* a change in shape of an intact fruit or vegetable which is not characteristic for the variety
- ◇ *Crack:* a cleavage without complete separation of the parts
- ◇ *Cut:* Penetration or division by the sharp edge of an object
- ◇ *Puncture:* a small hole or wound on the surface of the fruit made by a pointed object or stem of other fruits
- ◇ *Shatter cracks:* One or more tortuous cracks radiating from a point of impact.
- ◇ *Skinning and feathering:* The separation of periderm from the plant part by scraping, rubbing, etc. Feathering means the same except the separated periderm is still attached to the un-separated periderm
- ◇ *Split:* division or separation into parts
- ◇ *Stem and tearing:* skin break caused by separation of stem
- ◇ *Swell-cracking:* cracking due to uptake of water by osmotic pressure

Detection and Evaluation of product Damage

Detection and Evaluation of mechanical damage, particularly if damage is invisible can be a problem requiring special technique and instrumentation. The usual methods of evaluation are primarily descriptive. For example mechanical injuries to fruits are given such descriptive terms as hail damage, stem puncture, cracks and bruise. There are also specific classifications which are crop specific. In addition to number and size, age of the bruise also affects the quality of the fruit. Older bruises have either darker colour which does not blanch out in the cooking processes or have developed into corkiness. Both these indicate non usable fruit flesh and must be removed before processing. The fruit variety and the type of process for which the product is being used also have bearing on evaluation of damage. In the absence of standard, mechanical damages are evaluated using purely subjective methods such as minor, moderate, major and severe damage or based on some physical measurements' such as volume of bruised tissue in fruit and vegetables, mean diameter of bruised area, depth and volume of bruised tissues. The volume of bruised may be calculated using the formula for segment of a sphere with measured values of maximum depth and width of bruises as given below : $V = \pi h / 24 (3d^2 + 4h^2)$ where h is maximum depth of bruise and d average diameter of bruise.

In many cases injury to commodity cannot be detected by subjective visual method. The invisible damage may cause either internal defects, such as black spot in fruit and vegetables, or damage to the embryo and lower the quality of the product as seed. In such cases other methods of testing can be used. These tests can be destructive (product is damaged) or non destructive (product is not damaged). Some of the test methods include:

X-ray method the method identifies black spots and colour changes due to damage done to fruit and vegetables.

Light transmittance method: measuring the amount of light absorbed, the higher the amount of light absorbed the higher the % damage.

Electrical Impedance: It can be used to determine the extent of injury to tissue due to frost and other means of damage. It is based on the fact that healthy tissues have resistance and capacitance causing impedance, while dead tissue has no capacitance. Thus the ratio of low frequency impedance to high frequency impedance measure with a wide range of bridge is an indication of the degree of injury to the plant tissue.

Germination test: this is the surest way for detecting percentage damage in seeds. However, it should be noted that other factors apart from mechanical damage affect viability of seeds also visually damaged seeds may not necessarily have damaged embryo.

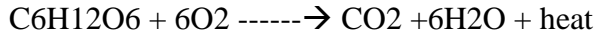
Bulk density method: this method can be used in some fruits to estimate damage. Bruising reduces resistance to compression of individual crop resulting in greater deformation and greater bulk density.

Assessing of mechanical damage to fruits and vegetables resulting from impact. A qualitative evaluation based on an arbitrary scale classifying damage in to skin damage, bruising damage, splitting etc is by estimating the energy consumed E_{ab} was presented by: $E_{ab} = (1 - e^2)WH$

Where e is coefficient of restitution W and H are respective weight and height of drop of the impacting fruit or vegetable.

Restitution coefficient is defined as the ratio of final to initial relative velocity component of the striking bodies in the direction normal to the contact surfaces. Denoted by e the ratio can be expressed as $e = V_2/V_1 = (h_2/h_1)^{1/2}$ Where V_2 and V_1 is the initial and final velocities and h_2 and h_1 donate height of rebound and height of drop in free fall.

Measuring the rate of respiration: Mthe rate of respiration by damaged tissues in fruit and vegetable wounding of plant tissue result in an increase in respiration rate. Respiration rate is expressed usually in terms of volume of CO_2 evolved per unit weight of product per unit time. The reaction equation for glucose sugar for example is



Respiratory CO_2 is measured by infrared gas analyzer (IRGA) which involves passing the exhaust air from the living tissue through an IRGA unit.

