LANDMARK UNIVERSITY, OMU-ARAN
DEPARTMENT OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

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

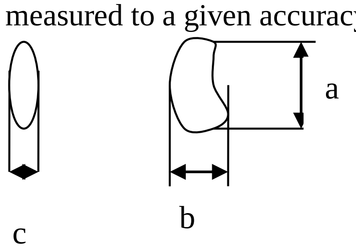
Properties and characteristics of agricultural materials in relation to their Processing and handling methods. Physical, mechanical, rheological, thermal, electrical and chemical properties. Introduction to agricultural product processing, Ambient temperature processing Materials cleaning, sorting and 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.

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

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

Aspect Ratio: Aspect ratio is computed as $Aspect\ ratio = \frac{Intermidiate\ diameter}{major\ diameter}$ 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 $\textit{slenderness ratio} = \frac{minor\ diameter}{major\ diameter}$

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

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

A_p = Largest projected area of object in natural rest position

A_c = Area of smallest circumscribing circle

Roundness can also be computed as:

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

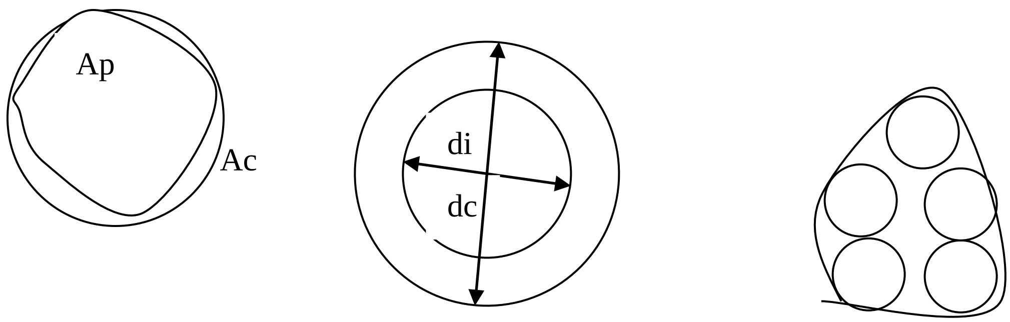
r = radius of curvature

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

dc is diameter of the smallest circumscribed circle

Sphericity is also defined based on axial dimensions as follows:

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

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:

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

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

$$specific\ gravity = \left[\frac{(W_a)object}{(W_a - W_w)both - (W_a - W_W)\sin\ker}\right]$$

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:

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

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:

$$Volume = 4/3\left(\pi a b^2\right)$$

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.

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

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:

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

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:

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

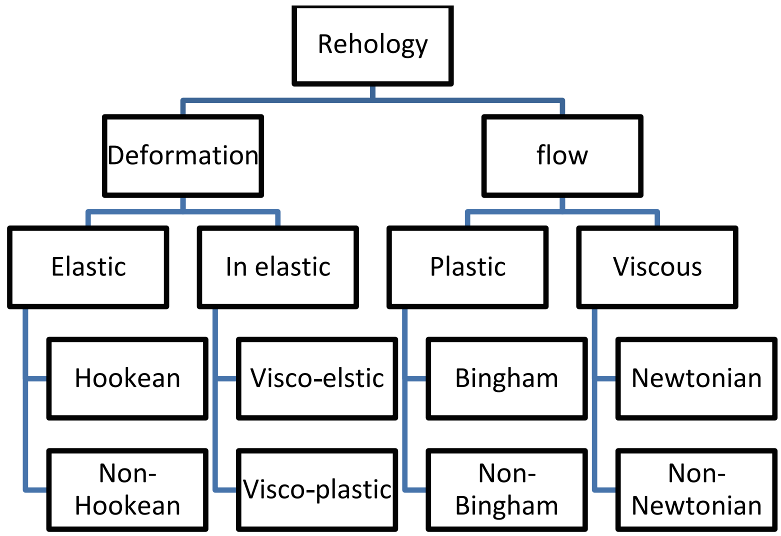
Moisture content on dry basis $MC_{db} = \frac{W_i - W_f}{W_f}$ where: W_i is the initial weight of the product before drying while W_f is the final weight of the product after drying. The wet base and dry base moisture content are related by the following equations:

$$MC_{wb} = MC_{db} / (1 + MC_{db})$$

$$MC_{db} = MC_{wb} / (1 - MC_{wb})$$

Mechanical Properties of Agricultural Products:

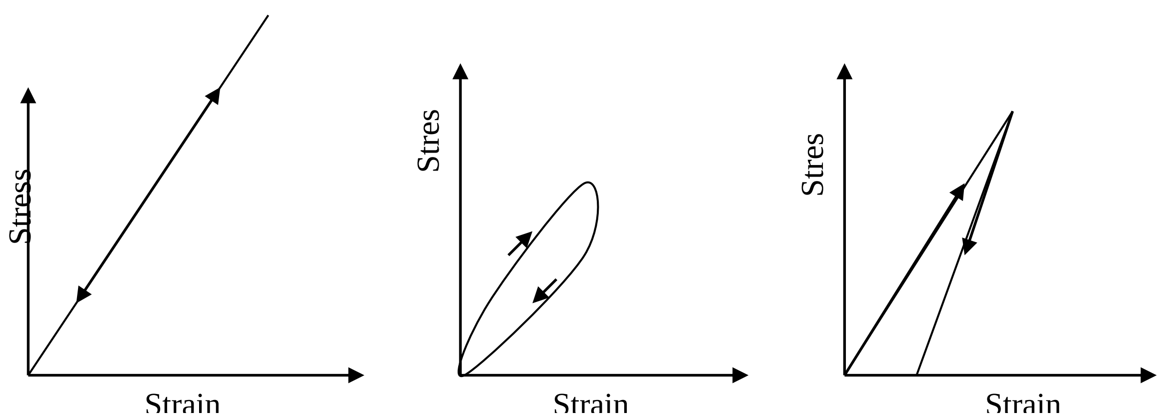
Mechanical property of agricultural product may be defined as those properties having to do with the behavior of the material under applied forces. Such properties include stress – strain behavior of material under static and dynamic loading, flow characteristics of material in air or in water. When 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.



Rehological 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 rehology 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.



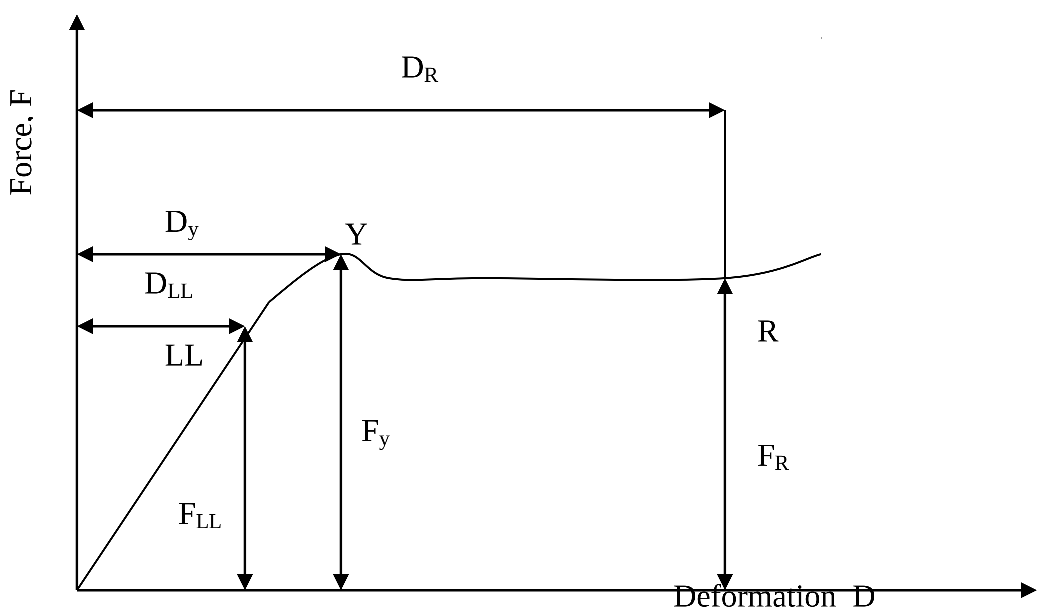
a b c

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 rehological 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 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 share or torsion test and is based on the original dimension of the cross section of 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 rapture 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 rapture 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 raptures under a load. In biological material rapture 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 rapture may occur in the early portion of the curve, while in a tough material rapture 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.

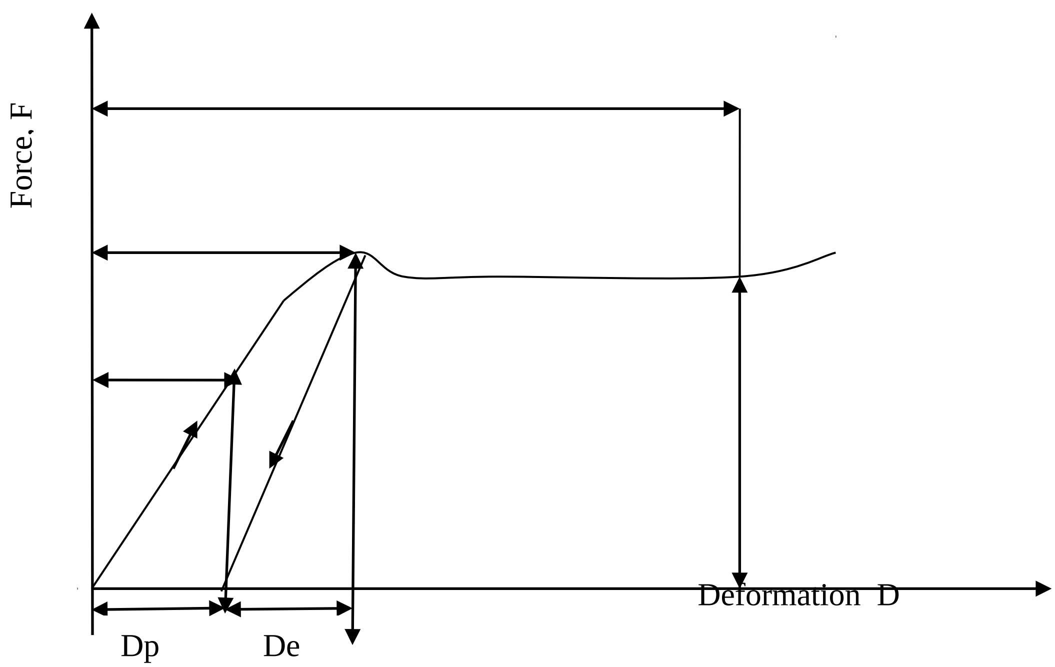
Modulus of elasticity or young's modulus the ratio of stress to corresponding strain below the proportional limit.

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

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

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.

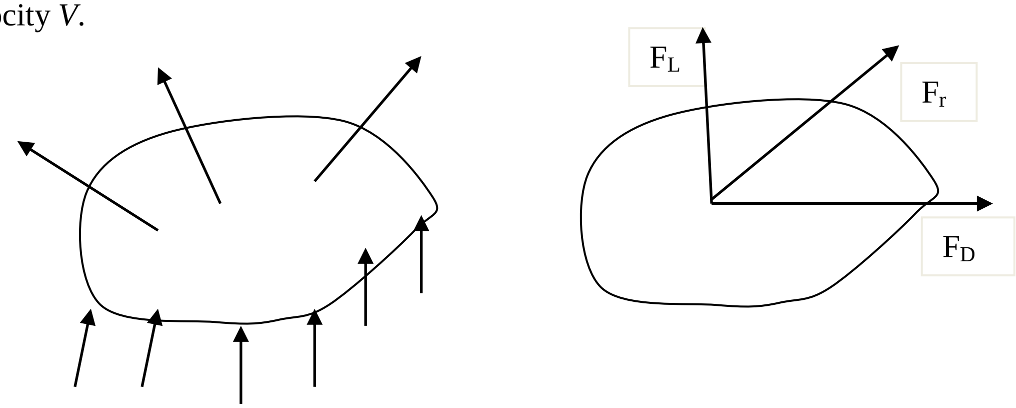


Degree of elasticity for loading – unloading curve D_e elastic or recoverable deformation; D_p plastic or residual deformation
Degree of elasticity is the ratio of elastic deformation to the sum of elastic and plastic deformation when a material is loaded to a certain load and then unloaded to zero load. Degree of elasticity is given as $D_e / (D_p + D_e)$
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 *Ap* 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:

$F_r = \frac{1}{2} C A_p \rho_f V^2$ *Where*: F_r is resistance or drag force
C overall drag coefficient
Ap 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: $C = \frac{1.328}{(\mathrm{Re})^{0.5}}$ while for turbulent flow it can be estimated as: $C = \frac{0.455}{(\log \mathrm{Re})^{2.58}}$ *Where*

Re is Reynolds Number and it is given as: $\mathrm{Re} = \frac{Vd\rho_f}{\eta}$ *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_p 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 fluids 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 between2130 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:

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

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

Where η is the viscosity of the fluid (Ns/m^2) or (Pas)

Assignment (CA 1) to be submitted on16/09/2016 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/m^3 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^oC is the flow turbulent or streamline? Viscosity of milk at 21^oC is $2.1x10^{-3}$ Pas and density is $1029kg/m^3$
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 $0.2m^3/s$ through a 20 cm diameter pipe compute the drag coefficient and the terminal velocity. Density and viscosity of air is 1.29 kg/m^3 and 1.91 x 10^{-5} Ns/m^{-2}
5) 100 g of grain was dried at 50^oC 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. Product 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^{o}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 x specific heat x ($T_2 - T_1$). 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^{o}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 (*Jm^{-1}s^{-1o}C^{-1}*):* This is the measure of materials 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 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 x ($h_2 - h_1$). 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 ($W/m^{2o}C$): 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 convicting medium temperature or the amount of hat 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 $h_s = k_f / x_f$ 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.

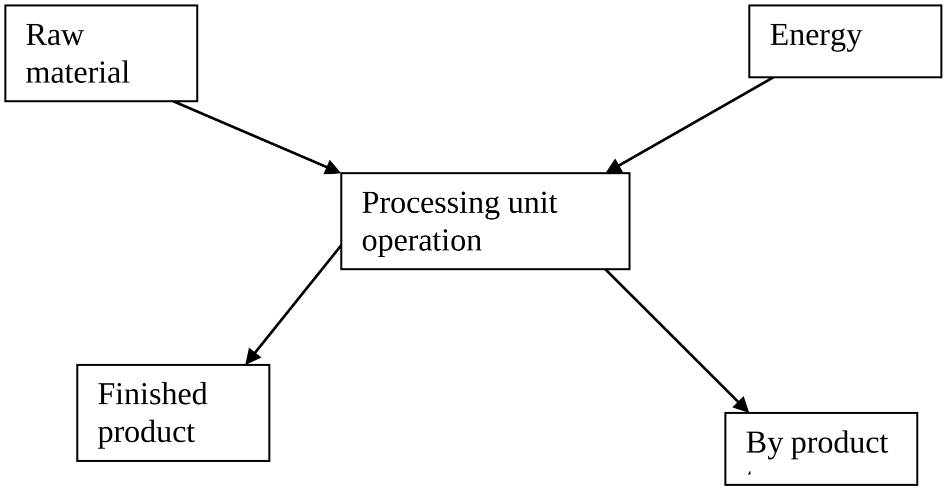


Figure 1. Processing of a raw material

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:

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

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

Shape and size sorting is the separation of food items in to 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 achieve 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^oC 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 is 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^oC. 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.

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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

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

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:

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

where *RR* is reduction ratio

- Example: granulated sugar with average size of 500 µm, is milled to powder sugar of 25µm using 12 hp motor. Will this motor be sufficient to reduce the sugar to 19 µm. 1hp = 745.7 W

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

$$Q_{th} = 60\pi N D_r D_p L \qquad \textit{which is equal to} \quad Q_{th} = 60\pi N D_r D_p L\rho$$

Where Q_{th} = theoretical capacity m^3/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/m^3

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 communition, 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:

$$fineness\ modulus\,(FM) = \sum \frac{weight\ of\ material\ retained\ on\ each\ sieve\ x\ mesh\ no}{100}$$

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:

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

Example: A sieve analysis of 200 g of powdered sugar showed the following result. Calculate: fineness modulus, average mean diameter and uniformity index

Sieve size (µm)	weight of material	mesh no
12.50	27.6	1
7.50	67.2	2
4.00	70.4	3
2.50	25.2	4
0.75	9.2	5

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:

$\sigma_m = \sqrt{\left[\frac{1}{n-1}\sum\left(x-\bar{x}^2\right)\right]}$ Where σ_m is the standard deviation, *n* the number of samples, *x* the concentration of the component in each sample and *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.

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

$$M_2 = \frac{\log\sigma_m - \log\sigma_\infty}{\log\sigma_0 - \log\sigma_\infty}$$

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

where σ_∞ is the SD of the perfectly mixed sample, σ_0 is the SD the sample at the start of the mixing

σ_0 is computed using:

$\sigma_0 = \sqrt{\left[V_1\left(1-V_1\right)\right]}$ 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.
Example: During the preparation of a dough, 800 g of sugar are mixed with 100 kg of flour. Ten 100g samples were taken after 1min, 5min and 10 min and analyzed for percentage sugar the result are as given below:

% after 1min	0.21	0.32	0.46	0.17	0.89	1.00	0.98	0.23	0.10	0.14
% after 5 min	0.85	0.80	0.62	0.78	0.75	0.39	0.84	0.96	0.58	0.47

% after 10 min	0.72	0.69	0.71	0.70	0.68	0.71	0.70	0.72	0.70	0.7

Calculate the mixing index for each mixing time assuming for perfect mixing 99.7% of sample will fall within σ_∞= 0.01%. plot the mixing index against time, calculate time required to get the perfect mixing with σ_∞= 0.01%.

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 diary 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 kneed 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. 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.

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 can be steam blanching or hot water blanching.

Pasteurisation: It is a relatively mild heat treatment, usually performed below 100^oC which is used to extend the shelf life of foods for several days (milk) or several months (bottled fruit). Pasteurization can be of packaged foods or unpackaged liquids. Some liquid foods (beers, fruit juice) are pasteurised after filing 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^oC. Unpackaged liquids are pasteurised using heat exchangers, such as plate heat exchanger.

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 is reduced either by 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.

Drying

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

Drying Methods:

Depending on the mode of heat and mass 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 fell 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.

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 bead dryer: Material is stalked into a relatively deep been 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 flaw dryer: For more uniform drying, the continuous flow dryer is used. Here both the drying air and grin 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 heated air 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 quite, 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.

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

$$R = \frac{h_c A}{\lambda}\left(\theta_a - \theta_s\right)$$

where R is rate of moisture removal (kg/s), hc (w/m^{2o}K) the surface heat transfer coefficient for convective heating, A (m^2) the surface area available for drying, θ_a average dry bulb temperature of drying θ_s average wet bulb temperature of drying air, λ (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.

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:

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

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:

$$V_{ap} = M_w / T_d$$

where Td is ideal drying time for a given product and Vap is the moisture pickup rate.

The quantity of energy required to vaporize one kg of water is called the latent heat of vaporization if it is from liquid or latent heat of sublimation if it is from solid. Latent heat depends on the absolute pressure. However, in calculating energy required for drying, the heat required to bring to boiling temperature must be added. This heat is called the specific heat capacity of the food. The specific heat capacity of a product is the amount of heat required to increase the temperature of 1 kg of the product by 1^{o}C.

Latent heat and specific heat of food stuff can be calculated if the percentage of water in the food is known. If the percentage is p then:

$$Specific heat = 4.19\,p/100 + 0.84(100 - p)/100 \ kJ/kg\,^oC \ above \quad freezing$$

$$= 2.1p/100 + 0.84(100 - p)/100 \ kJ/kg\,^oC \quad below freezing$$

$$Latent\ heat = 335\,p/100 \ kJ/kg$$

Example: 100 kg of food containing 80% of water is to be dried at 90^{o}C down to a moisture content of 10%. If the initial temperature of the food is 21^{o}C calculate the quantity of heat required, per unit weight of the original material for drying under atmospheric pressure. The latent heat of vaporization of water at 90°C and at standard atmospheric pressure is 2257kJ/kg. The specific heat capacity of the food is 3.8kJ/kg°C.

Psychometry and Psychometric 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 thermometer 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.

Example: If air at 50 °C and 10% RH is blown through a continuous dryer from which it emerges at a temperature of 35 °C. Estimate the quantity of water removed per kg of air passing and the volume of drying air required to remove 20 kg of water per h.

When heated air is used for drying the amount of moisture extracted by a cubic meter of air can be computed as follows:
$q_w = \rho_{air}(h_a - h_e)\eta_d$ where: q_w is amount of moisture extracted by the air (kg/m^3) *ha* is average absolute humidity of out coming air over the total drying period time in g/kg of drying air, *he* is absolute humidity of air entering the drying chamber in g/kg of drying air, η_d is the drying efficiency, ρ_{air} density of air (kg/m^3)

Freeze drying: In freeze drying and freeze concentration 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 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 sublimes 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.

Material Handling Methods in Processing and Storage

Efficient handling is the orginised movement of materials in the correct quantities, to and from the correct place, accomplished with a minimum of time, labour wastage and expenditure and with maximum safety. In processing industries large amount of materials in solid, semi liquid or liquid form is moved in to the industry, within the industry or out of the industry. A system approach applied to raw materials, ingredients, in-process stock and finished products creates optimum flows of materials, in the correct sequence throughout the production process and avoids bottlenecks or shortages. Movement of material in an industry includes but not limited to:

- Harvest and transportation of raw materials to store
- Movement of raw materials , semi processed foods and processed foods within the factory
- Collection and disposal of process waste
- Collection of packaged foods and movement to final product ware house
- Distribution to whole sellers and retailers
- Presentation of product for sale.

In a processing industry movement of materials may be achieved by:

1. Continuous method of handling eg.. conveyor, elevators
2. Unit loads product in bags, or packaged in cartons or creates or
3. Bulk handling, eg. Grain in bulk.

Advantages of efficient material handling techniques are:

- Savings of storage and operating space
- Better stock control
- Improved working conditions
- Improved product quality
- Lower risk of accidents
- Reduced processing time
- Lower cost of production
- Less wastage of materials and operating time

Storage Requirement of Agricultural Products.

Agricultural products are usually seasonal. Therefore for it to be available through the year it must be stored for a given period of time. Most farm produce begin to undergo deterioration as soon as they are harvested. The agents of spoilage include enzymes, environmental conditions (heat, moisture) insects and rodents, micro organisms and metabolism (respiration and transpiration). The main function of a food storage structure is to control the activities of these agents. In addition to food storage other items that need storage on the farm include; animal feed and fodder, fertilizer, milk machinery, supplies etc.. Therefore special care must be taken during storage. Storage is an important aspect of running a farm for a number of reasons as given below:

- To ensure steady supply of food throughout the year, since food harvest is seasonal
- To guarantee the availability of raw materials to feed the agro allied industries
- To keep planting material from generation to the other without loss of viability
- To stabilize food prices by stock pilling when food prices are low and releasing into the market when prices go up.
- To encourage farmers to produce more food since the excess of what they produce will not be lost

Storage requirement for grain and pulses: The quality factors to be preserved in grain storage depend on the requirements of the end user of the grain. Stored grain is subjected to the deleterious effects of grain pests, in particular to moulds, insects, and rodents. The degree of pest activity is a function of:

- the moisture content and temperature of the grain,
- the damage level of the grain,
- the foreign-material content of the grain,
- the type and hybrid of the grain, and
- the interstitial atmosphere around the grain (temperature and relative humidity).

In general, the lower the moisture content, the temperature, the damage level, and the foreign-material content of the grain, the longer it can be stored without being affected by one of the grain pests.

The most important factors to be considered during grain storage are moisture content of the grain, relative humidity and temperature of the storage environment. Agricultural products are hygroscopic, that is they have the tendency to exchange moisture with the storage atmosphere until equilibrium is reached. The moisture content of crops especially grains, oilseeds, etc. is required to be reduced to a minimum level known as 'safe level' before such crop can successfully be stored. The effect of relative humidity and temperature of the storage environment can be controlled by regular monitoring and ventilation of the store. In addition grains to be stored must well cleaned, devoid of broken grains and foreign materials.

Storage requirement for root and tuber crops: The storage loss for roots and tubers in developing countries vary from 5% to 100% depending on the crop, storage period and storage methods. The main causes of product loss in root and tuber storage are

- mechanical injury during harvesting and handling
- losses due to diseases, attacks on stored products by rodents or insects and
- Physiological losses.

Good agricultural practices before, during and after harvest can minimize losses due to the first two causes. However, physiological losses are as the result of respiration, loss of moisture (transpiration) and sprouting. Respiration, transpiration and sprouting is strongly affected by a number of **crop factors** and **environmental factors**. Because the end quality of a stored product is a direct result of the respiration activity, it is mandatory to have a proper management and control of these factors in order to optimize storage life. The most important **crop factors** are:

- *Species and Cultivars*
- *Moisture Content*
- *Surface and Volume Properties*
- *Stage of Development at Time of Harvest*
- *Wounding or mechanical damage*

While the **environmental factors** include:
Temperature
Relative humidity and
Gas composition
In root and tuber storage only sound tubers without any damage should be stored, damaged tubers should be cured before storage. The store should be clean and should not have access to rodents, there should be sufficient ventilation and should be constructed under a shed to reduce the effect of high temperature. Regular inspection of stored tubers is important to remove sprouts and rotted tubers, and to monitor the presence of rodents and other pests.