Topics covered:

- Unit operations of food processing viz. Cleaning, Grading, Sorting etc.
- Size reduction/Milling and its machineries for various unit operations.

By

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Unit Operations in Food Processing:

In food processing, chemical engineering and related fields, a unit operation is a basic step in a process. Unit operations involve a physical change or chemical transformation such as cleaning, grading, sorting, peeling, crystallization, evaporation, filtration, polymerization, isomerization, and other reactions. For example, in milk processing, homogenization, pasteurization, chilling, and packaging are each unit operations which are connected to create the overall process. A process may require many unit operations to obtain the desired product from the starting materials, or feed-stocks.

Cleaning

- Cleaning is the unit operation in which contaminating materials are removed from the food and separated to leave the surface of the food in a suitable condition for further processing.
- This may be accomplished by washing, screening, hand picking etc.
- Peeling fruits and vegetables may also be considered as cleaning operation. In vegetable processing, blanching also helps to clean the product.
- Cleaning should take place at the earliest opportunity in a food process both to prevent damage to subsequent processing equipment by stones, bone or metals, and to prevent time and money from being spent on processing contaminants which are then discarded.

Types of Cleaning

- **Wet cleaning**

- Wet cleaning is more effective than dry methods for removing soil from root crops or dust and pesticide residues from soft fruits or vegetables.
- It is also dustless and causes less damage to foods than dry methods. Different combinations of detergents at different temperatures allow flexibility in operation.

- **Dry cleaning**

- Dry cleaning procedures are used for products that are smaller, have greater mechanical strength and possess a lower moisture content (for example grains and nuts).
- After cleaning, the surfaces are dry, to aid preservation or further drying.
- The main groups of equipment used for dry cleaning are:

✓ air classifiers

✓ magnetic separators

✓ separators based on screening of foods

Cleaning Efficiency (η):

$$\eta = \frac{E(F-G)(E-F)(1-G)}{F(E-G)^2(1-F)}$$

where, E = fraction of clean seed at clean seed outlet

F = fraction of clean seed in feed

and G = fraction of clean seed at foreign matter outlets

Q1: During evaluation of an air screen grain cleaner with 2 screens 250 g samples were collected for analysis of clean seed fraction from different outlets. The data are presented in the following Table. Calculate the cleaning efficiency of the cleaner.

Sample fraction	Feed, g	Clean grain outlet, g	Blower outlet, g	Oversize outlet, g	Undersize outlet, g
Cleaned seed, g	231.25	246.5	1.25	4.5	2.0
Impurities, g	18.75	3.5	248.75	245.5	248.0

Solution:

(1) Fraction of clean seed at clean seed outlet:

$$E = \frac{246.5}{250.0} = 0.986$$

(2) Fraction of clean seed in feed:

$$F = \frac{231.25}{250.0} = 0.925$$

(3) Fraction of clean seed in foreign matter outlets:

$$G = \frac{1.25}{250.0} + \frac{4.5}{250.0} + \frac{2.0}{250.0} = 0.031$$

Therefore,

$$Cleaning\ efficiency = \frac{0.986(0.925 - 0.031)(0.986 - 0.925)(1 - 0.031)}{0.925(0.986 - 0.031)^2(1 - 0.925)} = 82.34\%$$

Scalping: Scalping refers to the removal of few large particles in an initial process.

Sorting:

- Sorting is the separation of foods into categories on the basis of a measurable physical property.
- Like cleaning, sorting should be employed as early as possible to ensure a uniform product for subsequent processing.
- The four main physical properties used to sort foods are size, shape, weight and colour.

Grading of Fruits and Vegetables

Grading of fruits and vegetables after harvesting is an essential step in post-harvest management. Grading of fruits and vegetables on the basis of physical characteristics like weight, size, colour, shape, specific gravity, and freedom from diseases depending upon agro-climatic conditions. The known methods of grading of fruits and vegetables are manual grading, size grading.

Grading of fruits and vegetables in the fresh form for quality is essential, as the people are becoming quality conscious day by day. Further, upon arrival of fruits and vegetables at the processing centres, they should be graded strictly for quality. The immature properly mature and over mature fruits and vegetable should be sorted out for the best attributes.

Definition of Grading:

- This term is often used interchangeably with sorting but strictly means 'the assessment of overall quality of a food using a number of attributes'.
- Sorting (that is separation on the basis of one characteristic) may therefore be used as part of a grading operation but not vice versa.
- Grading is carried out by operators who are trained to simultaneously assess a number of variables. For example, eggs are visually inspected over tungsten lights (termed 'candling') to assess up to twenty factors and remove those that are for example, fertilized or malformed and those that contain blood spots or rot.

For International market three general grades are considered as:

1) Extra class 2) Class 1st 3) Class 2nd.

1) Extra class:

The extra class is of superior quality posses the shapes and colour of the variety and without internal defect likely to affect the inherent texture and flavour. A 5% tolerance is allowed for errors. It must be carefully presented taking into accounts the uniformity of the produces in size colour, condition arrangement of the produce in the package quality and appearances of the packing or pre-packing material.

2) Class 1st:

Almost having a same quality is like the 'extra class' except that a 10% tolerance is allowed. Individual fruit is allowed a slight defect in shape, colour and miner skin defect which do not affect the general appearance for keeping qualities. In packing the size range may be wider and product need not always be arranged in the package.

3) Class 2nd:

This class product may exhibit some external or internal defects provided they are fit for consumption while fresh. This class is best fitted for local or short distance market. This category will satisfy the needs of customers who are not too demanding and for whom price is more important than quality.

Advantages of Grading:

1. Losses the selling price due to presence of substandard products or specimen can be easily avoided.
2. It increased marketing efficiency by facilitating buying and selling a produce without personal selection.
3. Grading enhanced to set good price for graded products.
4. Heavy marketing cost in packing and transportation can be avoided by grading.
5. By grading there is fairness to both buyers and sellers.
6. Properly graded vegetables and fruits are purchased by the consumer easily without inspection.

Grading of Fruits:

Generally, the fruits are graded on the basis of size, weight, sp. gravity, colour, variety, etc. Size grading is predominantly followed in almost all types of fruits on the basis of size. The fruits are graded as a small, medium, large and extra-large. On the basis of maturity, the fruits are graded as immature, properly mature and over mature. Grading on the basis of maturity decides both quality and shelf life. The Alphonso and Pairi mango fruits are graded on the basis of weight as less than 200 g, 200-249 g, 250-299 g, 300-349 g and more than 350 g. Out of these grades the weight grade 250-299 g account for about 30% of the fruits. The mango fruits are also graded on the basis of sp. gravity (3 grades on the basis of sp. gravity as less than 1.0 sp.gr, 1.0-1.02 and more than 1.02. The sp. gravity grade 1.0-1.02 accounts for about 50% of the Alphonso and Pairi mango fruits.

Grading of Vegetables:

The fruit vegetables such as bitter gourd, okra, bell pepper, brinjal, green chilli, etc. are also graded on the basis of size into three grades as small medium and large. The vegetables like tomato are graded on the basis of colour.

Size Reduction:

- Size reduction includes cutting, crushing, grinding and milling.
- Raw materials as such cannot be used in food industries due to their large size.
- The reduction in size is brought about by mechanical means without change in chemical properties of the material.

- Milling of grains to flour, grinding of sugar, milling of dried foods such as vegetables, cutting of meat, fruits & vegetables are some common examples of size reduction.

Grain Shape:

- Expressed in terms of sphericity 'ϕ'.
- For spherical particles of diameter D_p, the sphericity is equal to radius.
- For non-spherical particles, sphericity is:

$$\phi = \frac{6v_p}{D_p S_p}$$

where, D_p = equivalent diameter of particle

S_p = surface area of particle

v_p = volume of particle

Size:

To determine the size of food grains usually three mutual perpendicular lengths of particle are measured. These may be called as longest, intermediate and smallest lengths or simply length, breadth and thickness of the particle. The equivalent diameter of granular material can be expressed as cube root of the product of three mutually perpendicular lengths.

$$D_p = (l \times b \times t)^{1/3}$$

where, l = length of particle

b = breadth of particle

t = thickness of particle

D_p = equivalent diameter of particle

"The equivalent diameter is defined as the diameter of a sphere having the same ratio of surface to volume as that of the actual particle."

Principles of Size Reduction:

- An ideal size reducer should fulfil the following conditions, namely:

(1) Large capacity

(2) Should yield a pre-desired sized product or range of size

(3) Small power input requirement per unit of product handled

(4) Easy and trouble free operation

Necessary energy required for size reduction is:

$$E = -c\int \frac{dx}{X^n}$$

Rittinger's law: Work required in crushing is proportional to the new surface created. Rittinger assumed that size reduction is essentially a shearing procedure. Therefore, energy requirement is proportional to the square of the common linear dimension and thus the value of 'n' becomes 2.

$$E = c\left(\frac{1}{X_p} - \frac{1}{X_f}\right)$$

where, X_p and X_f = length of product and feed, respectively.

Kick's law: Kick assumed that the energy requirements for size reduction is a function of a common dimension of the material, therefore, the value of 'n' becomes 1.

$$E = c\ln\left(\frac{X_f}{X_p}\right)$$

Bond's law: Bond reported a method for estimating the power required for crushing and grinding operation. "According to this law the work required to form particles of size 'D_p' from very large feed is proportional to the square root of the surface to volume ratio of the product".

$$E = \frac{P}{f} = 0.3162 w_i\left[\frac{1}{\sqrt{D_p}} - \frac{1}{\sqrt{D_f}}\right]$$

where, P = power in, kW,

f = feed rate, t/hr

D_p = 80% of product passes through mesh of dia D_p, mm

D_f = 80% of feed passes through mesh of dia D_f, mm

w_i = work index

"The work index is the gross energy requirement in kilowatt-hour per tonne of feed needed to reduce a very large feed to such a size that 80% of the product passes through a 100 μm screen"

Size reduction procedures:

Mainly the following four methods are used in size reduction machines.

(1) Compression or crushing,
(2) Impact,
(3) Shearing, and
(4) Cutting.

Crushing:

- When an external force applied on a material excess of its strength, the material fails because of its rupture in many directions.
- The particles produced after crushing are irregular in shape and size.
- The type of material and method of force application affects the characteristics of new surfaces and particles.
- Food grain flour, grits and meal, ground feed for livestock are made by crushing process.
- Crushing is also used to extract oil from oilseeds and juice from sugarcane.

Impact:

- When a material is subjected to sudden blow of force in excess of its strength, it fails, like cracking of nut with the help of a hammer.
- Operation of hammer mill is an example of dynamic force application by impact method.

Shearing:

- It is a process of size reduction which combines cutting and crushing.
- The shearing units consist of a knife and a bar.
- In a good shearing unit the knife is usually thick enough to overcome the shock resulting from material hitting.
- In an ideal shearing unit the clearance between the bar and the knife should be as small as practicable and the knife as sharp and thin as possible.

Cutting:

- Size reduction is accomplished by forcing a sharp and thin knife through the material.
- In the process minimum deformation and rupture of the material results and the new surface created is more or less undamaged.
- An ideal cutting device is a knife of excellent sharpness and it should be as thin as practicable.
- The size of vegetables and fruits are reduced by cutting.

Size Reduction Machinery:

Size reducing devices are grouped as follows:

1. Crushers
2. Grinders
3. Fine grinders
4. Cutting machines

Crushers:

- These types of reducing machines squeeze or press the material until it breaks.
- Crushers are mostly used to break large pieces of solid materials into small lumps.
- Crushers are used in industrial operations, like mines etc.
- Use of crushers in agricultural operations is limited.

Crushing rolls:

- In agricultural operations crushing rolls are mainly used for extraction of juice from sugarcane.

Grinders:

- The grinders are used to mill the grains into powder.
- The grinder comprises a variety of size-reduction machines like attrition mills, hammer mills, impactors and rolling compression mills.

Attrition Mills:

- The grains are rubbed between the grooved flat faces of rotating circular disks.
- These mills are also known as burr or plate mills.
- The axis of the roughened disks may be horizontal or vertical (Fig.1.b)
- In attrition mill one plate is stationary and fixed with the body of the mill, while other one is rotating disk.
- The material is fed between the plates and is reduced by crushing and shear. Mills with different patterns of grooves, corrugations on the plates perform a variety of operations.
- In attrition mills the materials are slowly fed, overfeeding lowers the grinder's performance, also heat generation during milling increases.
- The disks of burr mills are usually 20 to 137 cm in diameter and are operated at 350 to 700 rpm. These mills are used for making whole grain and de-husked grain flour, but their use in spices grinding is limited.
- The fineness of grinding in burr mills is controlled by the type of plates and the gap between them. The spacing between the plates is adjustable and usually the arrangement is spring loaded to avoid damage to plates in case of over loading or to overcome the damage to plates by foreign material coming along with the feed.
- The salient features of a burr mill are its lower initial cost and lower power requirements.

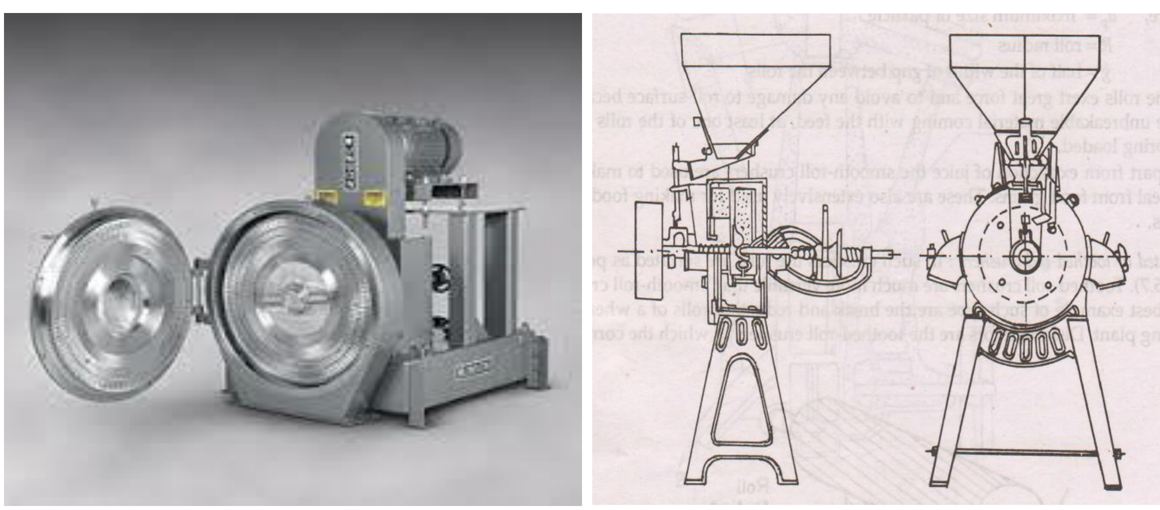

Fig.1 (a) Attrition mill (b) A vertical disk attrition mill

Hammer Mills:

- These mills contain a high-speed rotor, rotating inside a cylindrical casing. The shaft is usually kept horizontal. Materials are fed into the mill from the top of the casing and is broken by the rotating hammers and fall out through a screen at the bottom.
- The material or feed is broken by fixed or swinging hammers which are pinned to a rotor.
- The hammers are rotated between 1500 to 4000 rpm, strike and grind the material until it becomes small enough to pass through the bottom screen.
- Fineness of grinding is controlled by the screen size.
- Most of the size reduction is achieved by impact of hammers, though some amount of shear also takes place between the feed and screen and other mill parts.
- The salient features of hammer mill are their simplicity and versatility in design and work, freedom from damage during empty operation and less chances of damage of mill due to foreign objects.
- The capacity and power requirements of hammer will depend on the nature of feed to be ground. Commercial mills reduce solids between 60 to 240 kg/kW-hr of energy consumption. Hammer mills are used for poultry feed grinding, spices grinding.
- It was also found suitable for grinding of wet sorghum and millets and also for potato, tapioca, banana and similar flour making.

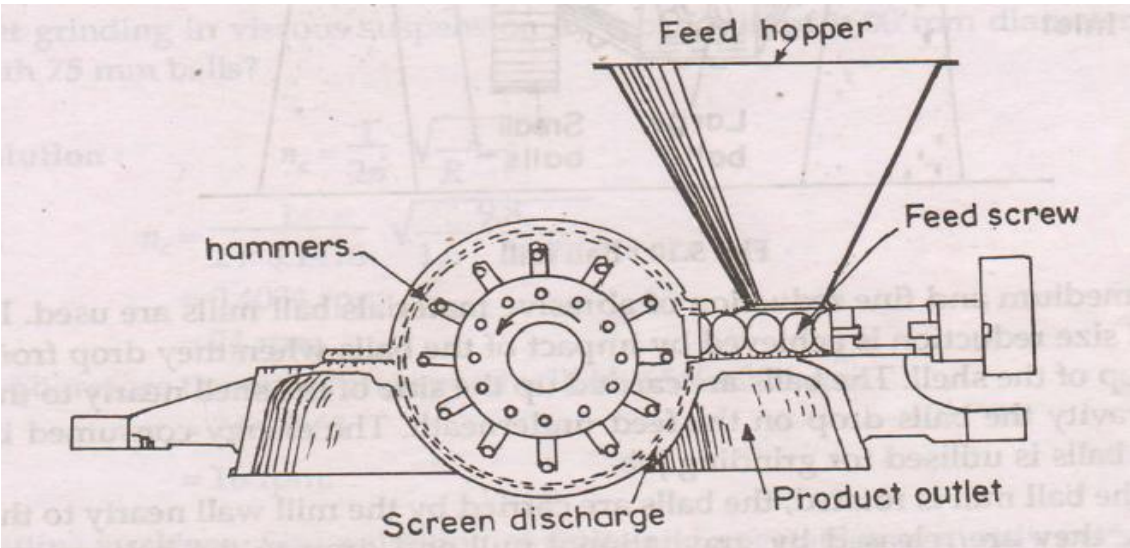

Fig. 2. Hammer mill

Ball Mills:

- The ball mill is a cylindrical or conical shell slowly rotating about a horizontal axis.
- Half of its volume is filled with solid grinding balls. The shell is usually made of steel lined with high carbon steel plate, porcelain or silica rock.
- For medium and fine reduction of abrasive materials ball mills are used. In a ball mill size reduction is achieved by impact of the balls when they drop from near the top of the shell.
- The balls are carried up the side of the shell nearly to the top. By gravity the balls drop on the feed underneath. The energy consumed in lifting the balls is utilized for grinding job.
- Centrifugal force keeps the ball in contact with the mill wall. Most of the grinding is done by the impact of balls. Due to centrifugal force, if the speed of rotation of mill is faster, the balls are carried to more distance. In case of too high speed, balls stick to mill wall and are not released. This is a stage of centrifuging.
- The rotational speed at which centrifuging occurs is known as critical speed.
- At this speed as the balls are released from the top, no impact occurs hence little or no grinding results. Therefore, the operating speeds must be kept less than the critical speed.

The critical speed can be determined by:

$$n_c = \frac{1}{2\pi}\sqrt{\frac{g}{R-r}}$$

where, n_c = critical speed, revolution/s

g = acceleration due to gravity, 9.80 m/s^2

R = radius of the mill, m

r = radius of the ball, m

"The rotational speeds of the ball mills are kept at 65 to 80% of the critical speed, with the lower values for wet grinding in viscous suspension".

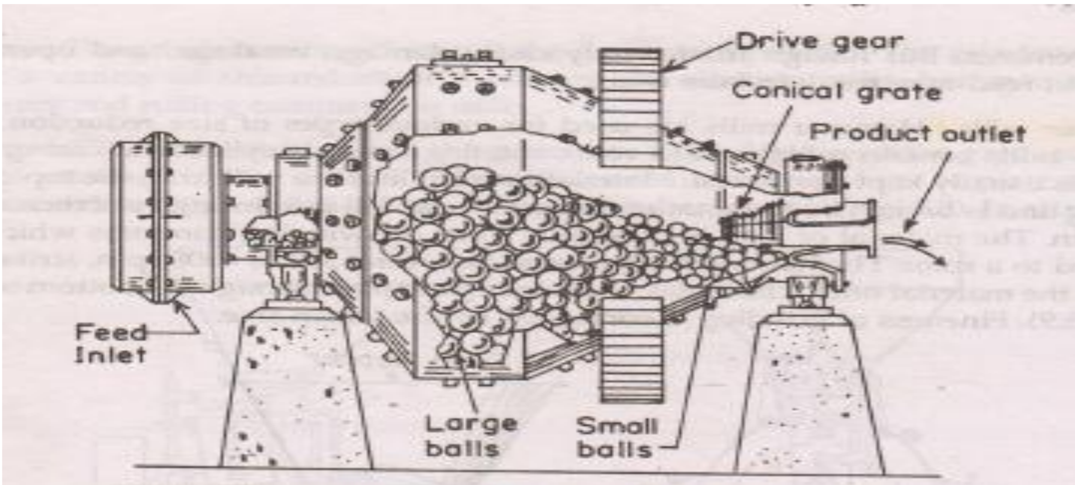

Fig. 3. Ball Mill