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The Role of Unit Operations in Agricultural Products Processing

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ABSTRACT: At the time of harvest, most foods are likely to contain contaminants, to have components which are inedible or to have variable physical characteristics (for example shape, size or colour). It is therefore necessary to perform one or more of the unit operations of cleaning, sorting, grading or peeling to ensure that foods with a uniformly high quality are prepared for subsequent processing. This paper examines the role of unit operations in agricultural products processing. The study adopted a desk review of existing literatures on unit operations in processing. Benefits of food processing include toxin removal, preservation, easing marketing and distribution tasks, and increasing food consistency. In addition, it increases seasonal availability of many foods, enables transportation of delicate perishable foods across long distances and makes many kinds of foods safe to eat by de-activating spoilage and pathogenic micro-organisms.

KEYWORDS: Contaminants, Deterioration, Unit operations, Processing.

1 INTRODUCTION

During the harvesting of agricultural products, most are likely to contain contaminants, to have components which are inedible or to have variable physical characteristics (for example shape, size or colour). It is therefore necessary to perform one or more of the unit operations of cleaning, sorting, grading or peeling to ensure that foods with a uniformly high quality are prepared for subsequent processing.

Unit operations are the processes involved in converting a raw product to the final product that is consumed by the end users. Therefore, the study of process engineering is an attempt to combine all forms of physical processing into a small number of basic operations, which are called unit operations. Food processes may seem bewildering in their diversity, but careful analysis will show that these complicated and differing processes can be broken down into a small number of unit operations. For example, consider heating of which innumerable instances occur in every food industry. There are many reasons for heating and cooling - for example, the baking of bread, the freezing of meat, the tempering of oils.

The essential concept of food processing is however to divide physical food processes into basic unit operations, each of which stands alone and depends on coherent physical principles. For example, heat transfer is a unit operation and the fundamental physical principle underlying it is that heat energy will be transferred spontaneously from hotter to colder bodies (Earle *et al.* 1966).

Important unit operations in the food industry are fluid flow, heat transfer, drying, evaporation, contact equilibrium processes (which include distillation, extraction, gas absorption, crystallization, and membrane processes), mechanical separations (which include filtration, centrifugation, sedimentation and sieving), size reduction and mixing.

1.1.1 SCREENING

Screening also called Size sorting or sieving is the separation of solids into two or more fractions on the basis of differences in size. It is particularly important when the food is to be heated or cooled as the rate of heat transfer is in part determined by the size of the individual pieces and variation in size would cause over-processing or under-processing.

Additionally, foods which have a uniform size are said to be preferred by consumers. Screens with either fixed or variable apertures are used for size sorting. The screen may be stationary or, more commonly, rotating or vibrating.

A. Fixed Aperture Screens

Two common types of fixed aperture screen are the flat bed screen (or sieve) and the drum screen (rotary screen or reel). The multideck flat bed screen (Figure 1.1.1a) has a number of inclined or horizontal mesh screens, which have aperture sizes from 20 to 125 mm, stacked inside a vibrating frame. Food particles that are smaller than the screen apertures pass through under gravity until they reach a screen with an aperture size that retains them. The smallest particles that are separated commercially are of the order of 50*m*µ.

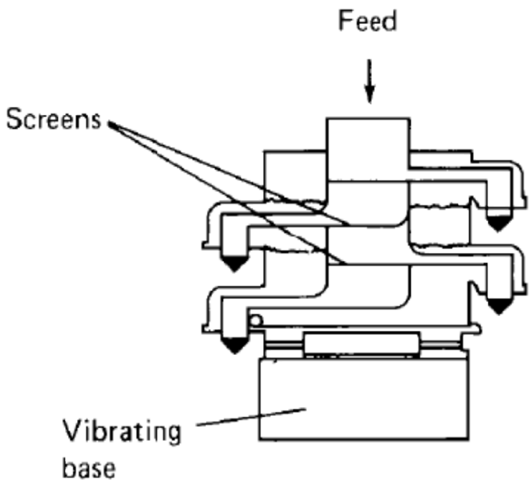

Fig.1.1.1(a) Multideck flat bed screen

The capacity of a screen is the amount of food that passes through per square metre per second. The rate of separation is controlled by:

- The shape and size distribution of the particles
- The nature of the sieve material
- The amplitude and frequency of shaking
- The effectiveness of methods used to prevent blocking (or blinding) of the sieves.

These types of screens are widely used for sorting dry foods (for example flour, sugar and spices).

The main problems encountered are:

- excessive moisture or high humidity, which causes small particles to stick to the screen or to agglomerate and form larger particles, which are then discharged as oversize
- blinding, particularly if the particle size is close to that of the screen aperture
- high feed rates, which cause the screens to become overloaded and small particles, are discharged with the oversized particles.

Where vibration alone is insufficient to separate particles adequately, a gyratory movement is used to spread the food over the entire sieve area, and a vertical jolting action breaks up agglomerates and dislodges particles that block sieve apertures.

Many types of drum screen are used for sorting small-particulate foods (for example nuts, peas or beans) that have sufficient mechanical strength to withstand the tumbling action inside the screen. Drum screens are almost horizontal (5–10º inclination), perforated metal or mesh cylinders. They may be *concentric* (one inside another), *parallel* (foods leave one screen and enter the next (Figure 1.1.1) or *series* (a single drum constructed from sections with different sized apertures). All types have a higher capacity than flat bed screens and problems associated with blinding are less severe than with flat bed screens. The capacity of drum screens increases with their speed of rotation up to a critical point. Above this the food is held against the screen by centrifugal force and results in poor separation. Similarly there is an increase in capacity with the angle of the screen up to a critical angle. Above this the residence time is too short and products pass through without separation.

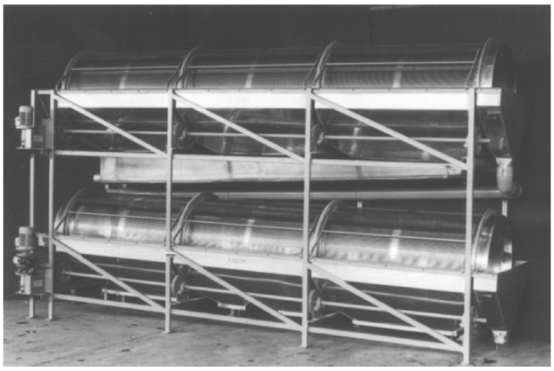

Fig.1.1.1 (b) Parallel drum screen

1.1.2 ASPIRATION CLEANING

Aspiration or winnowing machines are based on the difference in the terminal velocity of grain and chaff. Raw material (grain) is fed into a cylindrical column as shown in fig*1.1.2.* Air is forced up the column against the grain and chaff. The speed of the air is such that allows the grain to fall through a discharge gate while the lighter chaff is blown away.

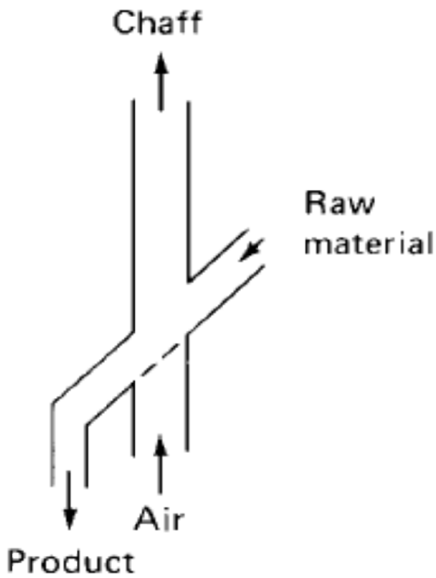

Fig. 1.1.2 Separation of chaff from grain by aspiration cleaning

1.1.3 SOAKING MACHINES

Soaking in still or moving water or fluids is effective only if dirt, or other surface undesirable, is present in small quantities and is loosely attached to the product. This method is frequently used in connection with other methods as a precleaner or soaker (Henderson *et al.* 1966). Soaking is done in large tanks. The effiency of soaking is increased by moving the water relative to the product or moving the product relative to the water. These can be achieved by the use of paddles or rotation of the equipment.

1.1.4 SPRAY BELT WASHERS

In spray washers, the product is moved slowly on a belt past a set of jets from a spray boom. In some machines, provision is made for turning the product as it moves on the belt.

1.1.5 SORTING MACHINES

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. Sorting is important because of the following reasons:

a) Sorted produce are better suited to mechanized operations

b) Sorting is necessary

The four main physical properties used to sort foods are size, shape, weight and colour.

SHAPE AND SIZE SORTING

The particle size distribution of a material is expressed as either the mass fraction of material that is retained on each sieve or the cumulative percentage of material retained.

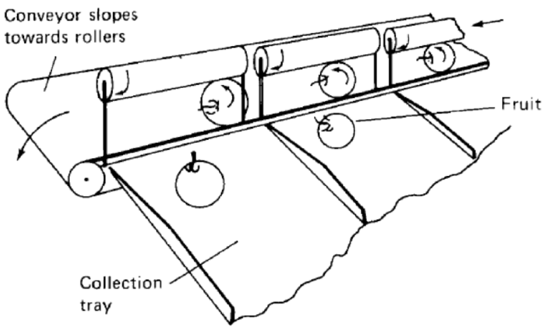

Fig.1.1.5 (a) Belt-and-roller sorter.

The shape of some foods is important in determining their suitability for processing or their retail value. For example, for economical peeling, potatoes should have a uniform oval or round shape without protuberances. Shape sorting is accomplished either manually or mechanically.

VARIABLE-APERTURE SCREENS

Variable-aperture screens have either a continuously diverging aperture or a stepwise increase in aperture. Both types handle foods more gently than drum screens and are therefore used to sort fruits and other foods that are easily damaged. Continuously variable screens employ pairs of diverging rollers, cables or felt-lined conveyor belts. These may be driven at different speeds to rotate the food and thus to align it, to present the smallest dimension to the aperture.

Fig. 1.1.5(b) Sorting lemons on a roller sorter.

Stepwise increases in aperture are produced by adjusting the gap between driven rollers and an inclined conveyor belt (Refer Figure on belt and roller sorter). The food rotates and the same dimension is therefore used as the basis for sorting (for example the diameter along the core of a fruit).

IMAGE PROCESSING

Image processing is used to sort foods on the basis of length, diameter, and number of surface defects and orientation of the food on a conveyor as well as colour. It has been used for example with maize cobs, which pass beneath three video cameras, placed 120º apart above a conveyor belt. The images of the surface of the cob are recorded and stored in the memory of a microprocessor. The information is then analyzed and compared with pre-programmed specifications for the product, and the cob is either rejected or moved into a group with similar characteristics.

COLOUR SORTING

Manual sorting by colour is still widely used but is increasingly expensive in both labour costs, operator training and the space required for sorting tables. There has therefore been considerable development of machine vision sorting systems which are said to have lower operating costs and greater accuracy than manual methods. These include monochrome (black and white), bichrome (4100 shades of red and green) and trichromatic or full colour (262 000 shades of red, green and blue, with optional infrared).Each is controlled by a programmable logic controller which has pre-set programs for different products that are easily changeable by operators using a video display. They are used for example, to sort potatoes for defects and blemishes by identifying dark areas on the potato surface. Light sensitive cells in the camera (termed 'pixels') produce a voltage that is proportional to the intensity of light received. An electronic circuit that receives a lower voltage than the pre-set value can thus detect darker objects or areas which reflect less light than normal. The voltage produced in the electronic circuit can be adjusted to alter the sensitivity of detection. Up to 10 tonnes of product per hour pass beneath the cameras on conveyors operating at 150–180 m per min. Defective items are removed by electronically controlled air jets that can operate for 20 milliseconds, thus covering 50 mm of the belt length in a single blast. In another system, vegetables in free-fall are scanned 1000 times per second, as they leave a conveyor belt, using concentrated helium-neon or laser light beams and a high-speed rotating mirror. The machine detects differences in reflectivity between good product and unwanted material.

Small-particulate foods may be automatically sorted at high rates using microprocessor controlled colour sorting equipment. Particles are fed into the chute one at a time. The angle, shape and lining material of the chute are altered to control the velocity of the pieces as they pass a photodetector. The colour of the background and the type and intensity of the light used for illuminating the food (including infrared and ultraviolet options) are closely controlled for each product. Photodetectors measure the reflected colour of each piece and compare it with pre-set standards, and defective foods are separated by a short blast of compressed air. The computer can store 100 named product configurations to enable rapid changeover to different products using an operator touchpad.

Typical applications include peanuts, rice, diced carrot, maize kernels, cereals, snack foods and small fruits.

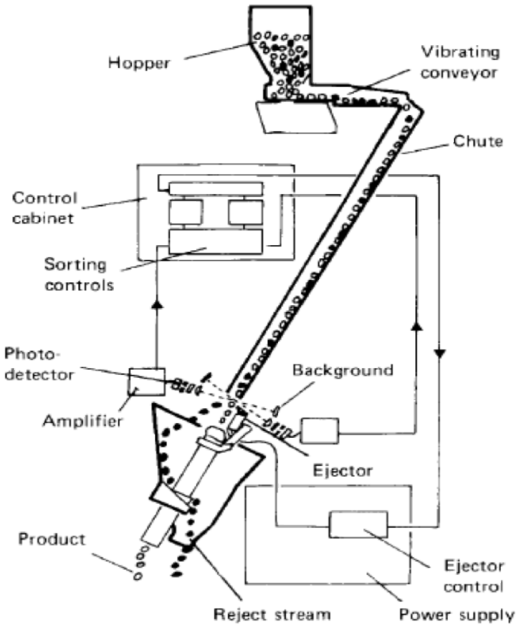

Fig. 1.1.5(c) Colour sorter.

A different type of equipment employs a sensor located above a conveyor belt, which views products as they pass beneath. The sensor detects up to eight colours and provides an alarm or control signal whenever a pre-selected colour passes the detector beam. It is also able to distinguish between different coloured foods which are to be processed separately. In a more sophisticated system, foods which have variations in colour over their surface are colour sorted by image processing. The foods are fed in rows on a roller conveyor beneath a video camera. The relative intensities of reflected red, green and yellow light are transmitted to the microcomputer which constructs a composite image of each piece of food, showing both the spread of colour and the mean colour of inspected foods. The computer compares the constructed image with pre-set specifications and activates a compressed air ejector or a mechanical deflector to remove rejected food. When this type of system is used to sort baked goods, it is also used to control directly the gas or electricity supply to the ovens, which is reported to reduce energy consumption in ovens by 20%. The sorter can be easily adapted to different foods, by operators using the microprocessor keypad.

WEIGHT SORTING

Weight sorting is more accurate than other methods and is therefore used for more valuable foods (for example eggs, cut meats and some tropical fruits). Eggs are sorted at up to 12 000 per hour into six to nine categories with a tolerance of 0.5 g. They are first graded by 'candling' and then pass to the weight sorter. This consists of a slatted conveyor which transports the eggs above a series of counterbalanced arms. The conveyor operates intermittently and while stationary, the arms raise and weigh the eggs. Heavy eggs are discharged into a padded chute and lighter eggs are replaced on the conveyor to travel to the next weigher.

Aspiration and **flotation** sorting use differences in density to sort foods and are similar in principle and operation to aspiration and flotation cleaning. Grains, nuts and pulses are sorted by aspiration. Peas and lima beans are sorted by flotation in brine (specific gravity, 1.1162–1.1362). The denser, starchy, over-mature pieces sink whereas the younger pieces float.

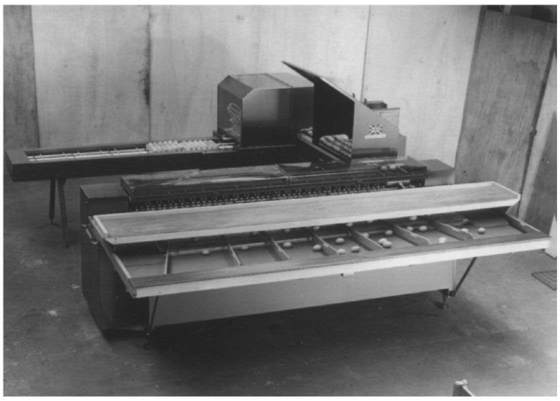

Fig.1.1.5(d) Egg sorter Grading

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. Meats, for example, are examined by inspectors for disease, fat distribution, bone to flesh ratio and carcass size and shape. Other graded foods include cheese and tea, which are assessed for flavour, aroma, colour, etc. Apples are graded with the assistance of coloured cards that show the required characteristics of different grades in terms of colour distribution across the fruit, surface blemishes and size and shape of the fruit.

In some cases the grade of food is determined from the results of laboratory analyses (for example wheat flour is assessed for protein content, dough extensibility, colour, moisture content and presence of insects). In general, grading is more expensive than sorting owing to the higher costs of skilled operators. However, many attributes that cannot be examined automatically can be simultaneously assessed, and this produces a more uniform high-quality product.

2 SIZE REDUCTION MACHINES

Raw materials often occur in sizes that are too large to be used and, therefore, they must be reduced in size. Size reduction or 'comminuition' is the unit operation in which the average size of solid pieces of food is reduced by the application of grinding, compression or impact forces. When applied to the reduction in size of globules of immiscible liquids (for example oil globules in water) size reduction is more frequently referred to as homogenization or emulsification. The size reduction of liquids to droplets is done by atomization. Size enlargement is achieved by extrusion, agglomeration or forming.

Size reduction has the following benefits in food processing:

- There is an increase in the surface-area-to-volume ratio of the food which increases the rate of drying, heating or cooling and improves the efficiency and rate of extraction of liquid components (for example fruit juice or cooking oil extraction.
- A similar range of particle sizes allows more complete mixing of ingredients (for example dried soup and cake mixes).

Size reduction and emulsification have little or no preservative effect. They are used to improve the eating quality or suitability of foods for further processing and to increase the range of products available. In some foods size reduction may promote degradation by the release of naturally occurring enzymes from damaged tissues, or by microbial activity and oxidation at the increased area of exposed surfaces, unless other preservative treatments are employed.

Different methods of size reduction are classified according to the size range of particles produced:

1. *Chopping, cutting, slicing and dicing*:
(a) Large to medium
(b) medium to small
(c) small to granular
2. *Milling* to powders or pastes of increasing fineness
3. *Emulsification* and *homogenization*

Grinding and Cutting

Grinding and cutting reduce the size of solid materials by mechanical action, dividing them into smaller particles. Perhaps the most extensive application of grinding in the food industry is in the milling of grains to make flour, but it is used in many other processes, such as in the grinding of corn for manufacture of corn starch, the grinding of sugar and the milling of dried foods, such as vegetables.

Cutting is used to break down large pieces of food into smaller pieces suitable for further processing, such as in the preparation of meat for retail sales and in the preparation of processed meats and processed vegetables.

In the grinding process, materials are reduced in size by fracturing them. The mechanism of fracture is not fully understood, but in the process, the material is stressed by the action of mechanical moving parts in the grinding machine and initially the stress is absorbed internally by the material as strain energy. When the local strain energy exceeds a critical level, which is a function of the material, fracture occurs along lines of weakness and the stored energy is released. Some of the energy is taken up in the creation of new surface, but the greater part of it is dissipated as heat. Time also plays a part in the fracturing process and it appears that material will fracture at lower stress concentrations if these can be maintained for longer periods. Grinding is, therefore, achieved by mechanical stress followed by rupture and the energy required depends upon the hardness of the material and also upon the tendency of the material to crack - its friability.

The force applied may be compression, impact, or shear, and both the magnitude of the force and the time of application affect the extent of grinding achieved. For efficient grinding, the energy applied to the material should exceed, by as small a margin as possible, the minimum energy needed to rupture the material. Excess energy is lost as heat and this loss should be kept as low as practicable.

The important factors to be studied in the grinding process are the amount of energy used and the amount of new surface formed by grinding.

A. SELECTION OF SIZE REDUCTION MACHINE

In selecting a size reduction machine, the factors to be considered include: hardness of feed; mechanical structure of feed; moisture content of feed; temperature sensitivity of feed; and cost.

Hardness of feed: Some products are harder than others. Therefore, in selecting a size reduction machine, it is important to know the mechanical strength of the product or feed. Such strength can be determined as the bioyield 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 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 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. The machine must be economically feasible for the user.

Temperature: For most size reduction machines, there is a temperature rise at the action zone. Products that contain oil will begin to release the oil at those points. Thus the machine should be such that the temperature rise is not too high.

B. EQUIPMENT FOR SIZE REDUCTION

Size reduction equipment is divided into crushers, grinders, ultra fine grinders, and cutting machines.

I. Crushers

Crushers do the heavy work of breaking large pieces of solid material into small lumps. A primary crusher operates on run-of-mine material, accepting anything that comes from the mine face and breaking it into 150 to 250-mm lumps. A secondary crusher reduces these lumps to particles perhaps 6 mm in size.

II.Grinders

Grinders reduce crushed feed to powder. The product from an intermediate grinder might pass a 40 mesh screen; most of the product from a fine grinder would pass a 200 mesh screen with a 74 µm opening.

III. Ultra fine grinder

An *ultra fine grinder* accepts feed particles no larger than 6 mm; the product size is typically 1 to 50 µm. *Cutters* give particles of definite size and shape, 2 to 10 mm in length.

These machines do their work in distinctly different ways. Compression is the characteristic action of crushers. Grinders employ impact and attrition, sometimes combined with compression; ultrafine grinders operate principally by attrition.

IV. Crushers

Crushers are slow-speed machines for coarse reduction of large quantities of solids. The main types are

- jaw crushers,
- gyratory crushers,
- smooth-roll crushers, and
- toothed-roll crushers.

The first three operate by compression and can break large lumps of very hard materials, as in the primary and secondary reduction of rocks and ores.

Jaw Crusher

In *a jaw crusher* the feed is admitted between two jaws, set to form a V open at the top. One jaw is stationary; the other, driven by an eccentric, reciprocates in a horizontal plane and crushes lumps caught between the jaws.

In a *gyratory crusher* a conical crushing head gyrates inside a funnel-shaped casing, open at the top. An eccentric drives the shaft carrying the crushing head. Solids caught between the head and the casing are broken and re-broken until they pass out the bottom.

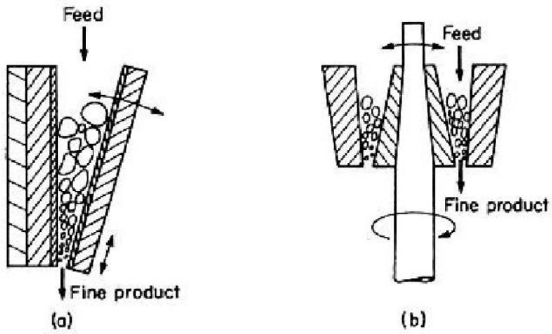

Fig.1.2.3 a) Jaw Crusher b) Gyratory crusher

Grinders

The term grinder refers to a variety of size reduction machines for intermediate duty. Product from a crusher is often fed to a grinder for further reduction. Some of the commercial grinders are hammer mills, impactors, rolling compression machines, attrition mills, and tumbling mills.

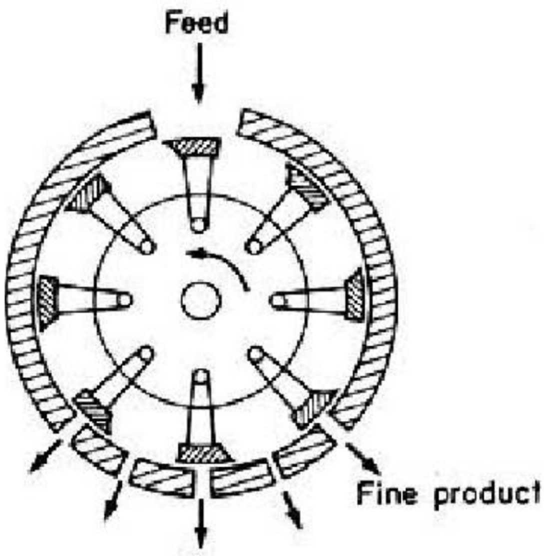

Figure 1.2.3 (c) Hammer mill

Hammer mills:

These mills all contain a high-speed rotor turning inside a cylindrical casing. Usually the shaft is horizontal. Feed dropped into the top of the casing is broken and falls out through a bottom opening. In a hammer mill, the particles are broken by sets of swing hammers pinned to a rotor disk. A particle of feed entering the grinding zone cannot escape being struck by the hammers. It shatters into pieces, which fly against a stationary anvil plate inside the casing and break into still smaller fragments. These in turn are rubbed into powder by the hammers and pushed through a grate or screen that covers the discharge opening.

Several rotor disks, 150 to 450 mm in diameter and each carrying four to eight swing hammers, are often mounted on the same shaft. The hammers may be straight bars of metal with plain or enlarged ends or with ends sharpened to a cutting edge. Intermediate hammer mills yield a product 25 mm to 20-mesh in particle size. In hammer mills for fine reduction, the peripheral speed of the hammer tips may reach 110 m/s; they reduce 0.1 to 15 tons/h to sizes finer than 200-mesh. Hammer mills grind almost anything-tough fibrous solids like bark or leather, steel turnings, soft wet pastes, sticky clay, hard rock. For fine reduction they are limited to the softer materials.

The capacity and power requirement of a hammer mill vary greatly with the nature of the feed and cannot be estimated with confidence from theoretical considerations. Commercial mills typically reduce 60 to 240 kg of solid per kilo watt hour of energy consumed.

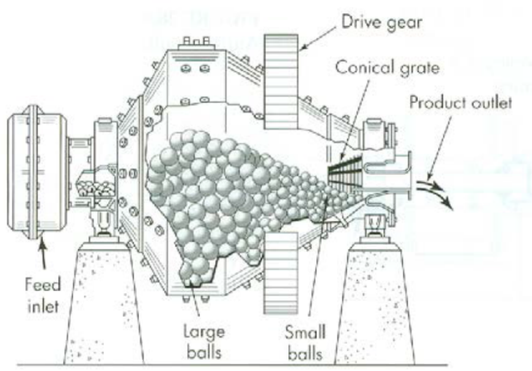

Figure1.2.3 (d) A conical ball mill

Ball Mill

In a ball mill or pebble mill, most of the reduction is done by impact as the balls or pebbles drop from near the top of the shell. In a large ball mill the shell might be 3 m in diameter and 4.25 m long. The balls are 25 to 125 mm in diameter; the pebbles in a pebble mill are 50 to 175 mm. A tube mill is a continuous mill with a long cylindrical shell, in which material is ground for 2 to 5 times as long as in the shorter ball mill. Tube mills are excellent for grinding to very fine powders in a single pass where the amount of energy consumed is not of primary importance. Putting slotted transverse partitions in a tube mill converts it into a compartment mill. One compartment may contain large balls, another small balls, and a third pebbles. This segregation of the grinding media into elements of different size and weight aids considerably in avoiding wasted work, for the large, heavy balls break only the large particles, without interference by the fines.

Segregation of the grinding units in a single chamber is a characteristic of the conical ball mill illustrated in above. Feed enters from the left through a 60°one into the primary grinding zone, where the diameter of the shell is a maximum. Product leaves through the 30° cone to the right. A mill of this kind contains balls of different sizes, all of which wear and become smaller as the mill is operated. New large balls are added periodically. As the shell of such a mill rotates, the large balls move toward the point of maximum diameter, and the small balls migrate toward the discharge. The initial breaking of the feed particles, therefore, is done by the largest ball dropping the greatest distance; small particles are ground by small balls dropping a much smaller distance. The amount of energy expended is suited to the difficulty of the breaking operation, increasing the efficiency of the mill.

The load of balls in a ball or tube mill is normally such that when the mill is stopped, the balls occupy about one half the volume of the mill. The void fraction in the mass of balls, when at rest, is typically 0.40. The grinding may be done with dry solids, but more commonly the feed is a suspension of the particles in water, increasing both the capacity and the efficiency of the mill.

When the mill is rotated, the balls are picked up by the mill wall and carried nearly to the top, where they break contact with the wall and fall to the bottom to be picked up again. Centrifugal force keeps the balls in contact with the wall and with one another during the upward movement. While in contact with the wall, the balls do some grinding by slipping and rolling over one another, but most of the grinding occurs at the zone of impact, where the free falling balls strike the bottom of the mill.

The faster the mill is rotated, the farther the balls are carried up inside the mill and the greater the power consumption and the capacity of the mill. If the speed is too high, however, the balls are carried over and the mill is said to be centrifuging. The speed at which centrifuging occurs is called the critical speed.

From a balance between the gravitational and centrifugal forces, the critical speed nc may be found from the equation

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

where g is the acceleration of gravity, R is the radius of the mill, and r is the radius of the grinding elements. The operating speed n must be less than nc.

Ultra Fine Grinders

Many commercial powders must contain particles averaging 1 to 20 µm in size, with substantially all particles passing a standard 325-mesh screen that has openings 44 µm wide. Mills that reduce solids to such fine particles are called ultra-fine grinders. Ultra fine wet grinding is done in agitated mills.

Cutting machines

In some size reduction problems the feed stocks are too tenacious or too resilient to be broken by compression, impact, or attrition. In other problems the feed must be reduced to particles of fixed dimensions. These requirements are met by machines known as granulators, which yield more or less irregular pieces, and cutters, which produce cubes, thin squares or diamonds.

2.1 Energy Requirement In Size Reduction

Grinding is a very inefficient process and it is important to use energy as efficiently as possible. Unfortunately, it is not easy to calculate the minimum energy required for a given reduction process, but some theories have been advanced which are useful.

These theories depend upon the basic assumption that the energy required to produce a change d*L* in a particle of a typical size dimension *L* is a simple power function of *L*:

$$\frac{dE}{dL} = KL^n \qquad 1$$

Where dE is the differential energy required, dL is the change in a typical dimension; L is the magnitude of a typical length dimension and K, n, are constants.

Kick assumed that the energy required to reduce a material in size was directly proportional to the size reduction ratio dL/L. This implies that n in eqn. 1 is equal to -1. If $K = K_K f_c$

where K_K is called Kick's constant and f_c is called the crushing strength of the material, we have:

$dE/dL = K_K f_c L^{-1}$

which, on integration gives:

$E = K_K f_c \log_e(L_1/L_2)$ 2

Equation (2) is a statement of Kick's Law. It implies that the specific energy required to crush a material, for example from 10 cm down to 5 cm, is the same as the energy required to crush the same material from 5 mm to 2.5 mm.

Rittinger, on the other hand, assumed that the energy required for size reduction is directly proportional, not to the change in length dimensions, but to the change in surface area. This leads to a value of -2 for n in eqn. (1) as area is proportional to length squared. If we put: $K = K_R f_c$

and so

$dE/dL = K_R f_c L^{-2}$ where K_R is called Rittinger's constant, and integrate the resulting form of eqn. 1, we obtain:

$E = K_R f_c(1/L_2 - 1$ 3

Equation 3 is known as Rittinger's Law. As the specific surface of a particle, the surface area per unit mass, is proportional to 1/L, eqn.3 postulates that the energy required to reduce L for a mass of particles from 10 cm to 5 cm would be the same as that required to reduce, for example, the same mass of 5 mm particles down to 4.7 mm. This is a very much smaller reduction, in terms of energy per unit mass for the smaller particles, than that predicted by Kick's Law.

It has been found, experimentally, that for the grinding of coarse particles in which the increase in surface area per unit mass is relatively small, Kick's Law is a reasonable approximation. For the size reduction of fine powders, on the other hand, in which large areas of new surface are being created, Rittinger's Law fits the experimental data better.

Bond has suggested an intermediate course, in which he postulates that n is -3/2 and this leads to:

$E = E_i (100/L_2)^{1/2}[1 - (1/q^{1/2})]$ 4

Bond defines the quantity E_i by this equation: L is measured in microns in eqn.4 and so E_i is the amount of energy required to reduce unit mass of the material from an infinitely large particle size down to a particle size of 100 mm. It is expressed in terms of q, the reduction ratio where $q = L_1/L_2$.

Note that all of these equations [eqns. (2), (3), and (4)] are dimensional equations and so if quoted values are to be used for the various constants, the dimensions must be expressed in appropriate units. In Bond's equation, if L is expressed in microns, this defines E_i and Bond calls this the Work Index.

The greatest use of these equations is in making comparisons between power requirements for various degrees of reduction.

3 CONCLUSION

At the time of harvest, most foods are likely to contain contaminants, to have components which are inedible or to have variable physical characteristics (for example shape, size or colour). It is therefore necessary to perform one or more of the unit operations of cleaning, sorting, grading or peeling to ensure that foods with a uniformly high quality are prepared for subsequent processing. .Benefits of food processing include toxin removal, preservation, easing marketing and distribution tasks, and increasing food consistency. In addition, it increases seasonal availability of many foods, enables transportation of delicate perishable foods across long distances and makes many kinds of foods safe to eat by de-activating spoilage and pathogenic micro-organisms.

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