-- 1: The Value of Size Reduction --

The breakdown of solid materials by the application of mechanical forces is also referred to as comminution. Size reduction operations can include grinding and cutting.

Size reduction in liquid foods (for example homogenisation) is covered in the "emulsification" topic in this series of articles.

The value of size reduction comes from:

- aiding the extraction of a constituent from a composite structure -- for example in making sugar from sugar cane
- satisfying consumer or functional requirements -- for example in manufacturing of icing sugar, pineapple rings or pieces
- increasing the ratio of surface area to volume so as to
  -- reduce drying time
  -- increase extraction rate
  -- decrease heating, cooking time etc
- improving mixing/blending -- for example in packaged soups, cake mixes etc

--- 2: Grinding Equipment ---

Principles

Forces for comminution can be applied in three basic ways:
-- compressive eg crushing rolls
-- impact eg hammer mills
-- shear eg attrition mills

Often, size has to be reduced through a number of stages (eg flour milling)

Reduction Ratio = F/P

where F = Average size of feed
P = Average size of product

Coarse crushers have reduction ratios of less than 8:1, but fine grinders can have reduction ratios as high as 100:1.

Crushing rolls

- two or more heavy steel cylinders revolve towards each other
- an overload compression spring protects the roller surfaces from damage, but hard foreign bodies should be removed
- the distance between the surfaces of the rollers is termed the *nip*
- force applied to the product is mainly compressive, but the use of "fluted" rollers and/or differential speeds of rotation can also introduce shear forces
- size reduction ratios are normally below five
- volumetric capacity is affected by speed, nip, diameter and length of the rollers

Calculations (Brennan pp 72 - 73): For the limiting case, when the particle is just pulled into the rolls by friction:

$$\tan (A/2) = \mu$$

where A = angle of nip (the angle formed by the tangents to the roll faces at the points of contact with the particle.)
μ = coefficient of friction between the particle and the rolls

The relationship of required roll diameter, D_r, to diameter of feed particles, D_f, and diameter of product particles, D_p, is given by:

$$\cos(A/2) = (D_r + D_p)/(D_r + D_f)$$

Example: A roll mill is available with rolls of 400 mm diameter, and capable of milling to an average product particle diameter of 0.05 mm. If the coefficient of friction for the material on the rolls is 0.12, what is the largest average diameter of feed particle which could be fed to the mill?

Answer: Since $\tan (A/2) = \mu$, $A/2 = \tan^{-1}0.12$ and thus $A/2 = 6.84^o$. That is, maximum angle of nip is 13.7^o. Since $\cos(A/2) = (D_r + D_p)/(D_r + D_f)$, then for 400 mm diameter rolls producing an average product particle diameter of 0.05 mm and

$$\cos(6.84) = (0.4 + 0.00005)/(0.4 + D_f)$$
$$0.993 = 0.40005/(0.4 + D_f)$$
$$0.4 + D_f = 0.40005/.993$$
$$D_f = 0.4029 - 0.4$$
$$D_f = 0.0029$$

and so the maximum diameter of feed material would be 2.9 mm.

Hammer mill

-- a high speed rotor carries a number of hammers around its periphery, inside a close fitting case containing a toughened breaker plate.

-- reduction is mainly by impact as the hammers drive the material against the breaker plate (shear may also have a role under "choke" feeding conditions)

-- final size is largely determined by the size of the retention screen through which discharge material must pass

-- regarded as general purpose mill, handling crystalline solids, fibrous materials, vegetable matter, sticky materials etc.

-- due to excessive wear, hammer mills are not recommended for the fine grinding of very hard materials

See http://www.mpd-inc.com/prod02.htm

Attrition mills

-- mainly utilise shear between a plate and a stationary surface, or between two plates for fine grinding

-- in a single disc mill the feed stock passes between a high speed rotating grooved disc and the stationary casing of the mill

-- in a double disc mill, two discs are required, rotating in opposite directions. The pin-disc mill carries pegs or pins which intermesh on the rotating elements, so that impact forces also play a significant part in the size reduction process.

-- in the Buhr mill, originally used in flour milling, the discs (or stones) are horizontal. The feed passes through the centre of the upper (stationary) disc, while the lower disc rotates. The material is subjected to shear between the two stones and exits around the periphery.

Ball mills and rod mills

-- a rotating (tumbling) or vibrating chamber is filled with steel balls or rods.

-- feed material is subjected to impact and shear due to the movement of the balls or rods. Shear predominates at low speeds, while impact becomes more important at higher speeds (if speed is too high, balls can be carried around the periphery and grinding ceases)

-- a variation is the use of a vibrating rather than rotating chamber.

A vibrating type of rod mill is supplied by SWECO – see http://www.sweco.com/ under "Products" A listing of a range of mill types (dry and wet milling) is available on the WWW through http://www.glenmills.com/

--- 3: Product factors influencing equipment selection ---

Hardness and abrasiveness of feed

In general harder materials require more energy to comminute, therefore a longer residence time (lower throughput) or higher capacity equipment will be required. More robust construction is also required. Hard material also tends to be more abrasive, so that more wear resistant materials may be desirable (eg manganese steel) and wearing parts should be easily replaceable. Slower speed is also desirable to reduce wear.

Internal structure of feed

If the material is crystalline or friable in nature, compressive forces are likely to be suitable. If few lines of weakness are present and new "cracks" have to be formed, impact or shear may be more effective.

Moisture content

Moisture can either aid or hinder comminution. With some materials, moisture above 2 - 3% may cause clogging of the mill, or agglomeration may occur. Too dry a condition can result in excessive dust. For some products milling may be carried out as a free flowing slurry eg wet milling of maize.

Temperature sensitivity

The heat generated by grinding can result in loss of heat sensitive components. Softening or melting may also be important - leading to clogging. In some cases cryogenic comminution may be necessary - cooling during milling using liquid nitrogen or dry ice eg in milling spices or size reduction of meat.

--- 4: Modes of operation of grinding equipment ---

Open circuit grinding

-- simplest method of operating a mill. Product passes straight through, no classifying screens, no recycling of oversize

-- wide size distribution results as some particles pass through quickly, others stay for some time (also resulting in higher energy consumption)

Free crushing

- as with open circuit, but residence time kept to a minimum, often by material falling through action zone under influence of gravity
- production of undersize reduced, and lower energy consumption, but large size range

Choke feeding

- discharge is restricted by inserting a screen in the outlet, so material stays choked in the action zone until reduced to a small enough size
- long residence time results in undersize particles and additional energy consumption
- useful to prevent oversize, and a large reduction ratio can be achieved

Closed circuit grading

- residence time kept short, but classifier system at the outlet separates oversize material and recycles it
- more energy efficient, with narrower range of final particle size
- additional cost of classifier system

Wet milling

- if material can be wet without harm, it may be advantageous to mill it as a slurry with a carrier liquid, often water
- eliminates dust problems and allows use of hydraulic separating techniques eg centrifugation
- often used where extraction of a soluble component is also required eg maize milling
- energy consumption high but tends to produce finer particles