

### --- 5: Energy used in grinding ---

As a force is applied to a substance, it begins to deform. Unless the *stress* (force per unit area) exceeds the *elastic limit* or *yield point* the substance will return to its original shape when the force is removed, and the stored energy is released as heat.

If stress is increased beyond the elastic limit, permanent deformation occurs until the *breaking stress* is exceeded - at this point the material fractures and breaks along a line of weakness.

As the size of a piece is reduced, there are fewer lines of weakness available, and the breaking stress which must be exceeded increases. There is therefore a substantial increase in energy requirement as the size of particles is reduced.

As little as 1% of the applied energy may be used for size reduction.

The amount of energy absorbed by a food before it fractures is determined by its hardness and tendency to crack (*friability*), which depends on the structure of the food.

Compression forces are used to fracture friable or crystalline foods, combined impact and shearing forces are required for fibrous foods, and shearing forces are used for fine grinding of softer foods.

Moisture content may significantly affect the energy used and the type of force required eg conditioning of wheat. Too high a moisture content can lead to agglomeration of particles which block the mill.

Various equations have been developed to calculate the energy required to reduce the size of particles. Two reasonably simple ones are:

**Kick's Law**, which states that the energy required to reduce the size of particles is proportional to the ratio of an initial dimension (eg diameter) to the final dimension. Energy required is given by:

$$E = K_K \ln(x_1/x_2)$$

where  $K_K$  = Kick's Constant  
 $x_1$  = initial dimension  
 $x_2$  = final dimension  
( $x_1/x_2$  = reduction ratio)

Kick's Law is best suited to coarse grinding where there is relatively little change in surface area.

**Rittinger's Law**, which states that the energy required to reduce the size of particles is proportional to the change in surface area of the particles.

$$E = K_R (1/x_2 - 1/x_1)$$

where  $K_R$  = Rittinger's Constant

Rittinger's Law gives better results for fine grinding where there is a much greater change in surface area.

Example: Food is milled from 6 mm to 0.12 mm particle diameter using a mill with a 7.5 kW motor. What reduction in throughput rate would you expect if the material was reduced to 0.08 mm instead of 0.12 mm?

Solution: Fine grinding (reduction ratio of 50), so assume Rittinger's Law applies. Power is the rate at which energy is consumed, so that power requirement is proportional to energy requirement. Therefore, for the original conditions,

$$7.5 = K_R (1/0.12 - 1/6)$$

$$7.5 = K_R (8.33 - 0.17)$$

$$K_R = 7.5/8.16$$

$$K_R = 0.92$$

For the changed conditions,

$$E = 0.92 (1/0.08 - 1/6)$$

$$E = 0.92 (12.5 - 0.17)$$

$$E = 11.3$$

That is, if the operation producing 0.12 mm particles was fully utilising the 7.5 kW delivered by the motor, at the same throughput rate it would require 11.3 kW to produce 0.08 mm particles.

Therefore, as only the original 7.5 kW is available, you would expect that throughput rate may have to be reduced to 7.5/11.3 or 0.66 of the original rate - a reduction of about one third or 34%.

### **--- 6: Size reduction of fibrous material - slicing, dicing, shredding, chopping, and pulping ---**

The previous methods are often used if the material is dry enough, but are generally not applicable for high moisture content items such as fruit, vegetables, and meat. For example, meat may be tempered to just below its freezing point to improve cutting efficiency.

In general, impact and shearing forces are applied, often by a cutting edge. Equipment may be similar in form to grinding equipment eg hammers replaced by knives or disc mills with studs or serrations. Often, more precise size reduction methods are required to produce particles of uniform size and shape. Operations include:

#### **Slicing**

-- rotary or reciprocating cutting knives are set to cut material to the desired thickness, perhaps as product is conveyed on a belt. Sometimes the food is held against the

- blade by centrifugal force, or sometimes the food may be held in a carriage as it travels across the blade
- an alternative for firmer fruits such as apples is forcing the fruit through a tube with stationary knife edges arranged radially along the length of the tube

### **Dicing**

- often involves the product passing through two sets of rotary knives at right angles
- an alternative is forcing the product through a grid, then cutting it off at the required length

### **Shredding**

- hammer mills may be used, the rotating shaft carrying a number of discs with impact edges around the periphery
- squirrel cage disintegrators use concentric cylindrical cages with cutting edges running along their length and rotating in opposite directions

### **Chopping**

A bowl chopper is commonly used for comminuting meats, harder fruits etc. A slow speed rotating bowl moves the ingredients beneath a set of high speed blades, achieving chopping and mixing

### **Pulping**

- brush or paddle finishers use brushes or paddles rotating inside a stationary screen

“Urschel” cutting equipment is recognised in the food industry as amongst the best available. Details of the equipment they supply can be found through their home page at <http://www.urschel.com/>

## **--- 7: Exercises ---**

1. You need to mill a fine grain to an average particle diameter of 0.5 mm, with little size spread around this average. Discuss the type/s of milling equipment you might use, and the mode in which it may be operated. Provide reasons for your choice/s (and reasons for rejecting other options).
2. What sorts of mechanisms might you use for the following size reduction tasks:
  - Slicing potatoes for “fries”
  - Slicing potatoes for “chips”
  - cutting sheeted material into individual muesli bars
1. You currently use a mill with a 5 kW motor to reduce the size of an ingredient from 3 mm diameter to around 1 mm diameter. You wish to reduce it further to 0.2 mm diameter. If you use the same type of mill for this second stage size reduction, what size motor would you estimate will be required?

2. You currently use a hammer mill to reduce a product from an average diameter of 3 mm to an average diameter of 0.04 mm. What percentage decrease in throughput might you expect if you were to produce a finer product, average diameter half that of the current product, using the same equipment?
3. The particle diameter of a material to be fed through a roll mill is 2 mm, and its coefficient of friction is 0.1. What is the minimum diameter of the rolls which could be used if a product diameter of 0.2 mm is required?

### --- 8: References ---

Fellows, P., **Food Processing Technology: Principles and Practice**, 2nd ed. (Woodhead Publishing Ltd., 2000) pp 98-110. This is a good review of a range of methods of size reduction.

Brennan, J.G., **Food Engineering Operations**, 3rd ed. (Elsevier Applied Science, London, 1990) Chap. 4, pp 67-85.

Earle, R.L., **Unit Operations in Food Processing** 2nd ed., (Pergamon Press, 1983) pp 129-163

Sanguansri, P., *Food Australia* 49(3):135 - 138 (1997), "Cutting mechanisms for minimally processed vegetables". This paper is particularly useful for its information on "futuristic" cutting methods - eg waterjet and laser cutting. Don't be concerned with the theoretical section on mechanical cutting.

Urschel Laboratories" How to cut food products : Catalog of precision size reduction equipment." (1988) Library Call No. TP373 .H68 1988. This book is well worth flicking through for the diagrams and pictures showing how this equipment works. This information is also available on the world wide web through <http://www.urschel.com/>, click on "Machines and Equipment".