Points to be covered

- Size reduction - Definition
- Principles of comminuting
- Characteristics of comminuted products
- Grinding and cutting
- Particle size distribution in comminuted products

Size reduction

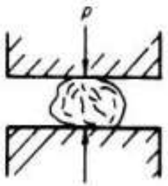
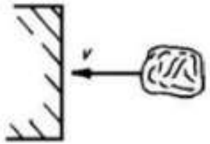
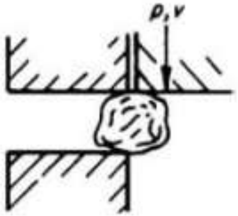
- Size reduction is "an unit operation in which large solid unit masses are reduced into small unit masses of coarse particles or fine particles by the application of external forces".
- Size reduction process is also termed as **Comminution/Diminution/ Pulverizations**.
- Solid pieces of food is reduced by the application of **grinding, compression or impact forces.**
- In many food processes it is frequently necessary to reduce the size of solid materials for different purposes.

Benefits of size reduction

- Increase in the surface-area-to-volume ratio of the food.
- Increases the rate of drying
- Increases the rate of heating or cooling
- Improves the efficiency and rate of extraction.
- Facilitating mixing and blending
- Facilitates heat exchange, chemical and biological reactions

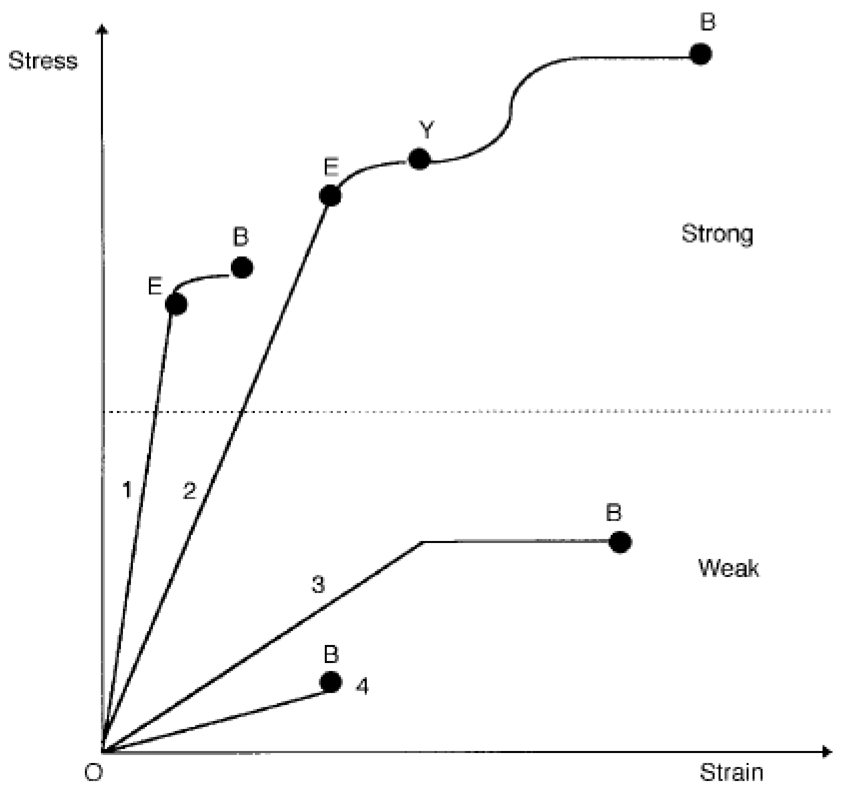
Forces Used in Size Reduction

- The types of forces commonly used in food processes are compressive, impact, attrition or shear and cutting
- In a comminution operation, more than one type of force is usually acting
- For example, crushing, grinding and milling take place in powdered flour, sugar and dried vegetable product

Force	Schematic diagram	Principle	Example of equipment
Compressive		Nutcracker	Crushing rolls
Impact		Hammer	Hammer mill
Attrition		File	Disc attrition mill
Cut		Scissors	Rotary knife cutter

Principles of comminuting

- The increase in stress at a site is proportional to the square root of the crack length perpendicular to the stress direction (Inglis, 1913).
- Initially some of the stress is absorbed
- Above the critical value the applied stress will cause fracture in the material
- When fracture occurs some of the stored energy is transformed into free surface energy which is the potential energy of the newly produced surfaces



Stess-strain diagram for various foods

(E = elastic limit; Y = yield point; B = breaking point; O–E = elastic region; E–Y = inelastic deformation; Y–B = region of ductility; (1) = hard, strong, brittle material; (2) = hard, strong, ductile material; (3) = soft, weak, ductile material and (4) = soft, weak brittle material.) (After Loncin and Merson (1979).

Cont.,

- **Compressive forces** are used for coarse crushing of hard materials.
- **Impact forces** can be regarded as general purpose forces.
- **Shear or attrition forces** are applied in fine pulverization when the size of products can reach the micrometer range.
- **Ultra-fine grinding** is associated with processes in which the sub-micron range of particles is attained.
- **Cutting** gives a definite particle size and may even produce a definite shape.

Characteristics of comminuted products

- Objective
  - Small particles from larger one
  - Small particles are desired
    - Either b/c of their large surface area
    - Or b/c of their shape, size and number
- Unlike an ideal process, an actual unit does not yield a uniform product (irrespective of the feed is uniformly sized or not)
- Particle size ranging from max. particle size (coarse) to min. particle size (fine)
- Ratio of diameters of largest and smallest particle is of the order of 10^4
- Comminuted products are smoothed by abrasion and their size is specified

Grinding and Cutting

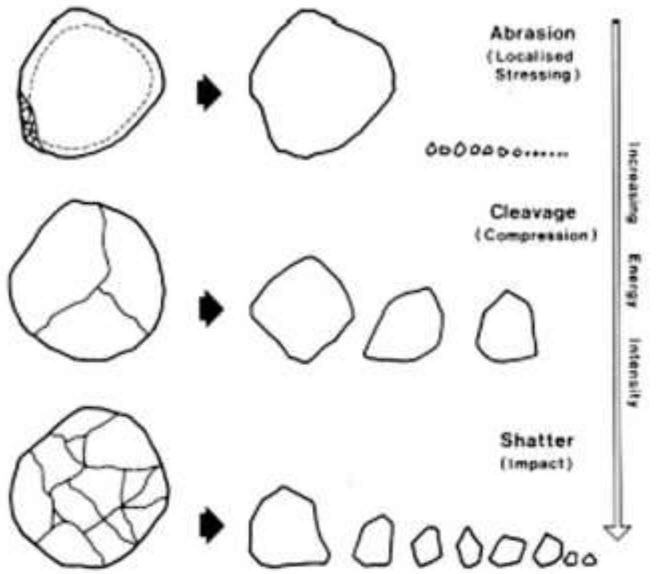
- Raw materials often occur in sizes that are too large to be used and therefore, they must be reduced in size.
- This size reduction operation divided into **two major categories** depending on whether the material is a **solid or a liquid**.
- **Solid** - operations are called **grinding and cutting**
- **Liquid** - operations are called **emulsification or atomization**.

Cont.,

- Grinding and cutting reduce the size of solid materials by mechanical action, dividing them into smaller particles
- Extensive application of grinding is observed in milling of grains, grinding of corn (corn starch), grinding of sugar, milling of dried foods – vegetables
- Cutting used to break down large pieces of food into smaller pieces suitable for further processing - e.g preparation of processed meat and processed vegetables.

Mechanism of grinding

- In the grinding process, materials are reduced in size by fracturing them.
- In the process, the material is stressed by the action of mechanical moving parts in the grinding machine
- Initially the stress is absorbed internally by the material as strain energy.



Stress → Strain → Fracture in lines of Weakness → Released Heat

Some of the energy is taken up in the creation of new surface, but the greater part of it is dissipated as heat.

Particle Size Distribution: Measurement Techniques

- There is a wide range of instrumental and other methods of particle size analysis available. Some of the more common methods are:

    1. Sieve Analysis
    2. Sedimentation methods
    3. Elutriation Techniques
    4. Microscopic Sizing and Image analysis
    5. Electrical Impedance method
    6. Laser Diffraction Method

Sieve analysis

- Standard screens are used to determine particles size in the range **b/w 76 mm to 38 μm.**
- Screens are known as **'testing sieves'**
- In 1910 set of sieves called **Tylor sieves** originated in USA adopted by US Bureau of Standards
- Opening of sieves are based on **200 mesh sieve** which has 200 square openings in one inch
- Next sieve opening is **√2 or 1.414 time larger**
- **Intermediate screen** ratios of **1.189** also available

Test Sieves


Upper and bottom collecting tray
Test sieves of punching sheets
Test sieves of woven wire mesh

Determination of Particle size distribution

- Three methods - to determine the size of the particles after size reduction
    1. Differential screen analysis
    2. Cumulative screen analysis
    3. Fineness modulus

https://www.youtube.com/watch?v=WOKgItPBmR8

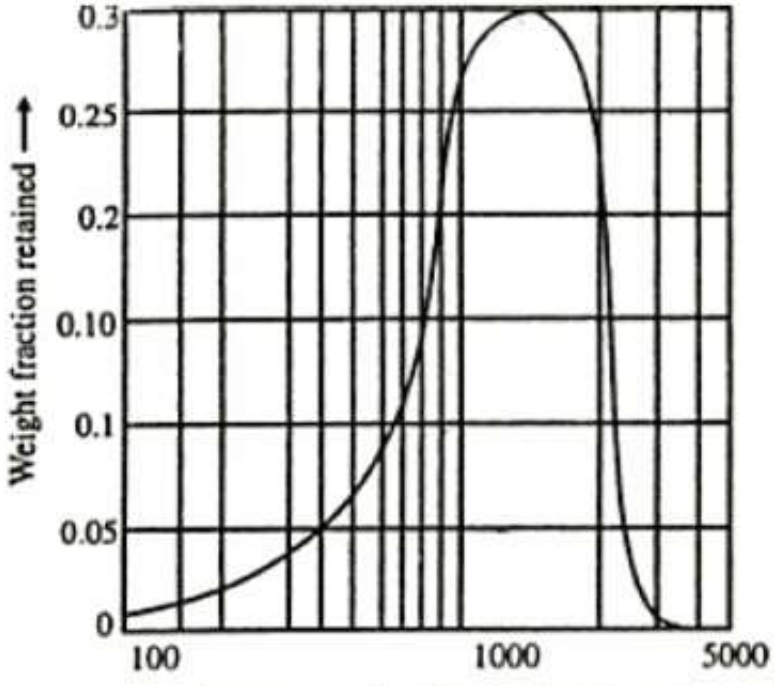
Screen Analysis Apparatus

Sl. No.	Mesh No.	Screen Opening D_{pi} (cm)	Mass retained on a screen m_i (gm)	Mass Fraction $x_i = m_i/M$	Average particle diameter $\overline{D_{pi}}$	Φ, Cumulative fraction Larger than $\overline{D_{pi}}$	Cumulative Fraction Smaller than $\overline{D_{pi}}$
1							1.00
2							
3							

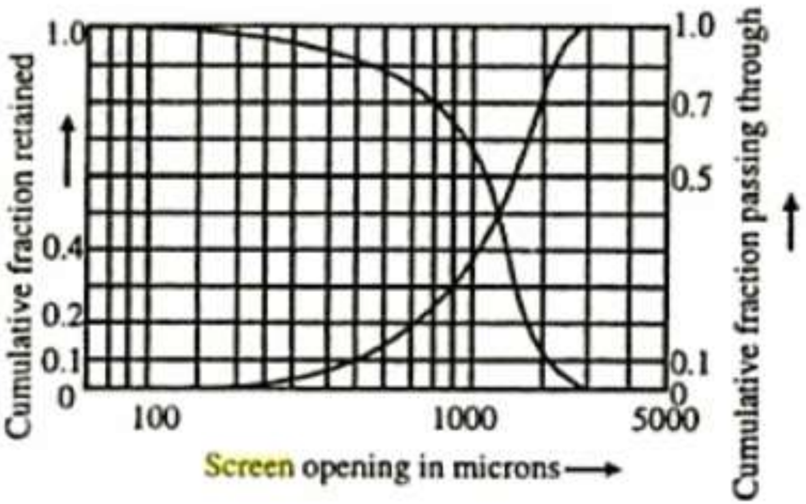
Pan						1.00	0.00
			$\sum m_i = M$	$\sum x_i = 1$			

Sl.No.	Mesh. No.	Screen Opening, D_{pi}, mm	Average particle diameter, D_{pi}	Mass retained on a screen, m_i (g)	Mass Fraction, xi =mi /M	φ, Cumulative fraction larger than D_{pi}	φ, Cumulative fraction smaller than D_{pi}
1.	4	4.75	0.000	0	0.000	0.000	1.000
2.	6	3.25	4.000	25	0.025	0.025	0.975
3.	8	2.399	2.825	125	0.127	0.152	0.848
4.	10	2.032	2.216	325	0.329	0.481	0.519
5.	14	1.405	1.719	250	0.253	0.734	0.266
6.	20	0.954	1.180	160	0.162	0.896	0.104
7.	30	0.592	0.773	50	0.051	0.946	0.054
8.	35	0.5	0.546	20	0.020	0.967	0.033
9.	50	0.296	0.398	10	0.010	0.977	0.023
10.	70	0.211	0.254	8	0.008	0.985	0.015
11.	100	0.157	0.184	6	0.006	0.991	0.009
12.	140	0.104	0.131	4	0.004	0.995	0.005
13.	200	0.075	0.090	3	0.003	0.998	0.002
	Pan	0	0.038	2	0.002	1.000	0.000
			Total	988	1.000		

Differential and Cumulative Screen Analysis Curves



Differential Analysis



Surface area of the particles

Surface area of the particles $A = NS_p = \dfrac{6}{\phi \rho_p D_p}$

Specific surface area of the particles

$$Ass = \frac{6m_1}{\phi \rho_p D_{p1}} + \frac{6m_2}{\phi \rho_p D_{p2}} + \ldots + \frac{6m_n}{\phi \rho_p D_{pn}}$$

$$= \frac{6}{\phi \rho_p} \sum_{i=1}^{n} \frac{m_i}{D_{pi}}$$

where, i = individual increment

n = number of increments

D_{pi} = average particle diameter in each increment

Volume Surface mean diameter, D_{vs}

$$D_{vs} = \frac{6}{\phi \rho_p A_{ss}}$$

$$D_{vs} = \frac{6}{\phi \rho_p \times \frac{6}{\phi \rho_p} \sum_{i=1}^{n} \frac{m_i}{D_{pi}}}$$

$$= \frac{1}{\sum_{i=1}^{n} \frac{m_i}{D_{pi}}}$$

Mass mean diameter, D_m

$$D_m = \sum_{i=1}^{n} m_i D_{pi}$$

Volume mean diameter, D_v

$$D_v = \left(\frac{1}{\sum_{i=1}^{n} \frac{m_i}{D_{Pi}^{3}}} \right)^{1/3}$$

Fineness Modules

- The fineness modulus indicates the uniformity of grind in resultant product
- Determined by adding the weight fractions retained above each sieve and dividing the sum by 100

Determination of Fineness Modulus

IS sieve No.	Weight of material retained, g	Percent material retained			Fineness Modulus	Average particle size, mm
100	0.0	7×0.0	=	0.0		$D = 0.135\,(1.366)^{F.M.}$ $= 0.317$ mm
70	1.4	6×0.56	=	3.36		
50	16.7	5×6.71	=	33.53	$\frac{274.03}{100}$	
40	36.7	4×14.45	=	57.80	$= 2.7403$	
30	82.2	3×33.01	=	99.03		
20	96.0	2×38.55	=	77.10		
15	8.0	1×3.21	=	3.21		
Pan	8.7	0×3.50	=	0.0		
Total				274.03		

The average particle size, D_p in mm represented in terms of fineness modulus can be estimated by the following equation (Fig 5.1)

$$D_p = 0.135\ (1.366)^{F.M.} \quad \ldots 5.6$$

Uniformity Index

- Course = (0.0 +1.4+16.7) /10 = 1.81 ≅ 2
- Medium = (36.7+82.2) / 10 = 11.89 ≅ 12
- Fine = (96.0+8.0+8.7) / 10 = 11.27 ≅ 11

- Uniformity index = 2 : 12 : 11

Result indicate that sample size is b/w medium to fine

Problem

Table 5.2 B: Characteristic screen analysis of ground wheat

Sieve size IS	Sieve Opening Dpi, mm	Average diameter in each increment Dpi mm	Mass fraction retained mi	Cumulative fraction smaller than Dpi
200	2.032	–	0.000	
170	1.676	1.854	0.015	
140	1.405	1.540	0.062	
120	1.201	1.303	0.104	
100	1.000	1.100	0.320	
70	0.708	0.854	0.208	
50	0.500	0.604	0.096	
40	0.420	0.460	0.078	
30	0.296	0.358	0.046	
20	0.211	0.254	0.031	
15	0.157	0.184	0.029	
Pan	–	0.078	0.011	

Sample Problem – Fineness modules

Problem : Sorghum (3.80 mm size) was milled by a burr mill at two different gaps between the burr stones. The flour was analysed by IS sieves for particle size determination as shown in Table given below. The power required to mill sorghum at first setting was 5.0 kW.

IS Sieve No.	*Mass fraction of flour retained over sieve, g*	
	I-setting	*II-setting*
100	—	—
70	10.1	1.5
50	16.7	13.3
40	36.0	36.1
30	82.2	74.8
20	96.0	104.6
15	8.0	8.4
Pan	0.0	11.3

Any questions / doubts?

Thank you