

**Gazi University**  
**Chemical Engineering Department**  
**ChE482 Chemical Engineering Laboratory III**  
**- Summer Intensive Program -**

# 5 – Size Reduction and Sieve Analysis

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# ABOUT THE EXPERIMENT

## Size Reduction & Sieve Analysis



### OBJECTIVE

- To find the experimental and theoretical power of the ball mill.
- Determination of the size distribution of the samples.



### EXPERIMENTAL SETUP

Armfield Solids Study Handling Bench



### OUTPUTS

- Calculation of experimental power
- Calculation of theoretical power
- Product size distribution graph
- By using the differential and cumulative sieve analysis, calculation of;
  - Particle size of the product,
  - Specific surface area,
  - Volume-surface average diameter

# SIZE REDUCTION

## Definition

### *Size Reduction*

- The term **size reduction** is applied to all the ways in which particles of solids are **cut or broken into smaller pieces**.
- Throughout the process industries solids are reduced by different methods for different purposes.

## Examples

### *For example,*

- Chunks of **crude ore** are crushed to workable size.
- **Synthetic chemicals** are ground into powder.
- **Sheets of plastic** are cut into tiny cubes or diamonds.

## Aim

### *Is reducing the size of the material a must/need?*

- Commercial products must often meet stringent specifications regarding the size and sometimes the shape of the particles they contain.
- Reducing the particle size also increases the reactivity of solids.
- It permits separation of unwanted ingredients by mechanical methods.
- It reduces the bulk of fibrous materials for easier handling and for waste disposal.

### *Ways to Reduce Size*

Solids may be broken in many different ways, but only four of them are commonly used in size-reduction machines:

- (1) compression,
- (2) impact,
- (3) attrition, or rubbing,
- (4) cutting

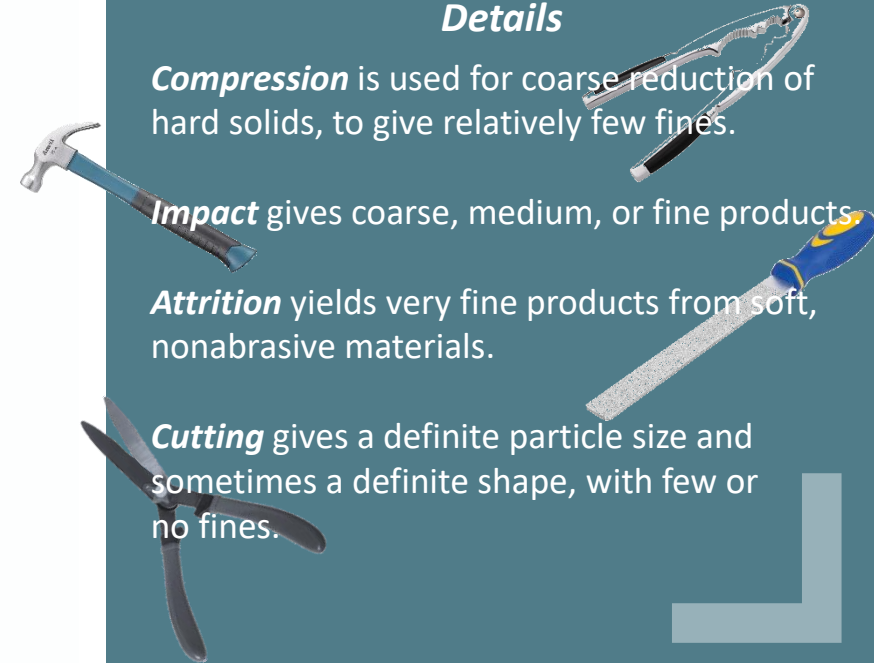
### *Details*

**Compression** is used for coarse reduction of hard solids, to give relatively few fines.

**Impact** gives coarse, medium, or fine products.

**Attrition** yields very fine products from soft, nonabrasive materials.

**Cutting** gives a definite particle size and sometimes a definite shape, with few or no fines.





# COMMINUTION

Fig.  
Industrial Ball Mill

## Definition

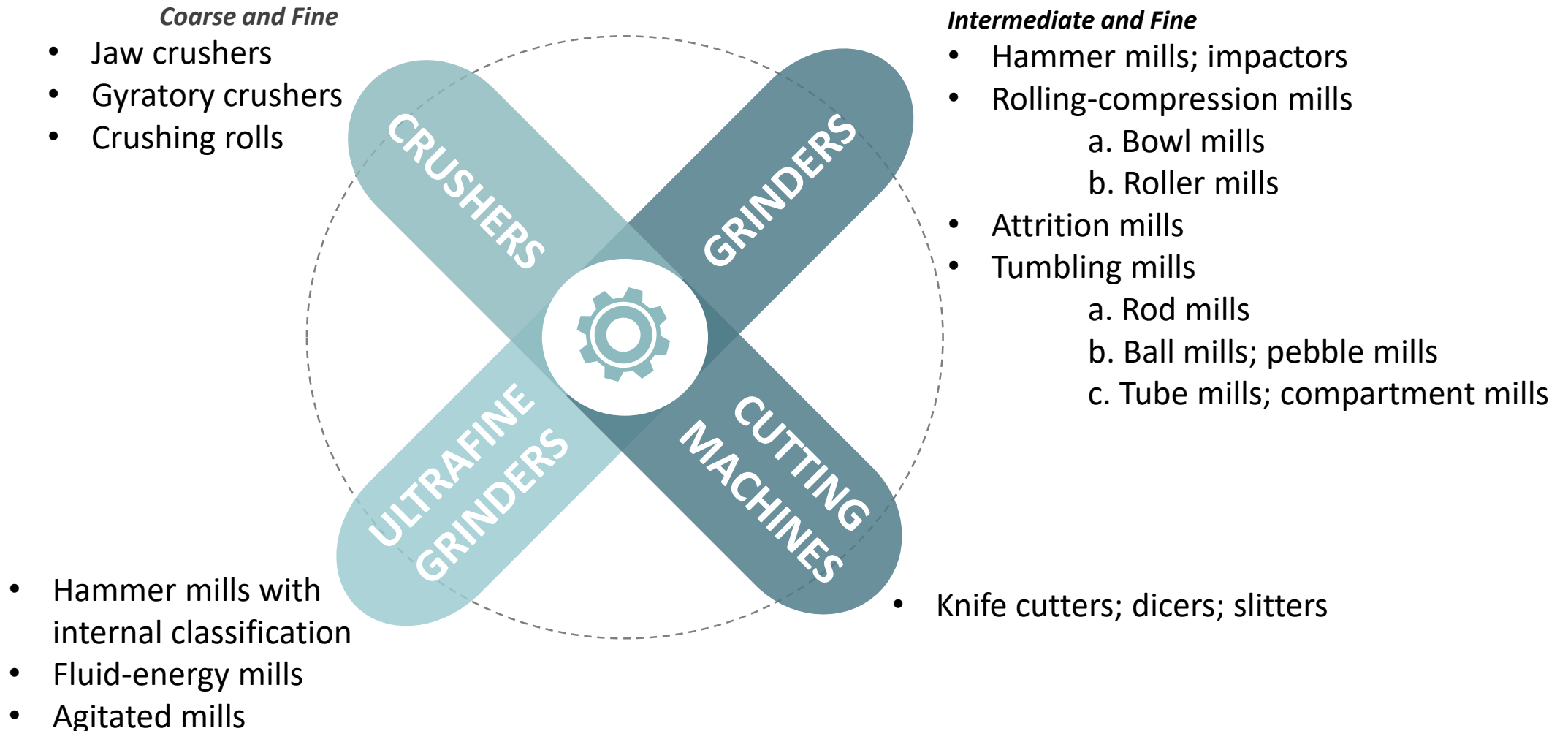
*Comminution* is a generic term for size reduction. *Crushers* and *grinders* are types of comminuting equipment.

## An ideal crusher or grinder would

- (1) have a **large capacity**,
- (2) require a **small power input per unit of product**,
- (3) yield a product of **the single size or the size distribution desired**.

- The **objective** of crushing and grinding is to **produce small particles from larger ones**.
- Smaller particles are desired either because of **their large surface** or because of **their shape, size, and number**.
- One measure of the **efficiency** of the operation is based on the **energy required to create new surface**.
- The surface area of a unit mass of particles increases greatly as the particle size is reduced.

# TYPES OF SIZE-REDUCTION MACHINES



# TYPES OF GRINDERS

The term grinder describes a variety of size-reduction machines for *intermediate* duty.

The product from a crusher is often fed to a grinder, in which it is *reduced to powder*. The chief types of commercial grinders are given here.

## Rolling-Compression Machines

- Action : Compression
- Product Size : 20 – 200 mesh

## Hammer Mills and Impactors

- Action : Impact
- Product Size : 4 – 325 mesh

## Attrition Mills

- Action : Attrition
- Product Size : Up to 200 mesh

## Tumbling Mill

- Action : Attrition and Impact
- Product Size : 10 – 200 mesh





## Principle

Works on the principle of the impact between the rapidly moving balls and the powder material, both enclosed in a hollow cylinder.



## Working

At low speeds, the balls roll over each other and attrition (rubbing action) will be the predominant mode of action.

THUS, **impact or attrition or both** are responsible for the size reduction.



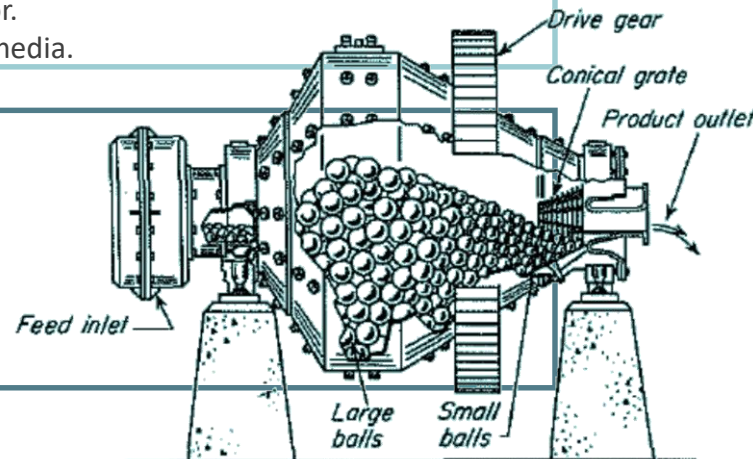
## Advantages

- **Very fine powder** can be produced.
- Used both for **wet and dry grinding processes**.
- Since the cylinder is a closed system, **toxic substances** can be grounded.
- **Low costs** of installation, operation and labor.
- Rods and bars can also be used as grinding media.



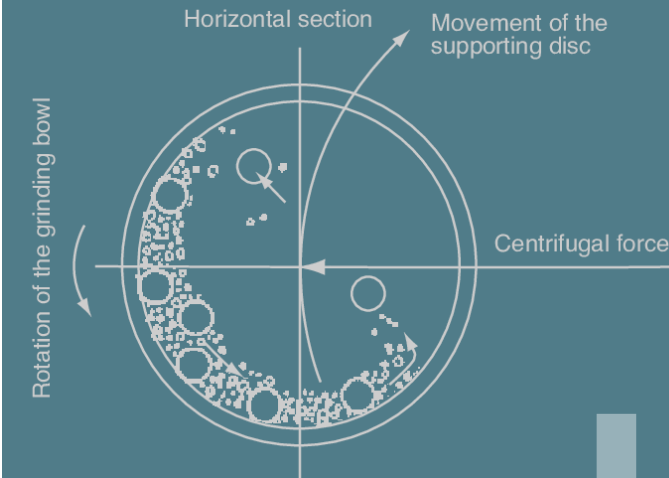
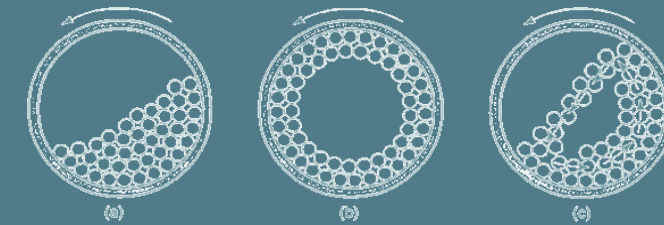
## Disadvantages

- **VERY noisy** machine.
- **Slow** process.
- Soft and fibrous material cannot be milled.



# BALL MILL

Also known as tumbling mill.



# ENERGY AND POWER REQUIREMENT

## Importance of Cost

The cost of power is a major expense in crushing and grinding, so the factors that control this cost are important.

## Rittinger's Law

A crushing law proposed by Rittinger in 1867 states that the work required in crushing is proportional to the new surface created. This "law," which is really no more than a hypothesis, is equivalent to the statement that the **crushing efficiency is constant** and, for a given machine and feed material, is **independent of the sizes of feed and product**

## Kick's Law

In 1885 Kick proposed another "law," based on stress analysis of plastic deformation within the elastic limit, which states that the **work required for crushing a given mass of material is constant** for the same reduction ratio, that is, the ratio of the initial particle size to the final particle size.

$$\frac{dE}{dX} = -\frac{C}{X^n}$$

$$E = K_R \left( \frac{1}{X_2} - \frac{1}{X_1} \right)$$

$$\begin{aligned} E &= C \ln \left( \frac{X_1}{X_2} \right) \\ &= K_K \log \left( \frac{X_1}{X_2} \right) \end{aligned}$$



# Bond Crushing Law and Work Index

A somewhat more realistic method of estimating the power required for crushing and grinding was proposed by Bond in 1952.

Bond postulated that 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.

Bond proposed the  $E_i$  as the **work index**.  $E_i$  is defined as the energy (kW-h/ton) required to pass through more than %80 of the particles from 100  $\mu\text{m}$  sieve

Material	$E_i^*$
Bauxite	9.45
Coal	11.37
Granite	14.39

\* When the material is dry, these values should be multiplied by 1.34

$$E = K_B \frac{1}{\sqrt{X_2}}$$

$$\frac{P}{T} = 1,46E_i \left( \frac{1}{\sqrt{D_P}} - \frac{1}{\sqrt{D_F}} \right)$$

P: Power, hp

T: Feeding speed, ton/min,

$D_F$ : Feeding diameter, ft,

$D_p$ : Product diameter, ft

# CHARACTERISTICS OF COMMINUTED PARTICLES

- Unlike an ideal crusher or grinder, **an actual unit does not yield a uniform product**, whether the feed is uniformly sized or not.
- The product always consists of a **mixture of particles, ranging from a definite maximum size to very small particles.**
- Some machines, **especially in the grinder class**, are designed to control the magnitude of the largest particles in their products, but **the fine sizes are not under control.**
- In some types of grinders fines are **minimized, but they are not eliminated.**
- If the feed is homogeneous, both in the shapes of the particles and in chemical and physical structure, the shapes of the individual units in the product may be quite uniform; otherwise, the grains in the **various sizes of a single product may differ considerably in shape.**



# SIEVE ANALYSIS

Also known as screen analysis.

Standard screens are used to measure the size (and size distribution) of particles in the size range between about 3 and 0.0015 in. (76 mm and  $38\ \mu\text{m}$ ).



## Mesh

- Testing sieves are made of **woven wire screens**, the mesh and dimensions of which are carefully standardized.
- The openings are **square**.
- **Each screen is identified in meshes per inch.**
- The actual openings are smaller than those corresponding to the mesh numbers, however, because of the thickness of the wires.



Fig. Sieves w/  
different mesh  
and pan



Fig.  
Sieve shaker

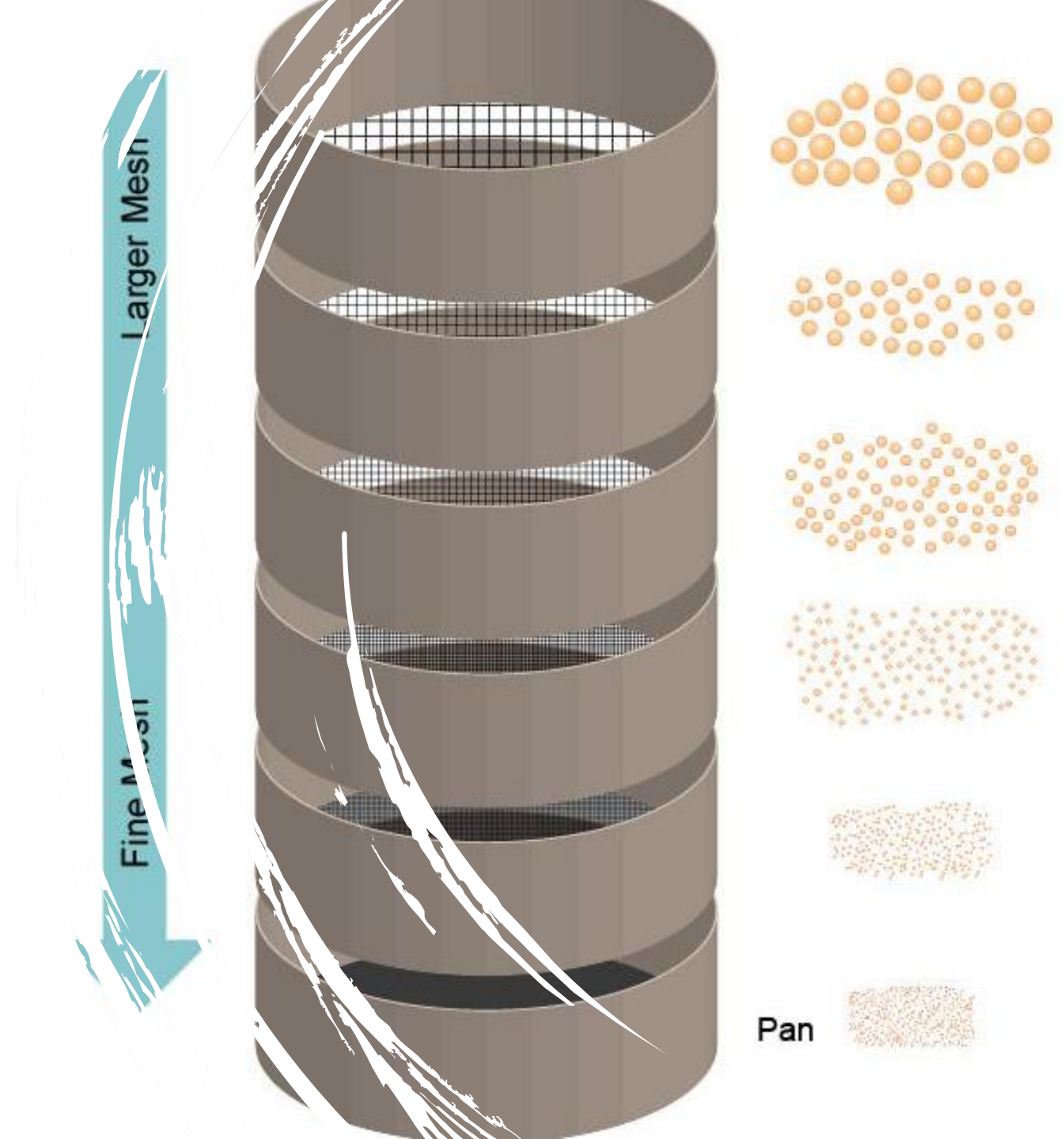


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- In making an analysis a set of standard screens is arranged serially in a stack, **with the smallest mesh at the bottom and the largest at the top**.
- The sample is placed **on the top screen** and **the stack shaken** mechanically for a definite time.
- The particles retained on each screen are removed and **weighed**, and the masses of the individual screen increments are converted to **mass fractions or mass percentages** of the total sample.
- Any particles that **pass the finest screen** are **caught in a pan** at the bottom of the stack.

Sieve Analysis

Points to Remark



## TYLER STANDARD SCREEN SCALE

Mesh	Clear opening, in.	Clear opening, mm	Approximate opening, in.	Wire diameter, in.
	1.050	26.67	1	0.148
†	0.883	22.43	$\frac{7}{8}$	0.135
	0.742	18.85	$\frac{3}{4}$	0.135
†	0.624	15.85	$\frac{5}{8}$	0.120
	0.525	13.33	$\frac{1}{2}$	0.105
†	0.441	11.20	$\frac{7}{16}$	0.105
	0.371	9.423	$\frac{3}{8}$	0.092
$2\frac{1}{2}$ †	0.312	7.925	$\frac{5}{16}$	0.088
3	0.263	6.680	$\frac{1}{4}$	0.070
$3\frac{1}{2}$ †	0.221	5.613	$\frac{7}{32}$	0.065
4	0.185	4.699	$\frac{3}{16}$	0.065
5†	0.156	3.962	$\frac{5}{32}$	0.044
6	0.131	3.327	$\frac{1}{8}$	0.036
7†	0.110	2.794	$\frac{7}{64}$	0.0328
8	0.093	2.362	$\frac{3}{32}$	0.032
9†	0.078	1.981	$\frac{5}{64}$	0.033
10	0.065	1.651	$\frac{1}{16}$	0.035
12†	0.055	1.397		0.028
14	0.046	1.168	$\frac{3}{64}$	0.025
16†	0.0390	0.991		0.0235
20	0.0328	0.833	$\frac{1}{32}$	0.0172
24†	0.0276	0.701		0.0141
28	0.0232	0.589		0.0125
32†	0.0195	0.495		0.0118
35	0.0164	0.417	$\frac{1}{64}$	0.0122
42†	0.0138	0.351		0.0100
48	0.0116	0.295		0.0092
60†	0.0097	0.246		0.0070
65	0.0082	0.208		0.0072
80†	0.0069	0.175		0.0056
100	0.0058	0.147		0.0042
115†	0.0049	0.124		0.0038
150	0.0041	0.104		0.0026
170†	0.0035	0.088		0.0024
200	0.0029	0.074		0.0021
For coarser sizing: 3- to 1½-in. opening				
			3	0.207
			2	0.192
			1½	0.148

# SIEVE ANALYSIS

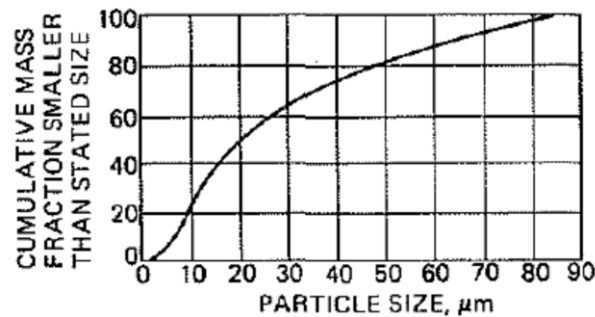
The characteristics of one common series, the Tyler standard screen series is given at the LHS.

This set of screens is based on the opening of the 200-mesh screen, which is established at 0.074 mm. The area of the openings in any one screen in the series is exactly twice that of the openings in the next smaller screen.



# MIXED PARTICLE SIZE AND SIZE ANALYSIS

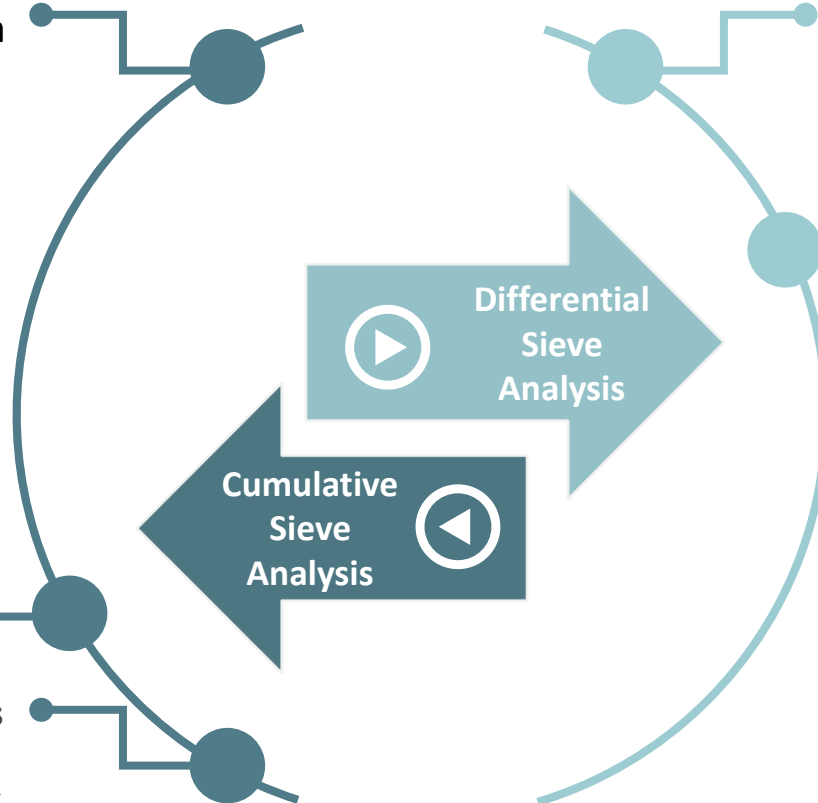
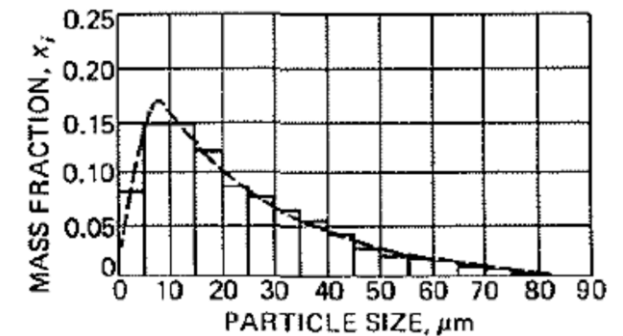
By adding, consecutively, the individual increments, starting with that containing the smallest particles, and tabulating or plotting the **cumulative sums against the maximum particle diameter in the increment.**



Equation for Cumulative Sieve Analysis

$$\Phi = \Delta\Phi_1 + \Delta\Phi_2 + \cdots \dots \dots = \sum_1^n \Delta\Phi_n$$

Information from such a particle-size analysis is tabulated **to show the mass or number fraction in each size increment as a function of the average particle size (or size range) in the increment.**



- In principle, methods based on **the cumulative analysis are more precise than those based on the differential analysis**, since when the cumulative analysis is used, **the assumption that all particles in a single fraction are equal in size is not needed.**
- **The accuracy of particle-size measurements**, however, is rarely great enough to warrant the use of the cumulative analysis, **and calculations are nearly always based on the differential analysis.**

# LAB EQUIPMENT

## ARMFIELD SOLIDS STUDY HANDLING BENCH



LHS : Tumbling Mixer | RHS : Ball Mill Grinder



## 1 - Grinding

- The experimental setup is shown in photograph on the left.
- Above, the details of this bench can be seen. The photograph above at the LHS is a **Tumbling Mixer** (though it is not a part of this experiment).
- Above, at the RHS, the **Grinder** is presented. There is a slide-open lid on its body part which is used to put the sample that is going to be grinded and the balls into the grinder.

# LAB EQUIPMENT

## ELECTRICITY METER

- 675 ROUNDS / kWh -



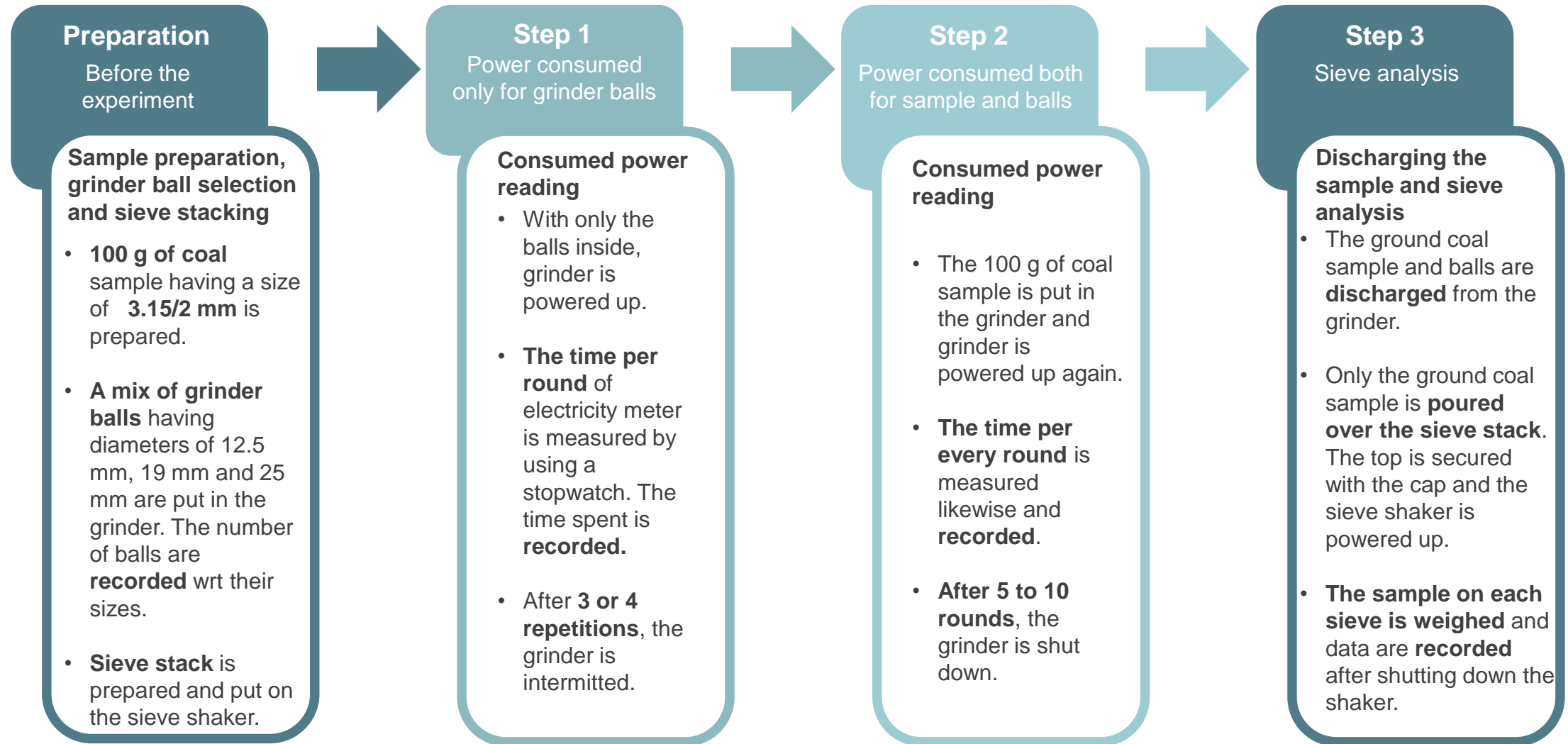
LHS : Grinding Balls | RHS : Sieve Shaker

## 2 – Grinding & Sieve Analysis

- The electricity consumed for grinding is read by using an electricity meter (photograph on the left).
- The photograph above at the **LHS** is the **Grinding Balls at different sizes** used in the experiment.
- At the RHS above, **Sieve Shaker** machine is seen. The sieves are placed on it (with a cap on and a tray at the very bottom) in between the two long screws and all of them are secured by using nuts.



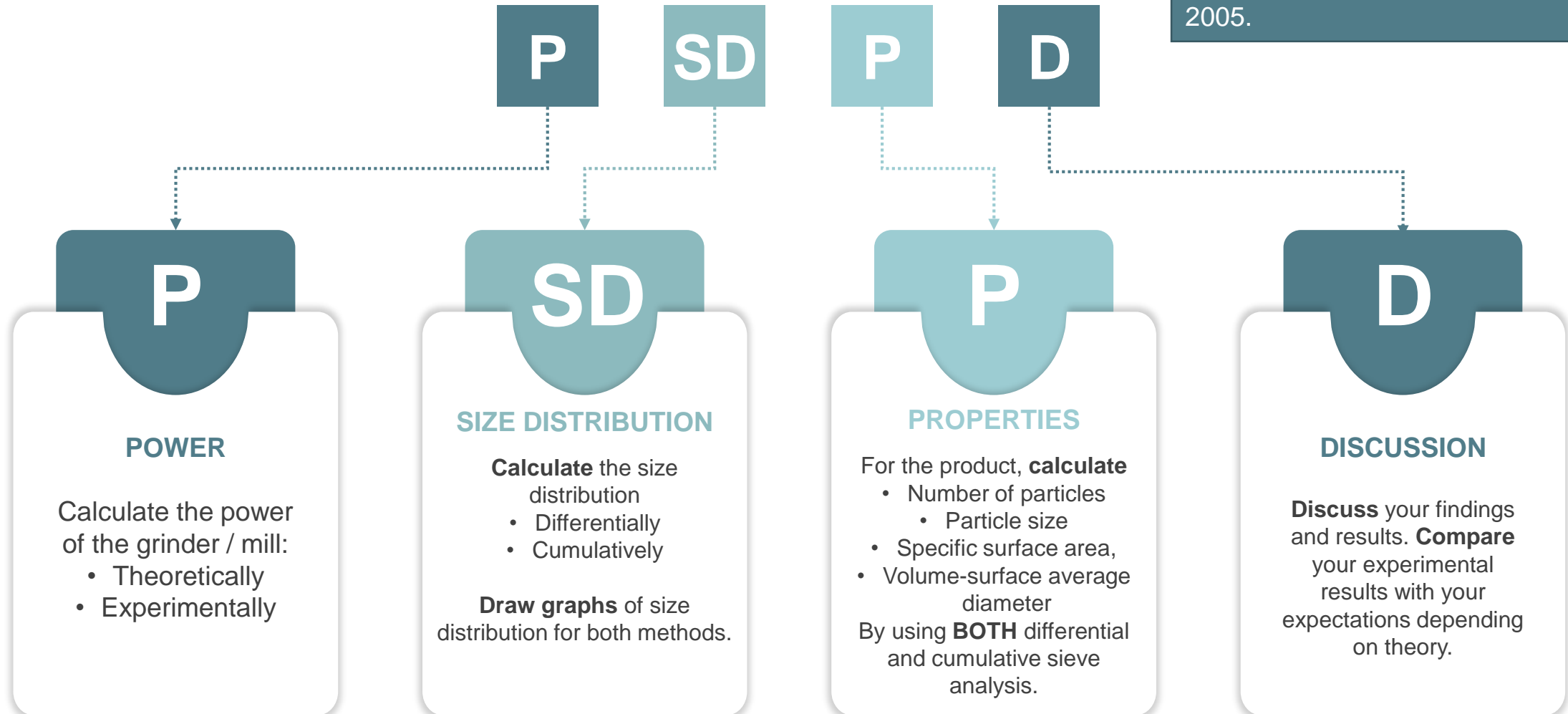
# EXPERIMENTAL PROCEDURE



# OUTPUTS

Please refer to the following reference for further information and for the calculations:

McCabe, W.J., Smith, J.C., Harriot, H., Unit Operations of Chem. Eng., 7<sup>th</sup> Int. Ed., McGraw Hill Book Co., New York, 2005.





# DATA SHEET

Initial coal sample weight : 100 g  
Feed Size : 3.15/2 mm  
Electricity meter : 675 rounds / kWh

Please refer to the following reference  
for further information and for the  
calculations:

McCabe, W.J., Smith, J.C., Harriot, H.,  
Unit Operations of Chem. Eng., 7<sup>th</sup> Int.  
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2005.

## 1 - GRINDING

Round # (Only for grinder balls)	Time spent per round (min)
1	2.42
2	2.45

Round # (For both sample and grinder balls)	Time spent per round (min)
1	2.30
2	2.37
3	2.38
4	2.38
5	2.40
6	2.40

## 2 - SIEVE ANALYSIS

Sieve #	Sieve Diameter (mm)	Weight of sample on the sieve (g)
1	2	48.2
2	1	30.9
3	0.500	12.2
4	0.25	5.1
5	0.125	2.6
Pan	-	1.0
Total		100