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A Review of Size Reduction techniques Using Mechanochemistry Approach

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Abstract

Size reduction is one of the most widely used unit operations in the chemical and allied industries. Comminution is the process of exposing materials to stress through collisions and reducing the size of bigger solid units into smaller unit masses. Stress and other impacts are transmitted to the larger unit via the mechanochemical process. Mills and crushers are two of the most used production technologies. The concept of mechanochemical reactions is not new; scientists have been using it for a long time.Even though many various size reduction techniques are available, the knowledge of the qualities of the material to be prepared is the most important factor. As a smart material, size reduction provides benefits like as enhanced surface area and the creation of unique slow/control nutrients (drugs, fertilizers...etc).

Key words: Size reduction, Mechanochemistry, Crusher, Ball milling..

1. Introduction

Recently, the increasing number of applications of mechanochemistry to the synthesis of chemicals and preparation of nano and fine materials has driven a novel, rapid surge of interest[1]. Therefore, the study of mechanically activated transformations is, presently, one of the most rapidly growing subjects in organic and materials chemistry. Yet, a lot ofthreatening issues discourage endeavors to shift technology from the laboratory domain to the industry one.

Particle size is one of the most important factors influencing the powder process, as it affects mixing, stream, and compaction qualities[2]–[4]. Reducing particle size is critical for increasing surface territory and flow properties. Larger estimated particles have problems with dissolvability since they need more time to dissolve[5]. In some rare circumstances, particles are not soluble in any liquids. Particles must be dissolved in a suspension with the same particle size as the dissolving particles in such circumstances. The significance of particle size in absorption is that when particle size decreases, the surface area of these particles increases, resulting in enhanced absorption[6], [7].

2. Mechanochemistry

The first definition of mechanochemistry was suggested by Ostwald in the late 19th century, originated from industrial phenomenology. In other words, from mineral processing and the related practices of combination and grinding, he studied chemical reactions from an energetic point of

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view[2], [8]–[10]. Heinicke,formulated a featured definition which has become accepted by the scientific community. He stated that mechanochemistry is a branch of chemistry that is concerned with chemical and physicochemical transformations of substances in all states of accumulation produced by the effect of mechanical energy [11], [12].
Another definition from the IUPAC Compendium of Chemical nomenclature states that mechanochemistry is a chemical reaction that is induced by the direct adsorption of mechanical energy[2], [4], [9], [13]. Tribochemistry, or impact chemistry, came from different origins but deals with similar subjects, and nowadays both expressions are unified as mechanochemistry [6], [14].
In 1974, Juhasz emphasized that processes influenced by mechanical activation can be divided into primary and secondary processes[11], [15]. The primary processes include the increase in internal and surface energies, increase of surface area and decrease of coherent energy of solids which all generally increase the reactivity of the mineral. The secondary processes such as aggregation, adsorption and crystallization take place spontaneously in activated systems during or after grinding has been completed [11], [12], [15], [16].

Mechanochemistry has been practiced for over a century, but the core question is which processes arethe subject of mechanochemistry is still debated. Moreover, as new areas of science and technology discover thepossibilities offered by mechanical treatment, the views on mechanochemistry shift to accommodate new systemsand phenomena[12], [16], [17].

3. Milling Types

The multi-stage character of mechanical activation (MA) requires high-energy mills with different working regimes (compression, shear, impact)[14], [15]. The principles of the most frequently applied mills are shown in Fig. 1.

There are several variables that influence the milling process, e.g., type of the mill, material of milling media, the ballto powder ratio, filling extent of the milling chamber, milling atmosphere, milling speed, milling time, etc[17]–[21]. The purpose of an ideal device for a mechanochemical synthesis (MCS) is to insert the maximum amount of energy into the treated solid to enable the accumulation of the inputenergy. This energy is responsible for the occurrence of defects, which greatly affect chemical reactivity[3], [4], [9], [22].

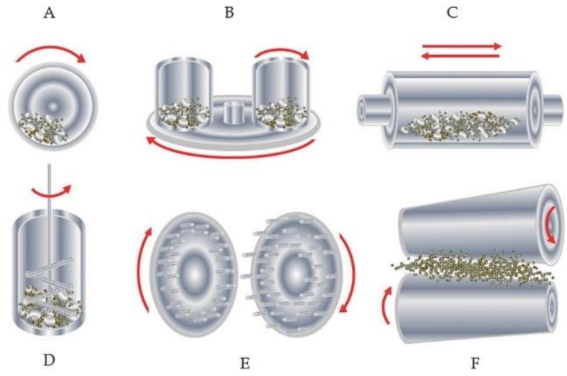


Fig. 1. Types of mills applied on mechanochemistry; A – ball mill, B – planetary mill, C – vibratory mill, D – stirring ball mill (attritor), E – pin mill, F – rolling mill[18].

The most significant advancement formaterial science in recent years has been the increased use of mechanical activation, mainly in organic synthesis[23]. Low-energy mechanical mixing/milling is used to enable solvent-free reactions and prepare co-crystals, whereas high-energy milling is used to break primary bonds. Mechanophores are signaling molecules that are embedded into materials[5], [6], [14], [20].

In powder metallurgy and mineral processing, the mechanical force of the ball milling (BM) technique is historically used to mix granular matter, reduce particle size, refine microstructure, and increase chemical reactivity[2], [5], [7], [13], [18], [24]. The unit operation is based on the transfer of mechanical energy to powders that occurs inside the reactor of a ball mill during collisions between milling instruments.

In the volumes of powder mixture caught either between colliding balls or between a ball and the reactor wall, processes on the mesoscopic and microscopic dimensions occur impulsively. Cold-welding and fracture, as well as physical and chemical reactions, can emerge from the mechanical deformation of powder particles[3], [10], [25], [26].

During high-energy milling, the size of crystals decreases to some critical value. Further energy supply to these crystals of limiting size causes further deformation of crystals, energy accumulation in the volume or at the surface of crystals, and subsequently amorphization[18].The particle size reduction is in many cases are complicated byparticle size enlargement, where smaller particles are puttogether to form larger entities in which the original particles can still be identified. This phenomenon, called the equilibrium state of milling, was experienced with solids, and is close lyrelated to the effects of aggregation and agglomeration[2]–[4], [18]–[20], [26].

Size reduction is the process of reducing bigger solid unit masses into smaller or finer particles utilizing various techniques such as jaw crushers, gyratory crushers, roll crushers, hammer mills, and ball mills[5], [14]. The attrition and impact principles are mostly applied here. Size reduction, also called as comminution, diminution, or pulverization, is accomplished primarily by two methods: precipitation and mechanical. Precipitation entails dissolving in a suitable solvent, while the mechanical phase entails submission to mechanical forces via grinding machines. The former is mostly utilized to make bulk pharmaceuticals, inorganic raw materials, and compounds such as magnesium and calcium carbonate[5], [11], [12], [27]–[30].Several factors influence size decrease. Moisture content, hardness, stickiness, toughness, slipperiness, abrasiveness, and other physical qualities are among them. Other material parameters, including as the product's coarse and bulk density, material structure, flow, form, and size, all have an impact on size reduction[6], [15], [31]–[33].

The primary goal of particle size reduction is to maximize particle surface area. Other benefits of size reduction include improved and uniform mixing of powders due to the particles' limited size range, quicker absorption, reduced sedimentation, improved physical appearance, and higher stability in the case of emulsions [15], [19], [27], [34], [35].

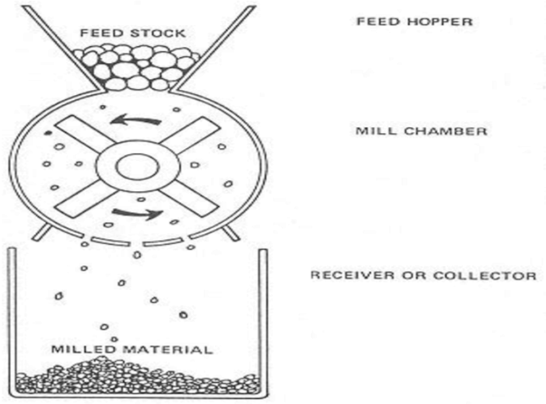
4. Mechanisms of Size Reduction

The mechanisms have shown that a variety of pressures are required to acquire a larger education[5], [18], [36]. The most typical method of size reduction is as follows: [Table1].

Parts of Size Reduction Equipment in General

Hopper, milling chamber, and Discharge chute

are the three basic components of a size reduction apparatus. (Figure 2)[5], [37].



Three basic mill components.

Figure 2: General Parts of Size Reduction Equipment (Three basic Components) [5], [37].

5. Types of Size Reduction Methods

Grinding, compression, and impact forces are examples of unit activities used in size reduction. Compression, impact, and attrition forces are among the forces involved.
During size reduction, the material is put under stress, and the resulting internal strains cause the material to deform or shatter. The hardness of the material, its structure, the amount of heat generated in the material, and its susceptibility to crack are all factors that influence the degree of deformation. Harder materials also need more energy to fracture[38], [39]. The sort of impact required for size reduction is determined by the nature of the materials. Softer materials, for example, require shearing forces, while fibrous materials require a mix of shearing forces and impact[2], [26].

Some of the common mechanical size reduction methods are listed as follows:

Equipment for cutting: Extensively used in the food industry for cutting of vegetable or meat products. A bowl chopper is a common example.
Equipment for milling: These include both grinders and crushers. Grinders make use of impact and shear forces for size reduction. Examples include hammer mills, roller mills and hammer mills[9]. Crushers can be commonly seen in usage in the sugar cane industry where, sugar cane is subjected to compression forces.
Equipment for homogenization: In homogenization, two immiscible liquids are combined into an emulsion thereby dispersing the particles. During

this the liquid is forced through a narrow nozzle resulting in shear, impact, turbulence, and compressive forces acting on the particles in the liquid[10], [13], [36], [40].

6. Equipment for size reduction:

6.1. Ballmill

The ball mill is made up of a zirconia, steel hollow cylindrical rotating shell coated with porcelain or high carbon steel plate. The shell can be filled with steel balls or stones up to half of its volume[40]. The balls are uniform in weight but vary in size depending on the amount of feed used. The size reduction is caused by the balls grinding against the substance to be comminuted. The size of the ball, the speed of rotation of the shell, and the feed rate all influence the particle size and form of the material to be comminuted[18], [40].

When the shell is turned, centrifugal forces inside the shell propel the ball along the mill wall, where it is dropped owing to gravitational force when it reaches a certain height.This ensures that the material is ground[18], [19], [19], [40]. Due to the controlled environment in a ball mill, the fine grinding of a wide range of materials and the grinding of dangerous substances are some of the additional advantages of ball mills[34], [37], [41], [42]

Fig. 3. *Planetary ball mill (Pulverisette-7, Fritsch, Germany).*

6.2. Hammermill

A fast-moving hammer is coupled to a high-speed rotor in a cylindrical case in a hammer mill. On a horizontal shaft are installed hammers with up to four digits. It works based on a collision between the hammer and the particles to be reduced in size. The materials are introduced into the hammer mill through the top of the metal casing and are directly exposed to the hammer during operation, resulting in size reduction. The particles are then gathered at the receiver after passing through a screen at the bottom. The feed rate, screen size, and rotor speed are all important aspects of size reduction. A hammer mill is usually turned at a speed of 2500-5000 rpm[37].

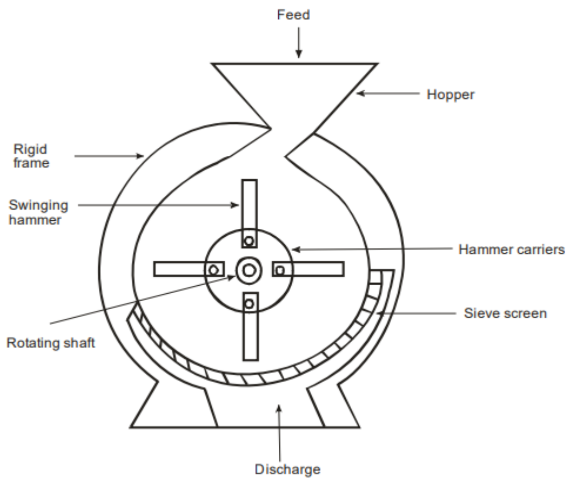


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Fig. 4. A Conventional Hammer Mill [37].

6.3. Jaw crushers

The jaw crusher is V-shaped, with one moveable jaw and the other fixed, forming a 10-20° angle between them. The materials for size reduction are introduced between the two jaws at the top, and the moveable jaw applies compressive force.

The jaw's size is reduced from top to bottom, with larger lumps in the higher half breaking and plunging into the lower, narrower portion below. At the next stroke, the cracked fragments are further decreased. The jaw crusher is normally run at 300 times per minute [5], [27] [37].

Table 1: Size reduction mechanisms and their approximate particle size[5], [34], [37]**.**

Methods	**Examples**	**Approximate size of particle ((µm)**
Attrition	Colloidal mill and Roller mill	1-50
Impact and attrition	Ball mill and Fluid energy mill	1-2000
Impact	Hammer mill and Disintegrator	50-8000
Compression	Roller mill and Pestle-Mortar	50-10,000
Cutting	Scissors, Cutter mill and Shears	100- 80,000

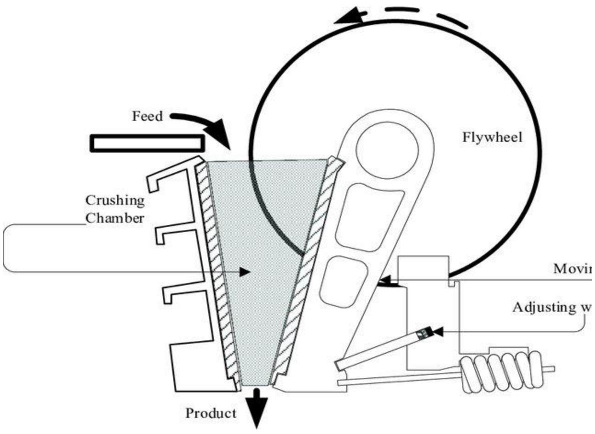


Fig. 5. V-shaped jaw crusher [5].

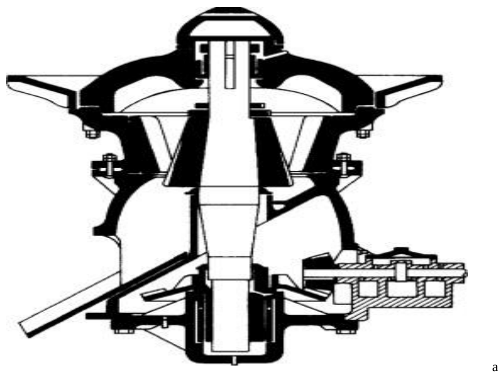


Fig. 6. Gyratory crusher[42]

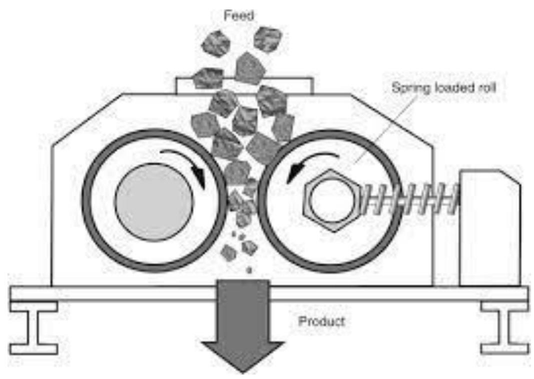
6.4. Gyratorycrusher

The solid materials are fed between circular jaws. The solid materials are introduced into a V–shaped notch between the metal casing and the head. Size reduction happens in this V-section where the materials are caught up and the comminuted particles pass out from the bottom. The speed of operation varies from 100 to 450 gyrations per minute. The gyratory crusher has added advantages like lower energy consumption and reduced maintenance compared to jaw crusher[42].

6.5. Rollcrushers

Roller crushers are made up of two equal-sized and smoothened rolls that rotate at the same speed, one clockwise and the other anti-clockwise. The two rollers are appropriately hefty, rotating on horizontal axes that are parallel. Depending on the use, the rolls can also be jagged. The key factor influencing the extent of size reduction is the coefficient of friction between the substance to be size decreased and the surface of the roller. In a roll crusher, larger particles can be accommodated since size reduction is impacted by impact, shear, and compression - all of which act in concert[43]

Fig. 7. Model of Roll crushers[43].



7. Advantages and applications of mechanochemical processing

The fundamentals features of mechanochemical processing include combustion reactions, formation of amorphous phases, phases of novel crystalline synthesis, mineral and waste processing, metals refining, ultrafine powder production, production of a fine dispersion of second-phase particles, an extension of solubility limits, refinement of the matrix microstructure and nanoparticle formulation, the possibility of alloying difficult-to-alloy elements, and extensibility [10], [13], [14]. Several of the most important applications/advantages of mechanochemistry in different fields of minerals and materials treatment are summarized below [18], [19], [40], [44], [45]:

- Regeneration of drilling mud, and production of drill-hole cementation mixtures.
- Increase of fertilizer efficiency.
- Production of special concretes for building.
- Simplifying the production of cement when milling the reactants by depressing the furnace temperature and reaction time.
- Grinding of clinker for improvement of compressive strength and reduction of the tuning time of concrete.
- Improving parameters of moreover processing of the product; increasing efficiency of reaction by changing the properties of the mixture.
- Creating ahigh-quality industrial material through processing some secondary materials (which could not be used in classic technological systems).
- Preparation of useful materials from initial sources that cannot be processed by other methods (e.g. converting appetites of low quality to fertilizer of approximately the same efficiency as superphosphates).
- Implementing certain high temperature reactions with acceptable rates at normal pressure.
- To integrate two or more technological processes (e.g., mixing, simultaneous refining and activation in the production of filled polymers during mechanical activation).
- To manufacture a new product of a high quality or with novel properties by mechanical processing of initial or intermediate products, which cannot be obtained by other methods[15], [44].

8. Conclusion

Mechanochemistry has made significant progress during the last ten years, it is one of the plethora types for size reduction instruments. The mechanochemical process of size reduction is major for diverse industries like chemical, pharmaceutical, agricultural, etc. Currently, an abundance of size reduction equipment with varying capacities and sizes is available. They could handle a wide variety of raw materials. The nature of feed to be processed is also as critical as the choice of size reduction equipment. Overall, size reduction helps in achieving uniform mixing, homogeneity, and ideal flow of the materials.

Conflict of Interests

The authors declare that they have no conflict of interests regarding this work.

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