Particle Size Reduction

Dr. Isra Dmour

Credit: Prof. Nizar Al-Zoubi

Particle Size Reduction

سحق

- Other terms used to describe the operation: milling, grinding, crushing, chopping, comminution, micronizing.

تقطيع

milling لها اقرب إلى grinding +

- Most materials used in pharmaceuticals must be milled at some stage during the production of raw material or dosage form

pre milling → عشان نخفف جهد الماكينة الاصلية

Milling	الطحن العام(تقليل حجم الجزيئات ميكانيكيا)
Grinding	الطحن بالاحتكاك او الضغط(للمواد الصلبة)
Crushing	السحق(كسر القطع الكبيرة الى اجزاء اصغر)
Chopping	التقطيع(للمواد مثل الاعشاب والجذور)
Communication	مصطلح عام يشمل كل عمليات تصغير الحجم سواء كانت سحق او طحن او تقطيع
Micronizing	التصغير الى حجم الميكروميتر او اقل

* للشو الهدف من عمليات تصغير الحجم ؟!

Particle Size Reduction

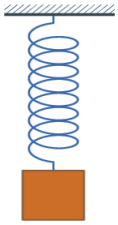
- ***Objectives of particle size reduction:*** distribution بتزيد
  1. Facilitating drug release (dissolution rate)
  2. Exposing cells prior to extraction extraction تحسن الخلايا قبل ← الدواء يوصل للخلايا اسرع
  3. Reducing the bulk volume of material → For storage (لسهولة التخزين)
  4. Facilitating drying
  5. Helping good mixing
  6. Increasing adsorption capacity
  7. Some excipients need to be in very fine powder to do well their function (lubricants, colors)

3

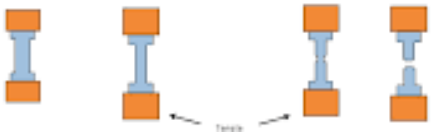
Theory of Size Reduction

Fracture mechanics

- Reduction of the particle size requires application of mechanical stress to the material.
- Materials respond to stress by **yielding**, with consequent generation of strain. تغير شكل الجزء لانتهاية القوة التي تعرضت
- **Hooke's law.** تكسر الجزء



- **Stress**: force
- **Strain**: deformation or elongation of a solid body due to applying a strs/force
- **Elastic**: reversible القوة لما اشيلها برجع الزجيرداني مكانه
- **Plastic**: permanent , irreversible لما اشيل القوة ما برجع الزجيرد



4

Hooke's law:
مقدار التشوه (strain) يتناسب طردياً مع القوة او الاجهاد (stress)

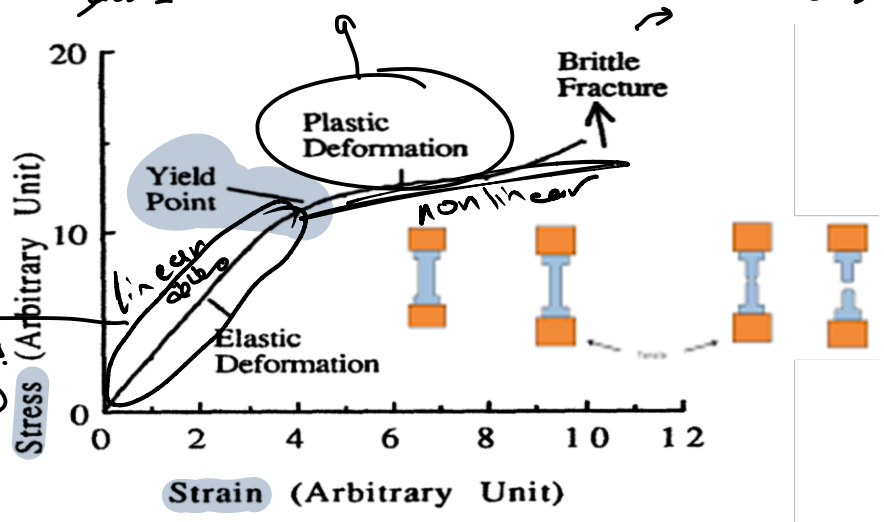


Fig. 19.1 Stress–strain diagram for a solid.

the yield point is the point on a stress-strain curve that indicates the limit of elastic behavior and the beginning of plastic behavior

5

Theory of Size Reduction

Fracture mechanics

- The initial portion of the stress-strain diagram is linear and is defined by Hooke's law.

- In this portion the deformation is reversible (elastic deformation), i.e. the particle retains its shape if the stress is removed.

- After a certain point (yield point) the relation becomes nonlinear and the deformation becomes irreversible (plastic deformation).

6

Theory of Size Reduction

Fracture mechanics

التكسر يبدأ عند نقطة ضعف عانت بالجزيء

انتشار الشقوق

Crack propagation

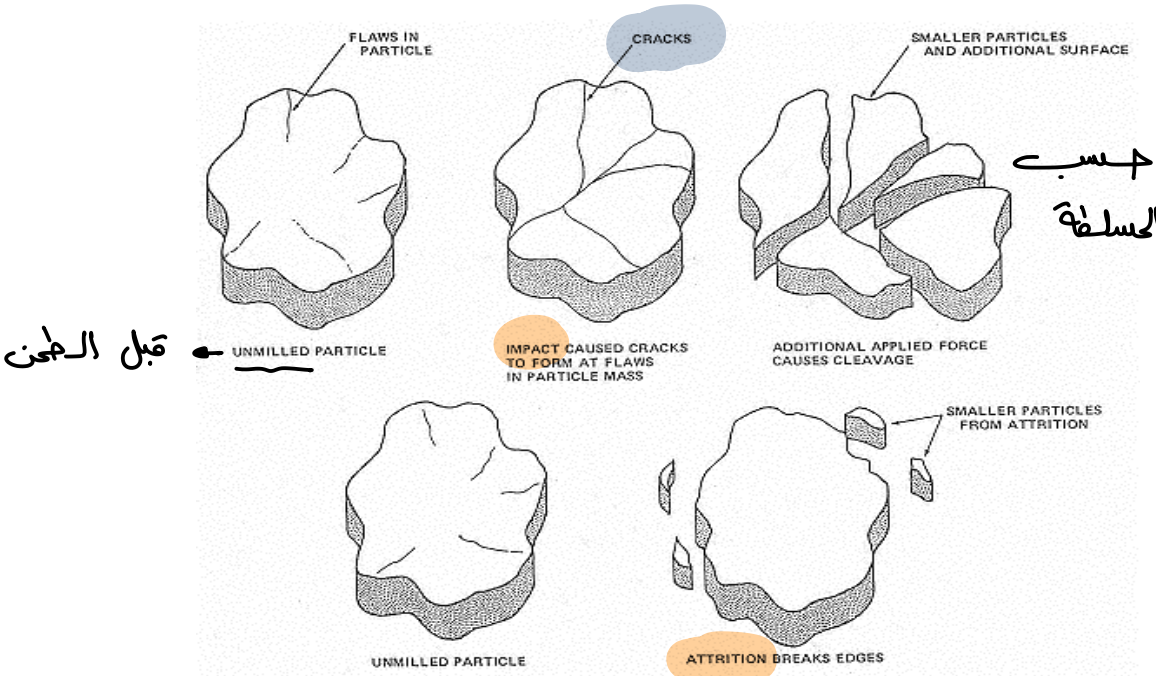
- Size reduction begins with the opening of any small cracks that were initially present.
- Flaws (defect) عيب
- Larger particles fracture more readily than small particles as they contain more cracks.

weakness point (cracks or flaws)

تكسر

7

* الجزيئ الاصغر يحتاج طاقة اعلى للكسر
* لانه فيهم تشققات اكبر Small الكثر من Large في cracks



التكسر يختلف حسب نوع القوة المسلطة على الجزيء

قبل الطحن

بعد التحجيم

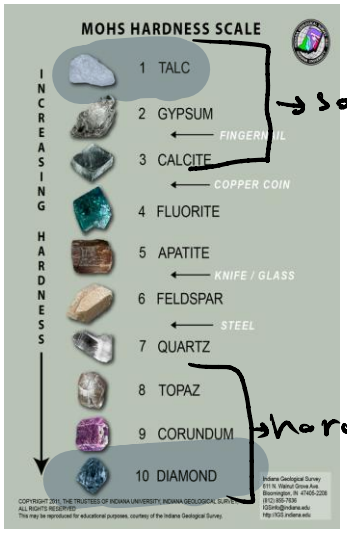
8

* العوامل إلي بتأثر على تصغير حجم الجزيء
* عشان اعرف على شو اطحن و ايش الماكينة المناسبة.

Influence of material properties on size reduction

بصنف المواد حسب صلابتها

Surface hardness (Mohs' scale)



- The hardness of material can be described qualitatively by its position in Mohs' scale.
  - Materials from 1-3 are described as soft
  - Materials from 8-10 are described as hard
- Hardness is related to abrasiveness. (شحط)
- Hard materials may cause abrasion to the mill.

الصلبة بتشحط الجهاز وبتخربه

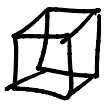
كل ما كانت المادة صلبة اكثر كانت قدرتها على شحط المواد الاقل صلابة اكبر.

Influence of material properties on size reduction

تركيبة المادة

Material structure

* Crystals بتكسر من عند الخطوط بين الجزيئات



- **Crystalline materials** fracture along crystal cleavage planes; noncrystalline materials fracture at random.

* إلي مش crystal بتكسروا بشكل عشوائي

الياف / خيوط

- ***Fibrous materials*** (e.g. crude drugs) need cutting or chopping action and can not be milled effectively by compression or impact.

* Fibrous بقطعهم تقطيع اذا بتضغط ما بطحن الشي.

Q: ؟ crude drug كيف بصغر حجمها
A: من خلال التقطيع answer

Influence of material properties on size reduction

Moisture content

- The presence of more than 5% water hinders comminution and often produces a sticky mass upon milling.

Stickiness

- Sticky materials may adhere to the surface of milling machine or the screen
- This is a problem of gummy and resinous materials.

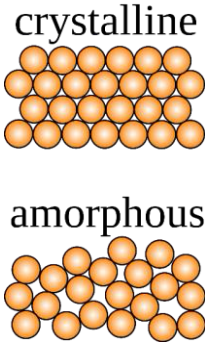
Toxicity and harm

Potential of explosion (fine)

11

Effect of size reduction on material properties

Milling of material may lead to:



1. Change of the polymorphic form
2. Dehydration of hydrates
3. Development of amorphous structure
4. Damage of thermolabile drugs due to heat involved.
5. Development of free static charge

12

* الطاقة الحتاجة لتكسير الجزيئات

Energy requirements

الأجهزة بتستخدم من 2% من الطاقة للتكسير

The most efficient mills utilize as little as 2% of the energy input to fracture particles.

- The rest of energy is lost in: Lost Energy → 98%

1. elastic deformation of unfractured particles (تشوه مرن للجزيئات الي ما تكسرت)
2. transport of materials within the milling chamber
3. friction between particles → الاحتكاك بين الجزيئات
4. friction between particles and mill الاحتكاك بين الجزيئات والجهاز
5. heat
6. vibration and noise الاهتزاز والضوضاء

* قوانين لحساب الطاقة الحتاجة للتكسير

Energy requirements

Energy ↔ surface area

Rittinger's theory يربط عملية التكسير بال surface area

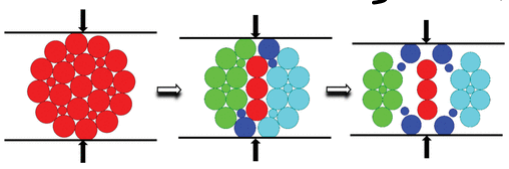
لـ الطاقة المستهلكة تتناسب طرديًا مع زيادة surface area الناتجة عن تكسير الجزيئات.

$$E = K_R(S_n - S_i)$$ positive

S_i : the initial surface area,

S_n : new surface area

K_R = Rittinger's constant of energy per unit area مقدار الطاقة لكل وحدة مساحة جديدة



Φ Energy ↔ diameter

Energy requirements

Kick's theory diameter/ن

$$E = K_K \log \frac{d_i}{d_n}$$

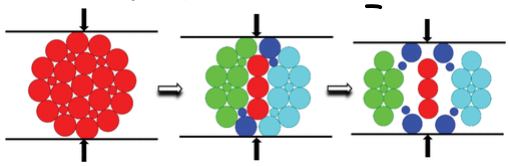
positive

d_i : the initial particle diameter,

d_n : new particle diameter

K_K = Kick's constant of energy per unit mass

ي كمية الطاقة لكل وحدة كتلة



بعض diameter

15

اشهر نظرية للطاقة

Energy requirements

Bond's theory

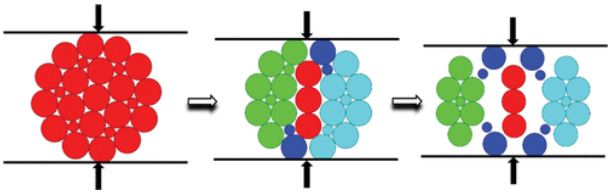
$$E = 2k_B\left[\frac{1}{d_n} - \frac{1}{d_i}\right]$$

positive

K_B : Bond's work index, الطاقة المطلوبة لطحن الحادة إلى حجم معين

d_i : the initial particle diameter,

d_n : new particle diameter



16

* تأثير الطحن على توزيع الحجم

Influence of milling on size distribution

- As milling progresses, the mean particle size decreases, and a material with initially a monomodal size distribution develops a bimodal size distribution. اكبار يقلوا
- The primary component gradually decreases in weight and the secondary component increases in weight. كانت كلها كبيرة بعدين صارت وحدة صغيرة
- Continued milling tends to eliminate the primary component to give a positively skewed (log normal) distribution with narrow size range.
- Milling rate follows first order kinetics

يعتمد على الكمية

* على ماذا دت كمية الجزيئات بتزيد سرعة الطحن

في البداية ، المادة ممكن تكون monomodal (كل الجزيئات تقريباً نفس الحجم) مع التكسير تبدأ تظهر bomodal distribution (مجموعة صغيرة من الجزيئات الكبيرة واخرى صغيرة) ، مع استرار الطحن ، الجزيئات الكبيرة تقل تدريجياً ويصبح التوزيع log normal (منحرف ايجابي) بحجم متقارب اكثر.

17

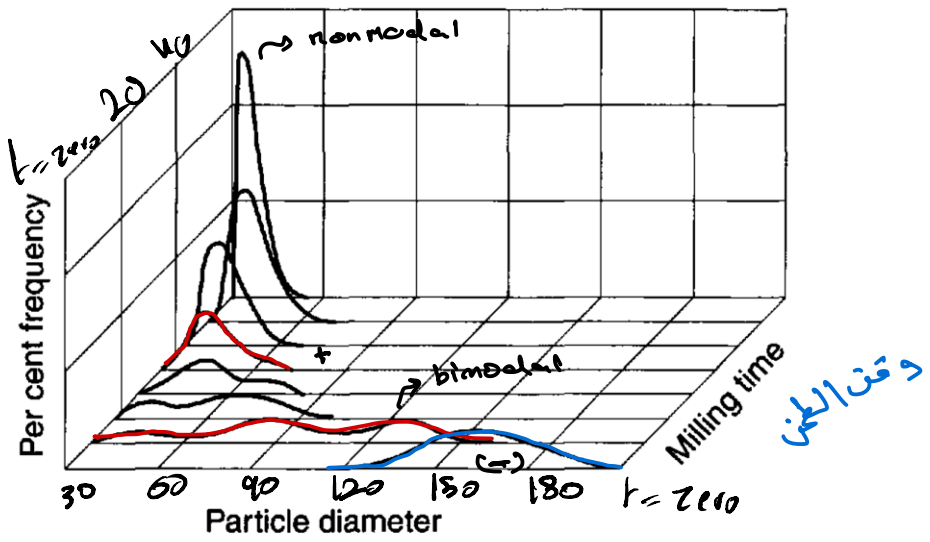
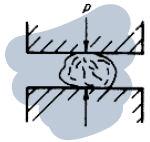
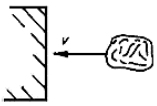
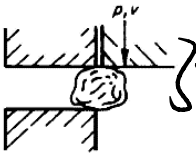
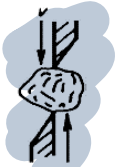


Fig. 11.2 Changes in particle size distributions with increased milling time.

18

Mechanisms of size reduction

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

19

Mechanisms of size reduction

- There are four different mechanisms of size reduction:

a) Cutting

The material (particle) is cut by means of sharp blades or knives.

b) Compression

The particle is crushed by application of pressure.

20

Mechanisms of size reduction

c) Impact → الجسيم يتعرض لضربة مفاجئة من جسم متحرك بسرعة او يضرب لسطح ثابت

The particle is hit by an object moving at high speed, or a moving object strikes a stationary surface. Hammer mill

D) Attrition الاحتكاك

This involves breaking down of the material by rubbing between two surfaces that are moving relative (**parallel**) to each other. Ball mill, Colloid mill

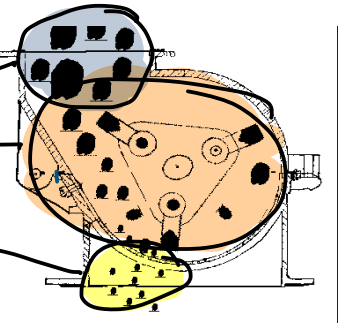
21

* شرح انواع mills

Size reduction methods

A mill consists of three basic parts:

1) Feed chute الفتحة اللي بنزل منها المادة
2) Grinding part الجزء اللي بصير عملية الطحن لقسها
3) Discharge chute الخرج اللي بطلع منه الحبيبات النهائي



- The manner (way and rate) in which an operator feeds a mill affects the product.
- In most cases the grinding effect is a combination of different mechanisms. Impact + attrition يمكن عندي جهاز يجمع بين * او compression + impact

22

بطحن الحادة بحرين بطلعها وبضيف اللي بعدها ← patch to patch
بطحن المادة وبتطلع لحالها وبضل ادخل مواد ← continue

Size reduction methods

- There are two ways of feeding: choke feeding and free feeding.
- In open-circuit milling, the operation is carried out so that the material is reduced to a certain size by passing it once through the mill.
- In closed-circuit milling, the discharge from the milling is passed through a classifier and the over-size particles are returned to the grinding chamber.
- closed-circuit milling is most valuable in reduction to fine and ultrafine size.

23

Cutting methods

- Cutter mill
  - Principle of operation: It consists of a feed, a series of knives attached to a rotor which act against a series of knives attached to the mill casing, and a screen fitted in the base which control the particle size.
  - **Uses**:
    - Coarse degree of size reduction of dried granulations
    - Grinding of crude drugs such as roots and barks before extraction

الاستخدامات:

تصغير حجم الحبيبات الجافة (granules) قبل ضغطها على شكل اقراص.

طحن crude drug (الادوية الخام) مثل الجذور او القشور قبل الاستخلاص.

24

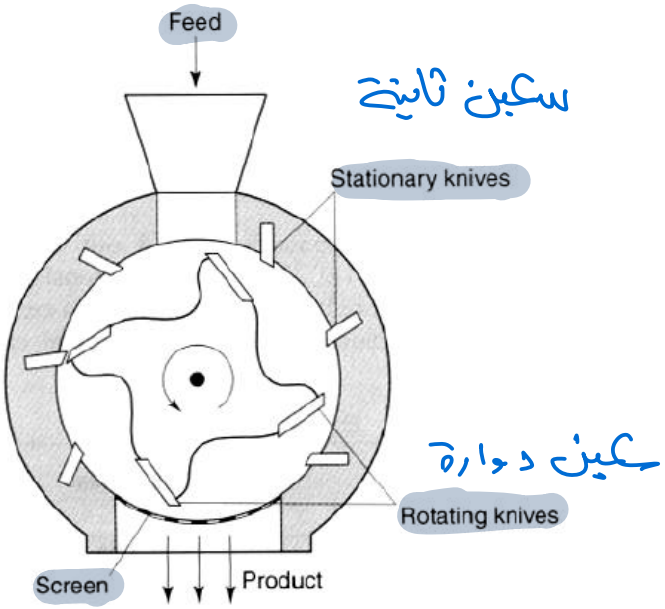


Fig. 11.6 Cutter mill.

25

Compression methods

اجهزة للكميات القليلة

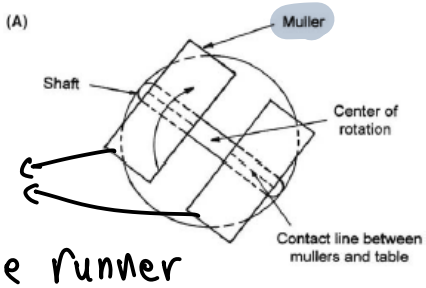
- Size reduction by compression can be carried out on a small scale by pestle and mortar. على نطاق صغير
- End runner and edge runner mills are mechanized forms of mortar and pestle-type compression. على نطاق اكبر

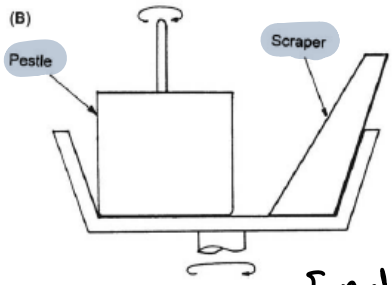
Edge

الاسطوانة بتلف

26

. Small Scale الاجهزة تستخدم لـ من هدول عين من :Q





2 muller

Edge runner

End runner

27

FIGURE 12.3 (A) Edge runner mill and (B) end runner mill.

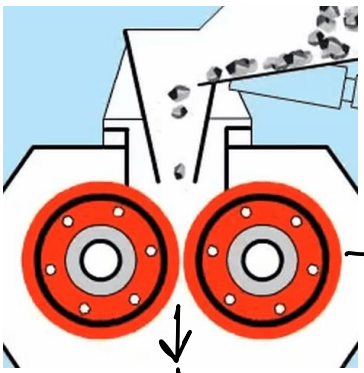
Compression methods

continue + open

Roller mills

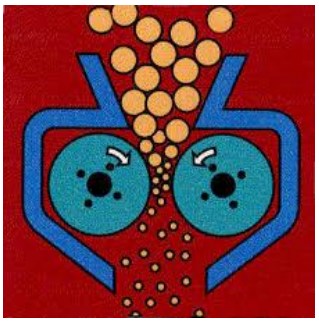
- Roller mills use two cylindrical rolls, mounted horizontally, and rotating about their longitudinal axis
- One of the rolls is driven directly while the second is rotated by friction as material is drawn through the gap between the rolls.
- Compression and attrition

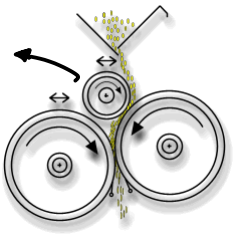
واحدة من الـ Roll موتيفة بمحرك والثانية بتتحرك نتيجة الاحتكاك بس تدخل العلوة بينهم.



حسب المسافة:-
المسافة الكبيرة ← ضغط
المسافة الصغيرة ← احتكاك

28





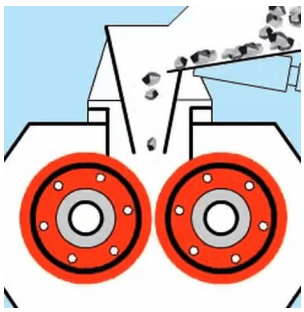
Roller mill (compression method)

Compression methods

Roller mills

* بتحكم بالمسافة حسب الحجم المطلوب

- The *gap* between the rolls can be adjusted to control the degree of size reduction.



* لتكسير بذور النباتات قبل extraction لتعيم القشرة

جهاز premilling

- Roller mills are used for crushing such as cracking seeds prior to extraction.
- This form should not be confused with the type used for milling ointments and pastes where both rolls are driven but at different speeds, so that size reduction occurs by attrition.

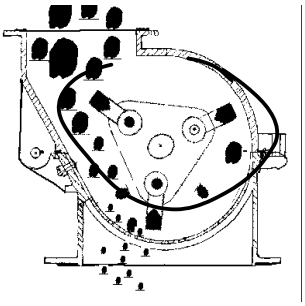
* في جهاز ثاني بشبهه بس الفرق انه هدا 2 Rolls هطوطين على مائف و المسافة بينهم صغيرة فهيز امتكال (attrition) , فبعطيني very fine particles ← ointment and pastes

* اشهر انواع الطواحين واكثرها استخداماً.

Impact methods

3 hammer

- Hammer mills
  - –Principle of operation: غلاف معدني قوي — محور مركزي
    - •It consists of a strong metal case enclosing a central shaft , to which a series of four or more hammers are attached. or three
    - •The material is ground by impact of the hammer or against the plates around the periphery casing.
    - •The material is retained until it is small enough to pass through the screen that forms the lower portion of the casing. Screen من خلال حجم معين بتنزل بس تتوصل لحجم



31

- close secret
- continue method

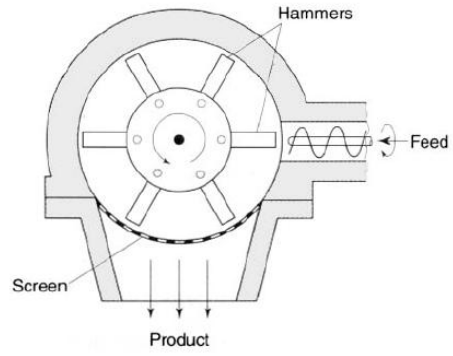
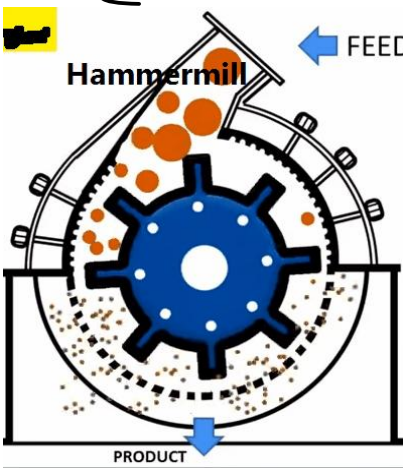


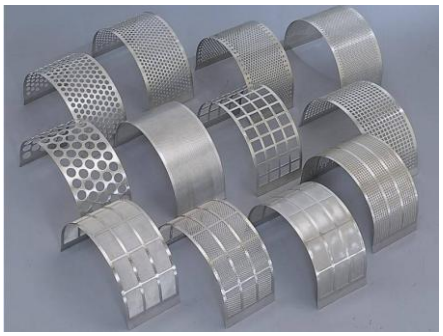
Fig. 11.9 Hammer mill.

32

Hammer mill

3 hammermill
(بتزيد سرعة الطحن)





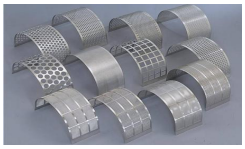
Screens for hammer mill

33

Impact methods

* عوامل بتأثر على milling بال hammer ① السرعة ② الشعك

- Hammer mills
  - Various shapes of hammers may be used.
  - The rate of feed must be controlled.
  - The speed of hammer is crucial. Low speed gives mixing rather than grinding while with higher speed, no enough time for the material to fall in the screen.
  - Thickness of screen affects the size of product



اذا كانت السرعة بطيئة رح يصير يعمل mix بدل milling.
اذا السرعة عالية رح يوصل للحجم المطلوب وما رح يقدروا يمروا من screen بسبب السرعة .

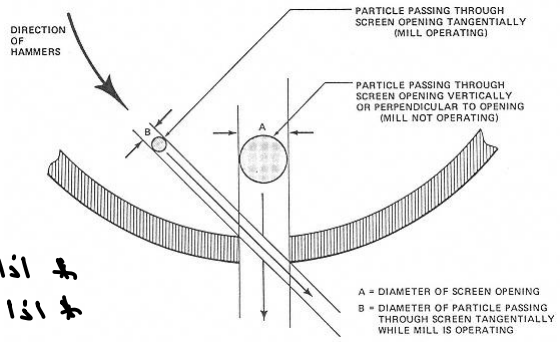
* الشعك لل screen ← لما يكون سميك, الجزيئات رح تخبط فيه وترجع لل mill
الشعك القليل تمام ✓

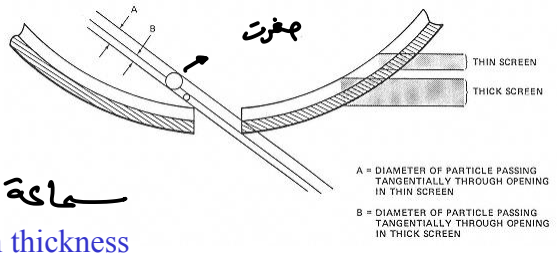
الماكينة واقفة (not operating)

① Effect of exiting particle angle through mill screen on exiting particle size.

زاوية خروج الجسيم من screen :

* اذا خرج الجسيم بزاوية حادة ، يكون حجمه اصغر
* اذا خرج بزاوية اكبر ، يكون حجمه اكبر.





سماكة الشاشة

② Effect of mill screen thickness on exiting particle size.

* شاشة سميكة = جسيمات اكبر
* شاشة رفيعة = جسيمات انعم

35

Impact methods

- Hammer mills
  - ***Advantages***:
    1. Rapid in action.
    2. Can be used almost for any type of milling (dry material, ointments and slurries).
    3. The size of product can be controlled by controlling the rotor speed, type and number of hammers, and screen size and thickness.

يمكن التحكم بحجم المنتج النهائي عن طريق ① + ② + ③ + ④

36

* في وحدة كاتبة الـ powder بتستخدم :-
بعض الـ compression + attrition

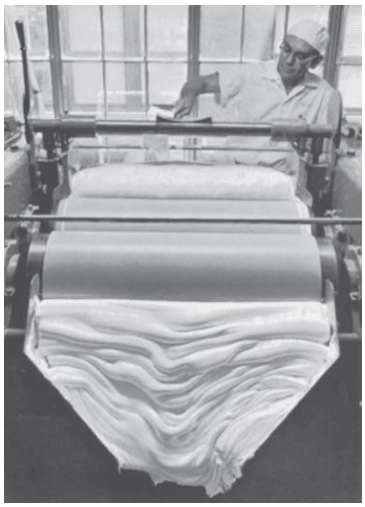
صف او احتكاك

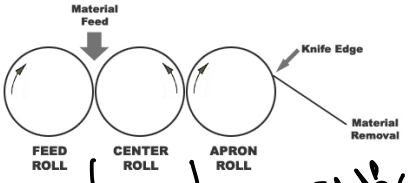
Attrition methods

Roller mills

- Principle of operation :
  - Roller mills use the principle of attrition for milling solids in suspensions, pastes or ointments.
  - Two or three porcelain or metal rolls are mounted horizontally with an adjustable gap, and rotate at different speed so that the material is sheared as it passes through the gap.

احتكاك





* الأسطوانات طولها قابلة للتعديل
المسافة بينها حسب حجم الجزيئات المطلوب

مسافة مختلفة لدوران بإتجاهات متعاكسة وسرعات مختلفة

* نوع متطور من attrition

Attrition methods

* طحن عالبلول مابيذوبوا بالي

Colloid Mills → wet milling بتناسب

- Colloid mills are a group of machines used for wet grinding dispersion, and preparation of emulsions.
- They operate by shearing relatively thin layers of material between two surfaces, one of which (rotor) is moving at a high angular velocity relative to the other (stator).

* واحد بتحرك وواحد ثابت

ثابت

* بقدر اغير المسافة من الصفر (اذا اردت طحن دقيق جدًا)

- The clearance is adjustable from virtually zero upward.
- The rotor is rotated at several thousand revolutions per minute, and the slurry of already fine material passes through the clearance under the action of centrifugal forces.
- Although very fine dispersions can be produced, they are not, as the name implies, of colloidal dimensions.

حكينا انه ما بقدر اطحن المادة الا لما يكون نسبة الرطوبة 5% بهاي الطحانة بطحن على نسبة رطوبة عالية 60% مثلاً .

للهوا التوكسيك بدي وسيلة ما تعمل dust فبطحن ب close method او هاي لانه فيها مي.

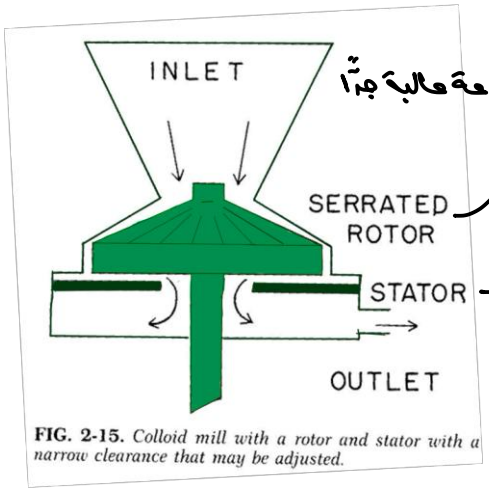


FIG. 2-15. *Colloid mill with a rotor and stator with a narrow clearance that may be adjusted.*

يدور بسرعة عالية جدًا

ثابت

The clearance is adjustable from virtually zero upward.

39

Combined impact and attrition methods

Ball mills

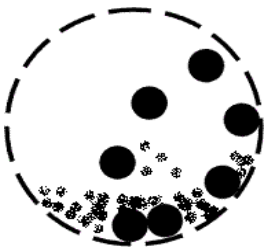
- ***Principle of operation***

  – Ball mills consist of a hollow cylinder mounted such that it can be rotated on its horizontal longitudinal axis.

  – Their size range from laboratory to industrial (Cylinder can be greater that 3 m).

  – The cylinder contain balls that occupy 30 – 50 % of the total volume.

اسطوانة مجوفة



الاسطوانة تلف بالأفق

مصنوعة عادة من مصن او بورسلان

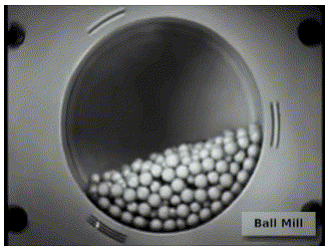
40

Combined impact and attrition methods

Ball mills

- ***Principle of operation***
  - Ball size depends on feed and mill size.
  - Balls with different diameter help to improve the product as the large balls tend to breakdown the coarse feed materials and the smaller balls help to form the fine product by reducing void spaces between balls.

لما تدور الطاحونة، الكرات ترفع بفعل الدوران وتنزل على المادة، تصدمها (impact) وتفركها (attrition) بنفس الوقت. وبالتالي الطحن ناتج من الصدمة +الاحتكاك.



41

Combined impact and attrition methods

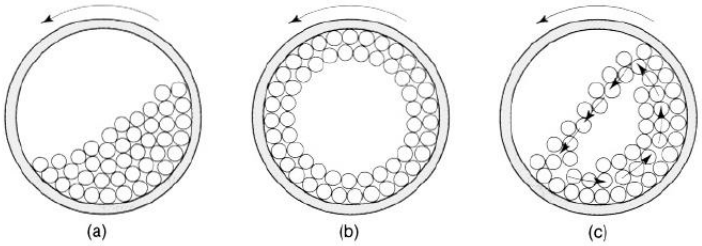
Ball mills

- The amount of material in the mill and the speed of rotation are very important factors.
- Too much feeding produces a cushioning effect and too little causes loss of efficiency and abrasion of the mill.
- At high speed, the balls are thrown out onto the mill wall by centrifugal forces, where at low speed the balls slide over each other with negligible amount of size reduction.

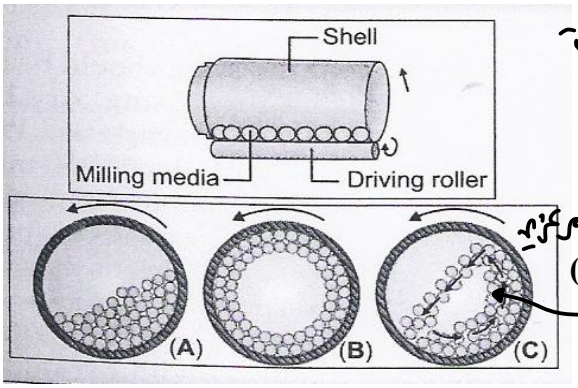
السرعة منخفضة :الكرات بتزحلق فوق بعضها(sliding) مافي طحن حقيقي.

السرعة عالية :الكرات تلتصق بجدار الطاحونة (centrifuging) ايضاً مافي طحن.

low speed high speed



optimum speed



(A)Sliding at low speed,
(B) Centrifuging at high speed,
(C) Cascading at optimum speed.

43

(Ball mill) تقطي مساحيق دقيقة جدًا (ادق من

Combined impact and attrition methods

* اسطوانة فيها كرات بس الفرق انه بتهتز ما بتلف

- Vibration mills
  - Principle of operation
    - The vibration mills are filled to about 80% total volume with porcelain or steel balls.
    - During milling the whole body of the mill is vibrated and size reduction occurs by repeated impactions.
    - Comminuted particles fall through a screen at the base of mill.

(closed sieve) Screen الجزيئات المطحونة بتنزل يـ

ليش بقدر اعبيها كرات 80% والي فوق (30-50)% لانه الدوان انا بحاجة اسمح للكرة توقع من فوق ،اما هون مش بحاجة لهاي المساحة.

44

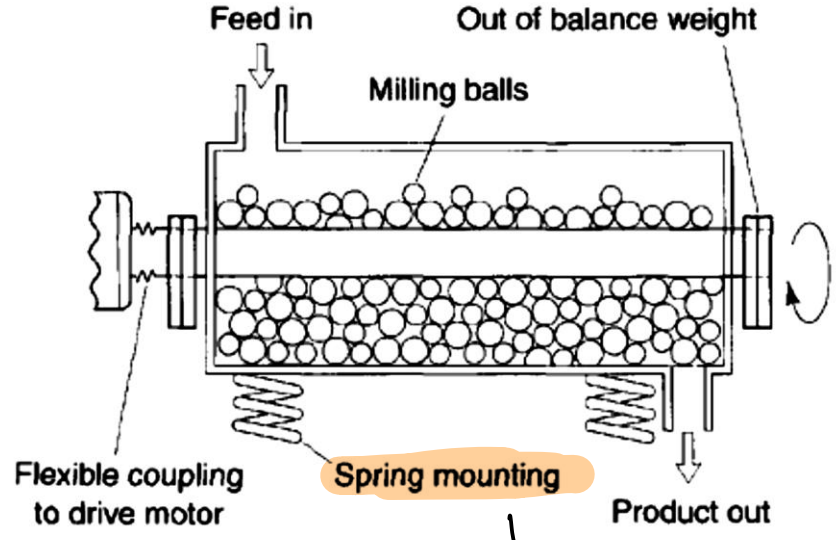
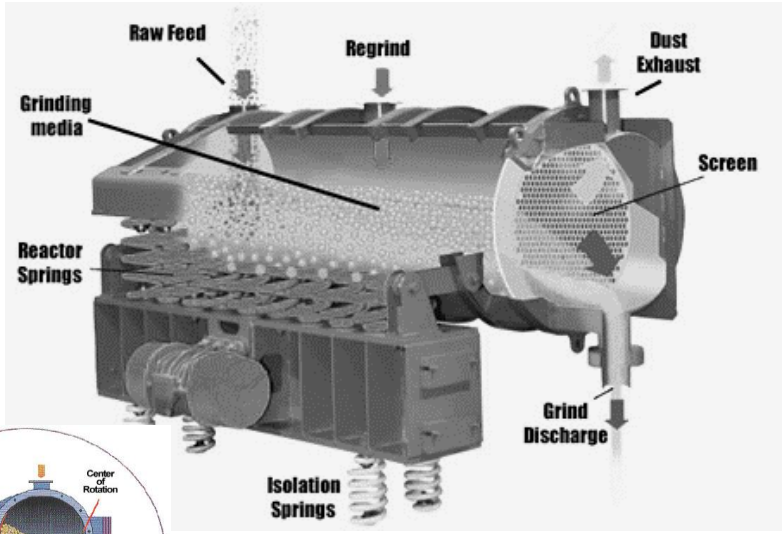
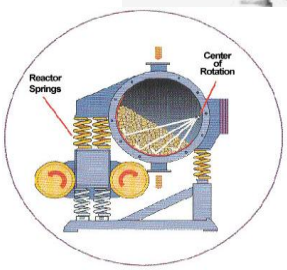


Fig. 11.10 Vibration mill.

active fins





Vibration mill

Combined impact and attrition methods

- Fluid energy mill
  - A typical form of this mill consists of a hollow toroid (loop) which has a diameter of 20 – 200 mm depending on the height of the loop which may be up to 2 m.
  - A fluid, usually air, is injected at high pressure through nozzle at the bottom of the loop, resulting in a high velocity circulation in a very turbulent manner.

47

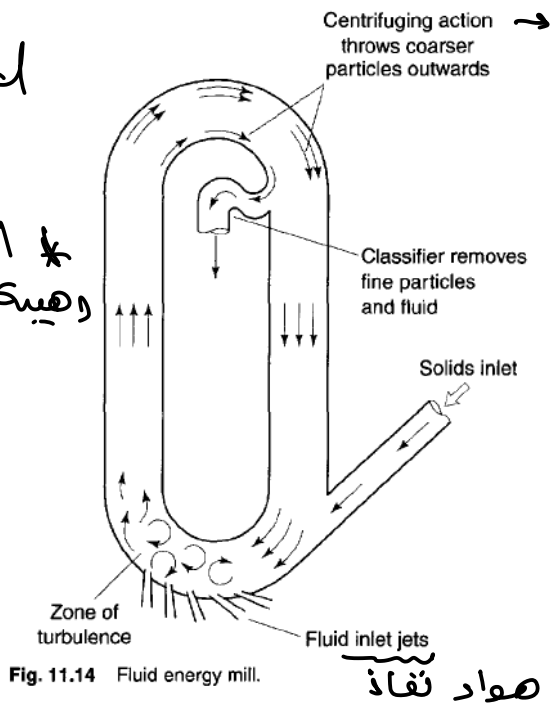


Fig. 11.14 Fluid energy mill.

48

Combined impact and attrition methods

- Fluid energy mill
  - The high kinetic energy of the air causes impact and some attrition forces to occur between the introduced particles which result in size reduction.
  - If fine powder is intended, the feed should be pre-milled to about 150 – 840 µm.
  - A classifier is incorporated so that particles are retained until sufficiently fine.

الجزيئات تدخل بتيار الهواء وتبدأ بالتصادم.

49

الجزيئات الخشنة تبقى تدور حتى تصغر كفاية.

لما تصير الجزيئات دقيقة بما فيه الكفاية ،تطلع من classifier مثبت اعلى الطاحونة.

Combined impact and attrition methods

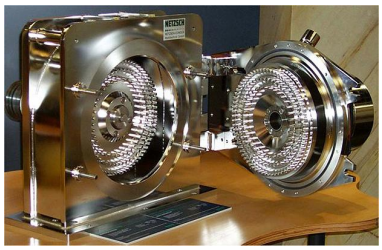
- Fluid energy mill
  - Advantages:
    1. Suitable for fine powder.
    2. Expansion of gases at the nozzle leads to cooling effect. This counteract the frictional heat, which may affect heat sensitive materials.

50

Combined impact and attrition methods

دبوس

- Pin mill
  - Principle of operation
    - It consists of two disks with closely spaced pins rotate against one another at high speed.



    - Particle size reduction occurs by impaction with pins and by attrition between pins as the particles travel outwards under influence of centrifugal force.

51

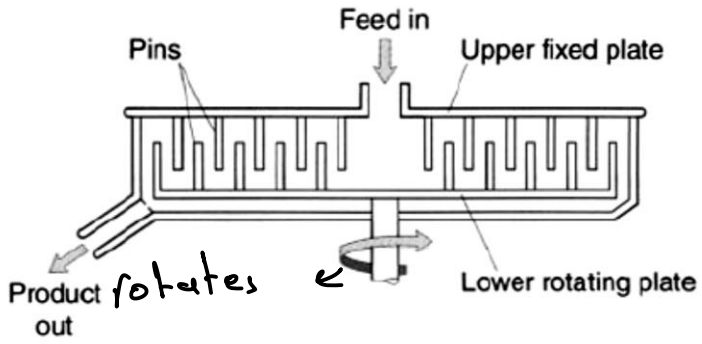
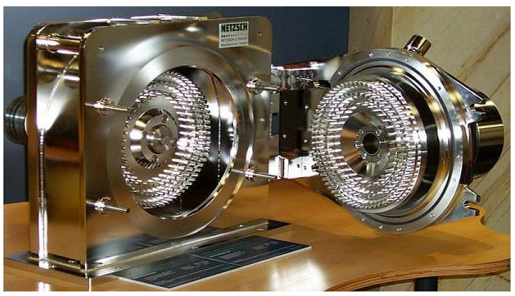


Fig. 11.15 Pin mill.



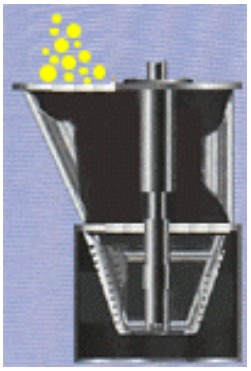
52

مكروطي غير صويب

Conical screen mill

3 in 1
all in one

- The conical mill operates by having the product being fed into the mill by gravity or vacuum. الشفط
- A rotating impeller forces the material outward to a conical screen surface, where it is sized and passed through the openings in the screen. مروحة دوارة شفرة تلتف وبتدفع الجزي ء ليروح لل screen وبفير الحجم
- The particles are subjected to impaction, attrition and compression.



Between two surfaces

Conical screen mill

- Conical mills come in a variety of sizes from tabletop lab models to full-size high-capacity machines for use in processing large quantities of material, and the impeller and screen can be customized for each individual use.

- The machines can be used not only to reduce the size of particles, but also for deagglomeration, sieving, dispersion, and mixing.

تمنع التكتلات

Conical screen mill

- The applications for a conical mill in pharmaceutical industry include:
  - Reclaiming broken pharmaceutical tablets by grinding them back into powder for re-forming.
  - Sizing wet granulated particles before drying, and sizing dry granulated particles after they've dried before tabletting.
- The conical mill has some marked advantages over the hammer mill:
  1. low noise, heat and dust
  2. a more uniform particle size
  3. flexibility to mill wet and dry material
  4. higher capacity

55

Conical screen mill

Critical milling factors

A. Impeller type

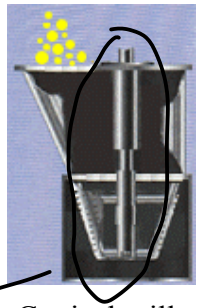
B. Screen type

C. Impeller/screen gap

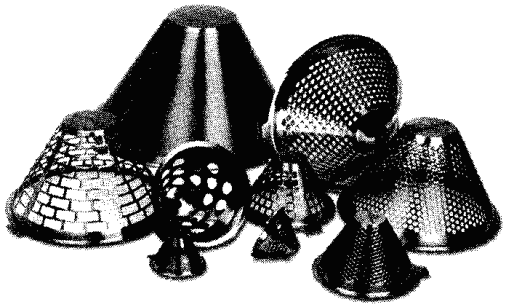
D. Velocity

E. Feed and discharge condition

56



Conical mill



Examples of conical screens

impeller

Examples of conical mill impellers

57

micro ornamental بو صل

Wet and dry milling

- The choice of dry or wet milling depends on the use of the product and its subsequent processing.
- If the product undergoes physical or chemical interaction with water, dry milling is recommended.
- Wet milling eliminates dust hazards and is beneficial to grind to lower size limits than dry milling.

Wet milling → الطحن بوجود سائل (ماء)

Dry milling → الطحن بدون وجود سائل (ماء)

58

Inert milling

- Under inert gas (nitrogen)
- For explosive, combustible and oxidizable products

59

Cryogenic milling

- Milling under low temperature
- Uses liquid nitrogen or carbon dioxide.

- Applications:
  - to enhance milling for soft, elastic and low-melting point materials by freezing them and making them brittle.
  - for milling of heat sensitive products

60

Selection of particle size reduction method

The selection of a size reduction method depends on:

1) Material properties

- Hardness
- Structure (Cutter mill for fibrous materials)
- Toxicity (Closed mills like ball mill)
- Explosion (wet grinding or use inert gas)

2) Properties of final product

- Degree of size reduction
- Shape (Attrition methods give spheroidal particles with better flow properties)

61

Selection of particle size reduction method

Size required	example of mill
Very coarse powder product (>1000 µm)	Cutter mill, Conical mill, Roller mills Hammer mills
coarse powder product (50-1000 µm)	Ball mills, Conical mill, Cutter mill, Hammer mills, Pin mill, Roller mills, Vibration mills
Fine powder product (< 50 µm)	Ball mills, Colloid mill, Fluid energy mill, Pin mill, Vibration mills

62

Selection of particle size reduction method

The selection of a size reduction method depends on:

3) Need for dust control

- Use closed mills (e.g. costly or toxic material)

4) **Sanitation** → مايكونش فيها تراكمات

- Ease of cleaning, sterilization
- For milling of sterile material the mill should be totally isolated (e.g. Ball mill).

63

Selection of particle size reduction method

The selection of a size reduction method depends on:

5) Capacity of the mill and production rate requirements

6) Economical factors

- Cost → pre milling
- Power consumption
- Space occupied

64

ركزوا منيح بالامتحان ربنا يوفقكم يارب💗