1 ST 2023/2024

Solid Particles

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Particle Characteristics

→ ٪. ممكن نفس الحجم لنسب المواد تختلف من مسافة الى اخرى . نسبتها، تحديد بعينة هون او بعد مسافة صغيرة. you have to know if it's homogeneous!

لأي عينة Particle!

The three most important characteristics of an individual particle are its:

Pure mixture

عمل عمليات لتحديد مكونات العينة ونسبها وكمياتها ونوعها والخصائص.

- **Particle Composition:** which determines such properties as density and conductivity, provided that the particle is completely uniform (homogeneous composition). In many cases, however, the particle is porous (فراغات) or it may consist of a continuous matrix in which small particles of a second material are distributed. (mixture)

range!! no fixed particle (خليط) size!!

- **Particle Size:** which affects properties such as the surface per unit volume and the rate at which a particle will settle in a fluid

diameter.

تذكر المنخل!

- **Particle Shape:** which may be regular, such as spherical or cubic, or it may be irregular as, for example, with a piece of broken glass. Regular shapes are capable of precise definition by mathematical equations.

مثال زجاج مكسر

صوامع الحبوب

- ➢ Operations systems of particles include storage in hoppers, flow through orifices and pipes, and metering of flows. design with using math!! and solve troubleshooting.
- ➢ It is frequently necessary to reduce the size of particles, or alternatively to form them into aggregates or sinters. raw materials have to be crushing 99% or enlargment 1%
- ➢ Sometimes it may be necessary to mix ~~two or~~ (بالدورة) more solids, and there may be a requirement to separate a mixture into its components or according to the sizes of the particles.

we have problems with the flow of solid so we have to Characterize the particle so we can predict the problems that could face me!!

Single particles

flow rate! * اكبر مشكلة هي التذبذب في

- The simplest shape of a particle is the sphere (because of its symmetry)
  كفيفك
- Sphere particle looks exactly the same from whatever direction it is viewed and behaves in the same manner in a fluid, irrespective of its orientation. هنا كيفما تجيب تعطيك نفس الشكل والحجم !!
- Frequently, the size of a particle of irregular shape is defined in terms of the size of an **equivalent sphere** although the particle is represented by a sphere of different size according to the property selected.

- Some of the important sizes of equivalent spheres are:

according to your objective

(a) The sphere of the same volume as the particle.

(b) The sphere of the same surface area as the particle.

(c) The sphere of the same surface area per unit volume as the particle.

(d) The sphere of the same area as the particle when projected on to a plane perpendicular to its direction of motion. الشكل بعدما يتشقلب بتعمل بعدها احسب diameter لأكثر شكل هي stable (الأكثر ثباتا)

while moving with a fluid.

(e) The sphere of the same projected area as the particle, as viewed from above, when lying in its position of maximum stability such as on a microscope slide for example.
بدل perpendicular بدي جاها منه فوق بس نفس مبدأ ال microscope.

(f) The sphere which will just pass through the same size of square aperture as the particle, such as on a screen for example. → منخل

(g) The sphere with the same settling velocity as the particle in a specified fluid.

settle ← تثبت عشان ال ٥٠/١٠ بدها particle في

عن طريق curve diameter و settling velocity!!

رفع ال surface area عن طريق تصغير الحجم (طحن)

Describing the size of a single particle

Regular-shaped particles

Shape	Sphere	Cube	Cylinder	Cuboid	Cone
Dimensions	Radius	Side length	Radius and height	Three side lengths	Radius and height

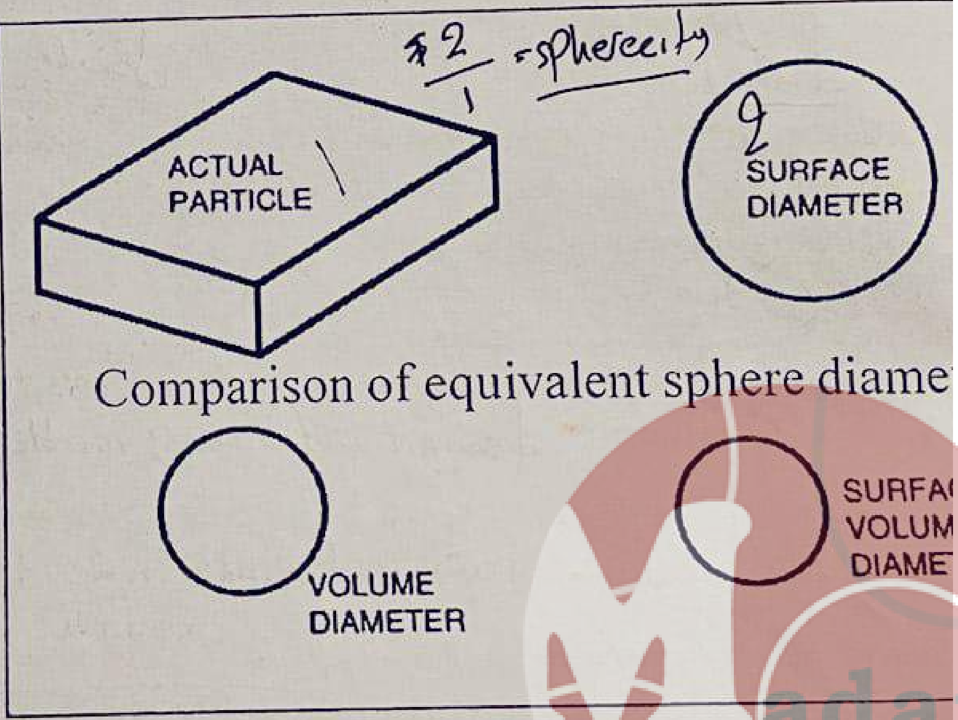
- The orientation of the particle on the microscope slide will affect the projected image and consequently the measured equivalent sphere diameter.
- Sieve measurement: Diameter of a sphere passing through the same sieve aperture.
- Sedimentation measurement: Diameter of a sphere having the same sedimentation velocity under the same conditions.

منخل

بتكون ع

x g P.

Liquid



Comparison of equivalent sphere diame

ehaves in

ze of an
ent size

[illegible]

Feret's statistical diameter

- **Feret's statistical diameter** is the mean distance apart of two parallel lines which are tangential to the particle in an arbitrarily fixed direction, irrespective of the orientation of each particle coming up for inspection.

قريبه هو للـ sphere وعا range 0.3 - 1 → sphere

- A measure of particle shape which is frequently used is the **sphericity** (which is a measure of how spherical (round) an object is):

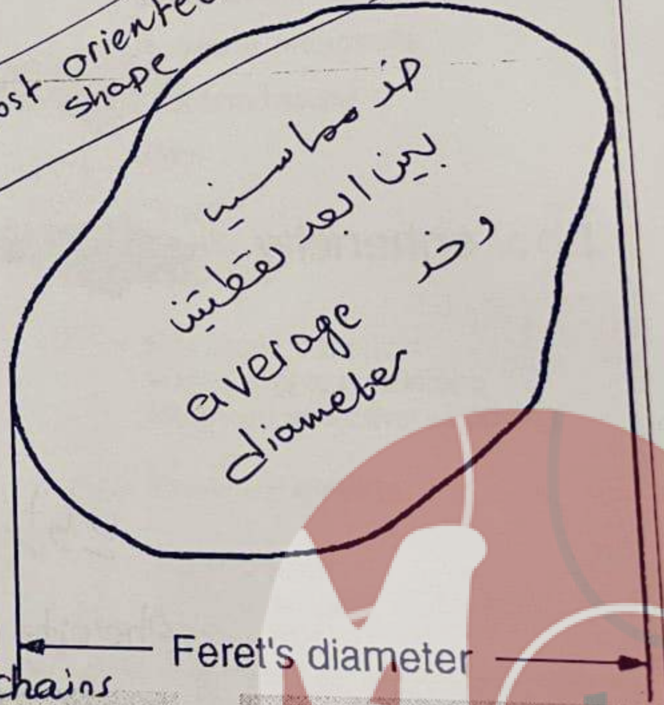
most oriented status shape

$$\psi = \frac{\text{surface area of sphere of same volume as particle}}{\text{surface area of particle}}$$

$$\Psi = \frac{\pi^{\frac{1}{3}}(6V_p)^{\frac{2}{3}}}{A_p}$$

Propane → polypropaline غاز (ربط) بلاستيك Linear branch 3D!

عادة للمواد البلاستيكية ذكاء فني Polymers متعددة



اذ مماسين بين البعد نقطتين وخد average diameter

Other properties of the particle which may be of importance are whether it is **crystalline or amorphous**, whether it is **porous**, and the ~~**properties**~~ **of its surface**, including **roughness and presence of adsorbed films.**

spaghetti before after

particle خشنة صعب يكون تقطع بال flow rate

crystalline : لا ترى فيه خلاء / ordered bonds/chains

amorphous : ترى فيه خلاء ex: زجاج / random bonds.

Calculation of

Calculation of Sphericity

Sphericity Φ_s is defined as $\Phi_s = \frac{6V_p}{D_p A_p}$ where V_p is the volume of the object, A_p is its surface area, and D_p is the diameter of a sphere with the same volume ($\pi D_p^3/6$).

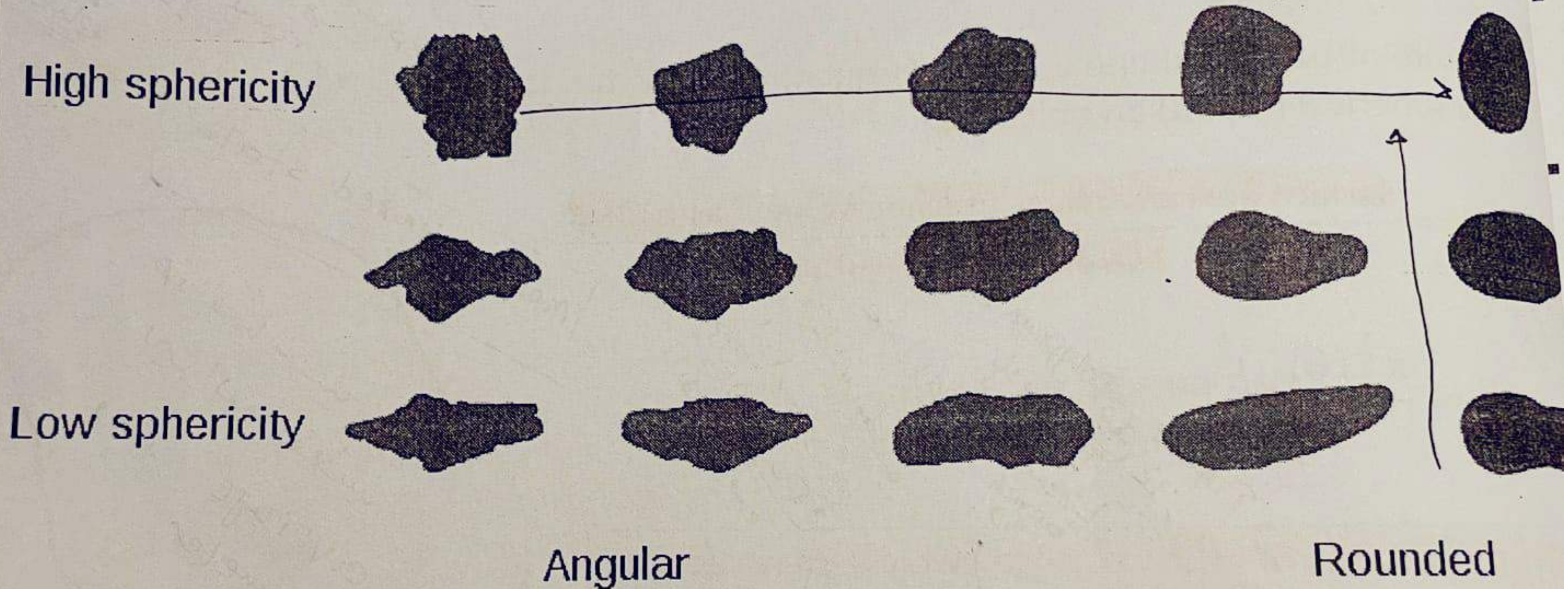
For a sphere of diameter d, $V_p = \pi d^3/6$, $A_p = \pi d^2$, $D_p = d$, and so $\Phi_s = 1$.

For a cylinder of diameter d and length L, $V_p = \pi d^2 L/4$, $A_p = \pi dL + \pi d^2/2$, $D_p = (6d^2L/4)^{1/3}$,

For a cube of width a, $V_p = a^3$, $A_p = 6a^2$, and $c = a^3$, and so

$$\Phi_s = \frac{6a^3}{(6/\pi)^{(1/3)} a (6a^2)} = \left(\frac{\pi}{6}\right)^{(1/3)} = 0.806$$

http://en.wikipedia.org/wiki/Sphericity



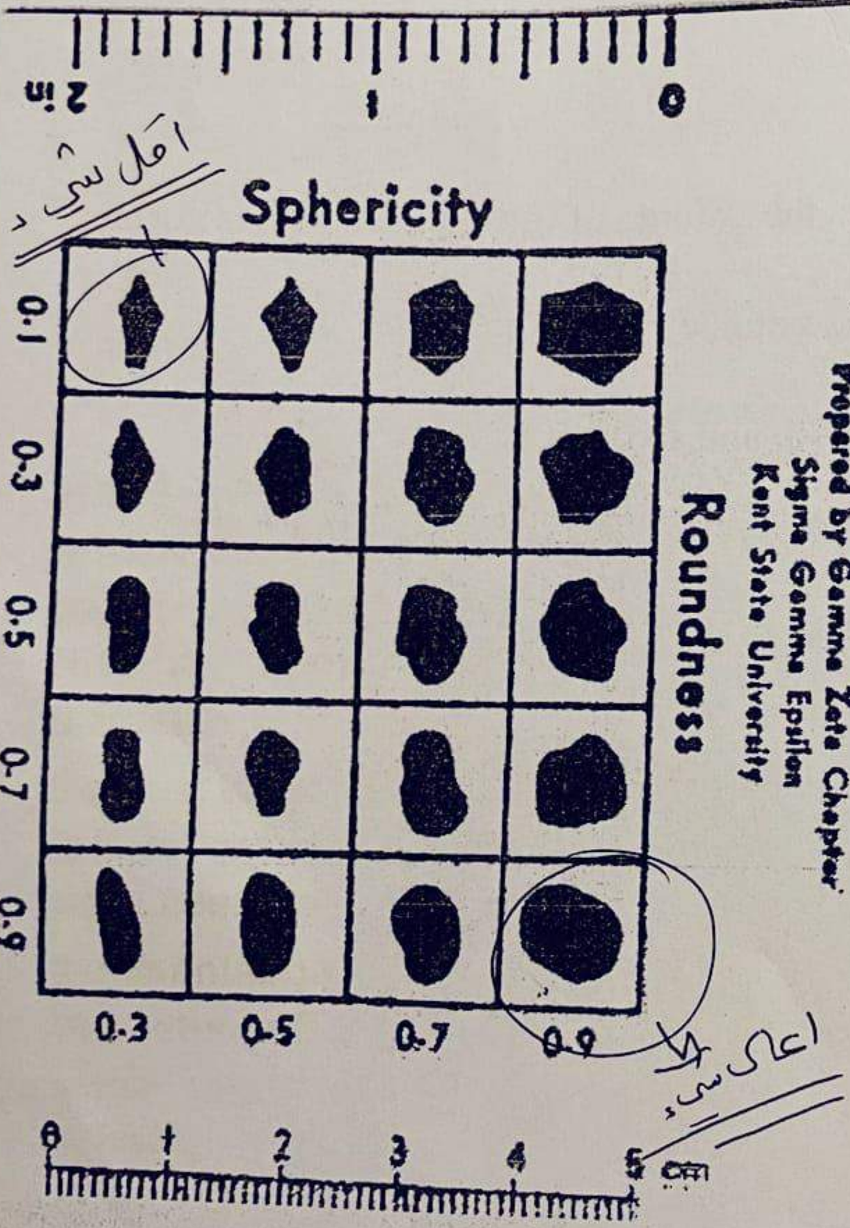
لها زوايا

لا يوجد زوايا

احسب لكل وحده sphercity

0.4-0.6 in our engineering

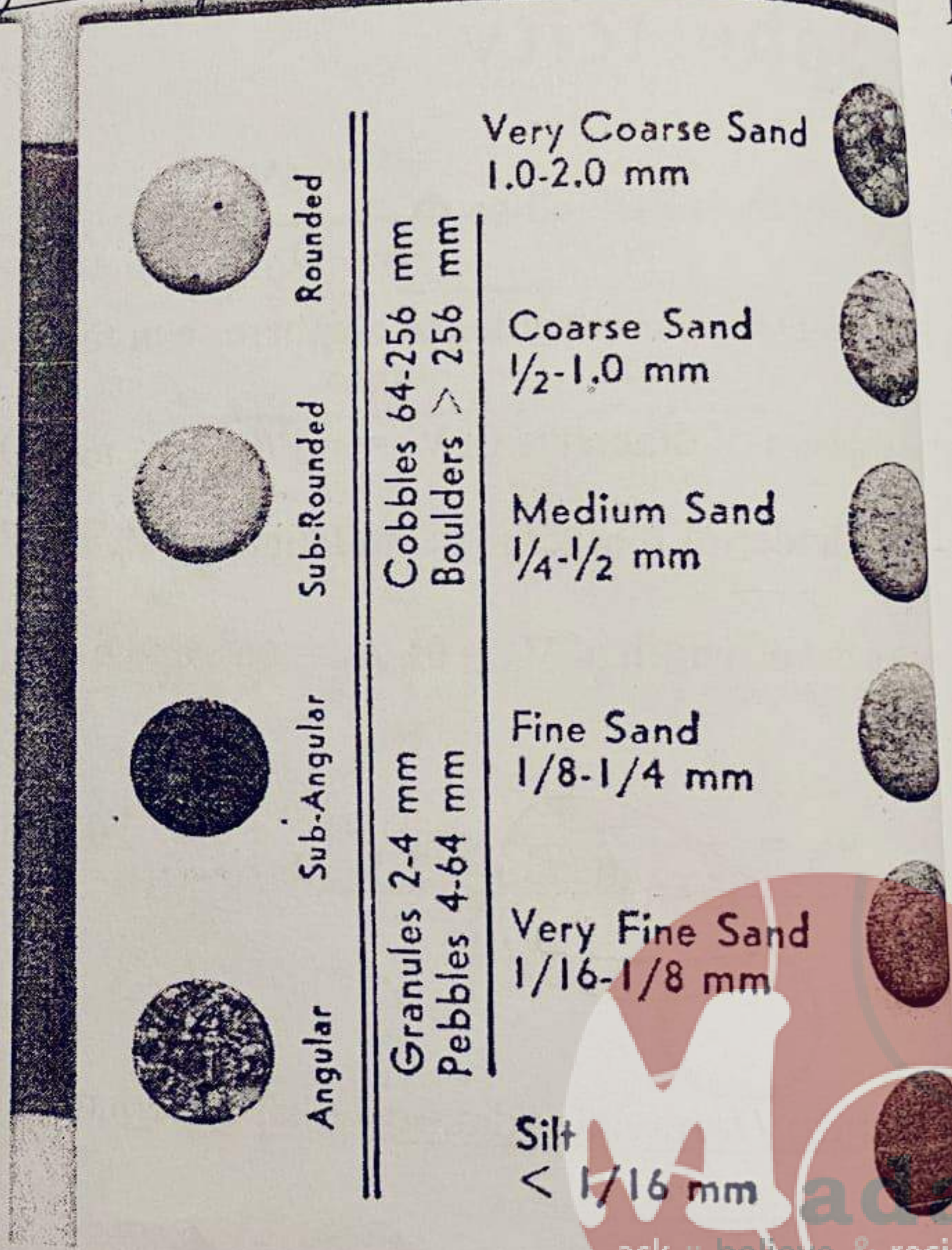
0.4-0.6 in our engineering



اقل شي

اعلى شي

Prepared by Gamma Zeta Chapter
Sigma Gamma Epsilon
Kent State University



Granules 2-4 mm
Pebbles 4-64 mm
Cobbles 64-256 mm
Boulders > 256 mm

Very Coarse Sand
1.0-2.0 mm

Coarse Sand
½-1.0 mm

Medium Sand
¼-½ mm

Fine Sand
1/8-1/4 mm

Very Fine Sand
1/16-1/8 mm

Silt
< 1/16 mm

نفتح المنخل من الاعلى ونحط وزن معين ونسكر بإحكام بين والغطا الفوقي والمنخل) البراغي ونركب لكمية

على Vibration معين

screening
Sieving (>50 µm) Volume
فصل

تسكر بغطاها وتنشد البراغي لإحكام الغلاقه

- Sieve analysis may be carried out using a nest of sieves, each lower sieve being of smaller aperture size. opening لل size اكبر

الفتحة حجمها

منه توسيع وانتشار وتوزيع واستطاع

- Generally, sieve series are arranged so that the ratio of aperture sizes on consecutive sieves is 2, $2^{1/2}$ or $2^{1/4}$ according to the closeness of sizing that is required. The are of openings in any one screen in the series is twice that of the openings in the next smaller screen.

المنخل العلوي الوسطى ضعف التحت

الفتحة من الحجم الاكبر للاصغر

composition نسبة ← هو معبأ - اخرجي. نتطلع وزن الصينية وهو فارغ

- Standard screens size range between 3 and 0.0015in. (76 mm and 38 micrometer).

كلما نزلنا بالمناخل كل ما صار الفتحة دقيقة.

(المنخل الفوقي له اعلى aparture size واقل mesh number

- The sieves may either be mounted on a vibrator, which should be designed to give a degree of vertical movement in addition to the horizontal vibration, or may be hand shaken.

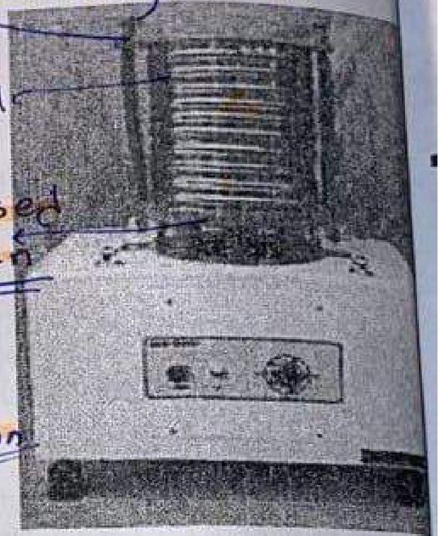
عشان particle تاخذ orientation صح!

- Passing of particle through an aperture depends not only upon its size, but also on the probability that it will be presented at the required orientation at the surface of the screen.

جهاز يركب عليه عدة مناخل، كل منخل عبارة عن صينية، على شكل mesh

aparture size: فتحة منخل

كل منخل له فتحات بحجم معين



the required orientation at the

mesh على شكل شبكة، كل منخل عبارة عن جريبة، مركب على عدة مناخل

كل منخل له فتحة بحجم معين

aparture size: فتحة منخل

mesh number: لكل منخل رقم تسمية

modified aparture size وكل al mesh no.

آخر منخل مصمت (pan) (جريبة مغلقة)!

universal standard!!

Screen analysis

- Since particles on any one screen are passed by the screen immediately ahead of it, then two number are needed to specify the size range of an increment, one for the screen through which the fraction passes, and the other on which it is retained, thus the notation 14/20 mean "though 14 mesh and on 20 mesh"

VIP

Passed through 14

retained ~~through~~ on 20

اول واحد من فوق

الرينج بتعتمد لفتحة من الأكبر الى الأصغر

0.833 → 1.168

then averge
1+2 / 2

اعلى شي

200
اقل شي

Flexible Choosing!!

ما بدخل بالحسابات

Mesh	Screen opening D_{pi}, mm
4	4.699
6	3.327
8	2.362
10	1.651
14	1.168
20	0.833
28	0.589
35	0.417
48	0.295
65	0.208
100	0.147
150	0.104
200	0.074
Pan	—

اسم

حجم الفتحة

ثابت

screen mesh no. Form

Standard

Later on we take average not range!!

Screening

طحن
or
mistake of orientation may lower the efficiency: → عكس لتوقعات :. $\xrightarrow{\text{result}}$ Lowering in flow rate

- The **efficiency of screening** is defined as the ratio of the mass of material which passes the screen to that which is capable of passing.

متوقعانا عن

اذا اللي مر اقل منه Capable

مثلاً

$$\frac{40}{90}$$

40 ← اكر

90 ← المتوقع انو يمر

- This will differ according to the size of the material.
- It may be assumed that the rate of passage of particles of a given size through the screen is proportional to the number or mass of particles of that size on the screen at any instant

- ~~Thus, if **w** is the mass of particles of a particular size on the screen at a time **t**, then:~~

$$\cancel{\frac{dw}{dt} = -kw}$$

~~where k is a constant for a given size and shape of particle and for a given screen. Thus, the mass of particles $(w_1 - w_2)$ passing the screen in time t is given by:~~

$$\cancel{\ln \frac{w_2}{w_1} = -kt}$$

or:

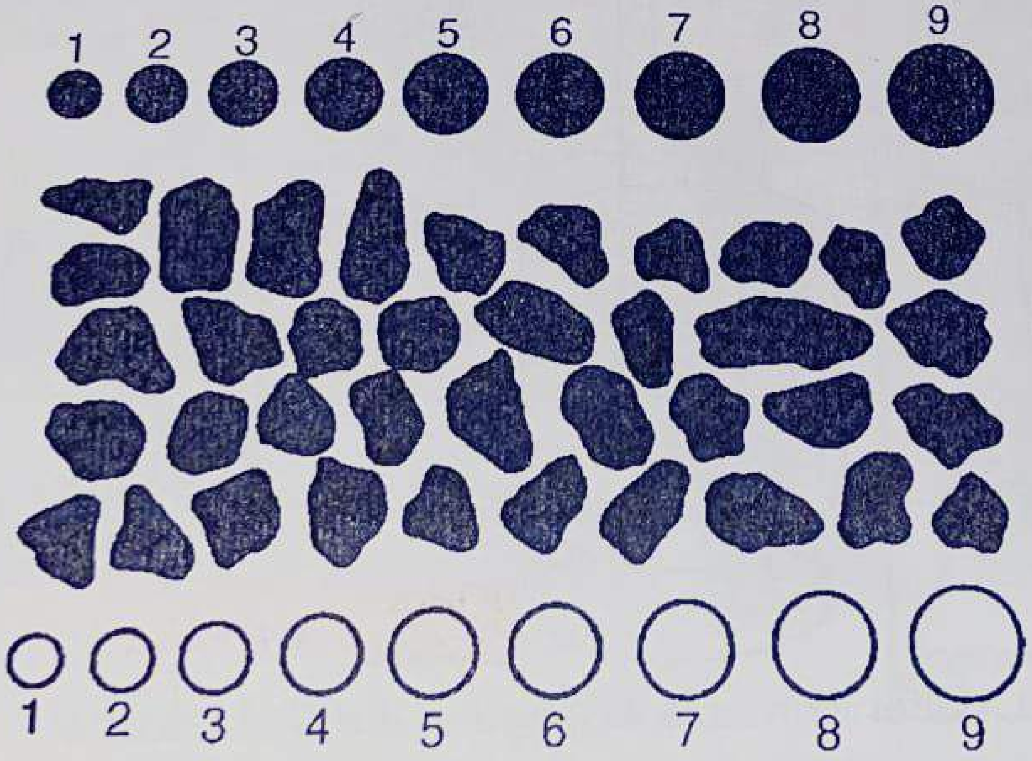
$$w_2 = w_1 e^{-kt}$$

Microscopic analysis (1–100 µm)

الطريقة ع لفرز الجزيئات حسب حجمهم ← Surface Area

عينة تحت المايكروسكوب واختار !!

- Microscopic examination permits measurement of the projected area of the particle and also enables an assessment to be made of its two-dimensional shape.
- Automatic methods of scanning have been developed. By using the electron microscope, the lower limit of size can be reduced to about 0.001 µm.



يأخذ صورة للسطح واختار

ثم

Ferit's diameter

ثم

Average

محطط curve بين
① voltage
② no. of particle

فقط الفولتية والتيار، non-conductive ال

① volume ② Surface Area ③ Count.

not diluted
nor concentrated

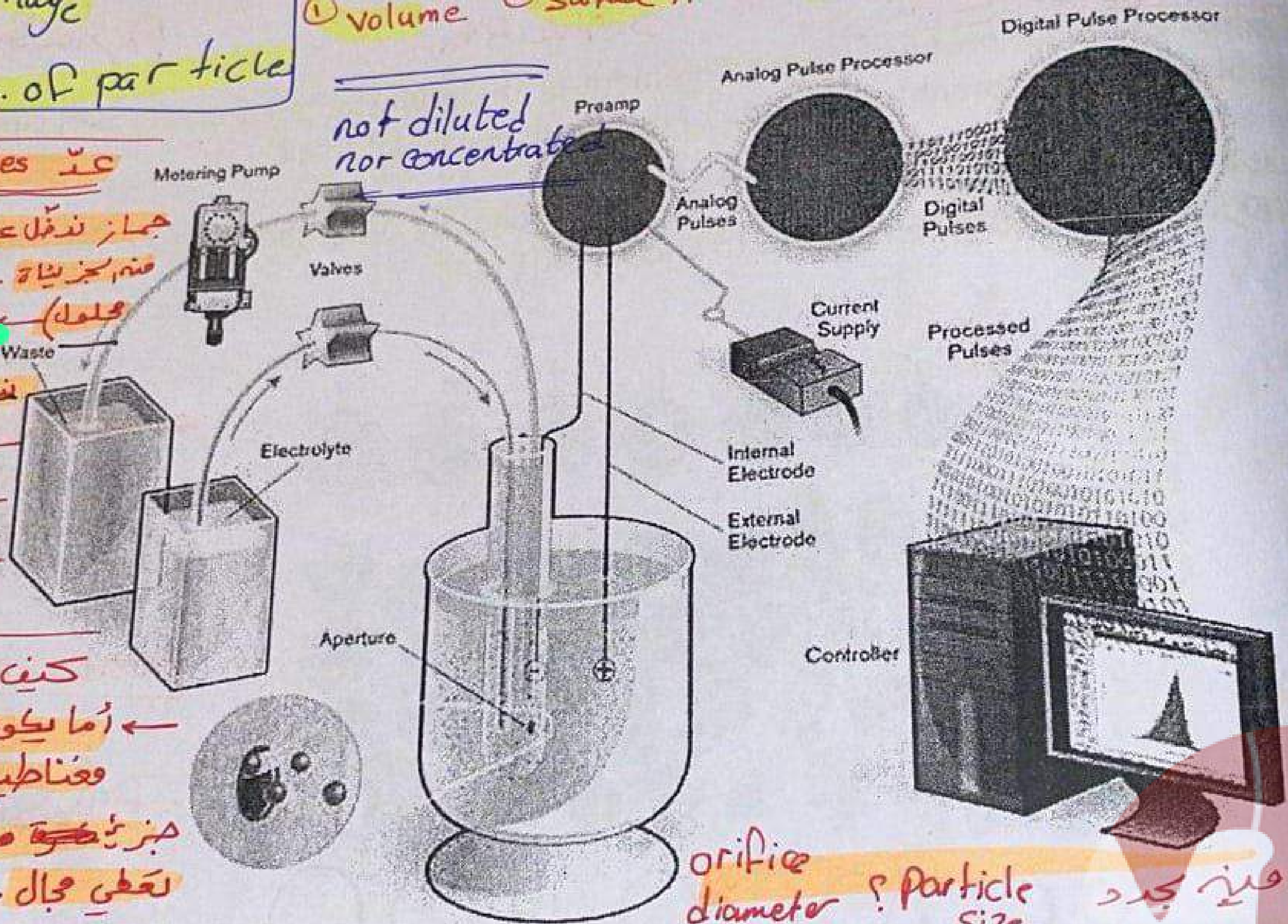
عدّ particles

جهاز ندخّل عليه suspension
منه بجزيئات ← (بنحلها في
محلول) ← تصبح معلقة ←

ندخلها في جهاز
يعمل Flow ←
يمرّ في Small orifice ←
ليبدأ العداد يعد ←

كيف يعد ؟!
← أما يكون عال orifice مجال
مغناطيسي. كل ما يمر
جزيئة مغناطيسية
تعطي مجال.

او مجال الكهربائي، فاذا كانت
الكادة موصلة كل ما تمر منه
المجال تكمل عندي الدارة



orifice diameter ؟ Particle size فيه يحدد

The Coulter Principle Applied in the Multisizer 4

M. Saidan

واذا كانت الكادة مش موصله والمحلول موصل
معناته لما تمر الجزيئ رح يظهر عندي انقطاع بالتيار ← وتعطي اشارة فولتية ويعدها

بشكله يطلع مؤشر voltage or انقطاع

Particle size distribution

- Particulate systems consist of particles of a wide range of sizes
- A quantitative indication of the mean size and of the spread of sizes of particulate systems should be given and represented by means of: → 10% have a part size from → to
  5% " " ...
  etc:

✓ *a cumulative mass fraction curve,*

Seives. المنخل

in which the proportion of particles *(x)* smaller than a certain size *(d)* is plotted against that size *(d)*.

> In most practical determinations of particle size, the size analysis will be obtained as a series of steps, each step representing the proportion of particles lying within a certain small range of size.

نحصل by نخل

كل وحدة تعلق بتاع. الافرع هي X ال على Cumulative

> From these results a cumulative size distribution can be built up and this can then be approximated by a smooth curve provided that the size intervals are sufficiently small.

Size distribution curve — cumulative basis

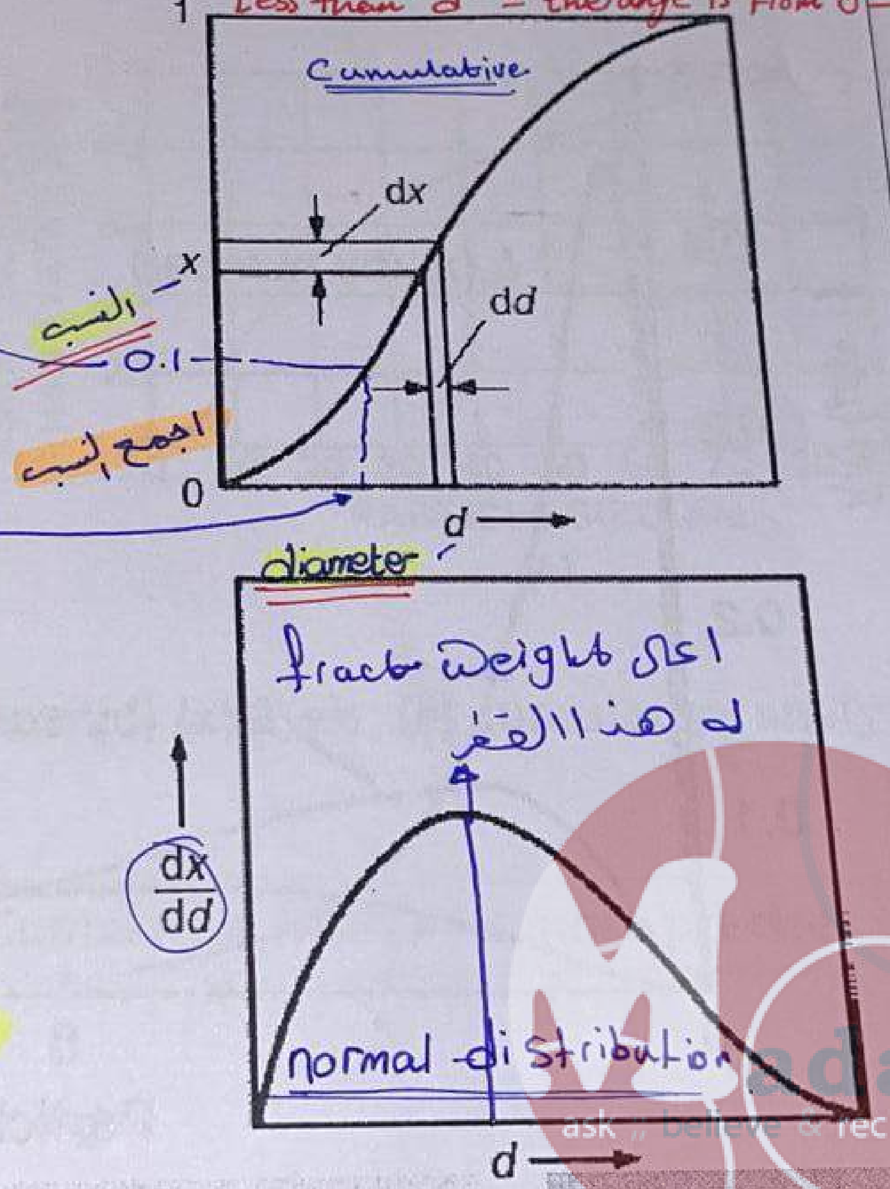
X: cumulative.

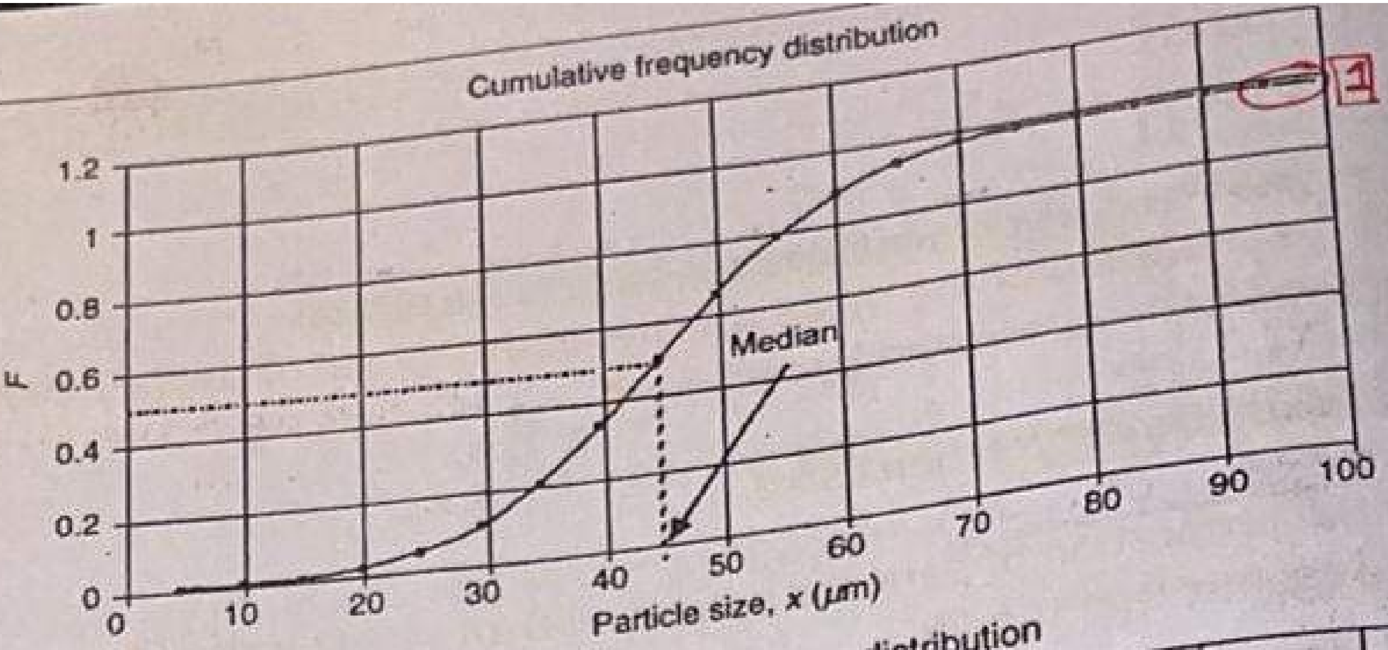
X: fraction of material that has diameter Less than 'd' = the range is from 0 → d

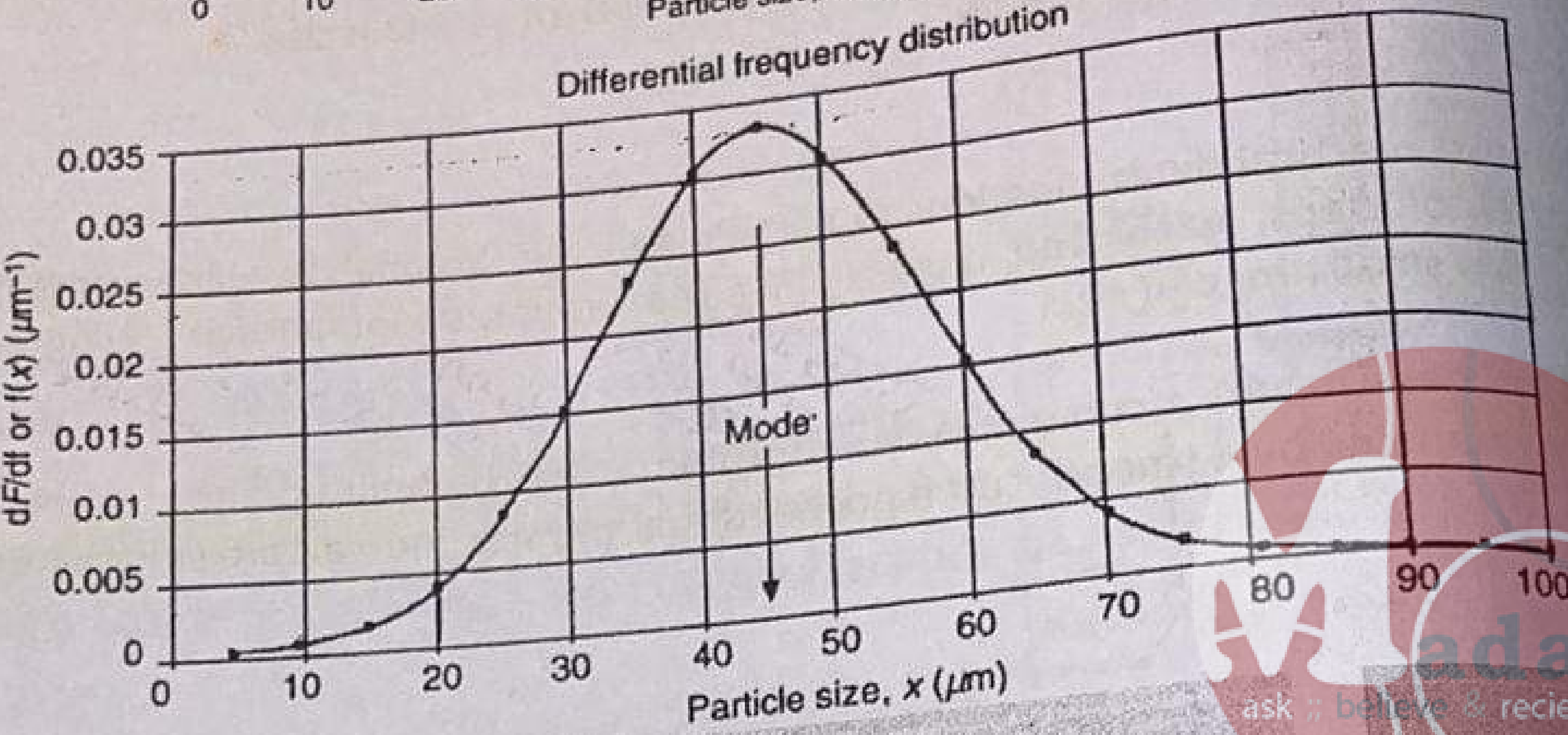
- The distribution of particle sizes can be seen more readily by plotting a *size frequency curve,* in which the slope (dx/dd) of the cumulative curve is plotted against particle size (d).

١٠٪ من العينة لما حجم اقل منه هو

- The most frequently occurring size is then shown by the maximum of the curve.
- For naturally occurring materials the curve will generally have a single peak.
- For mixtures of particles, there may be as many peaks as components in the mixture.
- If the particles are formed by crushing larger particles, the curve may have two peaks, one characteristic of the material and the other characteristic of the equipment.





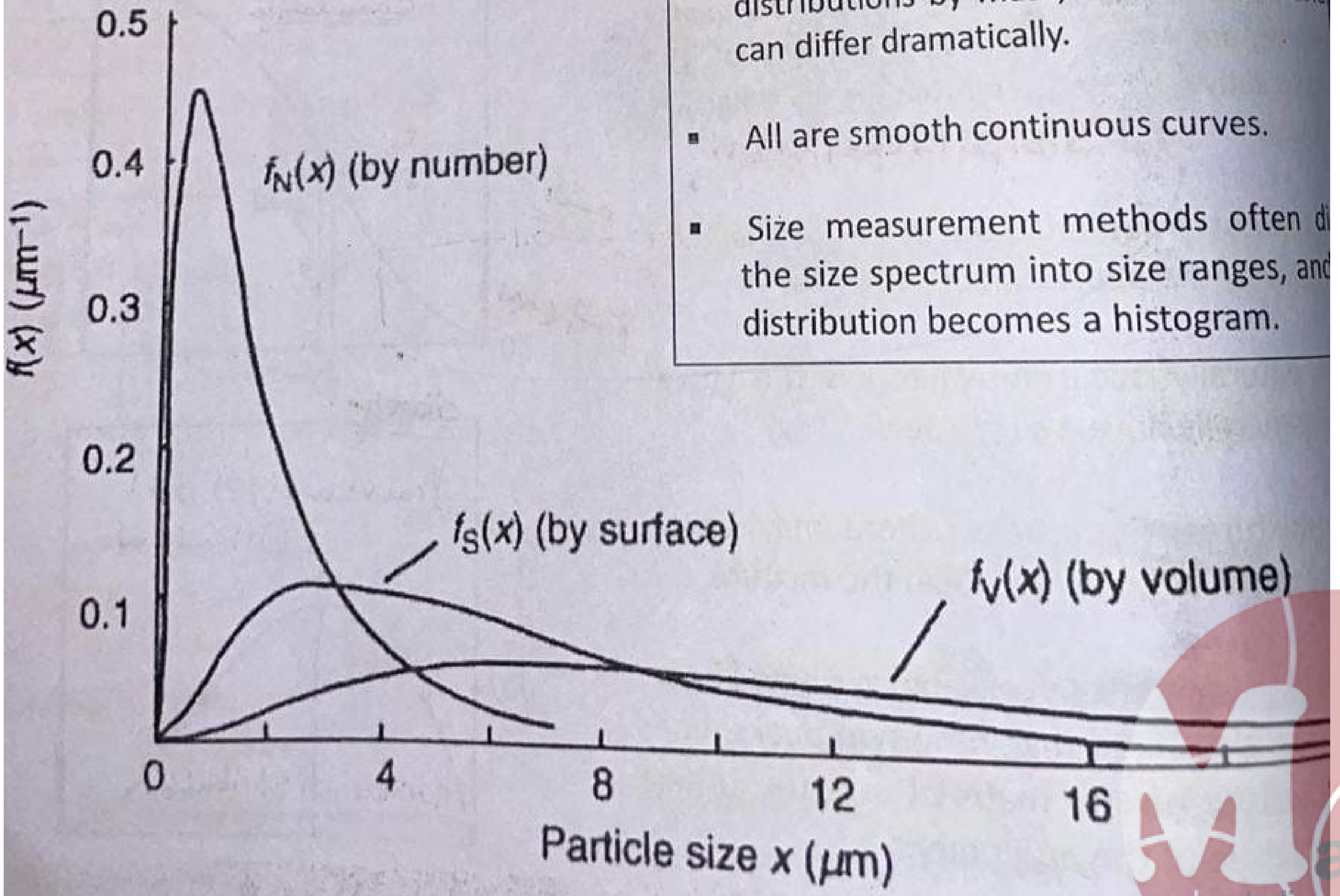


normal distribution

M. Saidan

Comparison between distributions

- For a given population of particles, t distributions by mass, number and surfa can differ dramatically.
- All are smooth continuous curves.
- Size measurement methods often di the size spectrum into size ranges, and distribution becomes a histogram.



Mixed particle size and size analysis

- In a sample of uniform particles of diameter D_p the total volume of the particles is m/ρ_p
- The volume of one particle is v_p , the number of particles in the sample N is

no. of particle

$$N = \frac{m \rightarrow \text{Total mass}}{\rho_p v_p}$$

mass of one particle

- The total surface area of particles is:

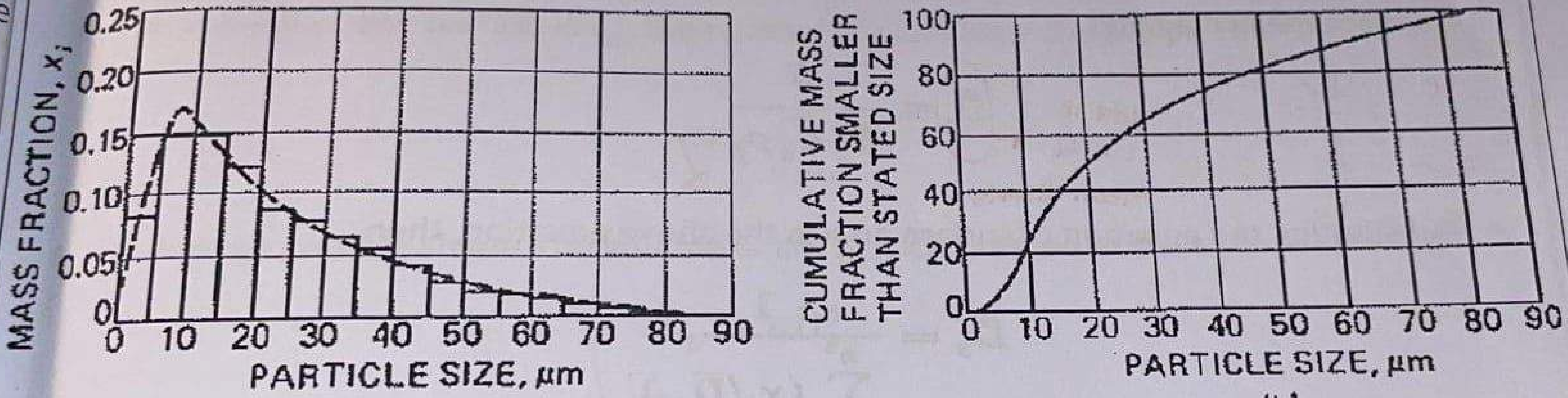
$$A = Ns_p = \frac{6m \rightarrow \text{total mass}}{\Phi_s \rho_p D_p}$$

if spherical the $\Phi_s = 1$ ✓

specific surface area for one particle

uniform

- Now to apply these equations to mixtures of particles having various sizes and densities, the mixtures should be screened and sorted into fractions (each of constant density and constant size).



(a)

(b)

Particle-size distribution for powder: (*a*) differential analysis; (*b*) cumulative analysis.

✓ Cumulative analysis is more precise

Specific Surface Area of Mixture

- If particle density and sphericity are known in each fraction, the surface area of particles is calculated by:

$$A_w = \frac{6x_1}{\Phi_s\rho_d\bar{D}_{p1}} + \frac{6x_2}{\Phi_s\rho_p\bar{D}_{p2}} + \cdots + \frac{6x_n}{\Phi_s\rho_p\bar{D}_{pn}}$$

$$= \frac{6}{\Phi_s\rho_p}\sum_{i=1}^{n}\frac{x_i}{\bar{D}_{pi}} \begin{matrix}\text{Column 3}\\ \text{Column 4}\end{matrix}$$

where subscripts = individual increments

x_i = mass fraction in a given increment

n = number of increments

$\bar{D}_{pi}$ = average particle diameter, taken as arithmetic average smallest and largest particle diameters in increment

Average Particle Size

- The average particle size of mixture particles is most probably expressed by volume-surface mean diameter

$$\frac{6}{\phi_s \rho} \times \frac{\phi \rho}{6}$$

volume Surfae mean diameter

$$\bar{D}_s \equiv \frac{6}{\Phi_s A_w \rho_p}$$

- Substituting the equation of surface area in the above equation, then

$$\bar{D}_s = \frac{1}{\sum_{i=1}^{n} (x_i/\bar{D}_{pi})}$$

- If the number of particles in each fraction is known (N_i) , instead of mass fraction, then the arithmetic mean diameter is used:

$$\bar{D}_N = \frac{\sum_{i=1}^{n} (N_i \bar{D}_{pi})}{\sum_{i=1}^{n} N_i} = \frac{\sum_{i=1}^{n} (N_i \bar{D}_{pi})}{N_T}$$

Where the (N_T) is the number of particles in the entire sample

- The mass mean diameter is calculated by:

Column 3 x 4

$$\bar{D}_w = \sum_{i=1}^{n} x_i \bar{D}_{pi}$$

- Dividing the total volume of the sample by the number of particles in the mixture gives **the average volume of a particle**. The diameter of such a particle is **the volume mean diameter** which is calculated by:

$$\bar{D}_V = \left[\frac{1}{\sum_{i=1}^{n} (x_i/\bar{D}_{pi}^3)} \right]^{1/3}$$

Volume mean diameter

Number of Particles in the Mixture

- The volume of one particle is v_p , the number of particles in the sample N is

$$N = \frac{m}{\rho_p v_p}$$

- For a given particle shape, the **volume** of any particle is proportional to its **(diameter)**^{3}

$$v_p = aD_p^3$$

*Where **a** is the volume shape factor (assuming it is independent on size))*

- Based on that, the number of particles in the mixture is:

$$N_w = \frac{1}{a\rho_p}\sum_{i=1}^{n}\frac{x_i}{\bar{D}_{pi}^3} = \frac{1}{a\rho_p \bar{D}_V^3}$$

HW1: Full assessment

$\frac{2.3+3.3}{2}$ ← Averag particle size to the particles stuck in mesh 8

standard: we take avg not range

افرجي لكل معفلين ورا بعض

(راكم ← جمع)

standard

standard

not Standard Data

الفرق بالعقل وصفاحي وأعتك العدد بيعتك عدد حجز بجزئيات

total

Mesh	Screen opening D_{pi}, mm	Mass fraction retained, x_i,	Average particle diameter in increment, $\bar{D}_{pi}$, mm	Cumulative fraction smaller than ~~1-column~~ 1 - column 3
			Dpi = avg particle	
4	4.699	$\frac{0}{1kg}$ 0.0000 → كلو مر منه ضلدلوا	—	1.0000
6	3.327	0.0251 $\frac{w}{1kg}$	4.013	0.9749
8	2.362	0.1250	2.845	0.8499
10	1.651	0.3207	2.007	0.5292
14	1.168	0.2570	1.409	0.2722
20	0.833	0.1590	1.001	0.1132
28	0.589	0.0538	0.711	0.0594
35	0.417	0.0210	0.503	0.0384
48	0.295	0.0102	0.356	0.0282
65	0.208	0.0077	0.252	0.0205
100	0.147	0.0058	0.178	0.0147
150	0.104	0.0041	0.126	0.0106
200	0.074	0.0031	0.089	0.0075
Pan	—	0.0075	0.037	0.0000

قديش من العينة مر منه هذا ال Dpi

0 - 1

100% from sample has a particle size lower than 4.699

2.5% from sample

1 - 2.51 → انحجز

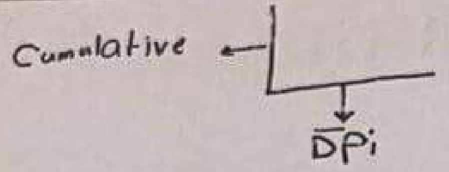
~~0.125~~ 15.9% from sample has a particle size from ~~0.833~~ to 1.168 and has an average diameter of 1.001

0.833

and has an average diameter of

Cumulative

mesh:



Cumulative (column 5):

[illegible]

Using the table in the previous slide

take care! column #2, 4

a sample of crush
quartz. The density of the particles is 2650 kg/m³ (0.00265 g/mm³), and the sha
factors are $a = 2$ and $\Phi_s = 0.571$. For the material between 4-mesh and 200-mesh
particle size, calculate (a) A_w in square millimeters per gram and N_w in particles p
gram, (b) $\bar{D}_V$, (c) $\bar{D}_s$, (d) $\bar{D}_w$, and (e) N_i for the 150/200-mesh increment. (f) Wh
fraction of the total number of particles is in the 150/200-mesh increment?

Particulate Solid in Bulk

behavior of solid particles in bulk !!

Storage in tanks.

بالأطنان

- The properties of solids in bulk are a function of the properties of the individual particles including their shapes and sizes and size distribution, and of the way in which the particles interact with one another, ✓

hoppers!

- Particulate solids present considerably greater problems than fluids in storage, in removal at a controlled rate from storage, and when introduced into vessels or reactors where they become involved in a process,

Liquid, gas أصعب منه

spaces when two solid particles face each other

- One of the most important characteristics of any particulate mass is its **voidage** *(the fraction of the total volume which is made up of the free space between the particles and is filled with fluid.)*

T/F

Porousity: within a particle

مسامات free volume between solid particle

- Low voidage ==== high density of packing of the particles.

= high surface area = low particle size!

voidage decreases with lowering particle size

فما بيسمح للفلويد بالمرور من خلاله.

- The way in which the particles pack depends not only on their physical properties, including shape and size distribution, but also on the way in which the particulate mass has been introduced to its particular location.

orientation ← كل وحدة كيف ترتيب تحت

(شكل + استقرار الجزيء يلعب دور كبير في ال Packing)

  - isometric particles = pack more densely than long thin particles or plates

↑ specity ↑ packing by dense

  - The more rapidly material is poured on to a surface or into a vessel, the more densely will it pack.

↓ spericity ↓ Low packing

isometric, spherical : packing more, density high

Low symmetry, Low sphericity: packing low, density low!!

T/F!

زي سكب الطحين في وعائين

كل ما تصفط حجم تحط مادة اكثر

bulk!! الكتلة!!

Agglomeration of particles

particle مجمعين ... ant to avoid it you have to do force onil

- Agglomeration arises from interaction between particles, as a result of which they adh
  التصاق
  to one another to form clusters.

{مجمّع}←

↓ friction occurs!!

- If the particles tend to agglomerate, poor flow properties may be expected.

high friction.

- If a significant amount of the material is in the form of particles smaller than 10 µm o the particles deviate substantially from isometric form, it may be inferred that the f characteristics will be poor.

Siggeregation تمايز | حبات احمر وابيض

فيه كتير الخلط بتشبكوا ببعض

Mechanisms leads to agglomeration

Causes of : عوامل

Long/thin
interlocking
تشابك ex: spagetti

1. ***Mechanical interlocking***. This can occur particularly if the particles are long and thin shape, in which case large masses may become completely interlocked.

vander Waal
تجاذب الجزيئات
و مع السطح

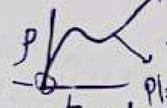
2. ***Surface attraction***. Surface forces, including van der Waals' forces, may give rise substantial bonds between particles, particularly where particles are very fine (<10 μm with the result that their surface per unit volume is high. In general, freshly form surface, such as that resulting from particle fracture, gives rise to high surface forces.

لما كل جزيء يكسر، القوى Wal تزيد

Solution: enlarge diameter

compression on edges
لما يكون عندي angular particle ممكن تتشابك و compres على وبالتالي ال Plasic welding

3. **Plastic welding.** When irregular particles are in contact, the forces between the partic will be borne on extremely small surfaces and the very high pressures developed m give rise to plastic welding.



Toughness لما تسحب مادة وتوصل لطول معين بعدها ما بترجع لشكلها السابق
بعد الكلام يرافقه حرارة

Charges Solution: تفريغ

4. **Electrostatic attraction.** Particles may become charged as they are fed into equipme and significant electrostatic charges may be built up, particularly on fine solids.

رطوبة : water content!!

humidity
surface tension
attract particle and bond bettween them

5. **Effect of moisture.** Moisture may have two effects. Firstly, it will tend to collect near t points of contact between particles and give rise to surface tension effects. Secondly, may dissolve a little of the solid, which then acts as a bonding agent on subseque evaporation.

Solution: اغلاق تام

6. **Temperature fluctuations** give rise to changes in particle structure and to grea cohesiveness.

التصاق!

Soln: hunger
ما يتعرض للهوا

themal a units. او اي

نتر — ضغط compression

Resistance to shear and tensile forces

لما يكون عندي bulk تأثير shear tens. اقل لما يكون ع كل Particles

- A particulate mass may offer a significant resistance to both shear and tensile forces, either when there is agglomeration and even in non-agglomerating powders,
- The greater the density of packing, the higher will be this resistance to shear and tension.

as well packing ↑, flow ↑, resistance ↑

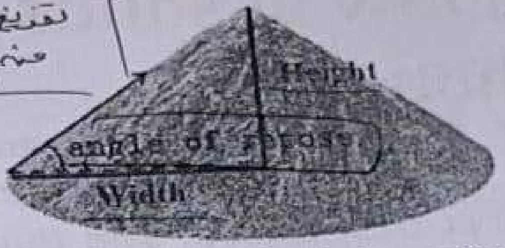
- The magnitude of the shear and tensile strength of the powder has a considerable effect on the way in which the powder will flow, and particularly on the way in which it will discharge from a storage hopper through an outlet nozzle.

shear ↑, friction ↑, flow ↓

Angles of repose and of friction

→ طحين سكر رز افرقهم ولاحظ فرعه
طول الجبل

particles لتشكيل
هرم، مخزانات



- A rapid method of assessing the behavior of a particulate mass is to measure its ***angle of repose***.
- *If solid* is poured from a nozzle on to a plane surface, it will form an approximately conical heap and the angle between the sloping side of the cone and the horizontal is the angle of repos,

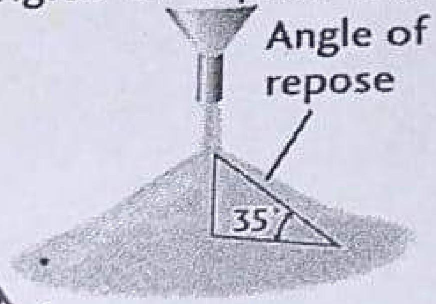
طرف قياس سحل زي قلاب الرمل → Dynamic angle of repose

- ① Dynamic angle of repose == the poured angle.
- ② Static angle of repose == the angle of slide

عبي kg من مادة ودورها عالهرم ؟

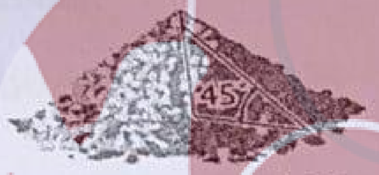
- Angles of repose vary from about 20◦ with free-flowing solids, to about 60◦ with solids with poor flow characteristics. In extreme cases of highly agglomerated solids, angles of repose up to nearly 90◦ can be obtained. Generally, material which contains no particles smaller than 100 µm has a low angle of repose.
- Powders with low angles of repose tend to pack rapidly to give a high packing density almost immediately.

كل ما كان حجم
الجزيء كبير
بعدها زاوية
أكبر



Fine sand

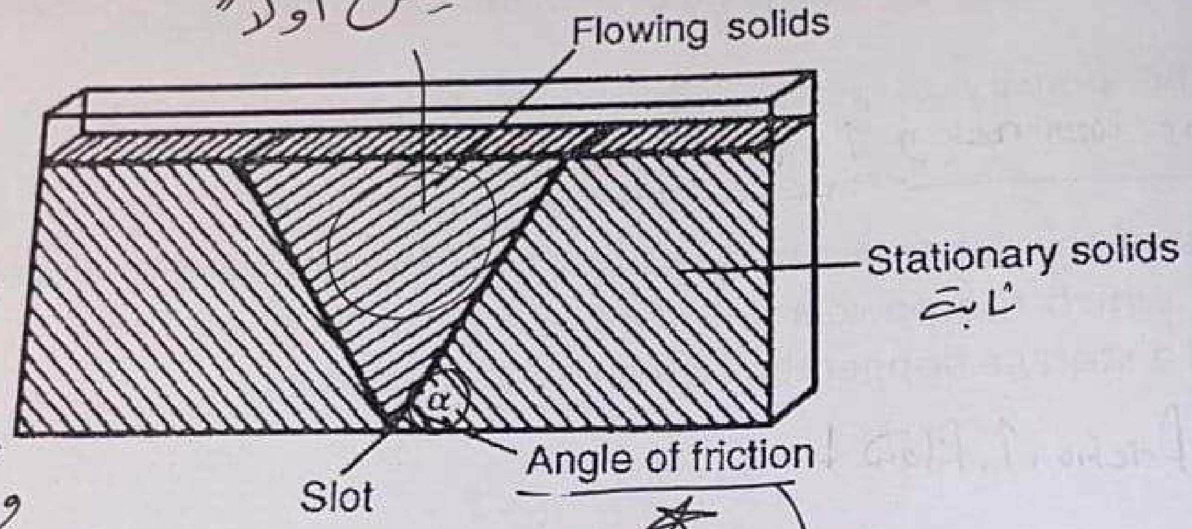
Coarse sand



Angular pebbles

Angle of friction

"ليفرغ اولا"



ثابتة

حوض سمك
عملت فيه حفره
وسكرتو بورقه
وجبت رمل عبيتو
وعنه تحت سحبت الورقة

~~كلما [illegible] الزاوية~~

كلما زادت زاد الانسياب فهو افضل

Read Coulson & Rishardson, page 24

كبر الزاوية قدر الامكان لزيادة الانسياب

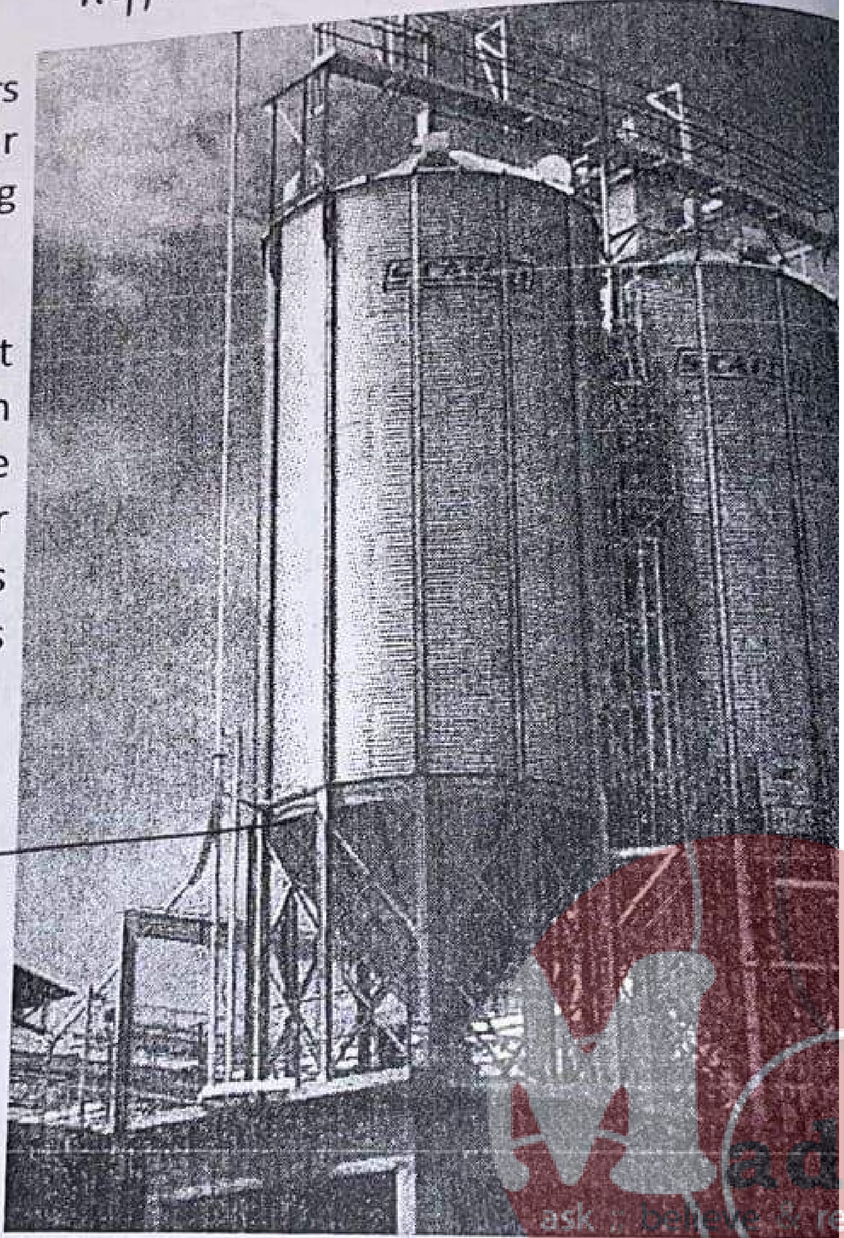
Cylo: ارتفاع عالي

hopper: ارتفاع اقل

Flow of solids in hoppers

- Frequently, solids are stored in hoppers which are usually circular or rectangular in cross-section, with conical or tapering sections at the bottom.

- The hopper is filled at the top and it should be noted that, if there is an appreciable size distribution of the particles, some segregation may occur during filling with the larger particles tending to roll to the outside of the piles in the hopper.



angle of repose

Low aggreg ← الزاوية التي يجسم عليها ميلان بحيث

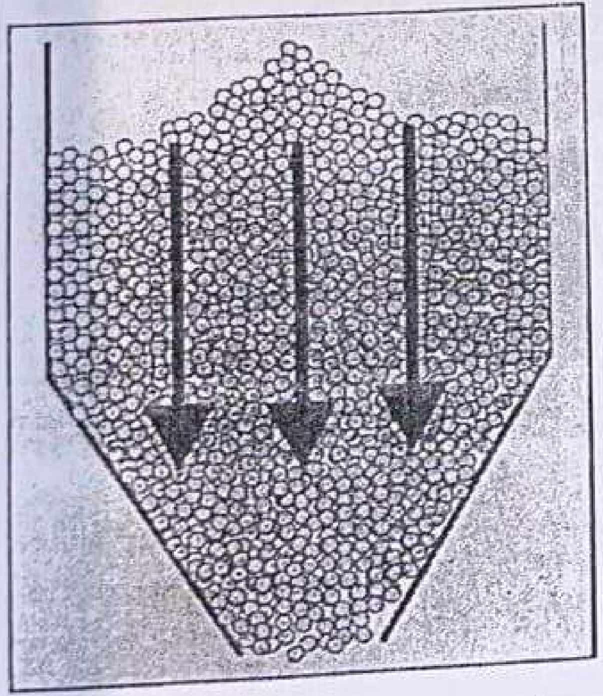
Particles discharge from the hopper

لما نطلع جزيئات منه vessel عندي مشاكل:

- In general, **tall thin hoppers** give better flow characteristics than **short wide ones** and the use **of long small-angle conical sections** at the base is advantageous.
- smooth surfaces give improved discharge characteristics.
- Monel metal cladding of steel is frequently used for this purpose.

Ideal mass flow

Particle سايز مختلف

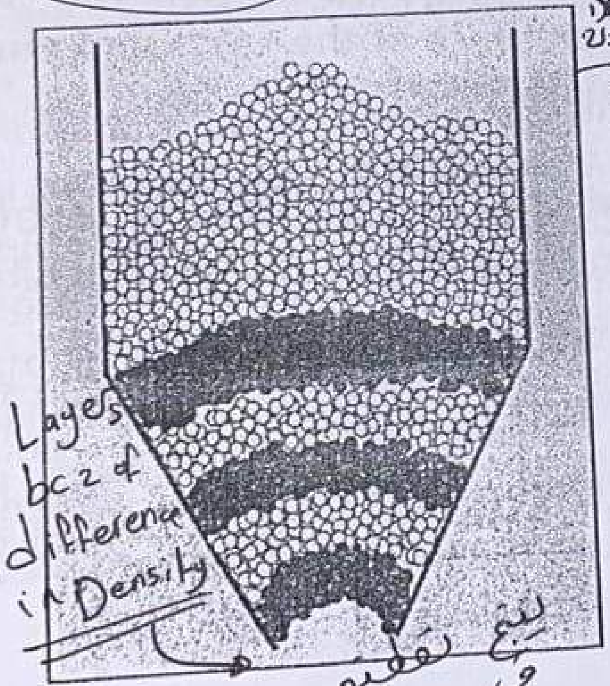


لما يكون عندي

"Bridging" "stable arches "

: segeregation : ترتيب الparticle حسب صفات معينة :

1) Density
2) size

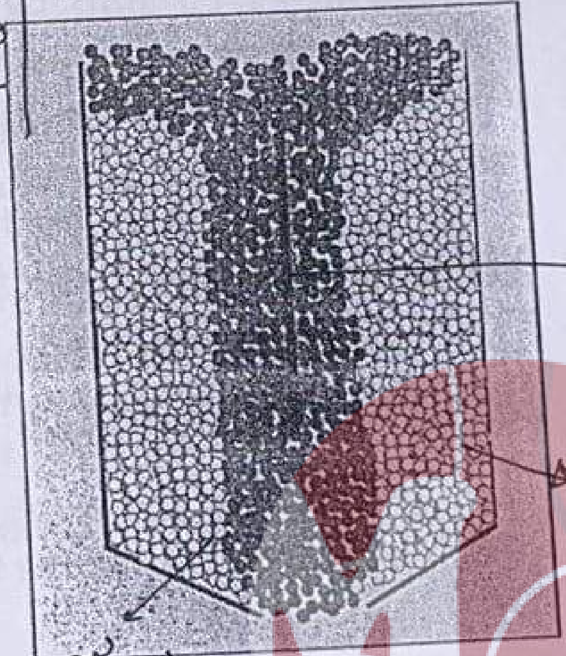


Layers bcz of difference in Density

بيتغ تقطيع في flowrate

"piping" or "rat-holing"

تحفير



اتجاه flow

ما بنزل

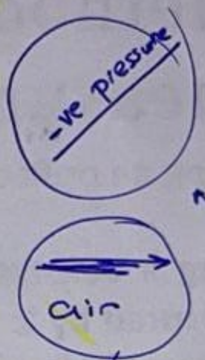
بعد وقت بتنزل مع الوقت وممكن تصير عنا segregation

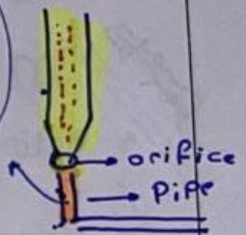
Read Coulson & Rishardson, pages 26 -27

Flow of solids through orifices

effective diamete

$$G = \frac{\pi}{4}\rho_s d_{\text{eff}}^{2.5} g^{0.5}\left(\frac{1-\cos\beta}{2\sin^3\beta}\right)^{0.5}$$





ودخل
ا خ

where: G is the mass flowrate,

ρ_s is the density of the solid particles.

d_{eff} is the effective diameter of the orifice (orifice - particle diameter).

g is the acceleration due to gravity, and

β is the acute angle between the cone wall and the horizontal.

Slowest rate is the limiting rate : bottle nick

معدل تفريغ المواد

- The discharge rate of solid particles is usually controlled by the size of the orifice or the aperture at the base of the hopper, though sometimes screw feeders or rotating table feeders may be incorporated to encourage an even flowrate.

  discharge rate يسرع ← orifice يدفش القاعدة كلها طالع من piston. →

- The effective diameter is the actual orifice diameter less a correction which is equal to between 1 and 1.5 times the particle diameter → effective diameter = actual X 1.5 ✓
- It has been found that the attachment of a discharge pipe of the same diameter as the orifice immediately beneath it increases the flowrate, particularly of fine solids. → تثبيت pipe بعد فتحة ال orifice
- Another method of increasing the discharge rate of fine particles is to fluidize the particles in the neighborhood of the orifice by the injection of air.

measure flowrate in silo:

mass lost / time

بنركبو على قبان للوزن بعدين نفرغ جزء منو ونأخذ فرق ونقسمه على الوقت

Measurement and control of solids flowrate

agglomeration ①
orientation ②
اكبر مشكلتين تواجهني في قياس ال flowrate :


قبان

- The flowrate of solids can be measured either as they leave the hopper or as they are conveyed.
- the hopper may be supported on load cells so that a continuous record of the mass of the contents may be obtained as a function of time.
- Alternatively, the level of the solids in the hopper may be continuously monitored using transducers covered by flexible diaphragms flush with the walls of the hopper. The diaphragm responds to the presence of the solids and thus indicates whether there are solids present at a particular level.

conveyed

- The problems associated with the measurement and control of the flowrate of solids are much more complicated than those in the corresponding situation with liquids.
- The flow characteristics will depend, not only on particle size, size range and shape, but also on how densely the particles are packed. In addition, surface and electric properties and moisture content all exert a strong influence on flow behavior, and the combined effect of these factors is almost impossible to predict in advance.

بقيس ال flowrate اكار وبعمل curve وبحسب $\dot{V} \longrightarrow \dot{m}$

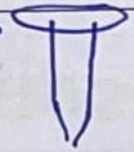
③ Source of radiation : فرص الاشعة المبعوثة والمستقبلة ومع calibration curve

بحسب $\dot{V}$ ثم مع الكثافة يتحول $\dot{m}$

(٣)

Methods for flow measurement

لما يقفل الـ cyl بنحطو : diaphram →



لما تنزل الـ particle

الـ diaphram بينزل ورا V

يقل مع الغرفجال original V عن

- Fitting an orifice plate at the discharge point from the hopper.

- Using a belt-type feeder in which the mass of material on the belt is continuously measured by load cells for example or by a nuclear densitometer which measures the degree of absorption of gamma rays transmitted vertically through the solids on the belt which is travelling at a controlled speed.

- Applying an impulse method in which a solids stream impacts vertically on a sensing plate orientated at an angle to the vertical. The horizontal component of the resulting force is measured by as load cell attached to the plate.

Flow Control

فزانة

- The rate of feed of solids may be controlled using screw feeders, rotating tables or vibrating feeders, such as magnetically vibrated troughs. →
- Volumetric rates may be controlled by regulating the speeds of rotation of star feeders or rotary valves.

سرعة الـ screw/...

هي بتحدد flow rate.

rbm

١٥٥ ٥.٢

Conveying of solids

١٥٨

نقل bulk من مكان الى اخر!

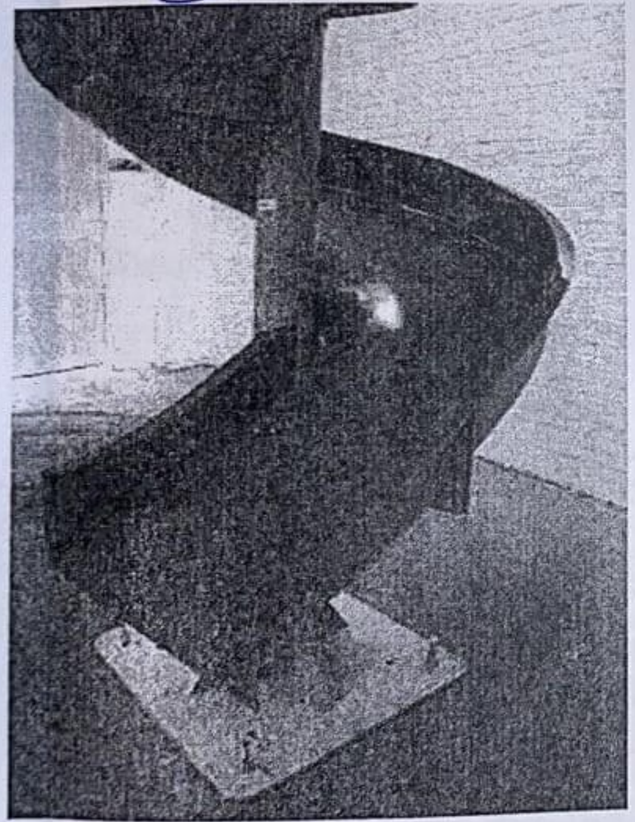
ناطحة سحاب

- **Gravity chutes**—down which the solids fall under the action of gravity.
- **Air slides**—where the particles, which are maintained partially suspended in a channel by the upward flow of air through a porous distributor, flow at a small angle to the horizontal. Closed area. فمناقل الى اعلى ← تحتاج نفخة ←

حزام ناقل

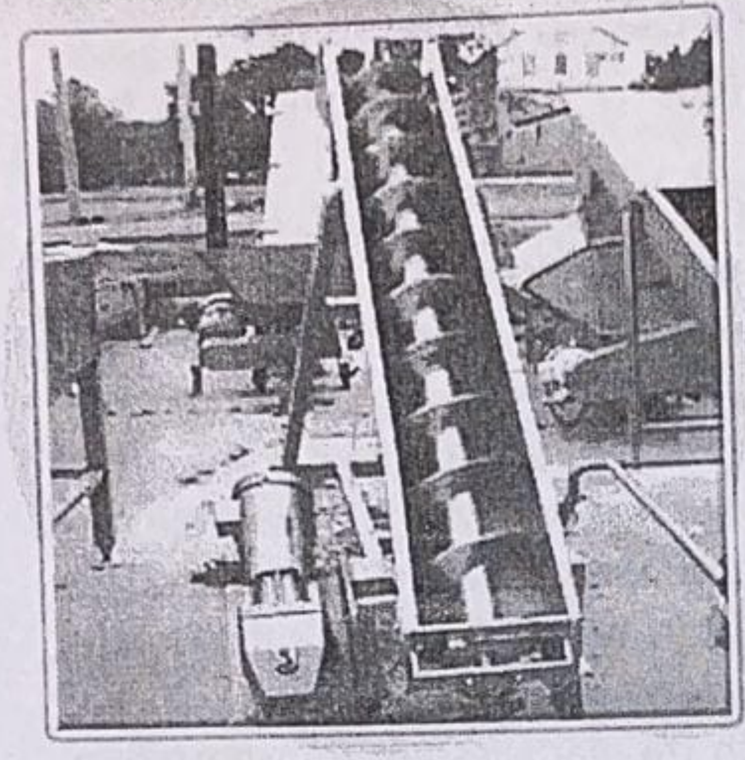
- **Belt conveyors**—where the solids are conveyed horizontally, or at small angles to the horizontal, on a continuous moving belt.
- **Screw conveyors**—in which the solids are moved along a pipe or channel by a rotating helical impeller, as in a screw lift elevator. وهو لما اطلع بعرف باله اوت.
- **Bucket elevators**—in which the particles are carried upwards in buckets attached to a continuously moving vertical belt (*See Figure 1.16. page 29, Coulson & Richardson*)
- **Vibrating conveyors**—in which the particles are subjected to an asymmetric vibration and travel in a series of steps over a table. During the forward stroke of the table the particles are carried forward in contact with it, but the acceleration in the reverse stroke is so high that the table slips under the particles. With fine powders, vibration of sufficient intensity results in a fluid-like behavior.
- **Pneumatic/hydraulic conveying installations**—in which the particles are transported in a stream of air/water. ~~000~~

Gravity chutes

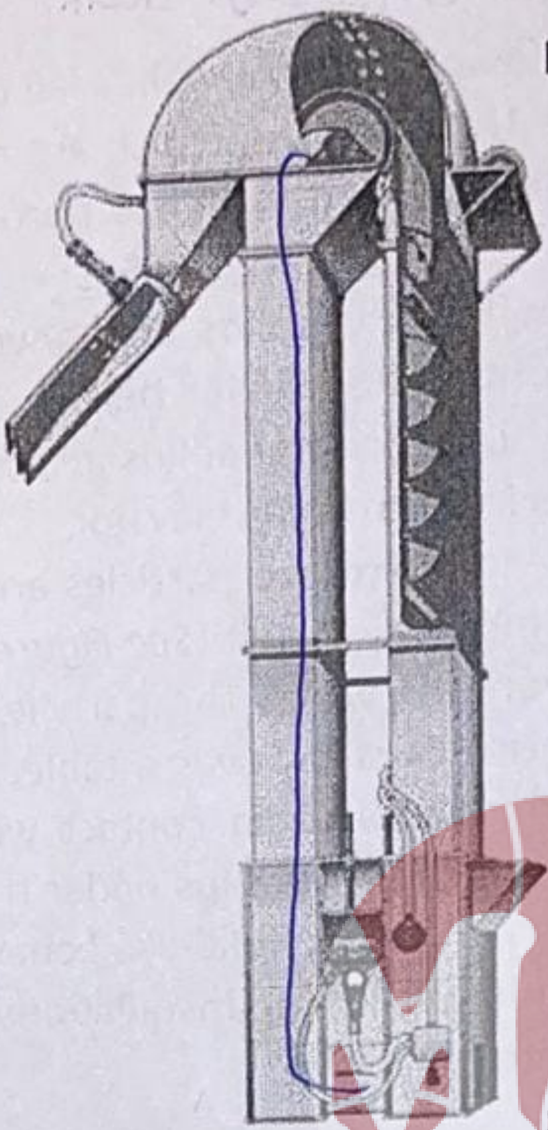


Belt conveyors

Screw conveyors



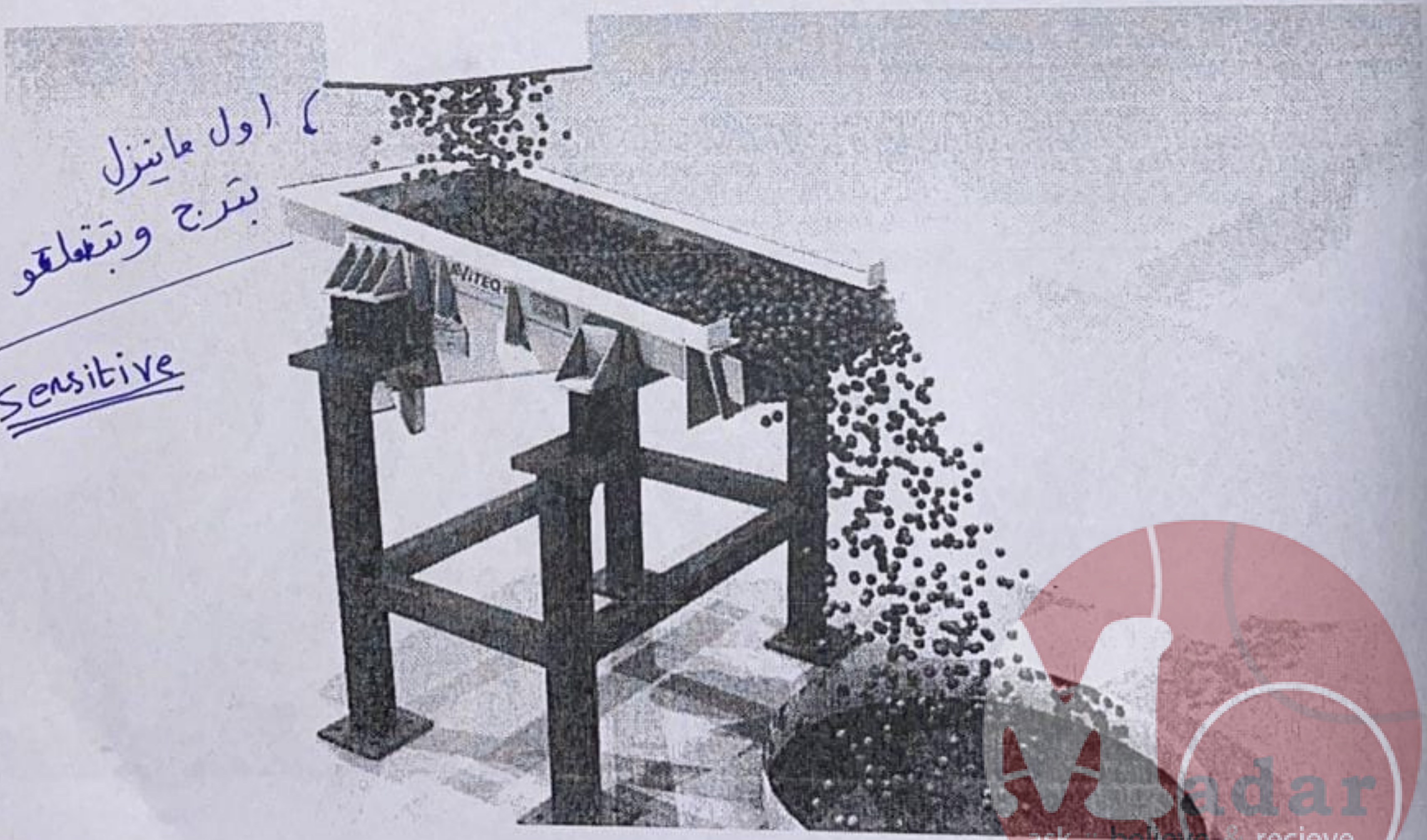
Bucket elevators



Vibrating conveyors

اول ما ينزل
بترج وبتقلقو

Sensitive



Mixing /blending. mechanisms

How to mix/time?!

to prepare a mixture of solid particles: فلصناعات لأدوية:

?Time needed to reach ideal mixing!

لو نقدر الوقت المطلوب رح يصل homo?!

flow/movement

A. Convective mixing, in which groups of particles are moved from one position to another, ✓

Particles of A is dominant!!. so it diffuses!!

B. Diffusion mixing, where the particles are distributed over a freshly developed interface, ✓

they may all used at the same time!!

A. Shear mixing, where slipping planes are formed ✓

نتقل جزيئات داخل فراغات جزيئات أخرى!!

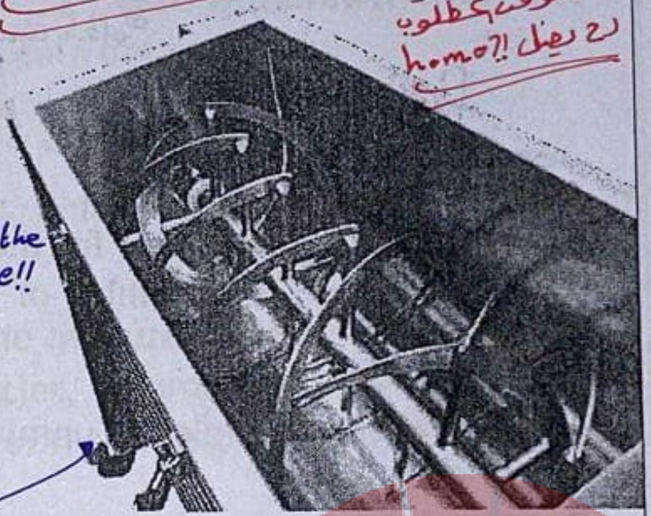
تحشير

يؤدي الى احتكاك

- These mechanisms operate to varying extents in different kinds of mixers and with different kinds of particles.
- A trough mixer with a ribbon spiral involves almost pure convective mixing, and

ملف حلزوني

- a simple barrel-mixer involves mainly a form of diffusion mixing.



The degree of mixing

statistical analysis → standard deviation that must be within the range!!

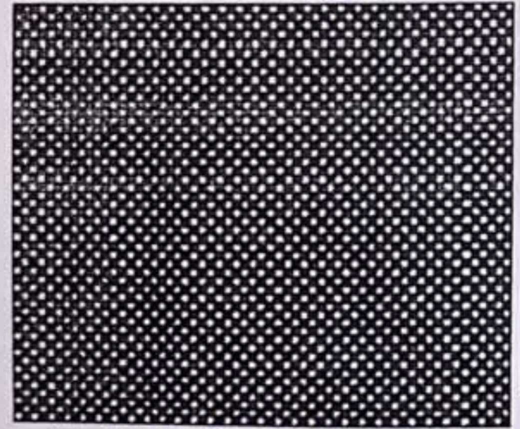
- It is difficult to quantify the degree of mixing, صعب نحدد جودة الخلط
- Statistical variation in composition among samples withdrawn at any time from a mix i commonly used as a measure of the degree of mixing of solid particles.

← ضبط جودة

س: كل ما نعمل باتش باخذ عينة: ① اما منه different batches ناخذ عينات او منه same batch ناخذ على وقت :: ← عشان نشوف جودة الخلط

- The standard deviation s (the square root of the mean of the squares of the individua deviations) or the variance s^2 is generally used.
- No perfect mixing: just a degree of randomness in which two similar particles may well b side by side

ideal



↳ Cannót acheive it!!

- No amount of mixing will lead to the formation of a uniform mosaic. فسيفساء
- Just overall uniformity but not point uniformity

بجي علينا كلما فش نقطة نقطة

→ time has to be obtimized to obtain the best degree of mixing.

For a completely random mix of uniform particles:

النسبة المطلوبة.

fully mixed on the best degree!! ←

$$s_r^2 = \frac{p(1-p)}{n}$$

n → particles

where s_r^2 is the variance for the mixture, p is the overall proportion of particles of one colour, and n is the number of particles in each sample.

However, in a completely unmixed system

unmixed at $t=0$ ←

$$s_0^2 = p(1-p)$$

بعدني ما شغلت mixer

which is independent of the number of particles in the sample

When a material is partly mixed, then the degree of mixing may be represented by some term *b*

كل ما قلّت

→ هاي زادت!!

المتغيرة الوحيدة

degree of mixing.

$$\leftarrow b = \frac{(s_0^2 - s^2)}{(s_0^2 - s_r^2)}$$

$$1 - b = \frac{(s^2 - s_r^2)}{(s_0^2 - s_r^2)}$$

- For diffusive mixing, ***b*** will be independent of sample size provided the sample is small.
- With convective mixing, ***1 – b*** depends on the size of the sample

Example

||H.W||

The performance of a solids mixer was assessed by calculating the variance occurring in the mass fraction of a component amongst a selection of samples withdrawn from the mixture. The quality was tested at intervals of 30 *s* and the data obtained are:

S^2 minimum varience

sample variance (−)	0.025	0.006	0.015	0.018	0.019
mixing time (s)	30	60	90	120	150

best time!!!

P

If the component analyzed represents 20 per cent of the mixture by mass and each of the samples removed contains approximately 100 particles, comment on the quality of the mixture produced and present the data in graphical form showing the variation of the mixing index with time.

n

Solution

For a completely unmixed system:

$$s_0^2 = p(1 - p) = 0.20(1 - 0.20) = 0.16$$

For a completely random mixture:

$$s_r^2 = p(1 - p)/n = 0.20(1 - 0.20)/100 = 0.0016$$

The degree of mixing b is given by equation 1.35 as: $b = (s_0^2 - s^2)/(s_0^2 - s_r^2)$ In this case, $b =$ $(0.16 - s^2)/(0.16 - 0.0016) = 1.01 - 6.313s^2$ The calculated data are therefore:

t(s)	30	60	90	120	150
s^2	0.025	0.006	0.015	0.018	0.019
b	0.852	0.972	0.915	0.896	0.890

اعتبرها rate بالواجب

خذ average c

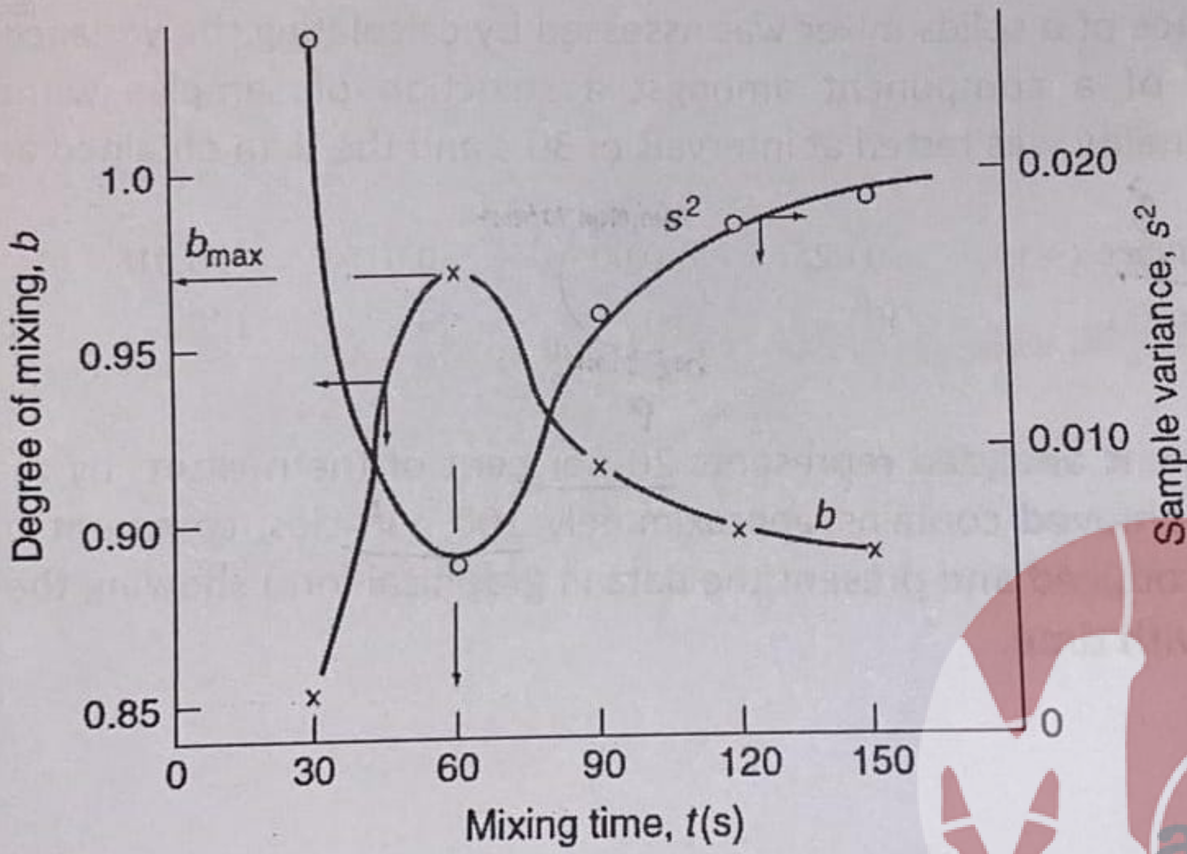
وعند certain time c

احسب b

الجيدة ≡ b

القيمة b ≡

b with time



It is clear that the degree of mixing is a maximum at $t = 60$s

The rate of mixing

Mixing involves obtaining an equilibrium condition of uniform randomness, the relation between ***b*** and time might be expected to take the general form:

$$\underline{\underline{\text{rate}}} \leftarrow b = 1 - e^{-ct}$$

ز) يعتمد

where ***c*** is a constant depending on the nature of the particles and the physical action of the mixer, as well as on:

بدنا speed نقيس عليه ال mixing

(a) the total volume of the material✓
(b) the inclination of the drum,
(c) the speed of rotation of the drum,
(d) the particle size of each component,
(e) the density of each component, and
(f) the relative volume of each component.

Solid Particles Separation

Screening. سابقا
Sedimentation.

- Separation depends on the selection of a process in which the behavior of the materia significantly influenced by some physical property.
  mainly density
- ✓ Sieving method is used if a material is to be separated into various size fractions. Sinc depends primarily on the size of the particles, also other physical properties such as shape of the particles and their tendency to agglomerate may also be involved
- ✓ Separation depends on the differences in the behavior of the particles in a moving fl and in this case the size and the density of the particles are the most important factors a shape is of secondary importance.
- ✓ Other separation processes make use of differences in electrical or magnetic properties the materials or in their surface properties.

or to extract Solids!!

- Solids are removed from fluids in order to purify the fluid although, in some cases, and particularly with liquids, it is the solid material that is the product.

- Separation processes are:

Precipitation: chemical reaction results in product that isn't soluble so by gravity it settels down

ترسيب

  - **Sedimentation**, in which the solids are allowed to settle by gravity through the liquid from which they are removed, usually as a pumpable sludge.

Physical

the settling is called sedimentation!

filterpaper/mesh

  - **Filtration**, in which the solids are collected on a medium, such as a porous material or a layer of fine particles, through which the liquid is pumped.

هيا او ماء داخل عوالق

الطرد المركزي!

  - **Centrifugal separation** in which the solids are forced on to the walls of a vessel which is rotated to provide the centrifugal force.

rbm

بلف فبطلع الفلويد فوقه و الدقائق الصلبة بالقاع

CAPECS+OPECS.

→ اذا عندك 2 chemicals بيجي جزيئات مختلف وكثافة مختلفة مغمورين داخل فلويد له كثافة.. لفصلهم يجب اللعب بكثافة الفلويد حتى تفصل by settling velocity

- In many cases it is possible to use the method to separate a mixture of two materials into its constituents, or to separate a mixture of particles of the same material into a number of size fractions.

Particle size

$$\frac{d_B}{d_A} = \left(\frac{\rho_A - \rho}{\rho_B - \rho}\right)^j \rightarrow \text{fluid}$$

بودرة

where $j = 0.5$ for fine particles, where Stokes' law applies, and $j = 1$ for coarse particles where Newton's law applies.

حجم بال mm الجزيء

اذا كان عندك وحدة fine

ووحدة . course

احسب مرة 0.5 ومرة 1

وطلع Density بعدها بتحتا رفلويد له كثافة بين الاول والثاني.

Example

A mixture of quartz and galena of a size range from 0.015 mm to 0.065 mm is to b separated into two pure fractions using a hindered settling process. What is the minimu apparent density of the fluid that will give this separation? The density of galena is 750 kg/m3 and the density of quartz is 2650 kg/m3.

Stokes' law applies

$$\frac{0.065}{0.015} = \left(\frac{7500-\rho}{2650-\rho}\right)^{0.5}$$

$$\rho = 2377\ \mathrm{kg/m^3}$$

Newton's law applies

$$\frac{0.065}{0.015} = \left(\frac{7500-\rho}{2650-\rho}\right)^{1.0}$$

$$\rho = 1196\ \mathrm{kg/m^3}$$

Thus, the required density of the fluid is between 1196 and 2377 kg/m3.

Gravity settling

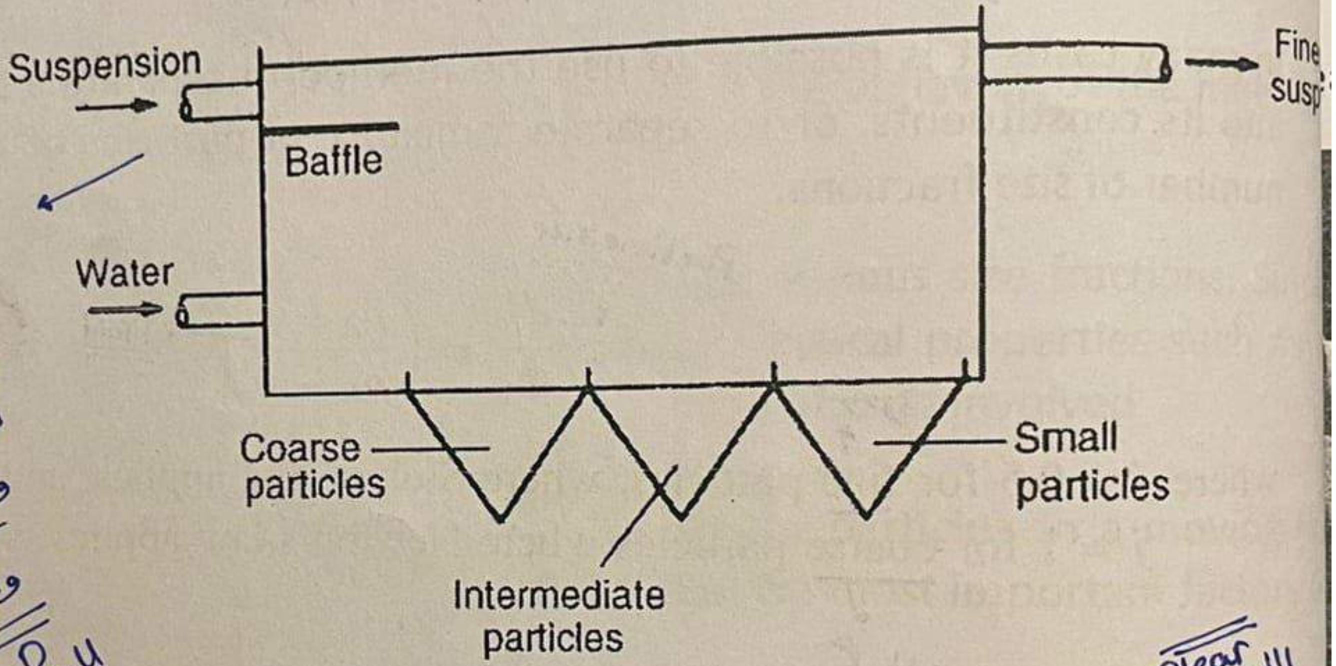
how to do this practically?!

The settling tank

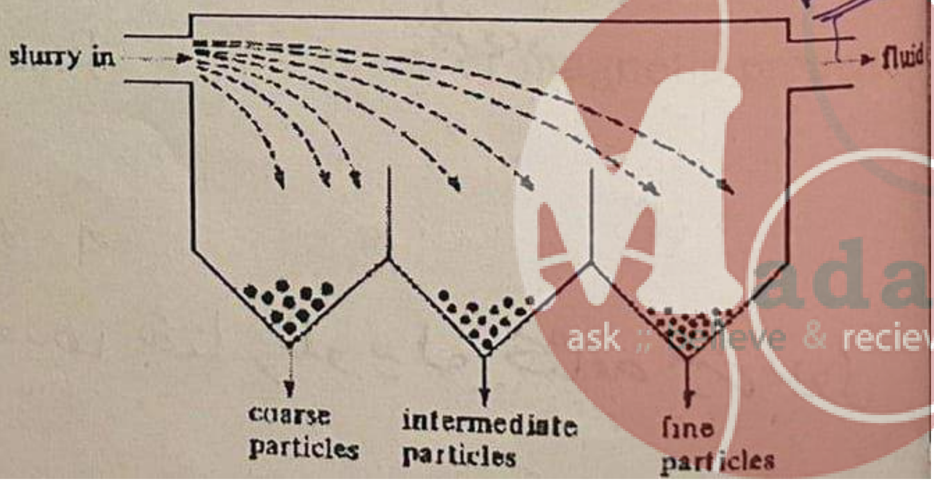
بدخل pipe
pipe بكب
جواه جزيئات معلقة وبجيد
عندي mixing turbelent
بعدين عندي تحت drain و
overflow من فوقه
واحسبه وقت

يسحب منه بجمع ← drain

by gravity, particles fall



Clear fluid!!



Read Coulson & Rishardson, pages 40 -46

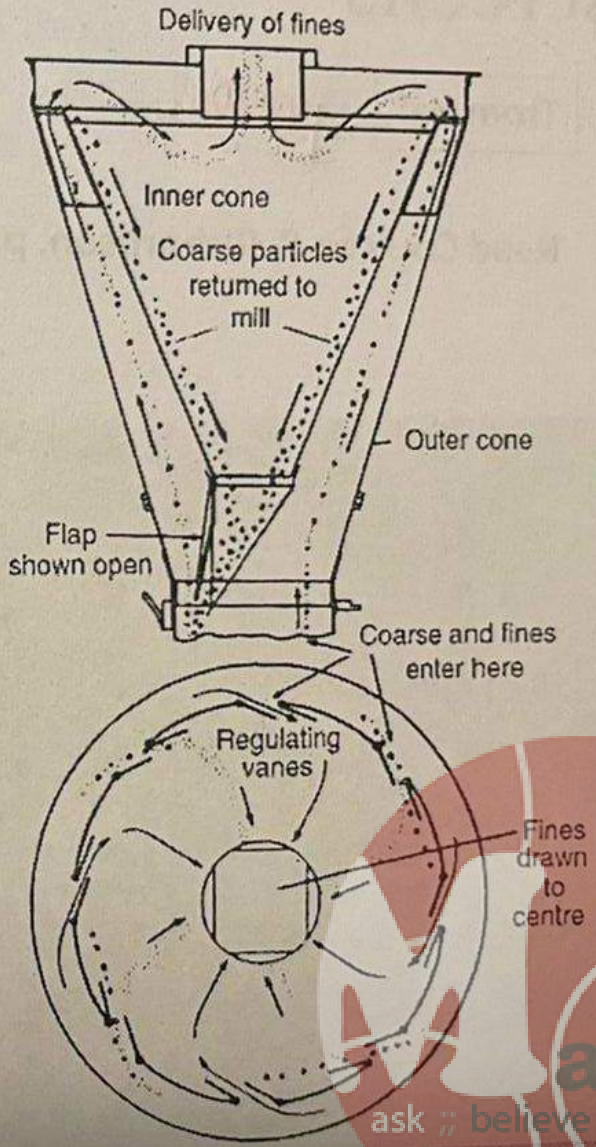
Centrifugal separators

65 65 21

Top clear

↓ density.

bottom



Read Coulson & Rishardson, pages **47-48**

Centrifugal pump. بتدخل جزيئات داخل فلويد على

ثم يبدأ يلف وبقوة الطرد المركزي تجمع الجزيئات بالأسفل.

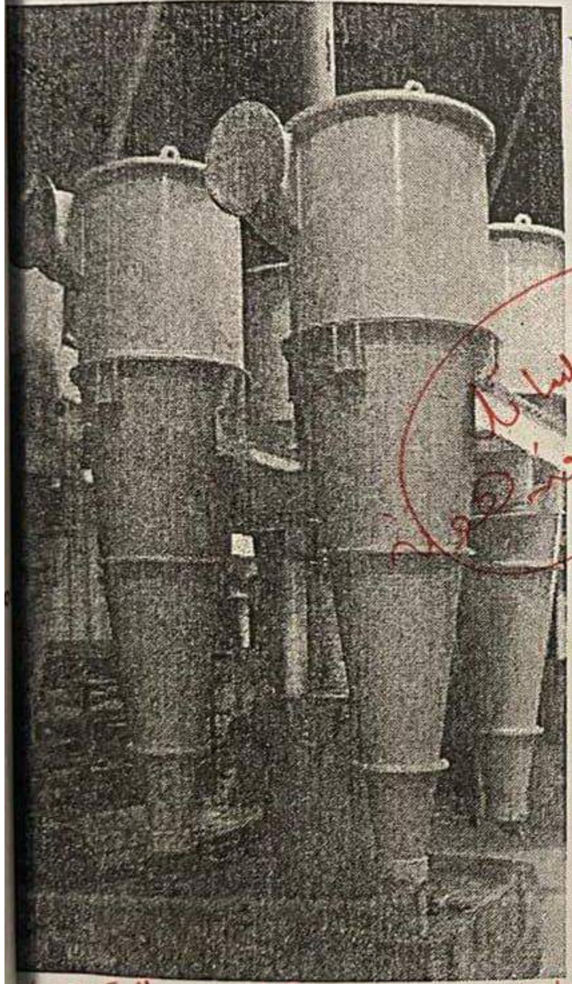
hydro cyclone; سائل " " "

best/one: Cyclone: اعرف انو الفلويد هوا

The hydrocyclone or liquid cyclone

حلزوي

Read Coulson & Rishardson, pages 49-56

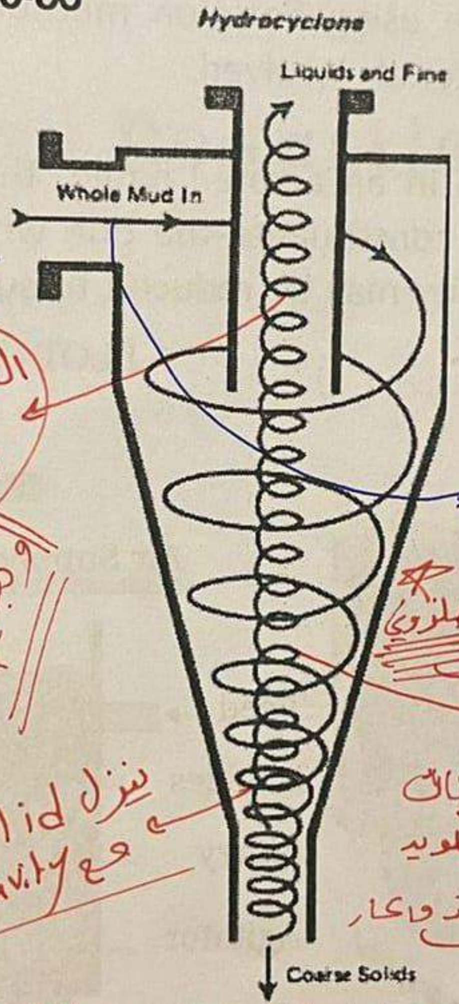

10m

Diameter قطر

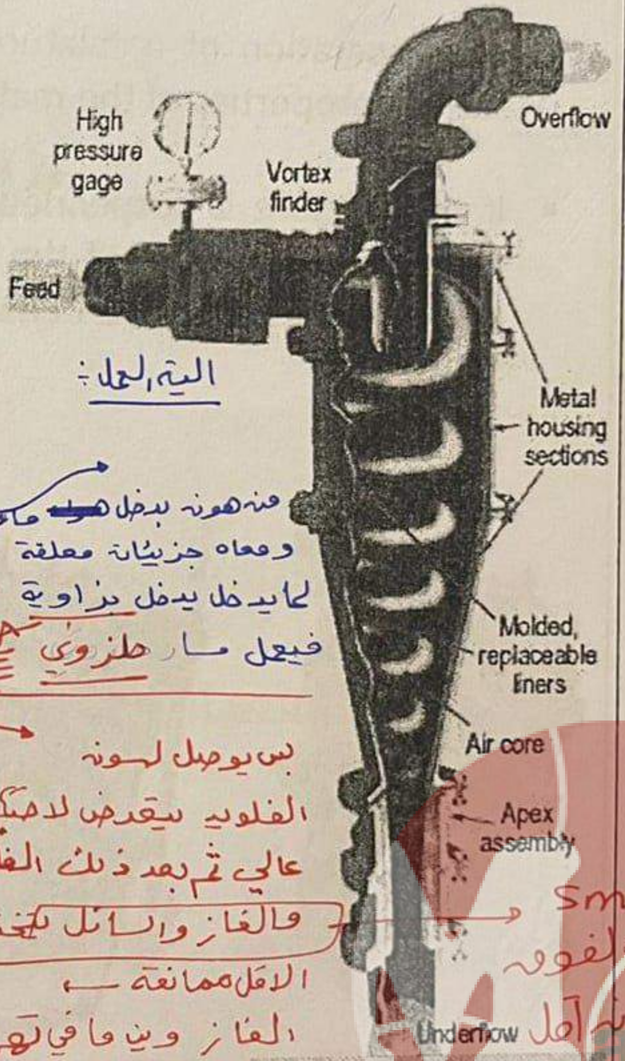
الغاز والسائل يطلعوا لفوق

والعبيد لعلية!!

solid ينزل مع gravity



حلزوي



الية العمل:

فمن هون بدخل ~~هوا~~ ماء ومعاه جزيئات معلقة لما يدخل يدخل بزاوية فيعمل مسار حلزوي

بس يوصل لهون الفلويد يتعرض لاحتكاك عالي ثم بعد ذلك الفلويد فالغاز والسائل تتخذ واحد الاقل ممانعة ←

smart يهرب لفوق لمكان أقل ممانعة

الغاز وين ما في تهريب غاز بطلع فيما بعد و Liquid بعدو solid.

الآن... وهون نازل الفلويد تحت السائل يشعر بممانعة

مع الجاذبية ينزل تحت!

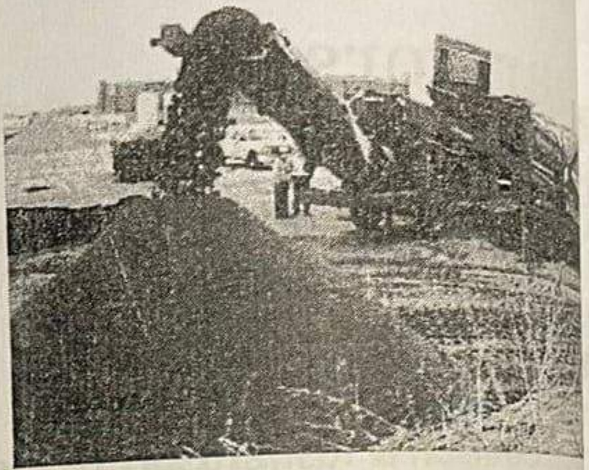
M. Saidan

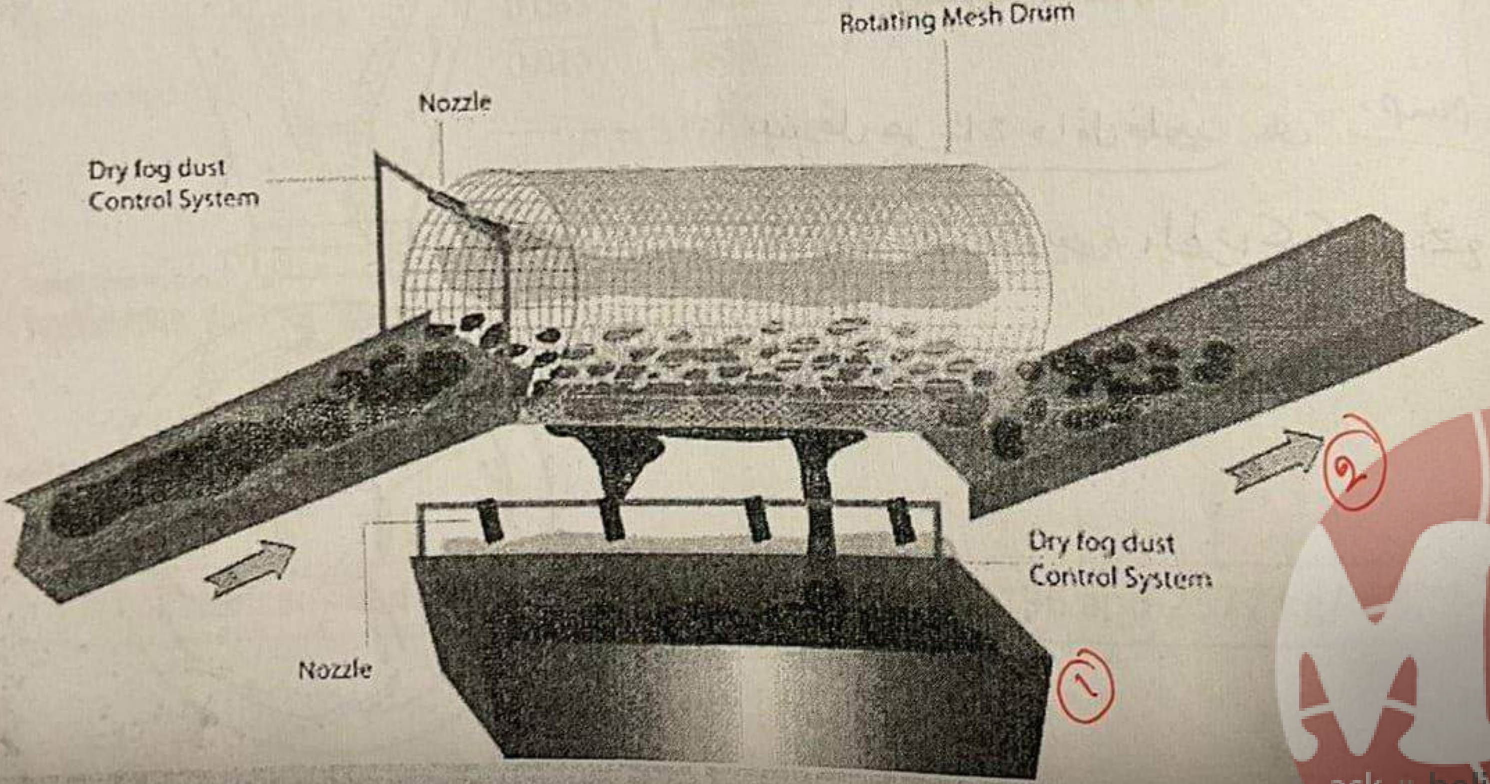
لانو القطر يقل فيصير backflow للسائل والصلب يكتسب قوة طرد مركزي

Sieves or screens

Trommel → movable

Read Coulson & Rishardson, pages 56-58





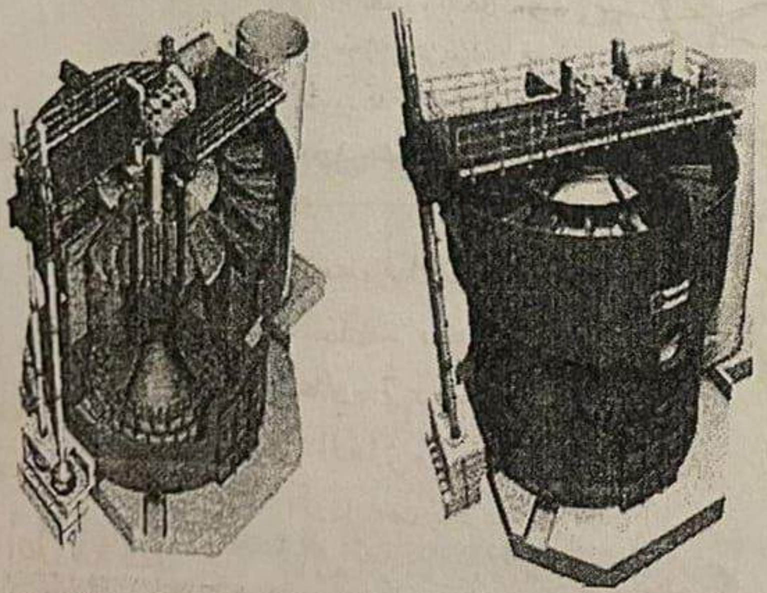
M. Saidan

Flotation

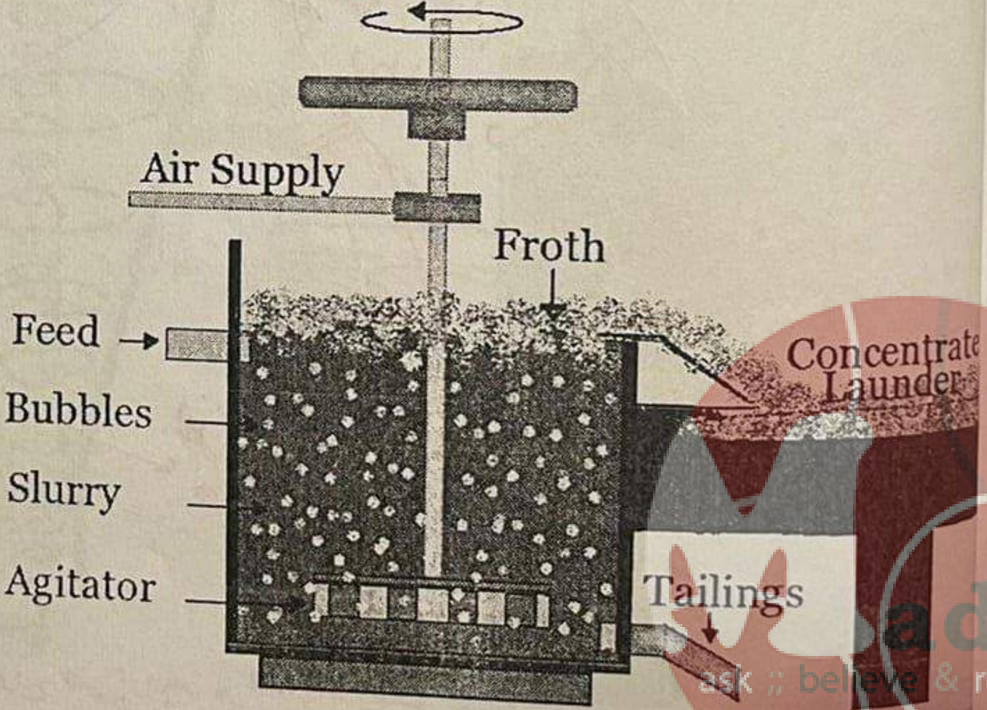
→ for oily particles

- The separation of a mixture using flotation methods depends on differences in t surface properties of the materials involved.

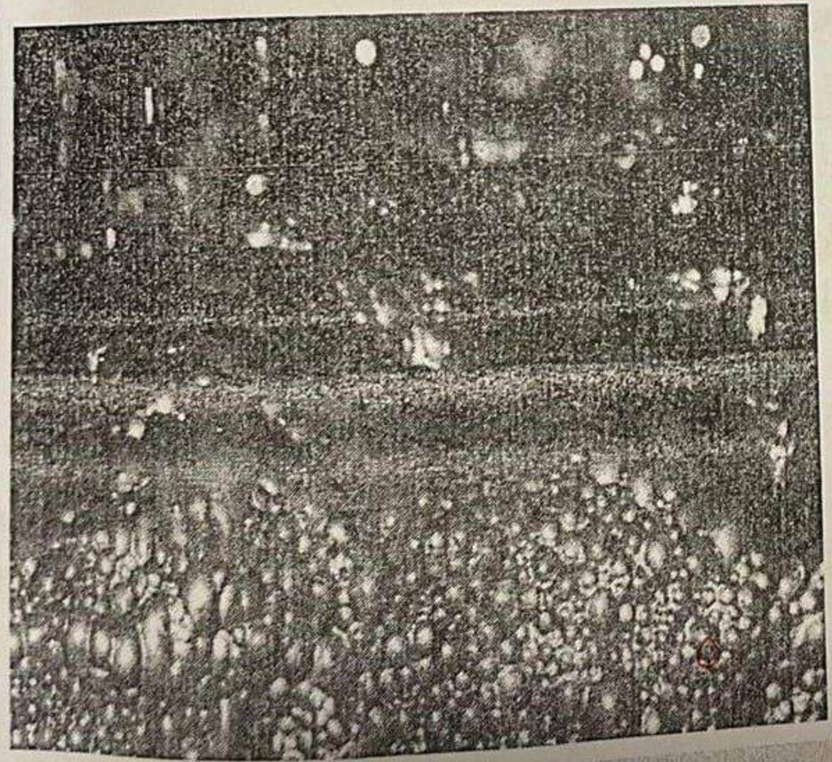
- If the mixture is suspended in an aerated liquid, the gas bubbles will tend to adh preferentially to one of the constituents–the one which is more difficult to wet by liquid–and its effective density may be reduced to such an extent that it will rise to surface.



FLOTATION PROCESS



Read Coulson & Rishardson, pages 62-67



8.11

Introduction

- reduction by crushing
- enlargment.

- Materials are rarely found in the size range required, and it is often necessary either to decrease or to increase the particle size.

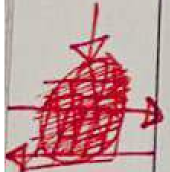
according to the Purpose!!

- The type of machine needed for size reduction/increasing depends, not only on the size of the feed and of the product, but also on such properties as compressive strength brittleness and stickiness.

hard
brittel
sticky
→ material ال properties تتغير ال, flowrate انما بيعتمد على ال, مابيمشي بس حجم الجزيئات

نوع equipment ← بجدولي

- Size reduction or comminution is an important step in the processing of many solid materials:



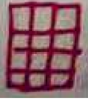
- ✓ To create particles in a certain size and shape
- ✓ To increase the surface area available for next process (contact area) — size in mm
- ✓ To liberate valuable minerals held within particles — benefitcation!! — تخلص منه فوائد

- Size reduction process : **extremely energy-intensive** and is **a very inefficient process**.

تصرف كهرباء — الماكنة بتروح الصوت — طاقة ضائعة — علل — الاعصار

- During the course of the size reduction processes, much energy is expended in causing plastic deformation and this energy may be regarded as a waste as it does not result fracture.

highly energy consuming ← plastic deformation ← التكسير



Particle Failure Mechanisms

- **Stress-strain behavior** force given

area under the curve = toughness

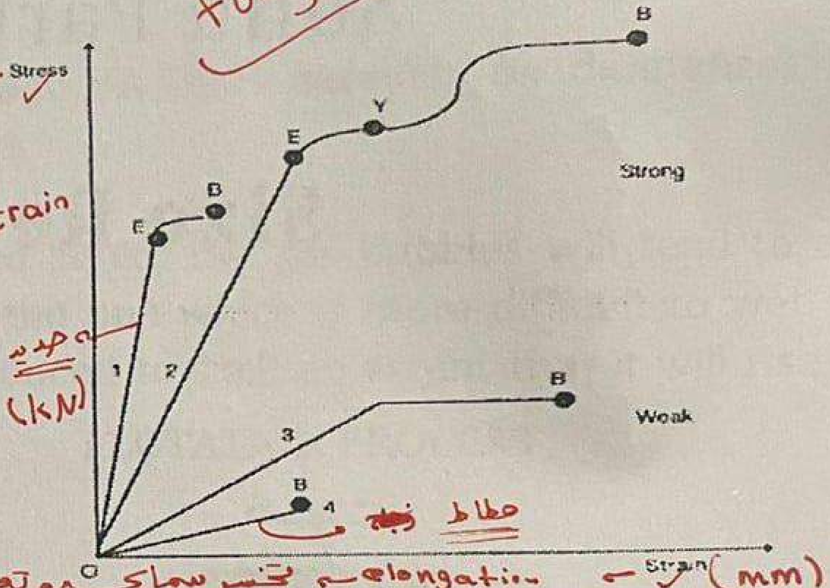
stress strain curve

elastic → plastic

قاسية
← hard : → surface → كيف بتصرف surface بهمني ع

هش brittel : → easy to break

high energy ← tough : → as a whole not only surface
صلبة
بتمر بكل المراحل :
eleastic → plastic → ...



حديد (kN)

مطاط

تنكسر بسماكه وتعطي طول!! ← elongation ← Strain (mm)

Fig. 4.1 Stess-strain diagram for various foods
(E = elastic limit; Y = yield point; B = breaking point; O–E = elastic region, E–Y = inelastic deformation region of ductility; (1) = hard, strong, brittle material; (2) = hard, strong, ductile material, (3) = soft, ductile material and (4) = soft, weak brittle material.) (After Loncin and Merson (1979))

- **Strain energy : energy stored in a body under tension**

  → not uniform but concentrated in splits, cracks, hollow parts, foreign inclusions, displacement

- The energy required to affect size reduction is related to the internal structure of material and the process consists of two parts, first opening up any small fissures which already present, and secondly forming new surface.

Energy Inefficiency

- Size reduction is a very inefficient process and only between 0.1 and 2.0 per cent of the energy supplied to the machine appears as increased surface energy in the solids. up to 2% of the energy we only need to break

98%
heat
sound
mecha
ضايع

- The efficiency of the process is very much influenced by the manner in which the load is applied and its magnitude. كيفية ال load بيضرب ع particle !!

انواع الفورسيس

- In addition the nature of the force exerted is also very important depending, for example, on whether it is predominantly a compressive, an impact or a shearing force. If the applied force is insufficient for the elastic limit to be exceeded, and the material is compressed, energy is stored in the particle. ال elastic ع الفاضي

اول ما تشيل الفورس ترجع لشكلها القبل !!

  - When the load is removed, the particle expands again to its original condition without doing useful work. The energy appears as heat and no size reduction is affected.

- A somewhat greater force will cause the particle to fracture, however, and in order to obtain the most effective utilization of energy the force should be only slightly in excess of the crushing strength of the material. The surface of the particles will generally be of a very irregular nature so that the force is initially taken on the high spots, with the result that very high stresses and temperatures may be set up locally in the material. ✱

بتروح ع الكيرف بتشوف maximum energy ع ال strain لحتى توصل
انو تتقطع معك العينة وتتكسر، حط عليها شوي زيادة قوة !!

Breakage of single particles

- All large lumps of material contain cracks and size reduction occurs as a result of **crack propagation** that occurs above a critical parameter, ***F***, where

[illegible] كسر ينتشر الكسر

$$F = \xcancel{\frac{\tau^2 a}{Y}}$$

~~where: a = crack length,~~
~~τ = stress, and~~
~~Y = Young's modulus.~~

- ➢ At lower values of *F*, elastic deformation occurs without fracture and the energy input is completely ineffective in achieving size reduction.

- ➢ The method of application of the force to the particles may affect the breakage pattern.

Fracture mechanisms:

- ➢ The four basic patterns are:
  - **(a) Impact** —particle concussion by a single rigid force. → اصطدام
  - **(b) Compression** —particle disintegration by two rigid forces. → بين فكين
  - **(c) Shear** —produced by a fluid or by particle –particle interaction. → مقص
  - (d) (d) **Attrition** —arising from particles scraping against one another or against a rigid surface. → particle قطعة

Energy for size reduction

from size → size

- It is impossible to estimate accurately the amount of energy required in order to effect a size reduction of a given material,
- A number of empirical laws have been proposed:

$$\frac{\mathrm{d}E}{\mathrm{d}L} = -CL^{p}$$

كل واحد قيمة

which states that the energy dE required to effect a small change dL in the size of unit mass of material is a simple power function of the size. If $p = -2$, then integration gives:

$$E = C\left(\frac{1}{L_2} - \frac{1}{L_1}\right)$$

from L_1 - L_2

Rittinger's law c

Writing $C = K_R f_c$, where f_c is the crushing strength of the material, then *Rittinger's law*, first postulated in 1867, is obtained as:

$$E = K_R \overset{\text{Strength of material}}{f_c} \left(\frac{1}{L_2} - \frac{1}{L_1}\right)$$

Since the surface of unit mass of material is proportional to $1/L$, the interpretation of thi law is that the energy required for size reduction is directly proportional to the increas in surface.

$$E= P/\dot{m}^o$$

where **P** is the power required, m^o is the feed rate to crusher

Kick's law C

Power: from hp → W
KW conversion

$$\frac{dE}{dL} = -CL^{p} \checkmark$$

If $p = -1$, then:

$$E = C \ln \frac{L_1}{L_2}$$

and, writing $C = K_K f_c$:

$$E = K_K f_c \ln \frac{L_1}{L_2}$$

- This supposes that the energy required is directly related to the reduction ratio L1/L2 which means that the energy required to crush a given amount of material from a 50 mm to a 25 mm size is the same as that required to reduce the size from 12 mm to 6 mm.

regardless what is L_1 and L_2

بيهمني النسبة

$$\underbrace{\frac{L_1}{L_2} = \frac{50}{25} = \frac{100}{50}}_{\text{نفس الطاقة}}$$

→ energy needed to reduce particle size from 1000-500 is the same as to reduce from ~~500~~ . 50-25

Bond crushing law and work index

c

Bond has suggested a law intermediate between Rittinger's and Kick's laws, by putting $p = -3/2$ in equation Thus:

$$E = 2C\left(\frac{1}{L_2^{1/2}} - \frac{1}{L_1^{1/2}}\right)$$

$$= 2C\sqrt{\left(\frac{1}{L_2}\right)}\left(1 - \frac{1}{q^{1/2}}\right)$$

where:

$$q = \frac{L_1}{L_2}$$

the reduction ratio. Writing $C = 5E_i$, then:

$$E = E_i\sqrt{\left(\frac{100}{L_2}\right)}\left(1 - \frac{1}{q^{1/2}}\right)$$

Bond terms E_i the *work index*, and expresses it as the amount of energy required to reduce unit mass of material from an infinite particle size to a size L_2 of 100 μm, that is $q = \infty$. The size of material is taken as the size of the square hole through which 80 per cent of the material will pass.

Example

A material is crushed in a Blake jaw crusher such that the average size of particle is reduc from 50 mm to 10 mm with the consumption of energy of 13.0 kW/(kg/s). What would the consumption of energy needed to crush the same material of average size 75 mm to average size of 25 mm:

a) assuming Rittinger's law applies?
b) assuming Kick's law applies?

Which of these results would be regarded as being more reliable and why?

Solution

a) *Rittinger's law.*

This is given by: $E = K_R f_c[(1/L_2) - (1/L_1)]$

Thus: $13.0 \; K_R f_c[(1/10) - (1/50)]$

and: $K_R f_c = (13.0 \times 50/4) = 162.5$ kW/(kg mm)

Thus the energy required to crush 75 mm material to 25 mm is:

$$E = 162.5[(1/25) - (1/75)] = \underline{\underline{4.33 \text{ kJ/kg}}}$$

✓

b) *Kick's law.*

This is given by: $E = K_K f_c \ln(L_1/L_2)$

Thus: $13.0 = K_K f_c \ln(50/10)$

and: $K_K f_c = (13.0/1.609) = 8/08$ kW/(kg/s)

Thus the energy required to crush 75 mm material to 25 mm is given by:

$$E = 8.08 \ln(75/25) = \underline{\underline{8.88 \text{ kJ/kg}}}$$

Energy utilisation

Energy is utilized in crushing as follows: why process is inefficient:-

(a) In producing elastic deformation of the particles before fracture occurs.
(b) In producing inelastic deformation which results in size reduction.
(c) In causing elastic distortion of the equipment.
(d) In friction between particles, and between particles and the machine.
(e) In noise, heat and vibration in the plant, and
(f) In friction losses in the plant itself.

- It is estimated that only about 10 per cent of the total power is usefully employed.

Nature of the material to be crushed

- The choice of a machine for a given crushing operation is influenced by the nature of the product required and the quantity and size of material to be handled.

- The more important properties of the feed apart from its size are as follows:

1. Hardness
2. Structure
3. Moisture content
4. Crushing strength
5. Friability
6. Stickiness
7. Soapiness

The Mohr Scale of Hardness

Materials are arranged in order of increasing hardness in the Mohr scale in which the first four items rank as soft and the remainder as hard. The Mohr Scale of Hardness is:

hardness تقاس ب

1. Talc طباشير
2. Rock salt or gypsum
3. Calcite
4. Fluorspar
5. Apatite
6. Felspar
7. Quartz
8. Topaz
9. Carborundum
10. Diamond.

اقسى شي

to select the appropriate machine!!

Solid Particles Separation

Screening . سابقا
Sedimentation.

- Separation depends on the selection of a process in which the behavior of the material significantly influenced by some physical property.
  mainly density

- ✓ Sieving method is used if a material is to be separated into various size fractions. Since i depends primarily on the size of the particles, also other physical properties such as the shape of the particles and their tendency to agglomerate may also be involved

- ✓ Separation depends on the differences in the behavior of the particles in a moving fluid, and in this case the size and the density of the particles are the most important factors and shape is of secondary importance.

- ✓ Other separation processes make use of differences in electrical or magnetic properties of the materials or in their surface properties.

sed i ment ation

so

ment minute

or to extract Solids!!

- Solids are removed from fluids in order to purify the fluid although, in some cases, and particularly with liquids, it is the solid material that is the product.

- Separation processes are:

Precepitation: chemical reaction results in product that isn't soluble so by gravity it settels down

ترسيب

  - **Sedimentation**, in which the solids are allowed to settle by gravity through the liquid from which they are removed, usually as a pumpable sludge.

Physical

the settling is called sedimentation!

Filterpaper/mesh

  - **Filtration**, in which the solids are collected on a medium, such as a porous material or a layer of fine particles, through which the liquid is pumped.

سهوا اوعاد داخل عوالق

الطرد المركزي!

  - **Centrifugal separation** in which the solids are forced on to the walls of a vessel which is rotated to provide the centrifugal force.

Pho

rbm بلف فبتلاقي الفلويد فوقه و الدقائقه الصلبة بالقاع

CAPECS + OPECS.

اذا عندك 2 chemicals بحجم جزيئات مختلف وكثافة مختلفة مغمورين داخل →
فلويد له كثافة... لفصلهم يجب اللعب بكثافة الفلويد حتى تفصل by settling velocity

- In many cases it is possible to use the method to separate a mixture of two materials into its constituents, or to separate a mixture of particles of the same material into a number of size fractions.

Particle size

$$\leftarrow \frac{d_B}{d_A} = \left(\frac{\rho_A - \rho}{\rho_B - \rho}\right)^j \rightarrow \underline{\underline{\text{fluid}}}$$

بودرة
↑
where $j = 0.5$ for fine particles, where Stokes' law applies, and
$j = 1$ for coarse particles where Newton's law applies.
↓
حجم بالـ mm
الجزيء

اذا كان عندك وحدة fine
ووحدة coarse .
احسبا مرة 0.5 ومرة 1
وطلع Density بعدها بتحتا، فلويد له كثافة بين الاول
والثاني.

Example

A mixture of quartz and galena of a size range from 0.015 mm to 0.065 mm is to b separated into two pure fractions using a hindered settling process. What is the minimum apparent density of the fluid that will give this separation? The density of galena is 750 kg/m3 and the density of quartz is 2650 kg/m3.

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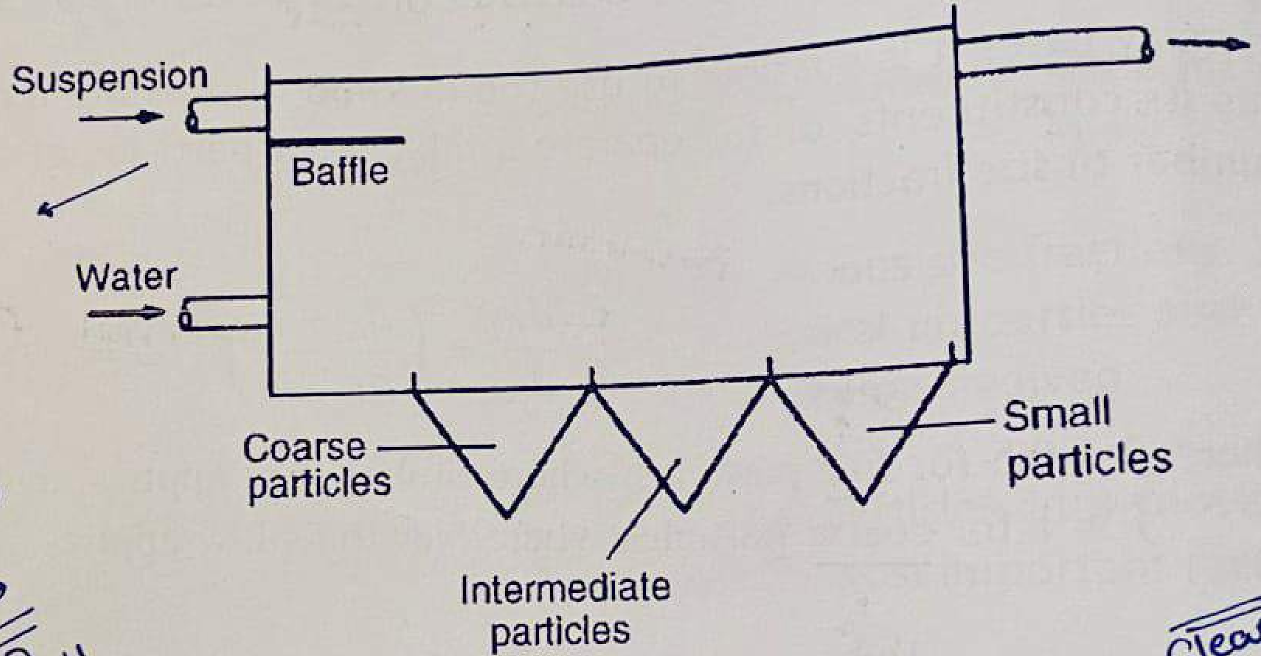
Thus, the required density of the fluid is between 1196 and 2377 kg/m3.

Gravity settling

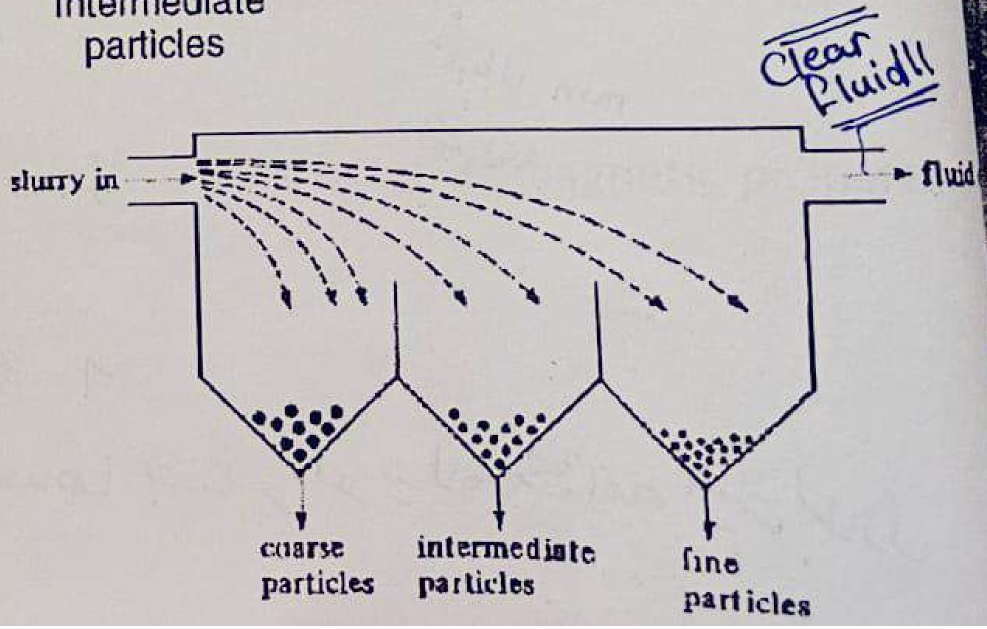
how to do this practically?!

The settling tank



بدخل pipe بكب pipe
جواه جزيئات معلقة والجيد
عندي mixing turbelent
لبعدين عندي تحت drain ← يسحب منه بتجمع
و overflow منه فوقة
واحسبه وقت

by gravity, particles fall



Coulson & Richardson pages 40 -46

Centrifugal separators

65 66

Top clear

↓ density.

bottom

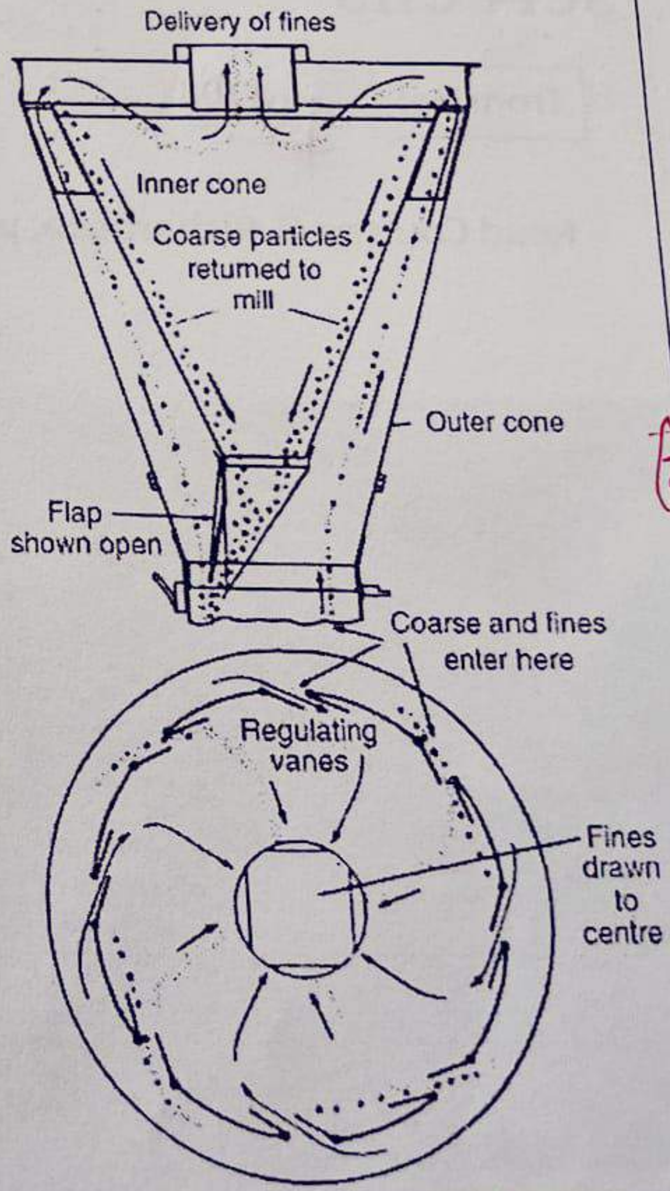
Read Coulson & Rishardson, pages 47-48

Centrifugal pump.

بتدخل جزيئات داخل فلويد على

ثم يبدأ يلف وبقوة الطرد المركزي تجمع الجزيئات

بالأسفل.



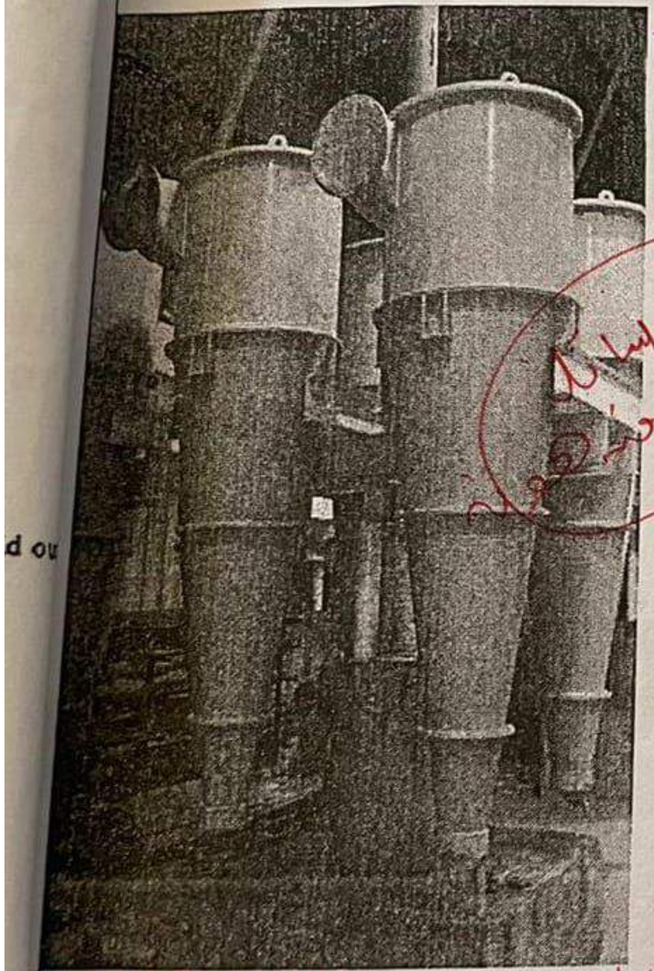
hydro cyclone: سائل ~ ~ ~

best/one: Cyclone: اعرف انو الفلويد هوا

The hydrocyclone or liquid cyclone

حلزوي

Read Coulson & Rishardson, pages 49-56



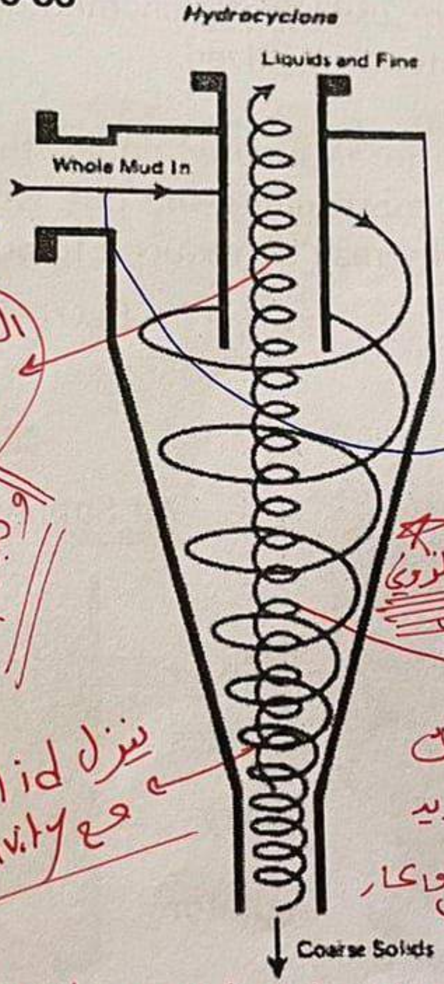
10m

Diameter
يقل

الغاز والسائل يطلعوا لفوق

وبعيد لعملية!

solid ينزل مع gravity



آلية العمل:

فمن هون بدخل ~~هوا~~ ماء ومعاه جزيئات معلقة لما يدخل يدخل بزاوية فيعمل مسار حلزوي

حلزوي

بس يوصل لهون الفلويد سيتعرض لاحتكاك عالي ثم بعد ذلك الفلويد فالغاز والسائل تتخذ واعار الاقل ممانعة ←

الغاز وين ما في تهريب غاز بطلع فيما بعد و Liquid بعدو solid.

الآن... وهو نازل الفلويد تحت السائل يشعر بممانعة

مع الجاذبية ينزل تحت!

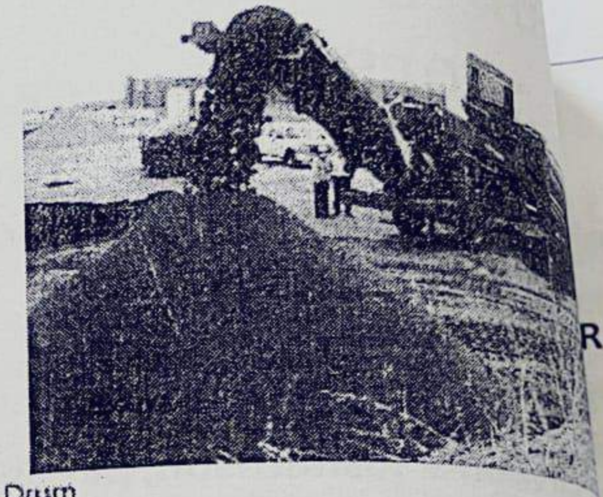
Smart يهرب لفوق لمكان أقل ممانعة

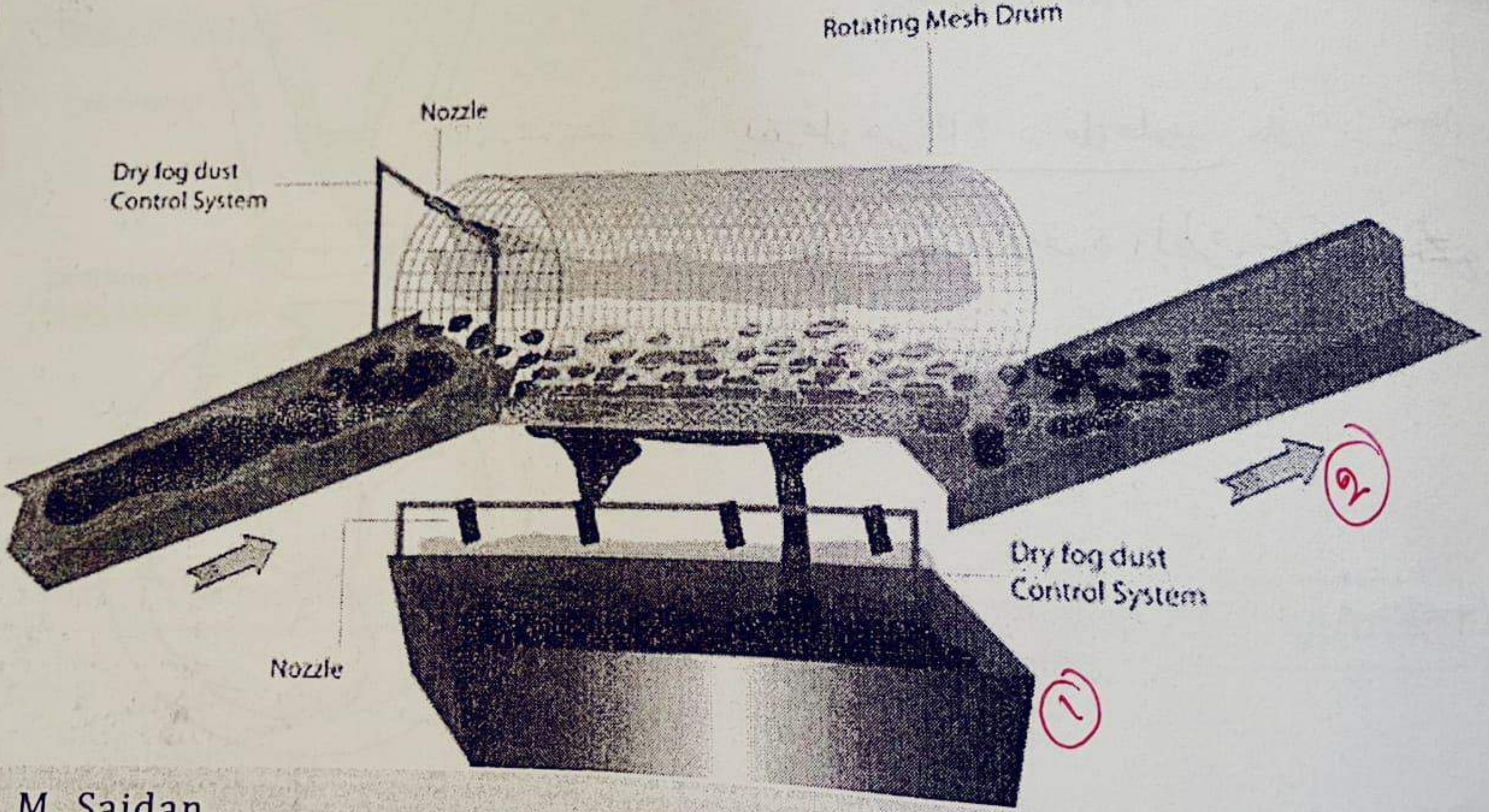
لانو القطر بقل فبصير backflow للسائل والصلب يكتسب قوة طرد مركزي

Sieves or screens

Trommel → movable

Read Coulson & Rishardson, pages 56-58



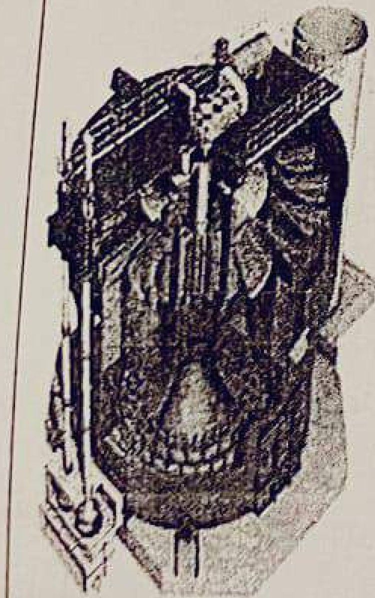


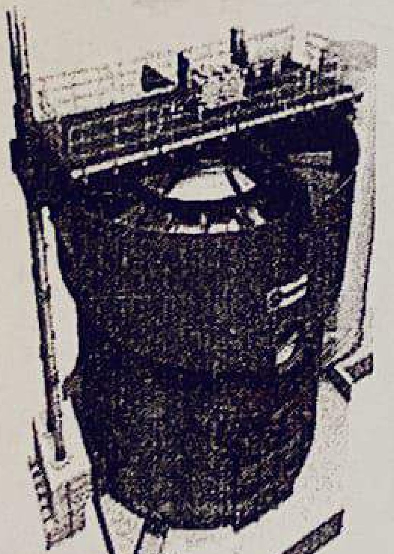
Read

Flotation → for oily particles

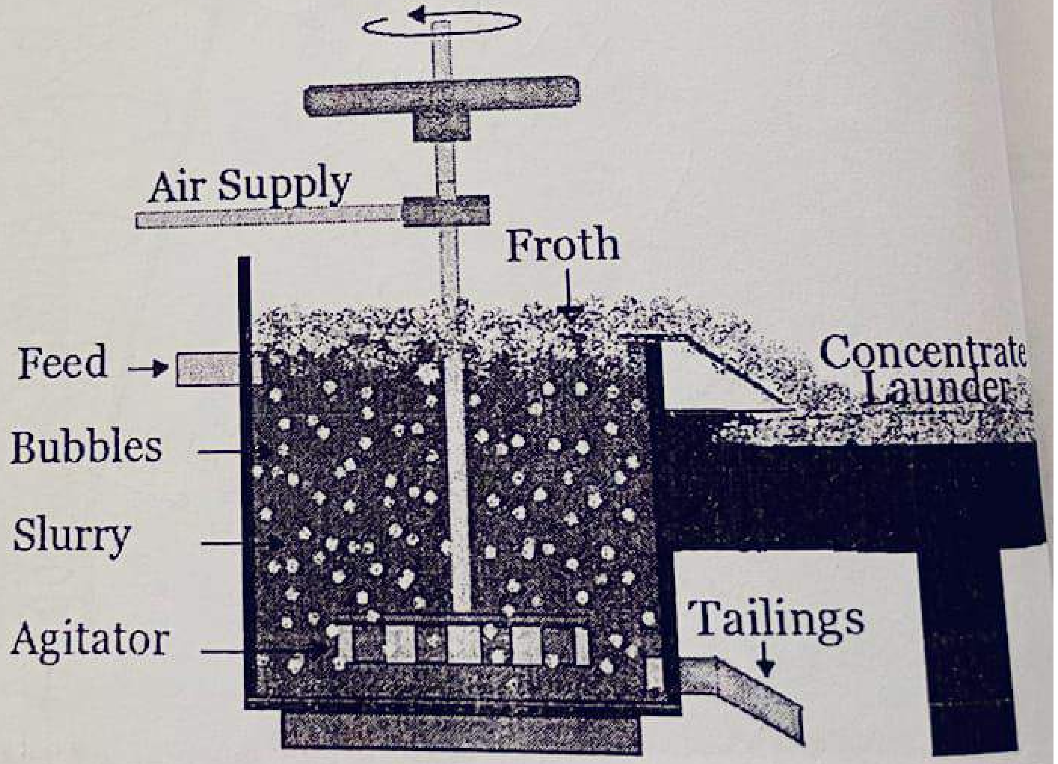
- The separation of a mixture using flotation methods depends on differences in surface properties of the materials involved.

- If the mixture is suspended in an aerated liquid, the gas bubbles will tend to adh preferentially to one of the constituents–the one which is more difficult to wet by liquid–and its effective density may be reduced to such an extent that it will rise to surface.

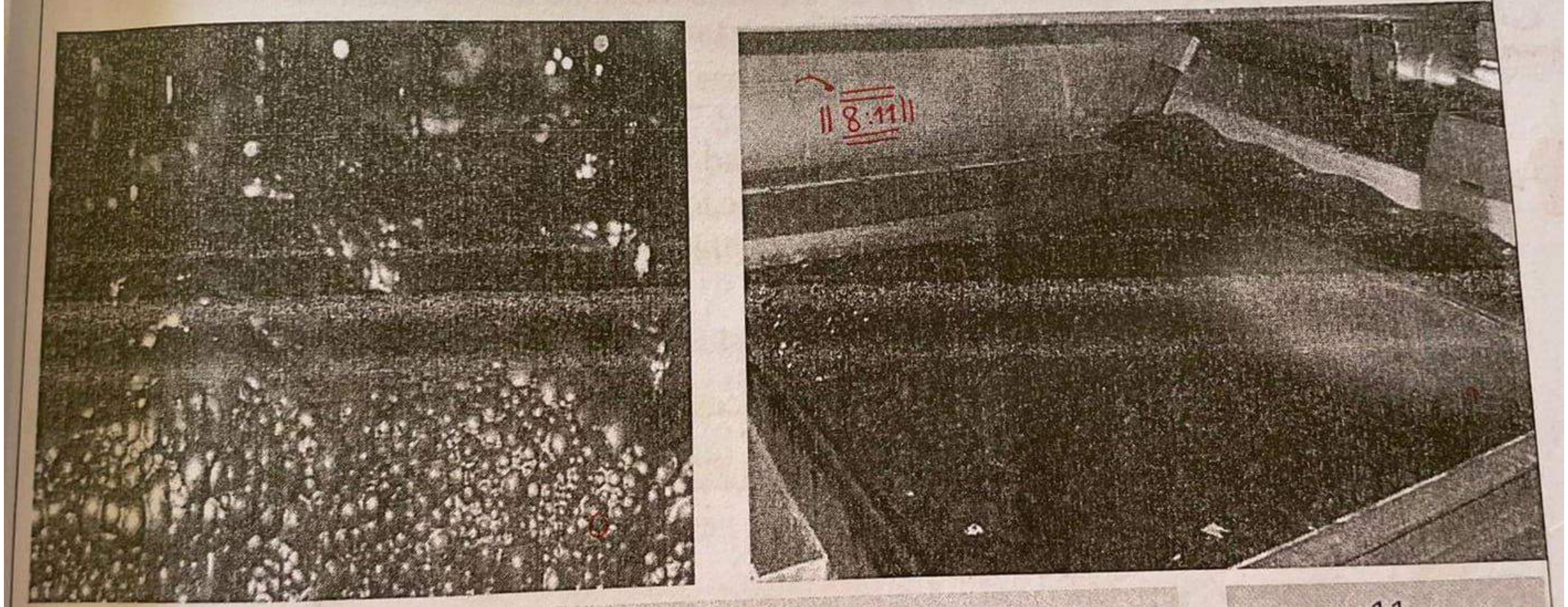




FLOTATION PROCESS



Read Coulson & Rishardson, pages 62-67



8.11

Solid Particulates:

Size Reduction

Dr. Motasem Saidan

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Introduction

- reduction by crushing
- enlargment.

- Materials are rarely found in the size range required, and it is often necessary either decrease or to increase the particle size.

According to the Purpose!!

- The type of machine needed for size reduction/increasing depends, not only on the size of the feed and of the product, but also on such properties as compressive strength, brittleness and stickiness.

hard
brittel
sticky → material ال properties تبعت انما بيمشي, flowrate حجم الجزيئ وال مابيمشيس

بجدولي ← نوع equipment

- Size reduction or comminution is an important step in the processing of many solid materials:

✓ To create particles in a certain size and shape

Size in mm ✓ To increase the surface area available for next process

Contact area

✓ To liberate valuable minerals held within particles — beneficiation!!

نخلص منه فوائد

الاولى الصغر

- Size reduction process : **extremely energy-intensive** and is **a very inefficient process**.

تصرف كهرباء

الطاقة بتروح الصوت

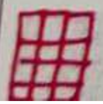
طاقة ضايعة

مهم

علل

- During the course of the size reduction processes, much energy is expended in causing plastic deformation and this energy may be regarded as a waste as it does not result in fracture.

التكسير → Plastic deformation → highly energy Consuming!



Consuming.

Particle Failure Mechanisms

- **Stress-strain behavior** force given

area under the curve = toughness

stress strain curve

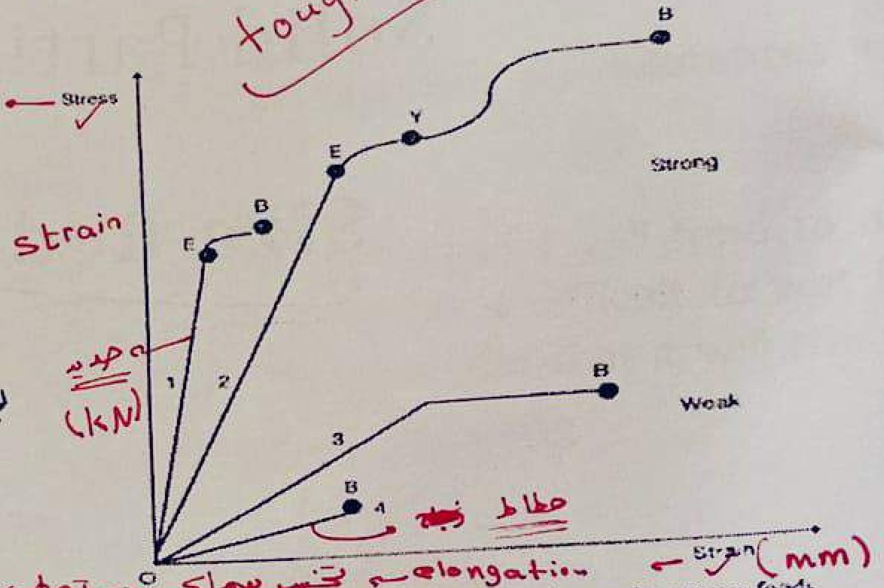


Fig. 4.1 Stess-strain diagram for various foods (E = elastic limit; Y = yield point; B = breaking point; O–E = elastic region. E–Y = unelastic deformati
region of ductility; (1) = hard, strong, brittle material; (2) = hard, strong, ductile material. (3) = so
ductile material and (4) = soft, weak brittle material.) (After Loncin and Merson (1979))

elastic ⟶ plastic

قاسية
← hard : → surface → كيف بتصرف surface بهمني ع

هش ~~~~ brittel : → easy to break

high energy ← tough : → as a whole not only surface
صلبة → بتمر بكل المراحل :
eleastic ⟶ plastic ⟶ ...

- **Strain energy : energy stored in a body under tension**

  → not uniform but concentrated in splits, cracks, hollow parts, foreign inclusions, displacement

- The energy required to affect size reduction is related to the internal structure o material and the process consists of two parts, first opening up any small fissures whi already present, and secondly forming new surface.

B
p

Energy Inefficiency

- Size reduction is a very inefficient process and only between 0.1 and 2.0 per cent of the energy supplied to the machine appears as increased surface energy in the solids. up to 2%. of the energy we only need to break

98%.
heat
sound
mecha
ضايع

- The efficiency of the process is very much influenced by the manner in which the load is applied and its magnitude. كيفية ال Load بضرب ع Particle !!

انواع الفورسيس

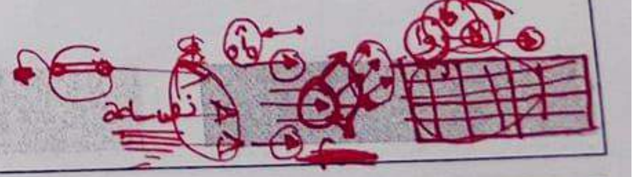
- In addition the nature of the force exerted is also very important depending, for example, on whether it is predominantly a compressive[1], an impact[2] or a shearing[3] force. If the applied force is insufficient for the elastic limit to be exceeded, and the material is compressed, energy is stored in the particle. ال elastic ع الفاضي

اول ما تشيل الفورس ترجع لشكلها القبل !!

  - ➢ When the load is removed, the particle expands again to its original condition without doing useful work. The energy appears as heat and no size reduction is affected.

- A somewhat greater force will cause the particle to fracture, however, and in order to obtain the most effective utilization of energy the force should be only slightly in excess of the crushing strength of the material. The surface of the particles will generally be of a very irregular nature so that the force is initially taken on the high spots, with the result that very high stresses and temperatures may be set up locally in the material. ☆

بتروح ع الكيرف بتشوف maximum energy ع ال Strain لحتى توصل
انو تتقطع معك العينة وتتكسر، حط عليها شوي زيادة قوة !!



Breakage of single particles

- All large lumps of material contain cracks and size reduction occurs as a result of **crack propagation** that occurs above a critical parameter, ***F***, where

الكسر كسر

نشر الكسر

$$\cancel{F = \frac{\tau^2 a}{Y}}$$

~~where: a = crack length,~~
~~τ = stress, and~~
~~Y = Young's modulus.~~

- At lower values of *F*, elastic deformation occurs without fracture and the energy input is completely ineffective in achieving size reduction.

- The method of application of the force to the particles may affect the breakage pattern.
- The four basic patterns are: fracture mechanisms:
  - (a) **Impact** —particle concussion by a single rigid force. → اصطدام
  - (b) **Compression** —particle disintegration by two rigid forces. → بين فكين
  - (c) **Shear** —produced by a fluid or by particle –particle interaction. → مقص
  - (d) (d) **Attrition** —arising from particles scraping against one another or against a rigid surface. → particle عرقة

Energy for size reduction from size → size

- It is impossible to estimate accurately the amount of energy required in order to effect a size reduction of a given material,
- A number of empirical laws have been proposed:

$$\frac{\mathrm{d}E}{\mathrm{d}L} = -CL^{\textcircled{p}} \longrightarrow$$

كل واحد قيمة

which states that the energy dE required to effect a small change dL in the size of unit mass of material is a simple power function of the size. If $p = -2$, then integration gives:

$$E = \textcircled{C}\left(\frac{1}{L_2} - \frac{1}{L_1}\right)$$

from $L_1 - L_2$

Rittinger's law c

Writing $C = K_R f_c$, where f_c is the crushing strength of the material, then *Rittinger's law*, first postulated in 1867, is obtained as:

$$E = K_R \overset{\text{Strength of material}}{f_c} \left(\frac{1}{L_2} - \frac{1}{L_1}\right)$$

Since the surface of unit mass of material is proportional to $1/L$, the interpretation of this law is that the energy required for size reduction is directly proportional to the increase in surface.

$$E = P/\dot{m}^o$$

where **P** is the power required, **m°** is the feed rate to crusher

Kick's law C

Power: from hp → W
KW
conversion

$$\frac{dE}{dL} = -CL^p ✓$$

If $p = -1$, then:

$$E = C \ln \frac{L_1}{L_2}$$

and, writing $C = K_K f_c$:

$$E = K_K f_c \ln \frac{L_1}{L_2}$$

- This supposes that the energy required is directly related to the reduction ratio L1/L2 which means that the energy required to crush a given amount of material from a 50 mm to a 25 mm size is the same as that required to reduce the size from 12 mm to 6 mm.

regardless what is L₁ and L₂

بحسب النسبة

$$\frac{L_1}{L_2} = \frac{50}{25} = \frac{100}{50}$$

نفس القيمة

→ energy needed to reduce particle size from 1000-500 is the same as to reduce from ~~500~~ . 50-25

Bond crushing law and work index

C

Bond has suggested a law intermediate between Rittinger's and Kick's laws, by putting $p = -3/2$ in equation Thus:

$$E = 2C\left(\frac{1}{L_2^{1/2}} - \frac{1}{L_1^{1/2}}\right)$$

$$= 2C\sqrt{\left(\frac{1}{L_2}\right)}\left(1 - \frac{1}{q^{1/2}}\right)$$

where:

$$q = \frac{L_1}{L_2}$$

the reduction ratio. Writing $C = 5E_i$, then:

$$E = E_i\sqrt{\left(\frac{100}{L_2}\right)}\left(1 - \frac{1}{q^{1/2}}\right)$$

Bond terms E_i the *work index*, and expresses it as the amount of energy required to reduce unit mass of material from an infinite particle size to a size L_2 of 100 μm, that is $q = \infty$. The size of material is taken as the size of the square hole through which 80 per cent of the material will pass.

Example

A material is crushed in a Blake jaw crusher such that the average size of particle is reduce from 50 mm to 10 mm with the consumption of energy of 13.0 kW/(kg/s). What would b the consumption of energy needed to crush the same material of average size 75 mm to a average size of 25 mm:

a) assuming Rittinger's law applies?
b) assuming Kick's law applies?

Which of these results would be regarded as being more reliable and why?

Solution

a) *Rittinger's law.*

This is given by: $E = K_R f_c[(1/L_2) - (1/L_1)]$

Thus: $13.0\ K_R f_c[(1/10) - (1/50)]$

and: $K_R f_c = (13.0 \times 50/4) = 162.5$ kW/(kg mm)

Thus the energy required to crush 75 mm material to 25 mm is:

$$E = 162.5[(1/25) - (1/75)] = \underline{\underline{4.33 \text{ kJ/kg}}}$$

✓

b) *Kick's law.*

This is given by: $E = K_K f_c \ln(L_1/L_2)$

Thus: $13.0 = K_K f_c \ln(50/10)$

and: $K_K f_c = (13.0/1.609) = 8/08$ kW/(kg/s)

Thus the energy required to crush 75 mm material to 25 mm is given by:

$$E = 8.08 \ln(75/25) = \underline{\underline{8.88\ \text{kJ/kg}}}$$

Energy utilisation

Energy is utilized in crushing as follows: why process is inefficient:-

(a) In producing elastic deformation of the particles before fracture occurs.
(b) In producing inelastic deformation which results in size reduction.
(c) In causing elastic distortion of the equipment.
(d) In friction between particles, and between particles and the machine.
(e) In noise, heat and vibration in the plant, and
(f) In friction losses in the plant itself.

- It is estimated that only about 10 per cent of the total power is usefully employed.

Nature of the material to be crushed

- The choice of a machine for a given crushing operation is influenced by the nature of the product required and the quantity and size of material to be handled.

- The more important properties of the feed apart from its size are as follows:

  1. Hardness
  2. Structure
  3. Moisture content
  4. Crushing strength
  5. Friability
  6. Stickiness
  7. Soapiness

The Mohr Scale of Hardness

Materials are arranged in order of increasing hardness in the Mohr scale in which the first four items rank as soft and the remainder as hard. The Mohr Scale of Hardness is:

hardness تقاس ب

1. Talc اطرى شي
2. Rock salt or gypsum
3. Calcite
4. Fluorspar
5. Apatite
6. Felspar
7. Quartz
8. Topaz
9. Carborundum
10. Diamond.

اقسى شيء

to select the appropriate machine!!

Types of Crushing Equipment

يعني مكونات ال crusher

Coarse crushers	Intermediate crushers	Fine crushers
Stag jaw crusher	Crushing rolls	Buhrstone mill
Dodge jaw crusher	Disc crusher	Roller mill
Gyratory crusher	Edge runner mill	NEI pendulum mill
Other coarse crushers	Hammer mill	Griffin mill
	Single roll crusher	Ring roller mill (Lopulco)
	Pin mill	Ball mill → *
	Symons disc crusher	Tube mill
		Hardinge mill
		Babcock mill

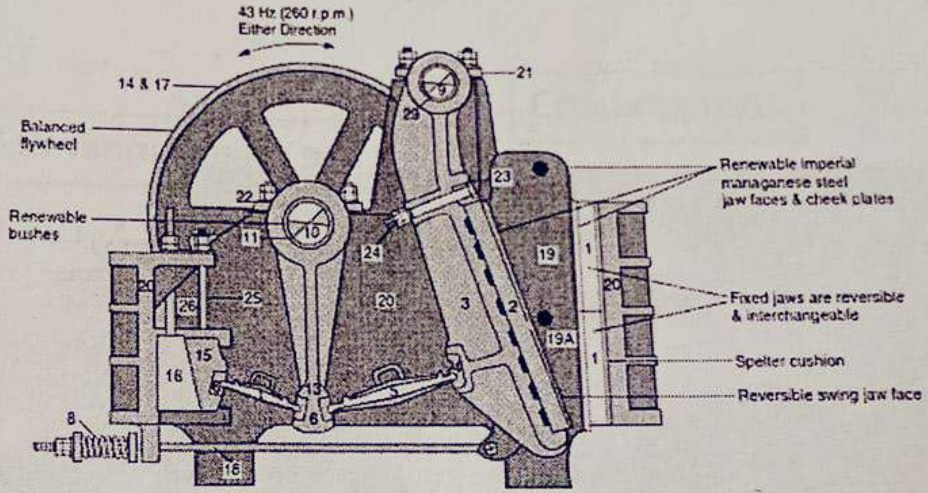
Read through page 106 -137 R&C Reference Book

Coarse Crushers

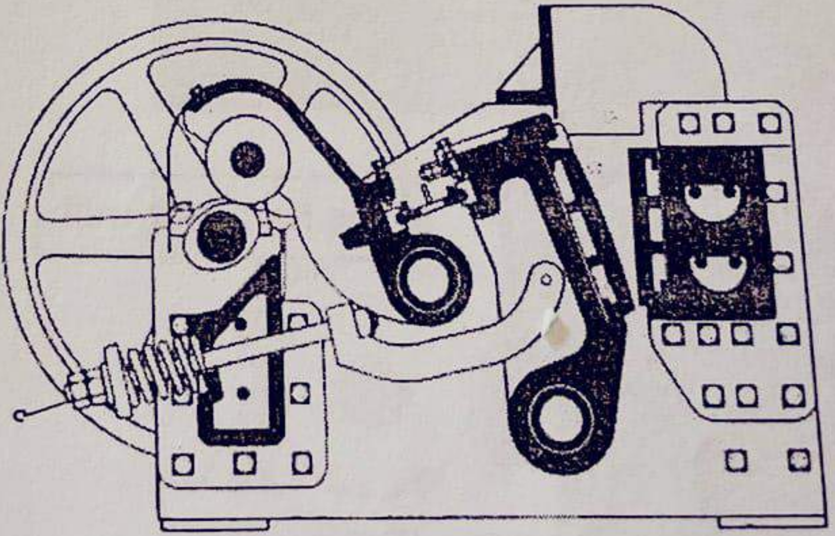
The Stag jaw crusher

فك

الحجم فيه اقل ← اعلى



The Dodge jaw crusher



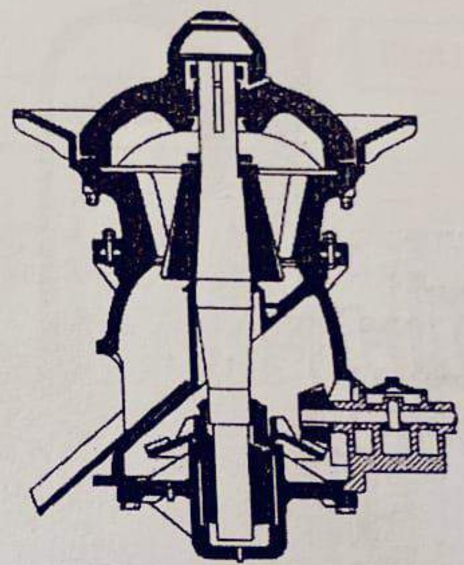
ذراع

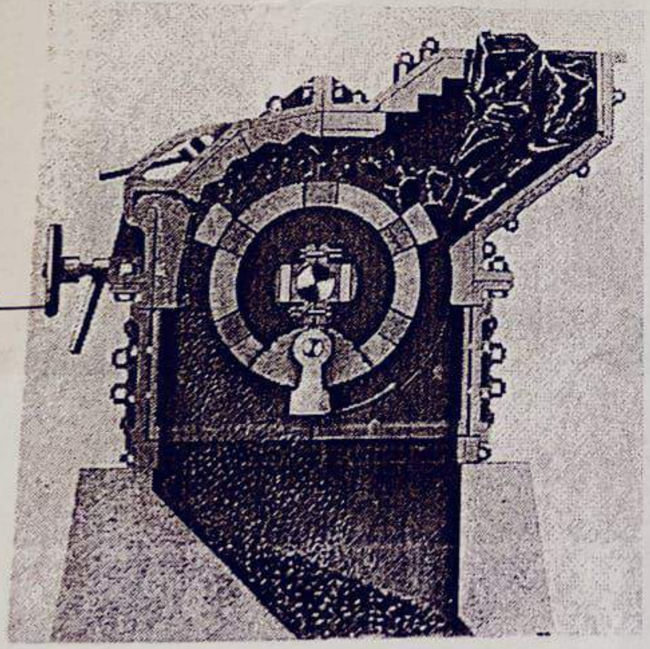
Coarse Crushers

الذراع هو يحرك الفك

The gyratory crusher

Continuous flow!!



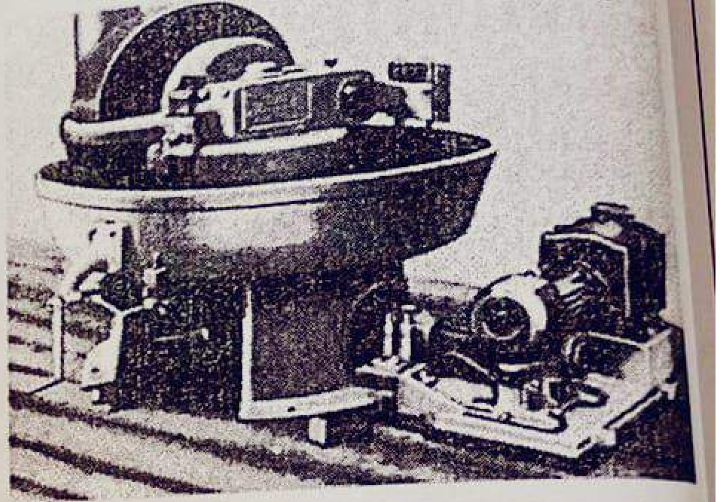


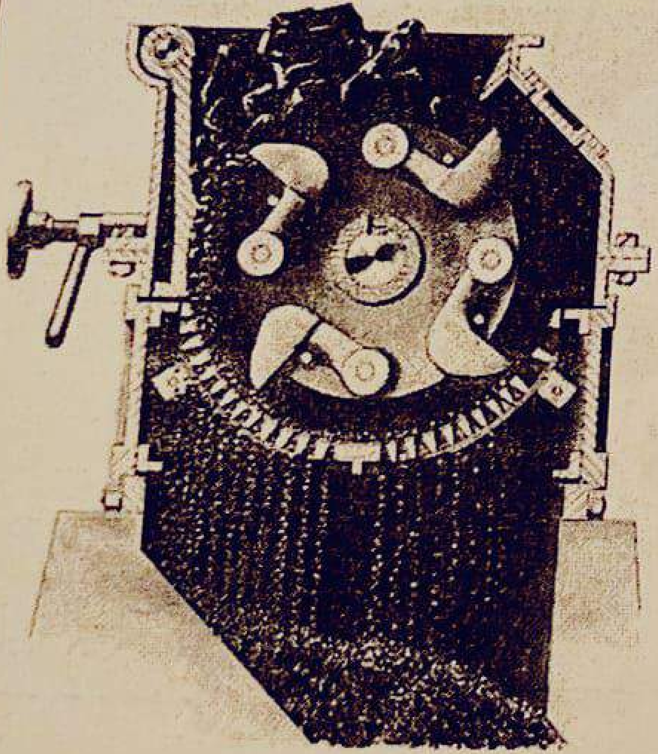
Rotary materials breaker

Intermediate crushers

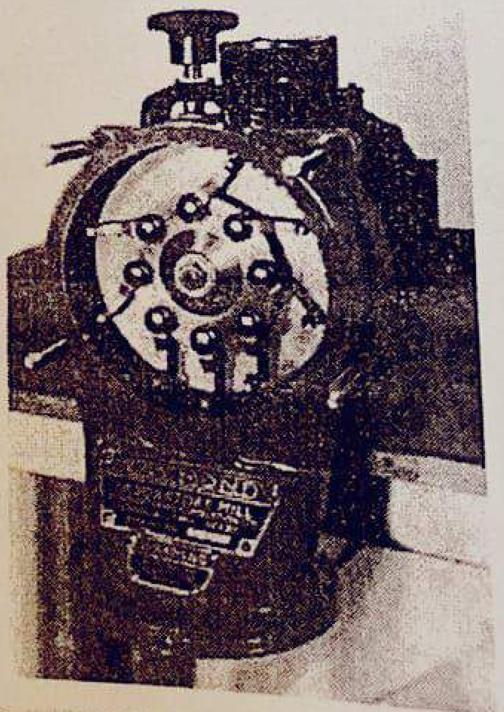
The edge runner mill

جاروشة



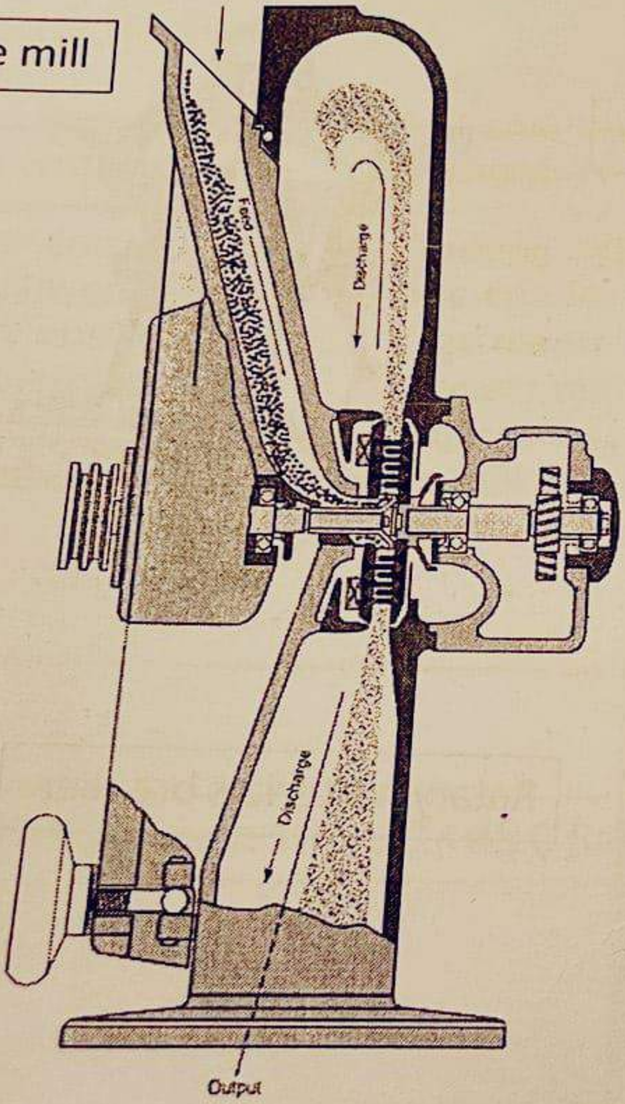


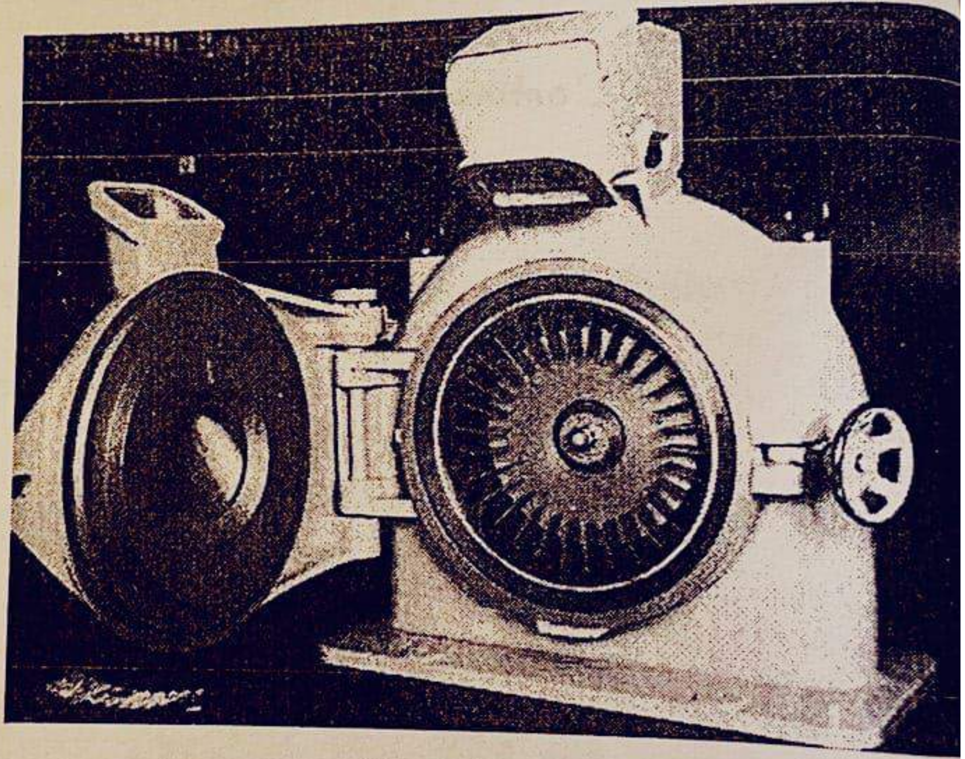
The hammer mill



Intermediate crushers

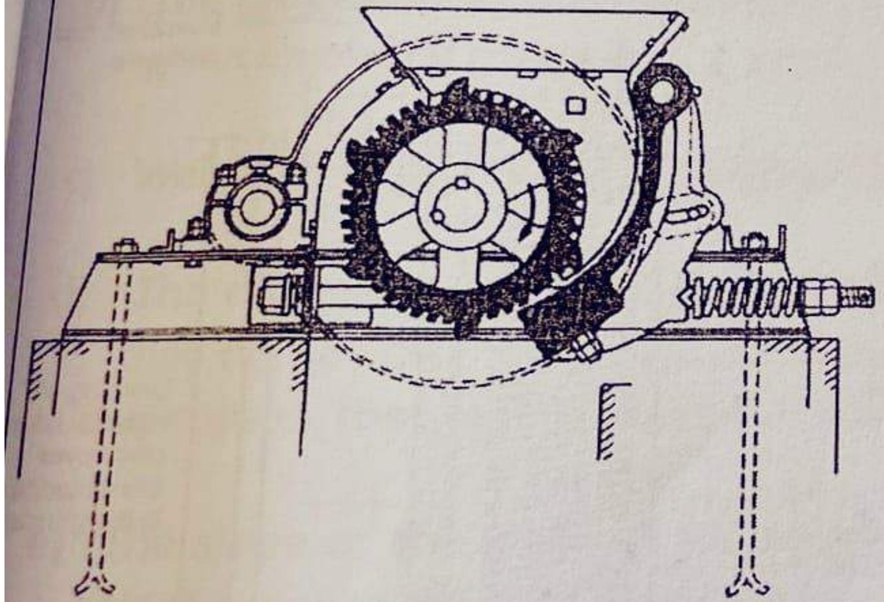
The pin-type mill



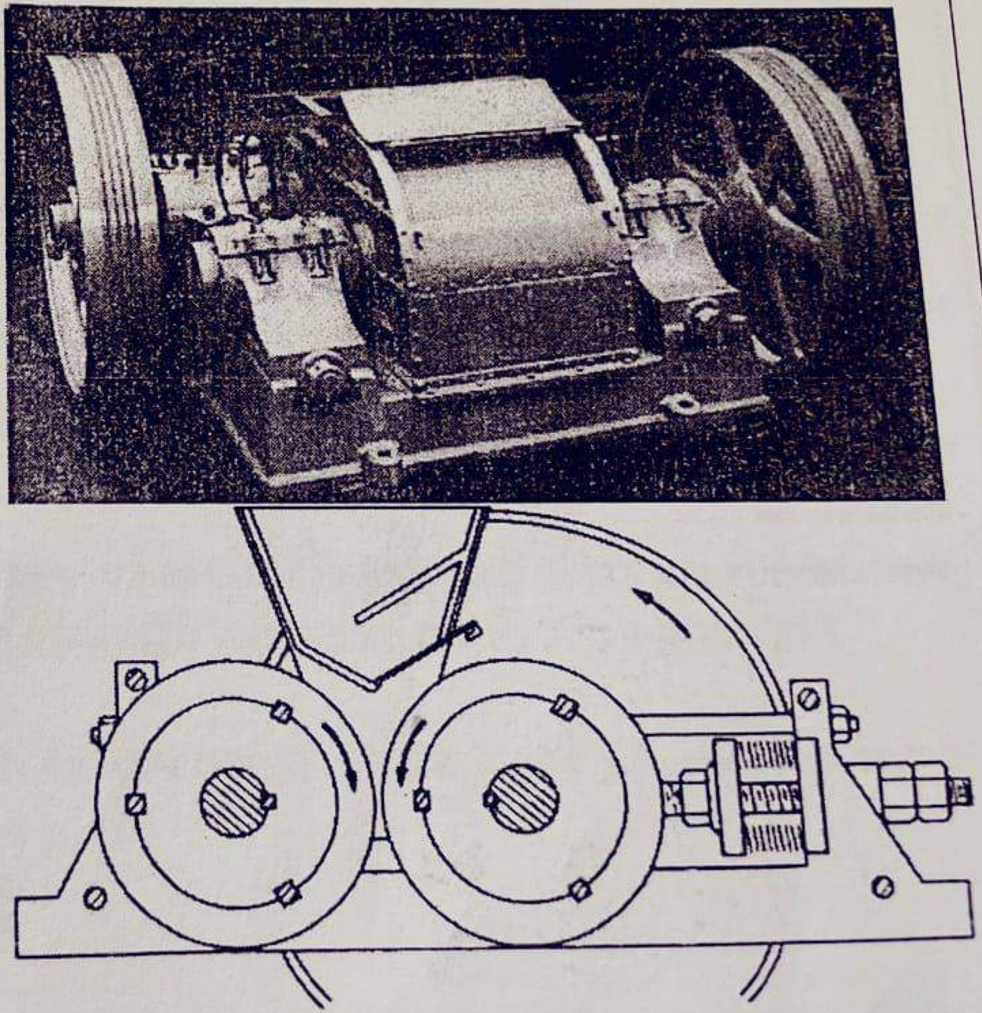


Intermediate crushers

The single roll crusher

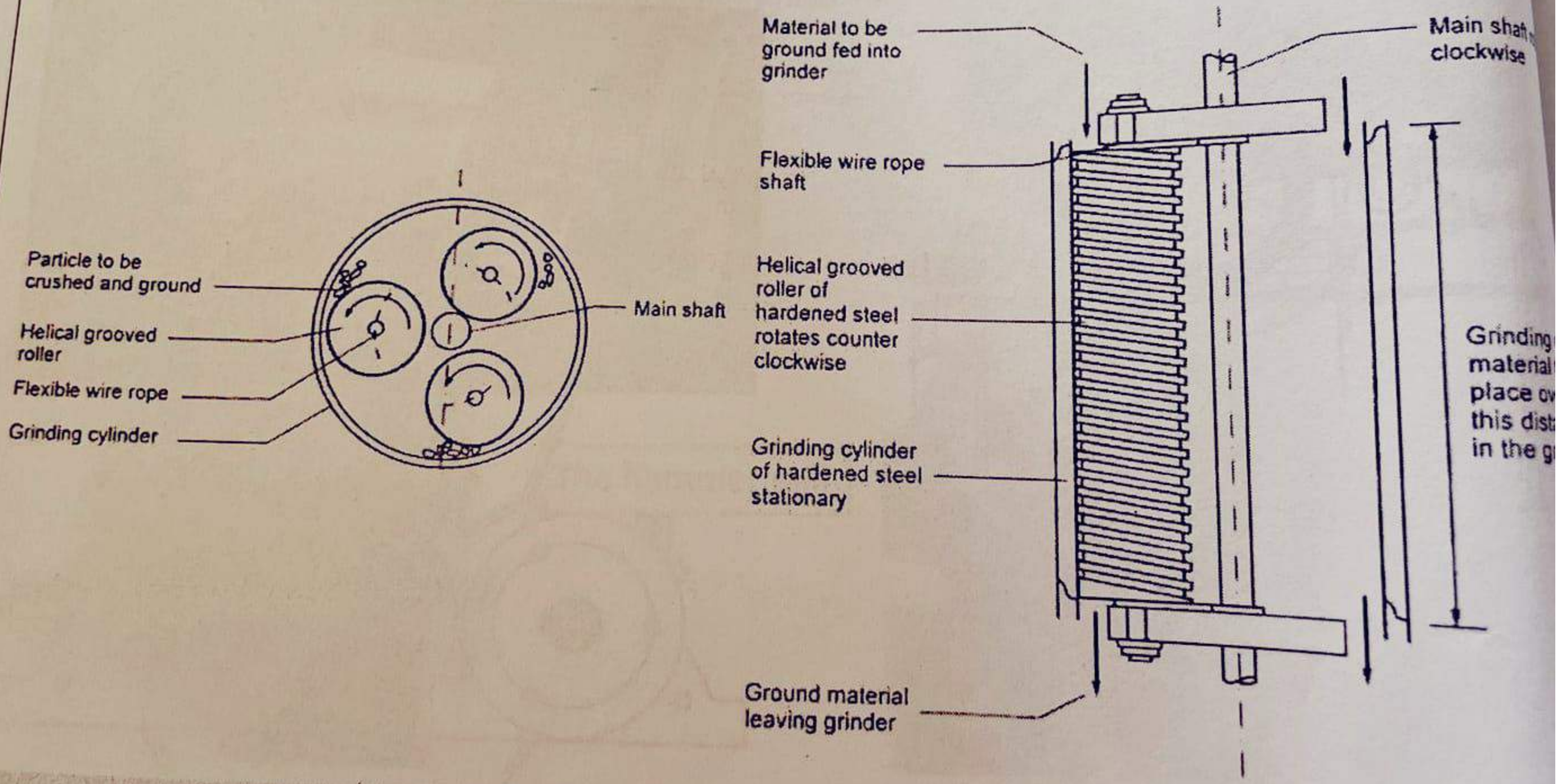


Crushing rolls



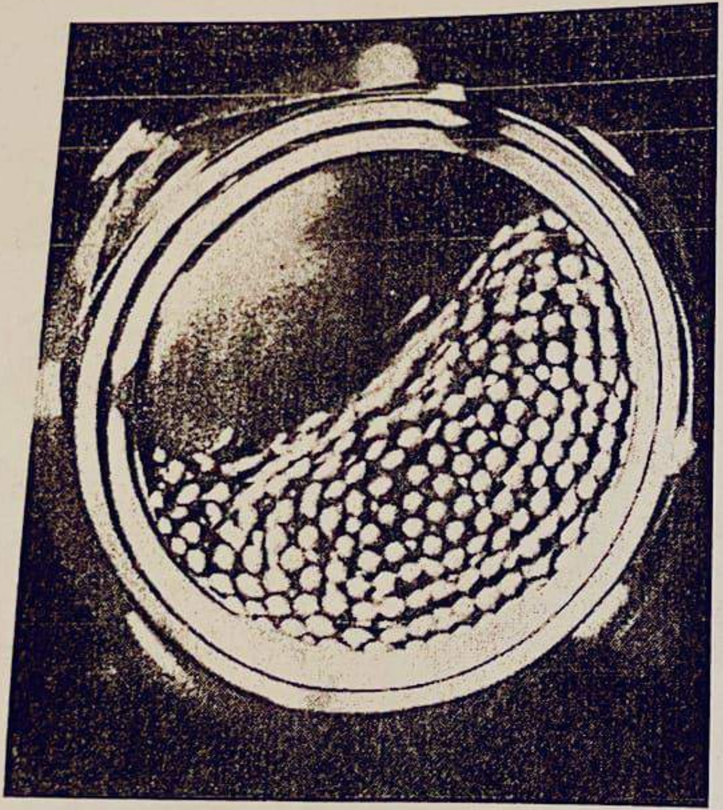
Fine crushers

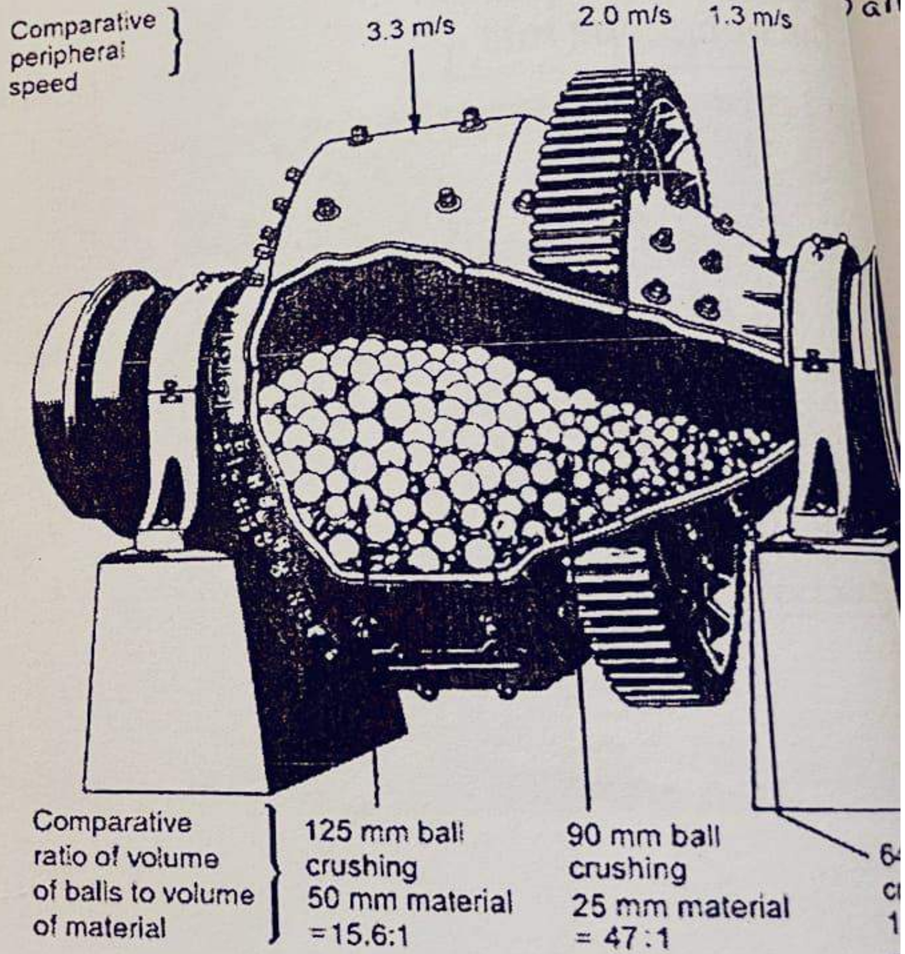
The Szego grinding mill



اذا بدك حجم جزيئات مختلف، تختار حجم الكرات نفسو.
،، ،، ،، ،، نفسو، تختار حجم الكرات مختلف.

The ball mill





Ball mill: Factors influencing the size of the product

تلعب دور بحجم المنتج

a) **The rate of feed.** With high rates of feed, less size reduction is effected since the material is in the mill for a shorter time.

high flowrate → ~~~~ time of crushing is low ← منتج الطحن اعلى
من المطلوب .

b) **The properties of the feed material.** The larger the feed the larger is the product under given operating conditions. A smaller size reduction is obtained with a hard material.

→ كما زاد المدخل ، زاد الناتج .

c) **Weight of balls.** A heavy charge of balls produces a fine product. → مع زيادة الحجم ، بتزيد قوة الصدم ← يطحن اكثر فاكثر.

d) **The diameter of the balls.** Small balls facilitate the production of fine material although they do not deal so effectively with the larger particles in the feed. For most economical operation, the smallest possible balls should be used.

كما زاد slope ← زادت flowrate !! اكيد

e) **The slope of the mill.** An increase in the slope of the mill increases the capacity of the plant because the retention time is reduced, although a coarser product is obtainned.

f) **Discharge freedom.** Increasing the freedom of discharge of the product has the same effect as increasing the slope. → adjust/optimise !!

…. Factors influencing the size of the product

الكرات تتزحلق بين بعض ← ① ماتكونه rotation بطيئة بحيث يحصل ازاحة (زحلقة)

② مايكونه r b m عشانه الكرات ما تلتصق بالجدار, particle

g) The speed of rotation of the mill. At low speeds of rotation, the balls simply roll over one another and little crushing action is obtained. At slightly higher speeds, the balls are projected short distances across the mill, and at still higher speeds they are thrown greater distances and considerable wear of the lining of the mill takes place. At very high speeds, the balls are carried right round in contact with the sides of the mill and little relative movement or grinding takes place again. The minimum speed at which the balls are carried round in this manner is called the critical speed of the mill and, under these conditions, there will be no resultant force acting on the ball when it is situated in contact with the lining of the mill in the uppermost position, that is the centrifugal force will be exactly equal to the weight of the ball.

30% تقريبا يتعبأ كرات

(h) The level of material in the mill. Power consumption is reduced by maintaining a low level of material in the mill, and this can be controlled most satisfactorily by fitting a suitable discharge opening for the product. If the level of material is raised, the cushioning action is increased and power is wasted by the production of an excessive quantity of undersize material.

Advantages of the ball mill

(استشات في)

عشان يشيل الdust اليطلع !!

i. The mill may be used wet or dry although wet grinding the product.

ii. The costs of installation and power are low. بتصير تكلفته من ذات نفسها بعد اول مرة !!!

iii. The ball mill may be used with an inert atmosphere for the grinding of explosive materials.

iv. The grinding medium is cheap.

v. The mill is suitable for materials of all degrees of (vi) It may be used for batch or continuous operation.

Specialized applications

I. ✓ Electrohydraulic crushing
II. Ultrasonic grinding
III. Cryogenic grinding
IV. Explosive shattering

Read through R&C page: 137

Size Enlargement of Particles

- The finer the particles, the greater is their specific surface, and the gravitational forces acting on the particles may not be great enough to keep them apart during flow.

- The flowability of particulate systems can sometimes be improved by the use of "glidants", which are very fine powders which are capable of reducing interparticle friction by forming surface layers on the particles, thereby combating the effects of friction arising from surface roughness; they can also reduce the effects of electrostatic charges.

- Fine particles may be difficult to discharge from hoppers as particles may cling to the walls and also form bridges at the point of discharge.

- Particle size may be a critical factor since very fine particles may be exhaled, and very large particles may have a negligible effect on health. In this respect, it may be noted that the particular health hazard imposed by asbestos is largely associated with the size range and shape of the particles and their tendency to collect in the lungs.

- The size of particles may be increased from molecular dimensions by growing them by crystallization from both solutions and melts. Here, dissolving and recrystallizing may provide a mechanism for controlling both particle size and shape. It may be noted, that fine particles may also be condensed out from both vapors and gases.

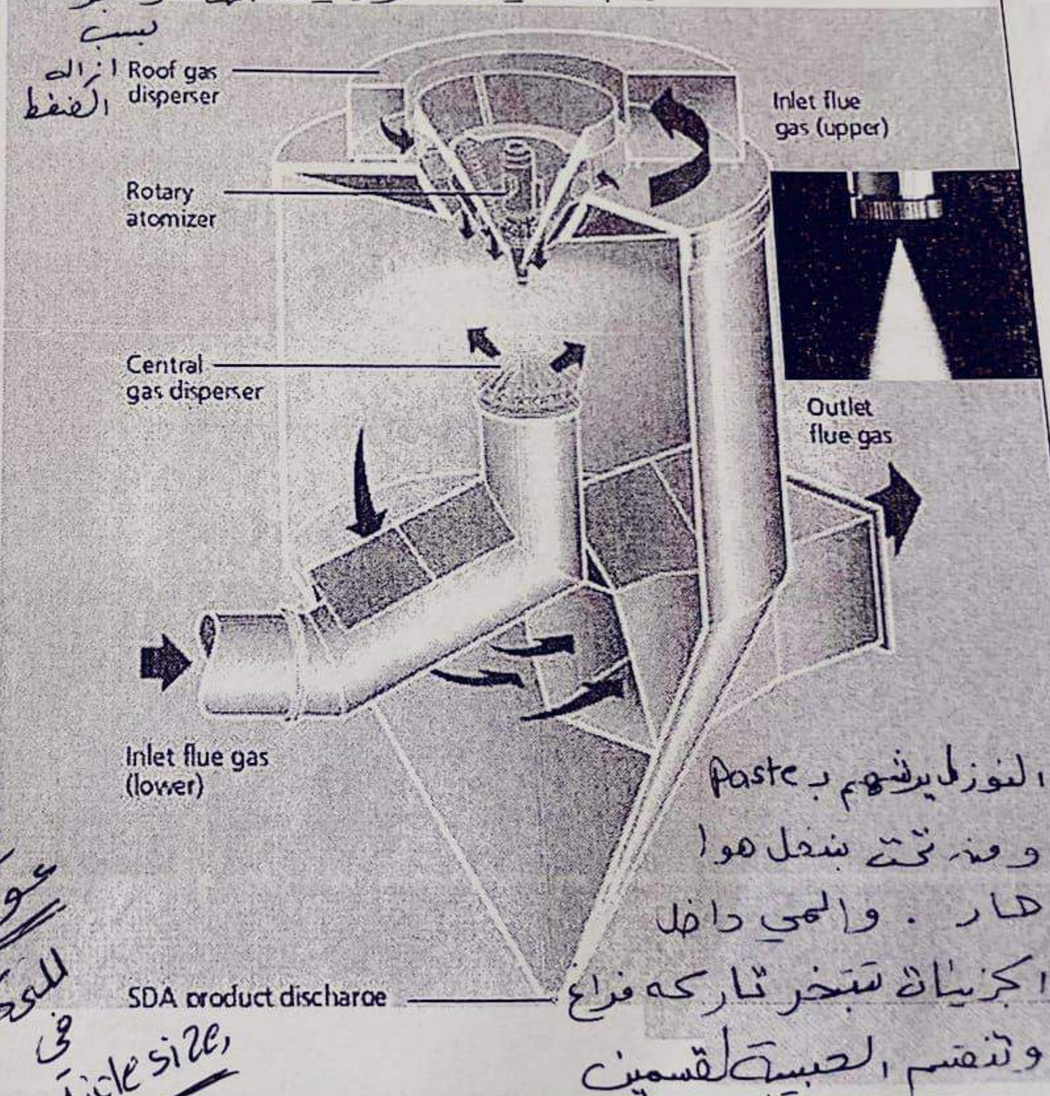
Size enlargement processes

- **Spray drying** In this case, particle size is largely determined by the size of the droplet of liquid or suspension, which may be controlled by a suitably designed spray nozzle. The aggregates of dried material are held together as a result of the deposition of small amounts of solute on the surface of the particles. For a given nozzle, the drop sizes will be a function of both flowrate and liquid properties, particularly viscosity, and to a lesser extent of outlet temperature. In general, viscous liquids tend to form large drops yielding large aggregates.

Pressure
فتحة nozzle
Viscous paste قديش
Δ Tempretwe

٤ عوامل للتحكم في Particle size,

عبئ المواد عن طريق خلطها مع حي
بنخلطها على spray drier
الراس تبعو منه فوق فيو noozle
اي جزيء بنزل منه نزول بكونه حجما او اكبر
بسبب
ازالة الضغط



النوزل بيرشهم ب paste
ومن تحت بندخل هوا
حار . والمي داخل
الجزيئات تتبخر تاركه فراغ
وتنقسم الحبيبة لقسمين

….. Size enlargement processes

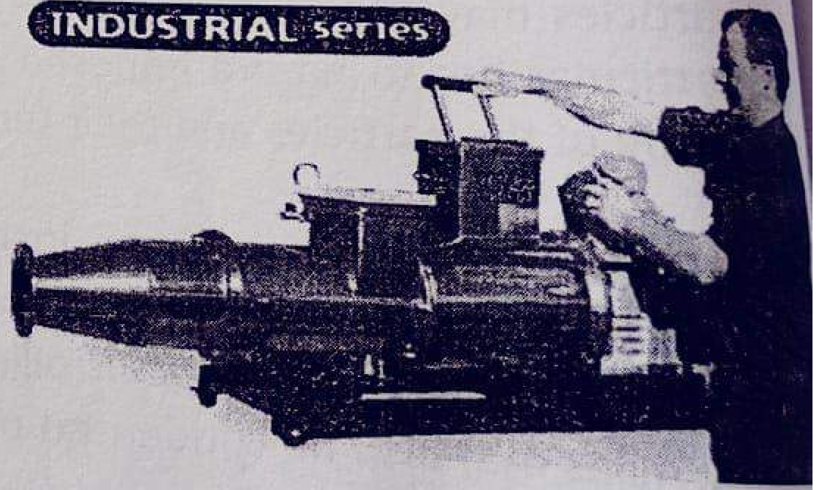
الفرق انو noozle فتحته اكبر!!

- **Prilling** in which relatively coarse droplets are introduced into the top of a tall, narrow tower and allowed to fall against an upward flow of air. This results in somewhat larger particles than those formed in spray dryers.

- **Fluidized beds** in this case, an atomized liquid or suspension is sprayed on to a bed of hot fluidized particles and layers of solid build up to give enlarged particles the size of which is largely dependent on their residence time, that is the time over which successive layers of solids are deposited. These are used, particularly with large particles. In this case, the rapid circulation within the bed gives rise to a high level of inter-particle impacts.

Postpone

- **Pug mills and extruders** that is a combination of ribbing and shearing and mixing. Densification and extrusion are both achieved in a single operation. The feed, which generally has only a small water content, is subjected to a high energy input which leads to a considerable rise in temperature. The action is similar to that occurring in an extruder. High degrees of compaction are achieved, leading to the production of pellets with low porosity with the result that less binder is required.



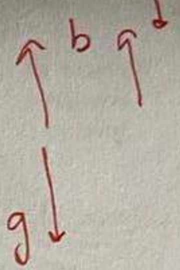
- **Elevated temperatures:** with many materials, agglomeration may be achieved by hea as a result of which softening occurs in the surface layers. For the formation of po metal sheets and discs, high temperatures are required.

- **Pressure compaction:** If a material is subjected to very high compaction forces, it may formed into sheets, briquettes or tablets. In the tableting machines used for produ pills of pharmaceuticals, the powder is compressed into dies, either with or without addition of a binder.

Powder compaction may also be achieved in roll processes, including briquetting, which compression takes place between two rollers rotating at the same speed —that without producing any shearing action. In pellet mills, a moist feed is forced through holes where the resistance force is attributable to the friction between the powder the walls of the dies.

Solid Particulates

Motion of Particles in Fluid



Dr. Motasem Saidan

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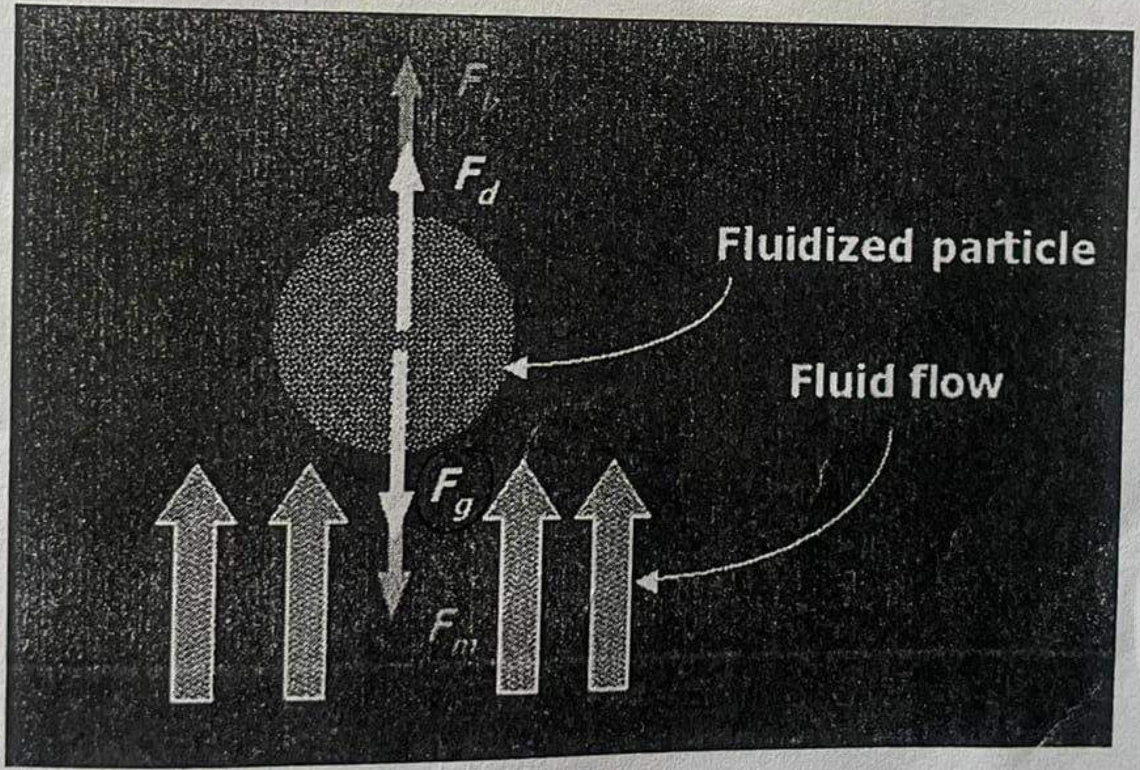
Mechanics of Particle Motion

- For a rigid particle moving through a fluid, there are 3 forces acting on the body
  - The ① **external force** (ⓐ gravitational or ⓑ centrifugal force) ✓ → لتحت
  - The **buoyant force** (طفو) (opposite but parallel direction to external force) ✓ → لفوق
  - The **drag force** (opposite direction to the particle motion) → عكس الحركة



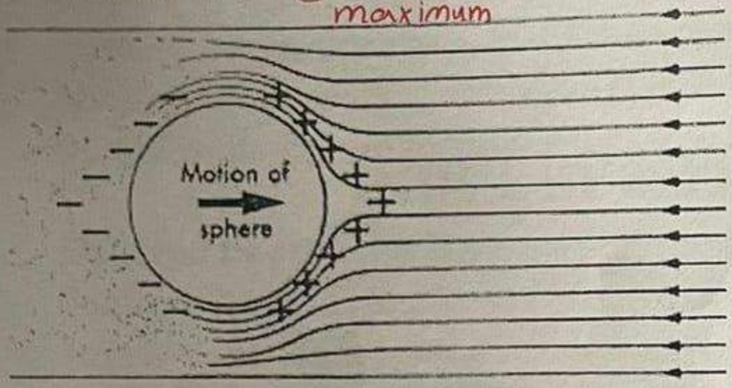
The shape of the object mainly affects the drag force!! ✓

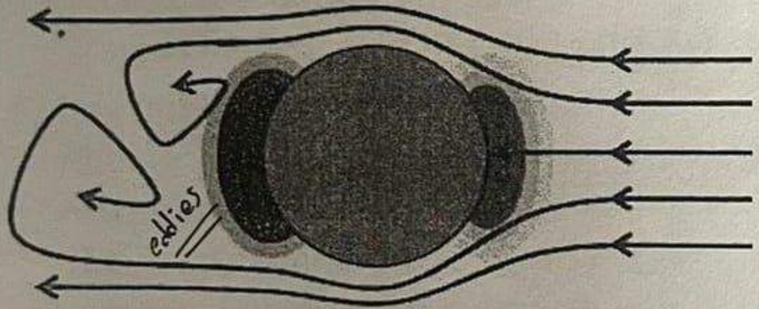
Drag Force

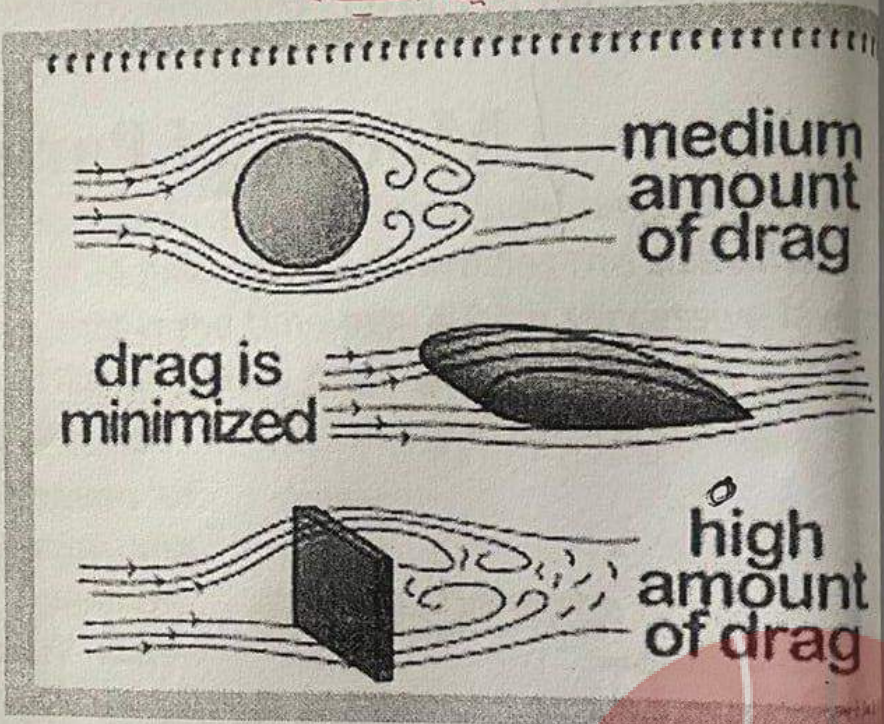
لما كان يعني spherical ← يعني drag كان minimum.

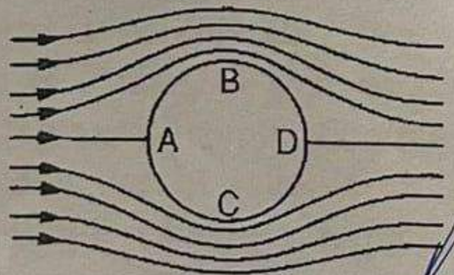
Perpindicular " " " ← يعني drag كان maximum

انسيابية









$\boxed{F = ma}$

One-dimensional Motion of Particle through Fluid

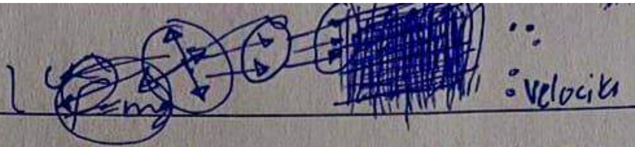
- Consider a particle of mass **m** moving through a fluid under the action of an ex force F_e. Let the velocity of the particle relative to the fluid be u, let the buoyant on the particle be F_b and let the drag be F_D, then

مشتقة الزمنية للسرعة هي التسارع !!

$$\underbrace{m\boxed{\frac{du}{dt}}}_{F=ma} = \underbrace{F_e}_{\text{قوة Flow}} - \underbrace{F_b}_{\text{عكس}} - \underbrace{F_D}_{\text{عكس الحركة}} \qquad (1)$$

- The external force (F_e) - Expressed as a product of the mass (**m**) and the acceler (a_e) of the particle from this force

$$F_e = m\underbrace{\boxed{a_e}}_{9.81 \text{ or centrifugal}} \qquad (2)$$



The buoyant force (F_b) – Based on Archimedes' law, the product of the mass of the fluid displaced by the particle and the acceleration from the external force.

Archimedes

- ☐ The volume of the particle is $Vp = \dfrac{m}{\rho_p}$
  volume of displaced fluid.
- ☐ The mass of fluid displaced is $m = \dfrac{m}{\rho_p}\rho$

كرة لو غطستها بماء رح يصير عندي
فرق بال V ، الفرق هاد هو V
تبع الكرة .

where ρ is the density of the fluid. The buoyant force is given by

$$F_b = \frac{m\rho a_e}{\rho_p} \qquad (3)$$

The drag force (FD)

$$F_D = \frac{\overset{\text{drag}}{C_D} u^2 \rho A_p}{2} \qquad (4)$$

where C_D is the drag coefficient, A_p is the projected area of the particle in the plane perpendicular to the flow direction.

acc

divided by mass

- By substituting all the forces in the Eq. (1)

$$\frac{du}{dt} = a_e - \frac{\rho a_e}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} = a_e \frac{\rho_{p-}\rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} \qquad (5)$$

$a_e\left(1 - \frac{\rho}{\rho}\right) -$

Case 1: Motion from gravitational force

$$\frac{du}{dt} = g\frac{\rho_{p-}\rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} \qquad (6)$$

Case 2 : Motion in a centrifugal field

$$a_e = r\omega^2$$

radius

angular velocity.

$$\frac{du}{dt} = r\omega^2 \frac{\rho_p - \rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} \qquad (7)$$

r = radius of path of particles

ω = angular velocity, rad/s

In this equation, ***u*** is the velocity of the particle relative to the fluid and is directed outwardly along a radius.

Settling Velocity → لما تثبت → Terminal Velocity !!

Terminal Velocity → design

- **In gravitational settling,** *g* is constant (9.81m/s2)
- The acceleration (a) decreases with time and approaches zero.
- The particle quickly reaches a constant velocity which is the maximum attainable under the circumstances.
- This maximum settling velocity is called **terminal velocity.**

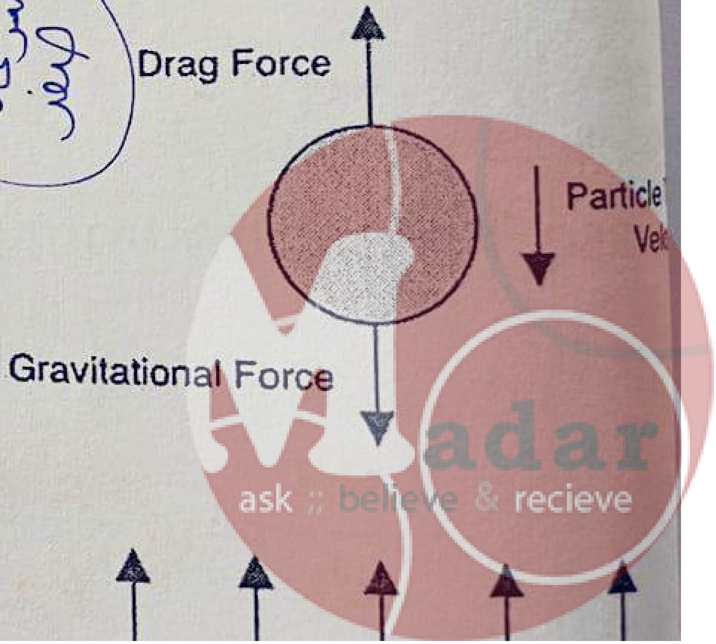
صفر = تسارع ← (تثبت) ع ← توصل لاقصى ← Terminal

drag force ↑ as long as Velocity ↑

$$\frac{du}{dt} = g\frac{\rho_p - \rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} = 0 \qquad (8)$$

التغير بالسرعة صفر

$$u_t = \sqrt{\frac{2g(\rho_p - \rho\ )m}{A_p \rho_p C_D \rho}} \qquad (9$$



6'0 sr 30k 5% 96

- For **spherical particle** of diameter D_p moving through the fluid, the terminal velocity is given by

$$m = \frac{1}{6}\pi D_p^3 \rho_p \qquad A_p = \frac{1}{4}\pi D_p^2$$

- Substitution of ***m*** and ***A_p*** into the equation for ***u_t*** gives the equation for **gravity settling** of spheres

$$\boxed{u_t = \sqrt{\frac{4gD_p(\rho_p - \rho)}{3C_D\rho}} \qquad (12)}$$

Frequently used

- **In motion from a centrifugal force**, the velocity depends on the radius
- The acceleration is not constant if the particle is in motion with respect to the fluid.
- In many practical use of centrifugal force, is small ($\frac{du}{dt} = \sim 0$) thus, it can be neglected to give

$$\frac{du}{dt} = r\omega^2 \frac{\rho_p - \rho}{\rho_p} - \frac{C_D u^2 \rho A_p}{2m} = 0 \quad (10)$$

$$u_t = \omega \sqrt{\frac{2r(\rho_p - \rho\ )m}{A_p \rho_p C_D \rho}} \quad (11)$$

Reynolds Number

(Drag, Reynold) relation:-

- Particle Reynolds Number

$$Re = \frac{uD_p\rho}{\mu}$$

u : velocity of fluid stream
D_p: diameter of the particle
ρ : density of fluid
μ : viscosity of fluid

➢ For the case of creeping flow, that is flow at very low velocities relative to the sphere, the Navier–Stokes equations, give:

تأثير القوة على جزيء في سكون
على قيمة قليلة لـ R و V

friction ثلثيها
Drag ثلثه

$$F = 3\pi\mu du$$

(i) skin friction: $2\pi\mu du$
(ii) form drag: $\pi\mu du$
total $3\pi\mu du$

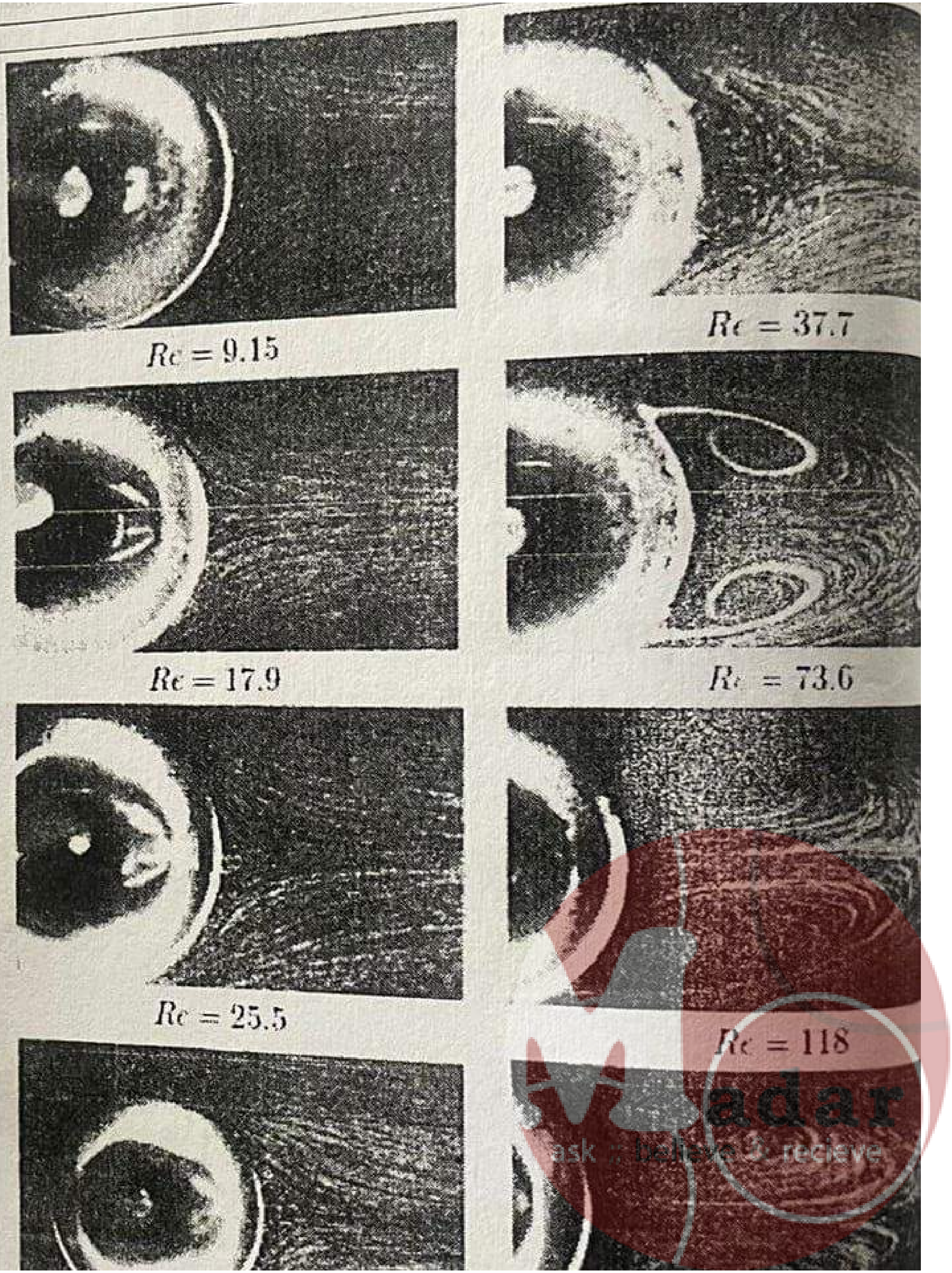
➢ This equation is known as **Stokes' law** and it is applicable only at very low values of the particle Reynolds number and deviations become progressively greater as ***Re*** increases.

تأثير R
حول Drag و friction

Particle moves
with constant
fluid, v.v

- As R_e increases, skin friction becomes proportionately less and, at values greater than about 20, flow separation occurs with the formation of vortices in the wake of the sphere.

- At high Reynolds numbers, the size of the vortices progressively increases until, at values of between 100 and 200, instabilities in the flow give rise to vortex shedding. The effect of these changes in the nature of the flow on the force exerted on the particle is now considered.



بدنا نحل علاقة مع R منحجة و another dimensionless parameter غير drag 5

ain effect

Drag Coefficient

بدنا نحل علاقة 2 dimensionles

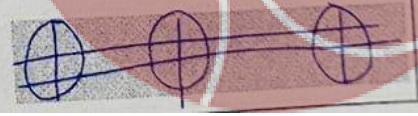
- **Drag coefficient** is a function of Reynolds number (N_{RE}).

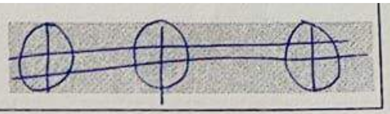
- The drag curve applies only under restricted conditions:
  - i. The particle must be a solid sphere;
  - ii. The particle must be far from other particles and the vessel wall so that the flow pattern around the particle is not distorted;
  - iii. It must be moving at its terminal velocity with respect to the fluid.
- The most satisfactory way of representing the relation between drag force and velocity involves the use of two dimensionless groups:

The first group is the particle Reynolds number $Re'(= ud\rho/\mu)$. x-axi
The second is the group $R'/\rho u^2$, in which R' is the force per unit projected area of particle in a plane perpendicular to the direction of motion.

Y-axis

وبعبر السرعة





وبغير السرعة وبغير اتجاهه معاً، بنازل

- For a sphere, the projected area is that of a circle of the same diameter as the sphere.

Thus:

$$\text{Force} \rightarrow R' = \frac{F}{(\pi d^2/4)}$$

and

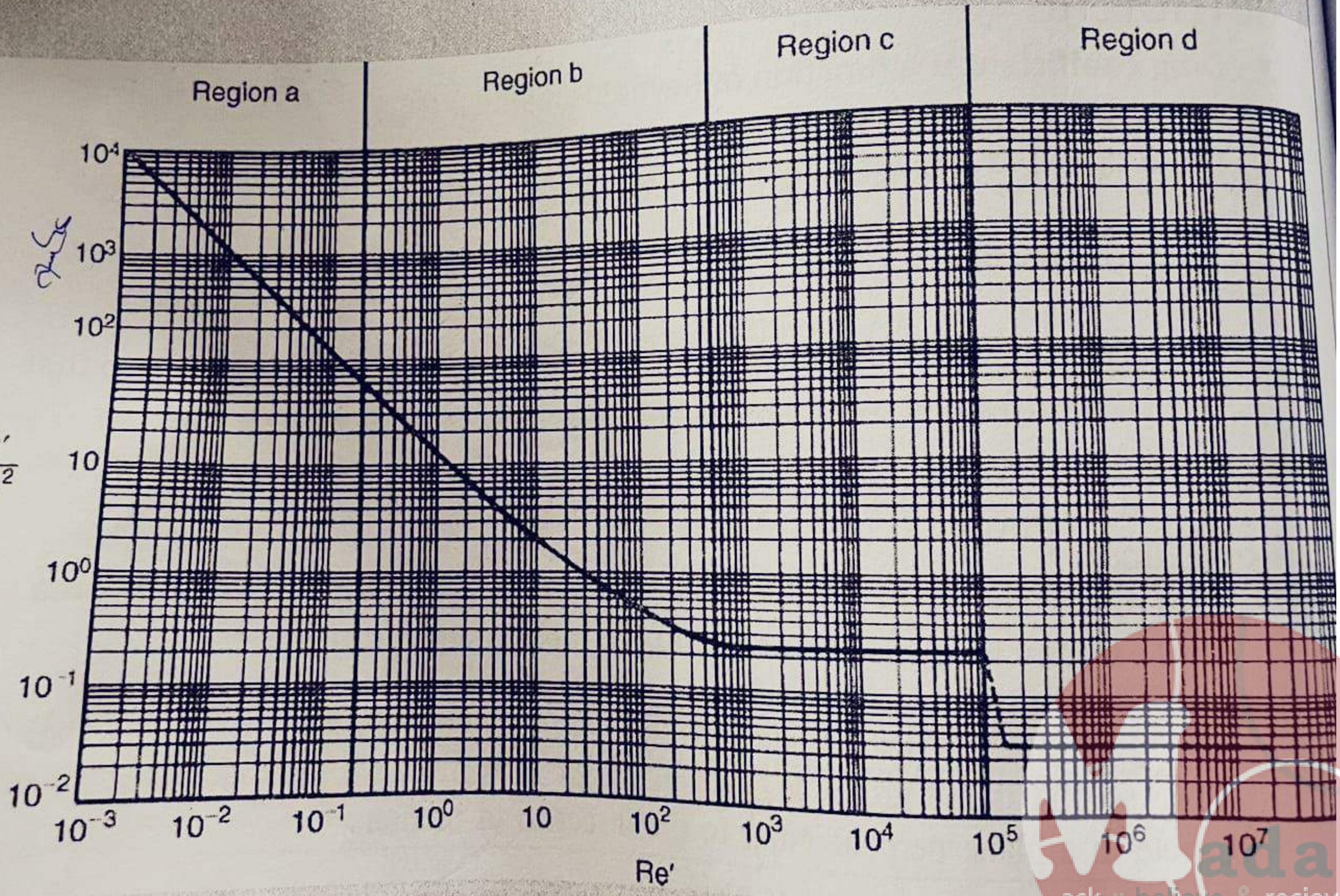
$$\frac{R'}{\rho u^2} = \frac{4F}{\pi d^2 \rho u^2}$$

$R'/\rho u^2$ is a form of *drag coefficient*, often denoted by the symbol C'_D. Frequently, a drag coefficient C_D is defined as the ratio of R' to $\frac{1}{2}\rho u^2$.

Thus:

$$C_D = 2C'_D = \frac{2R'}{\rho u^2}$$

It is seen that C'_D is analogous to the friction factor $\phi(= R/\rho u^2)$ for pipe flow, and C_D is analogous to the Fanning friction factor f.


Region a
Region b
Region c
Region d
10^4
10^3
10^2
10
10^0
10^{-1}
10^{-2}
$\frac{R'}{\rho u^2}$
10^{-3}
10^{-2}
10^{-1}
10^0
10
10^2
10^3
10^4
10^5
10^6
10^7
Re'

Region (a) $(10^{-4} < Re' < 0.2)$

At very **low values of the Reynolds number**, the force *F* is given by **Stokes' law**:

[illegible]

$$\frac{R'}{\rho u^2} = 12\frac{\mu}{ud\rho} = 12Re'^{-1}$$

In this region, the relationship between $\frac{R'}{\rho u^2}$ and Re' is a straight line of slope

The limit of 10^{-4} is imposed because reliable experimental measurements have been made at lower values of Re'.

$$R' = 12\rho u^2\left(\frac{\mu}{ud\rho}\right) = \frac{12u\mu}{d}$$

$$F = \frac{12u\mu}{d}\frac{1}{4}\pi d^2 = 3\pi\mu du$$

mathmo

Region (b) $(0.2 < Re' < 500\text{–}1000)$

99.9

X → 70

$m \rightarrow n$

a 2×200 = mm

n

n total

In this region, the slope of the curve changes progressively from -1 to 0 as Re' increases.

Coef additions

Thus:

$$\frac{R'}{\rho u^2} = 12Re'^{-1} + \boxed{0.22} \rightarrow \text{from diag: irregular shape}$$

Stokes' law

Additional non-viscous effects

mass

mass / n

m / mm

4.92 × 10^{32}

- A reasonable approximation for values of Re' up to about 1000:

$$\frac{R'}{\rho u^2} = 12Re'^{-1}(1 + 0.15Re'^{0.687})$$

$$R' = \frac{12u\mu}{d}(1 + 0.15Re'^{0.687})$$

$$F = 3\pi\mu du(1 + 0.15Re'^{0.687})$$

Region (c) $(500–1000 < Re' < \text{ca } 2 \times 10^5)$

In this region, Newton's law is applicable and the value of $R'/\rho u^2$ is approximately constant giving:

$$\frac{R'}{\rho u^2} = 0.22$$

$$R' = 0.22\rho u^2$$

$$F = 0.22\rho u^2 \tfrac{1}{4}\pi d^2 = 0.055\pi d^2 \rho u^2$$

Region (d) $(Re' > \text{ca } 2 \times 10^5)$

When Re' exceeds about 2×10^5, the flow in the boundary layer changes from streamline to turbulent and the separation takes place nearer to the rear of the sphere. The drag force is decreased considerably and:

$$\frac{R'}{\rho u^2} = 0.05$$

$$R' = 0.05\rho u^2$$

$$F = 0.0125\pi d^2 \rho u^2$$

Terminal falling velocities :

- If a spherical particle is allowed to settle in a fluid under gravity, its velocity will increase until the accelerating force is exactly balanced by the resistance force.

- The accelerating force due to gravity is given by:

$$= (\tfrac{1}{6}\pi d^3)(\rho_s - \rho)g$$

where ρ_s is the density of the solid.

The terminal falling velocity u_0 corresponding to region (a) is given by:

Or if the particle has started from rest, the drag force is given by :

$$(\tfrac{1}{6}\pi d^3)(\rho_s - \rho)g = 3\pi\mu d u_0$$

and:

Case 1
Stocks
Law

$$u_0 = \frac{d^2 g}{18\mu}(\rho_s - \rho)$$

اذا ما صدر
Stock /Newton
صار التشتت

The terminal falling velocity corresponding to region (c) is given by:

$$(\tfrac{1}{6}\pi d^3)(\rho_s - \rho)g = 0.055\pi d^2 \rho u_0^2$$

or:

~~Case A~~
~~Stocks~~
~~Law~~

$$\leftarrow \quad u_0^2 = 3dg\frac{(\rho_s - \rho)}{\rho}$$

Under terminal falling conditions, velocities are rarely high enough for ***Re'*** to approach 10^5, with the small particles generally used in industry.

Assumptions

In the expressions given for the drag force and the terminal falling velocity, the followi
assumptions have been made:

A. That the settling is not affected by the presence of other particles in the fluid. T condition is known as "**free settling**". When the interference of other particles appreciable, the process is known as "**hindered settling**".

B. That the walls of the containing vessel do not exert an appreciable retarding effect.

C. That the fluid can be considered as a continuous medium, that is the particle is lar compared with the mean free path of the molecules of the fluid, otherwise the partic may occasionally "slip" between the molecules and thus attain a velocity higher th that calculated.

1/

9:00

①

1-2:00

Terminal Velocity for two materials

- If for a particle of material **A** of diameter $\boldsymbol{d_A}$ and density $\boldsymbol{\rho_A}$, Stokes' law is applicable, then the terminal falling velocity $\boldsymbol{u_{0A}}$ is given by equation

$$u_{0A} = \frac{d_A^2 g}{18\mu}(\rho_A - \rho)$$

$$\underline{F = ma} \downarrow$$

Similarly, for a particle of material B:

$$u_{0B} = \frac{d_B^2 g}{18\mu}(\rho_B - \rho)$$

The condition for the two terminal velocities to be equal is then:

$$\frac{d_B}{d_A} = \left(\frac{\rho_A - \rho}{\rho_B - \rho}\right)^{\textcircled{1/2}} \longrightarrow \text{Stocks}$$

1 → newton

If Newton's law is applicable, equation 3.25 holds and:

$$u_{0A}^2 = \frac{3d_A g(\rho_A - \rho)}{\rho}$$

and

$$u_{0B}^2 = \frac{3d_B g(\rho_B - \rho)}{\rho}$$

For equal settling velocities:

$$\frac{d_B}{d_A} = \left(\frac{\rho_A - \overset{\text{Liquid}}{\rho}}{\rho_B - \rho}\right)$$

In general, the relationship for equal settling velocities is:

$$\frac{d_B}{d_A} = \left(\frac{\rho_A - \rho}{\rho_B - \rho}\right)^S$$

where $S = \frac{1}{2}$ for the Stokes' law region, $S = 1$ for Newton's law and, as an approximation, $\frac{1}{2} < S < 1$ for the intermediate region.

Galileo number (Ga)

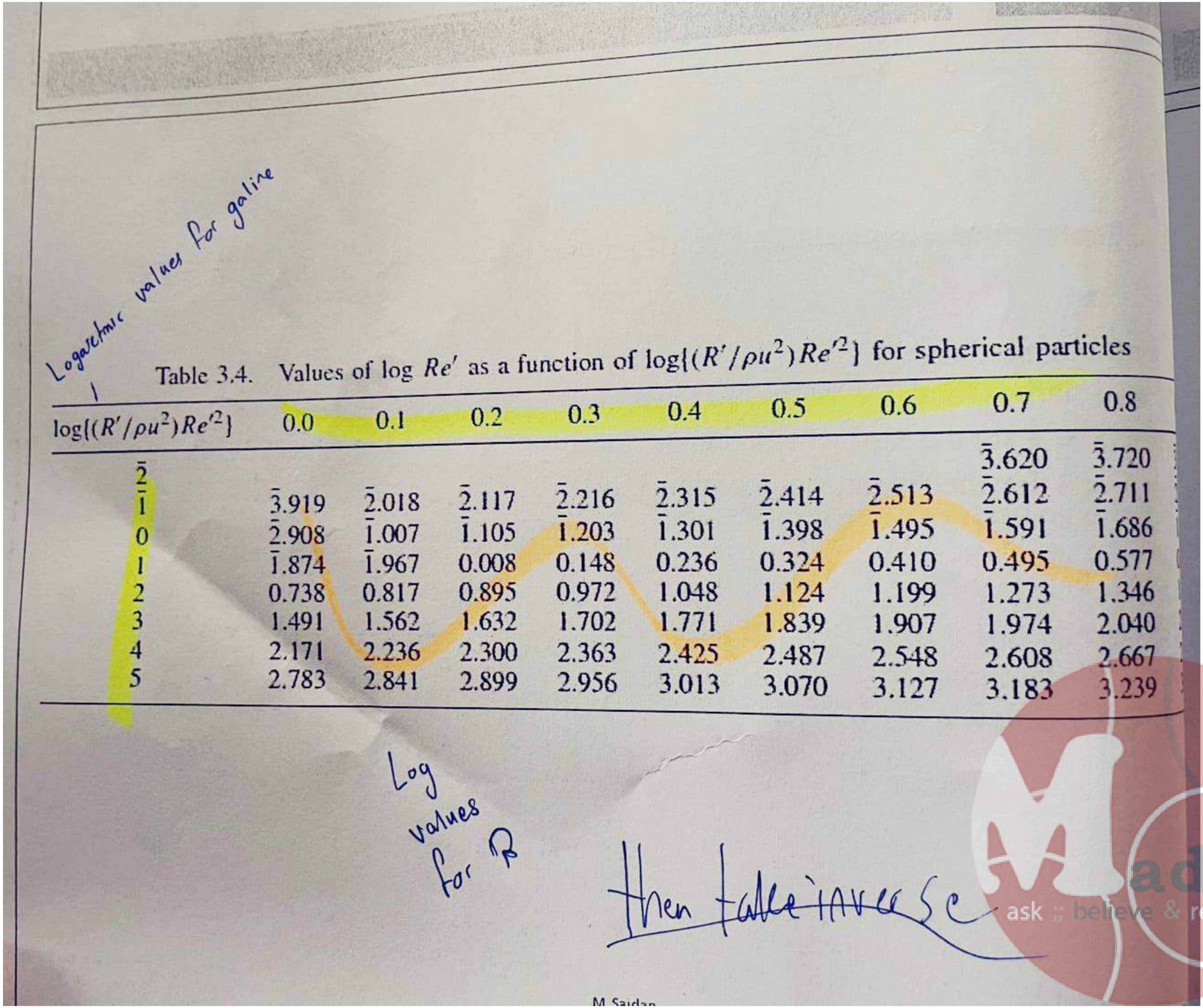
The dimensionless group $(R'_0/\rho u_0^2)Re_0'^2$ does not involve u_0 since:

$$\frac{R'_0}{\rho u_0^2}\frac{u_0^2 d^2 \rho^2}{\mu^2} = \frac{2dg(\rho_s - \rho)}{3\rho u_0^2}\frac{u_0^2 d^2 \rho^2}{\mu^2}$$

$$= \frac{2d^3(\rho_s - \rho)\rho g}{3\mu^2}$$

The group $\dfrac{d^3\rho(\rho_s - \rho)g}{\mu^2}$ is known as the Galileo number Ga

$$\boxed{\frac{R'_0}{\rho u_0^2} Re_0'^2 = \tfrac{2}{3} Ga}$$



Logarethmic values for galine

Table 3.4. Values of log Re' as a function of $\log\{(R'/\rho u^2)Re'^2\}$ for spherical particles

$\log\{(R'/\rho u^2)Re'^2\}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
$\bar{2}$								$\bar{3}.620$	$\bar{3}.720$
$\bar{1}$	$\bar{3}.919$	$\bar{2}.018$	$\bar{2}.117$	$\bar{2}.216$	$\bar{2}.315$	$\bar{2}.414$	$\bar{2}.513$	$\bar{2}.612$	$\bar{2}.711$
0	$\bar{2}.908$	$\bar{1}.007$	$\bar{1}.105$	$\bar{1}.203$	$\bar{1}.301$	$\bar{1}.398$	$\bar{1}.495$	$\bar{1}.591$	$\bar{1}.686$
1	$\bar{1}.874$	$\bar{1}.967$	0.008	0.148	0.236	0.324	0.410	0.495	0.577
2	0.738	0.817	0.895	0.972	1.048	1.124	1.199	1.273	1.346
3	1.491	1.562	1.632	1.702	1.771	1.839	1.907	1.974	2.040
4	2.171	2.236	2.300	2.363	2.425	2.487	2.548	2.608	2.667
5	2.783	2.841	2.899	2.956	3.013	3.070	3.127	3.183	3.239

Log values for R

then take inverse

Example

What is the terminal velocity of a spherical steel particle, 0.40 mm in diameter, settling in an oil of density 820 kg/m^3 and viscosity 10 mN s/m^2? The density of steel is 7870 kg/m^3.

Solution

For a sphere:

$$\frac{R_0'}{\rho u_0^2} Re_0'^2 = \frac{2d^3(\rho_s - \rho)\rho g}{3\mu^2}$$

$$= \frac{2 \times 0.0004^3 \times 820(7870 - 820)9.81}{3(10 \times 10^{-3})^2}$$

$$= 24.2$$

$$\log_{10} 24.2 = 1.384$$

From Table 3.4: $\log_{10} Re_0' = 0.222$

Thus: $Re_0' = 1.667$

and: $u_0 = \dfrac{1.667 \times 10 \times 10^{-3}}{820 \times 0.0004}$

$$= 0.051 \text{ m/s or } \underline{\underline{51 \text{ mm/s}}}$$

Non-Spherical Particles

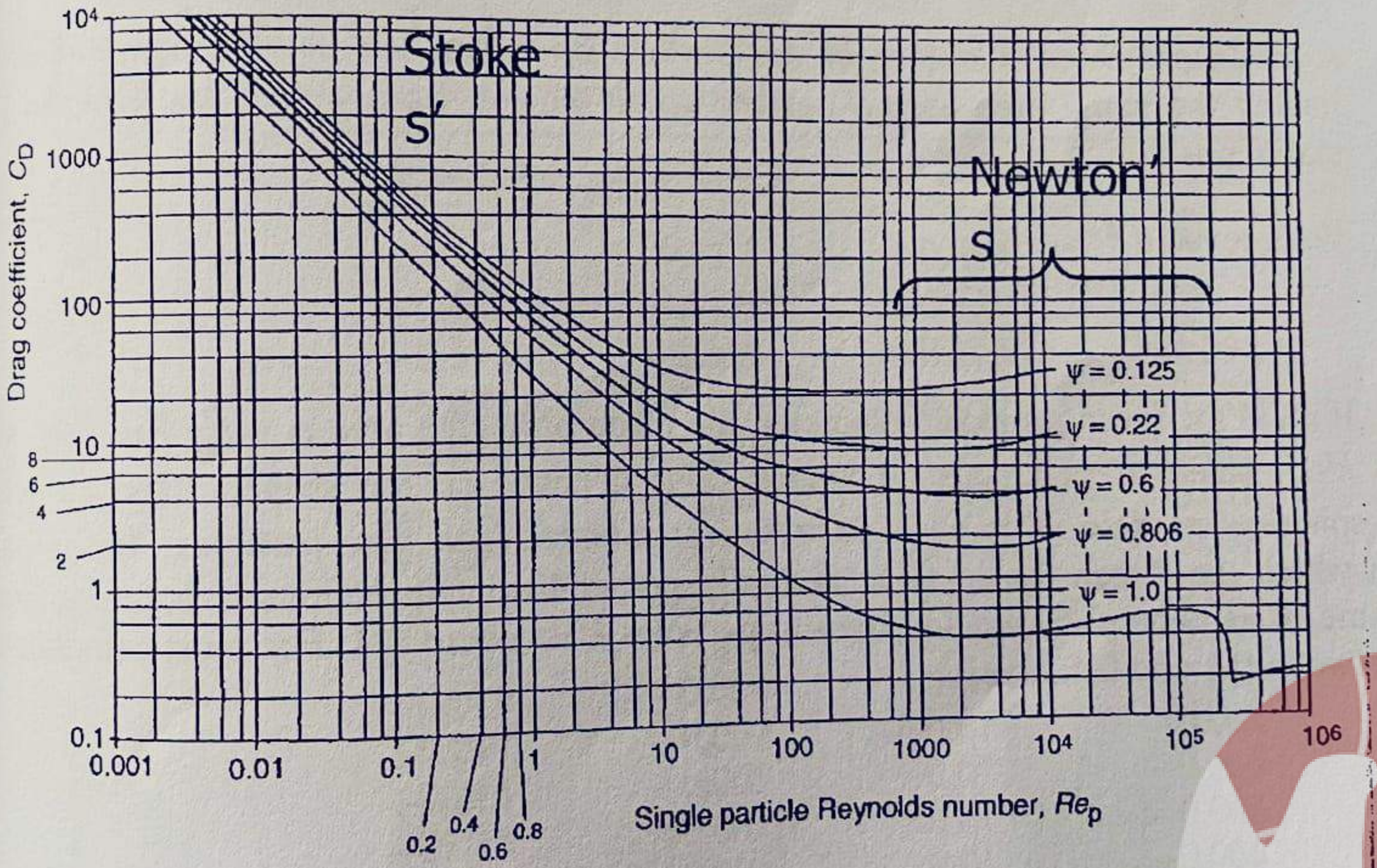


Figure 1.3 Drag coefficient C_D versus Reynolds number Re_p for particles of sphericity ψ ranging form 0.125 to 1.0 (note Re_p uses the equivalent volume diameter)

Terminal falling velocities of non-spherical particles

For a non-spherical particle:

total drag force, $F = R'_0 \frac{1}{4} \pi d_p^2 = (\rho_s - \rho) g k' d$

Thus:

$$\frac{R'_0}{\rho u_0^2} = \frac{4k' d_p g}{\pi \rho u_0^2} (\rho_s - \rho)$$

$$\frac{R'_0}{\rho u_0^2} Re_0'^2 = \frac{4k' \rho d_p^3 g}{\mu^2 \pi} (\rho_s - \rho)$$

and:

$$\frac{R'_0}{\rho u_0^2} Re_0'^{-1} = \frac{4k' \mu g}{\pi \rho^2 u_0^3} (\rho_s - \rho)$$

Heywood Approach

- A mean projected diameter of the particle ***dp*** is defined as the diameter of a circle having the same area as the particle when viewed from above and lying in its most stable position.
- Volume= $K' d_p^3$

If d_p is the mean projected diameter, the mean projected area is $\pi d_p^2/4$ and the volume is $k'd_p^3$, where k' is a constant whose value depends on the shape of the particle. For a spherical particle, k' is equal to $\pi/6$. For rounded isometric particles, that is particles in which the dimension in three mutually perpendicular directions is approximately the same, k' is about 0.5, and for angular particles k' is about 0.4. For most minerals k' lies between 0.2 and 0.5.

Table 3.7. Corrections to log Re' as a function of $\log\{(R'/\rho u^2)Re'^2\}$ for non-spherical particles

$\log\{(R'/\rho u^2)Re'^2\}$	$k' = 0.4$	$k' = 0.3$	$k' = 0.2$	$k' = 0.1$
$\bar{2}$	−0.022	−0.002	+0.032	+0.131
$\bar{1}$	−0.023	−0.003	+0.030	+0.131
0	−0.025	−0.005	+0.026	+0.129
1	−0.027	−0.010	+0.021	+0.122
2	−0.031	−0.016	+0.012	+0.111
2.5	−0.033	−0.020	0.000	+0.080
3	−0.038	−0.032	−0.022	+0.025
3.5	−0.051	−0.052	−0.056	−0.040
4	−0.068	−0.074	−0.089	−0.098
4.5	−0.083	−0.093	−0.114	−0.146
5	−0.097	−0.110	−0.135	−0.186
5.5	−0.109	−0.125	−0.154	−0.224
6	−0.120	−0.134	−0.172	−0.255

Table 3.8. Corrections to log Re' as a function of $\{\log(R'/\rho u^2)Re'^{-1}\}$ for non-spherical particles

$\log\{(R'/\rho u^2)Re'^{-1}\}$	$k' = 0.4$	$k' = 0.3$	$k' = 0.2$	$k' = 0.1$
$\bar{4}$	+0.185	+0.217	+0.289	
$\bar{4}.5$	+0.149	+0.175	+0.231	
$\bar{3}$	+0.114	+0.133	+0.173	+0.282
$\bar{3}.5$	+0.082	+0.095	+0.119	+0.170
$\bar{2}$	+0.056	+0.061	+0.072	+0.062
$\bar{2}.5$	+0.038	+0.034	+0.033	−0.018
$\bar{1}$	+0.028	+0.018	+0.007	−0.053
$\bar{1}.5$	+0.024	+0.013	−0.003	−0.061
0	+0.022	+0.011	−0.007	−0.062
1	+0.019	+0.009	−0.008	−0.063
2	+0.017	+0.007	−0.010	−0.064
3	+0.015	+0.005	−0.012	−0.065
4	+0.013	+0.003	−0.013	−0.066
5	+0.012	+0.002	−0.014	−0.066

Example

What will be the terminal velocities of mica plates, 1 mm thick and ranging in area from 6 to 600 mm^2, settling in an oil of density 820 kg/m^3 and viscosity 10 mN s/m^2? The density of mica is 3000 kg/m^3.

Solution

	smallest particles	largest particles
A'	6×10^{-6} m^2	6×10^{-4} m^2
d_p	$\sqrt{(4 \times 6 \times 10^{-6}/\pi)} = 2.76 \times 10^{-3}$ m	$\sqrt{(4 \times 6 \times 10^{-4}/\pi)} = 2.76 \times 10^{-2}$ m
d_p^3	2.103×10^{-8} m^3	2.103×10^{-5} m^3
volume	6×10^{-9} m^3	6×10^{-7} m^3
k'	0.285	0.0285

$$\left(\frac{R'_0}{\rho u^2}\right) Re_0'^2 = \frac{4k'}{\mu^2 \pi}(\rho_s - \rho)\rho d_p^3 g \qquad \text{(equation 3.52)}$$

$$= (4 \times 0.285/\pi \times 0.01^2)(3000 - 820)(820 \times 2.103 \times 10^{-8} \times 9.81)$$

= 1340 for the smallest particles and, similarly, 134,000 for the largest particles.

Thus:

	smallest particles	largest particles
$\log\left(\frac{R'_0}{\rho u_0^2} Re_0'^2\right)$	3.127	5.127
$\log Re'_0$	1.581	2.857 (from Table 3.4)
Correction from Table 3.6	−0.038	−0.300 (estimated)
Corrected $\log Re'_0$	1.543	2.557
Re'_0	34.9	361
u_0	0.154 m/s	0.159 m/s

Thus it is seen that all the mica particles settle at approximately the same velocity.

Temp. , Contact area

Introduction

← بنرتب particles على شكل معين بحجم معين فوق بعضهم بعض وبضل فراغات بين هاي particles

- Most of technical process, liquid or gases flow through beds of solid particles.

Example: Flow of fluid (gas, liquid) through granular bed (Solid) ← bed مرور اي فلويد بين الفراغات الموجودة بال ←

i. A single fluid flow through a bed of granular solid

← الهدف من الفراغات: بزيد ال surface area جوا ال bed ← بتعطي S.A بقوليك قليل!!

ii. Two phase countercurrent flow of liquid and gas through packed columns.

↓ efficiency of removal يحسّن { كل phase جاي من سايد تا يلتقو ليصير تفاعل }

- Single fluid flow through a granular bed or porous medium involves in;

  - ✓ fixed bed reactor
  - ✓ filtration
  - ✓ adsorption
  - ✓ seepage of underground water or petroleum

زي خزان الديزل

adsorbs Chlorine in water ← بشيل الكلور من الماء

bed ~~adsorbs~~ ↑ فلتر الفحم

الحوض

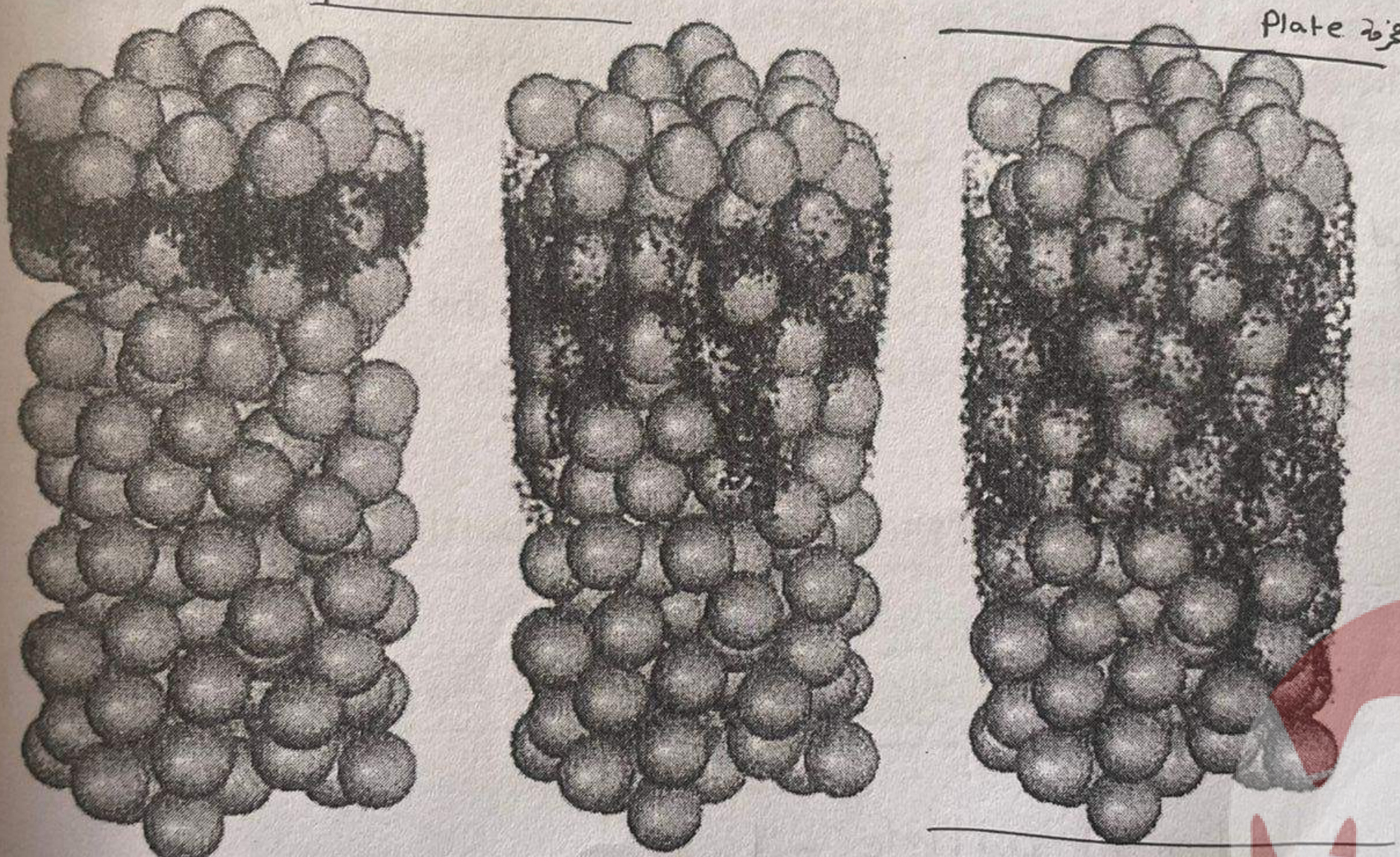
% remov

[illegible] ①

Porous packed bed

free volume
هو ال porous

الكرات ثابتة .



جزء Plate

Plate
جزء للتثبيت

Darcy Law and Permeability

- Permeability measurement is conducted to determine the surface power

نفاذية

مقياس النفاذية

مائع fluid

- **Darcy's Law:** the average velocity, as measured over the whole area of the bed, is directly proportional to the driving pressure and inversely proportional to the thickness of the bed.

يسري

flow

①

$$u_c = \frac{K(-\Delta P)}{l} = \overset{\text{Paramater of permitivility!!}}{\overset{\uparrow}{B}}\frac{(-\Delta P)}{\underset{\text{viscosity}}{\mu} l}$$

$$B = \frac{K}{\mu}$$

where $-\Delta P$ is the pressure drop across the bed,

l is the thickness of the bed,

u_c is the average velocity of flow of the fluid, defined as $(1/A)(dV/dt)$,

A is the total cross sectional area of the bed,

V is the volume of fluid flowing in time t, and

K is a constant depending on the physical properties of the bed and fluid.

where μ is the viscosity of the fluid and B is termed the permeability coefficient for the bed, and depends only on the properties of the bed.

volume

Specific surface and Voidage

كل m^3 ع يعطي Area

The general structure of a bed of particles can often be characterised by the specific surface area of the bed S_B and the fractional voidage of the bed e./ε → voidage

S_B is the surface area presented to the fluid per unit volume of bed when the particles are packed in a bed. Its units are (length)$^{-1}$.

Plaid block فتح

- Voidage/porosity (ε) -The fraction of the volume of the bed not occupied by so material. It is dimensionless and given by;

$$\varepsilon = \frac{\text{volume of the bed} - \text{volume of particles}}{\text{volume of bed}}$$

$$= 1 - \frac{\text{volume of particles}}{\text{volume of bed}}$$

Volume fraction of particles = $1 - \varepsilon$.

الي تعبا جزيئات

before bed now particles.

Specific surface area of the particles ($\underline{S}$ or $\underline{a_v}$) or S_p

- The Specific surface area of the particles equals to the surface area of a particle divided by its volume. Its units are (length)^-1

$$a_v = \frac{S_p}{v_p}$$

S_p : surface area of a particle in m²
v_p: volume of particle in m³

S

VIP a : specific surface area of bed : S
VIP S or Sp or av : " " " " particle

- For a spherical particle,

$$\overset{\text{particle}}{a_v} = \frac{6}{D_p}$$

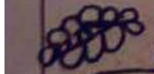
D_p : diameter in m

* = Particles as a whole

$$\boxed{S = \frac{\overset{\text{surface area}}{\pi d^2}}{\underset{\text{volume}}{\pi(d^3/6)}} = \frac{6}{d}}$$

- For a packed bed of non-spherical particle, the effective particle diameter D_p is defined as

$$D_p = \frac{6}{a_v}$$



percolation

volume of cylinder / sphere } you have to know them!!

peretation

Volume of cylinder
sphere
cube
conical
} you have to know them!!

Since (1 − ε) is the volume fraction of particles in the bed,

$$\underbrace{a = a_v(1-\varepsilon)}_{\star} = \frac{6}{\boxed{D_p}}(1-\varepsilon)$$

اذا مش
~~fegat~~ sphere
دبر حالك !!

where a is the ratio of total surface area in the bed to total volume of bed (void volume plus particle volume) in m^{-1}.

Table 4.1. Properties of beds of some regular-shaped materials (R&C page 193)

Example

A packed bed is composed of cylinders having a diameter $D = 0.02$ m and a length $h = D$. The bulk density of the overall packed bed is 962 kg/m^3 and the density of the solid cylinders is 1600 kg/m^3.

(a) Calculate the void fraction ε.

(b) Calculate the effective diameter D_p of the particles.

(c) Calculate the value of a

Solution: For part (a), taking 1.00 m^3 of packed bed as a basis, the total mass of the bed is (962 kg/m^3)(1.00 m^3) = 962 kg. This mass of 962 kg is also the mass of the solid cylinders. Hence, volume of cylinders = 962 kg/(1600 kg/m^3) = 0.601 m^3. Using Eq. (3.1-6),

$$\varepsilon = \frac{\text{volume of voids in bed}}{\text{total volume of bed}} = \frac{1.000 - 0.601}{1.000} = 0.399$$

For the effective particle diameter D_p in part (b), for a cylinder where $h = D$, the surface area of a particle is

$$S_p = (2)\frac{\pi D^2}{4}\ \text{(ends)} + \pi D(D)\ \text{(sides)} = \tfrac{3}{2}\pi D^2$$

The volume v_p of a particle is

$$v_p = \frac{\pi}{4}D^2(D) = \frac{\pi D^3}{4}$$

Then,

$$a_v = \frac{S_p}{v_p} = \frac{\frac{3}{2}\pi D^2}{\frac{1}{4}\pi D^3} = \frac{6}{D}$$

Finally, :

$$D_p = \frac{6}{a_v} = \frac{6}{6/D} = D = 0.02 \text{ m}$$

Hence, the effective diameter to use is $D_p = D = 0.02$ m. For part (c),

$$a = \frac{6}{D_p}(1 - \varepsilon) = \frac{6}{0.02}(1 - 0.399) = 180.3 \text{ m}^{-1}$$

Fluid flow through beds (Carman–Kozeny equations)

تفاصيل اكثر
ل flow

للمسار المتعرج velocity
Slide 3

Streamline flow—Carman–Kozeny equation

- The pore space in the bed is assumed to be a tube with equivalent diameter which satisfies the following assumptions:
  - The internal surface area is equal to the surface area of particles
  - The free space is equal to that in granular bed.

torto
متعرج

- If the free space in the bed is assumed to consist of a series of missing

$$u_1 = \frac{d_m'^2}{K'\mu} \frac{(-\Delta P)}{l'} \quad ②$$

✓

where: d_m' is some equivalent diameter of the pore channels,
K' is a dimensionless constant whose value depends on the structure of the bed.
l' is the length of channel, and
u_1 is the average velocity through the pore channels.
μ is the viscosity of the fluid,

$$d'_m = \frac{e}{S_B} = \frac{e}{S(1-e)}$$

$$\boxed{S_B = S(1-e)}$$

e is the fractional voidage

$$\frac{e}{S_B} = \frac{\text{volume of voids filled with fluid}}{\text{wetted surface area of the bed}}$$

$$= \frac{\text{cross-sectional area normal to flow}}{\text{wetted perimeter}}$$

$$\frac{e}{S_B} = \frac{1}{4}\ \text{(hydraulic mean diameter)}$$

Then taking $u_1 = u_c/e$ and $l' \propto l$,

$$\boxed{\begin{aligned} u_c &= \frac{1}{K''}\frac{e^3}{S_B^2}\frac{1}{\mu}\frac{(-\Delta P)}{l} \\ &= \frac{1}{K''}\frac{e^3}{S^2(1-e)^2}\frac{1}{\mu}\frac{(-\Delta P)}{l} \end{aligned}}$$

K'' is generally known as Kozeny's constant and a commonly accepted value for K'' is 5

K'' is dependent on porosity, particle shape, and other factors.

The permeability coefficient is given by:

$$B = \frac{1}{K''}\frac{e^3}{S^2(1-e)^2}$$

Inserting a value of 5 for K''

$$u_c = \frac{1}{5}\frac{e^3}{(1-e)^2}\frac{-\Delta P}{S^2 \mu l}$$

For spheres: $S = 6/d$ and:

$$u_c = \frac{1}{180}\frac{e^3}{(1-e)^2}\frac{-\Delta P d^2}{\mu l}$$

$$= 0.0055\frac{e^3}{(1-e)^2}\frac{-\Delta P d^2}{\mu l}$$

For non-spherical particles, the Sauter mean diameter d_s should be used in place o

Streamline and turbulent flow

Since equation applies to streamline flow conditions, though CARMAN and others have extended the analogy with pipe flow to cover both streamline and turbulent flow conditions through packed beds.

In this treatment a modified friction factor $R_1/\rho u^2_1$ is plotted against a modified Reynolds number Re_1. This is analogous to plotting $R/\rho u^2$ against Re for flow through a pipe

The modified Reynolds number Re_1 is obtained by taking the same velocity and characteristic linear dimension d'_m as were used in deriving equation 4.9. Thus:

$$Re_1 = \frac{u_c}{e}\frac{e}{S(1-e)}\frac{\rho}{\mu}$$

$$= \frac{u_c\rho}{S(1-e)\mu}$$

*R*1 can be related to the properties of the bed and pressure gradient as follows:

Considering the forces acting on the fluid in a bed of unit cross-sectional area and thickness *l*, the volume of particles in the bed is $l(1-e)$ and therefore the total surface is S $l(1-e)$ ·

Thus the resistance force is $R_1 S\ l(1-e)$ This force on the fluid must be equal to that produced by a pressure difference of ΔP across the bed. Then, since the free cross-section of fluid is equal to ***e***:

$$(-\Delta P)e = R_1 Sl(1-e)$$

and

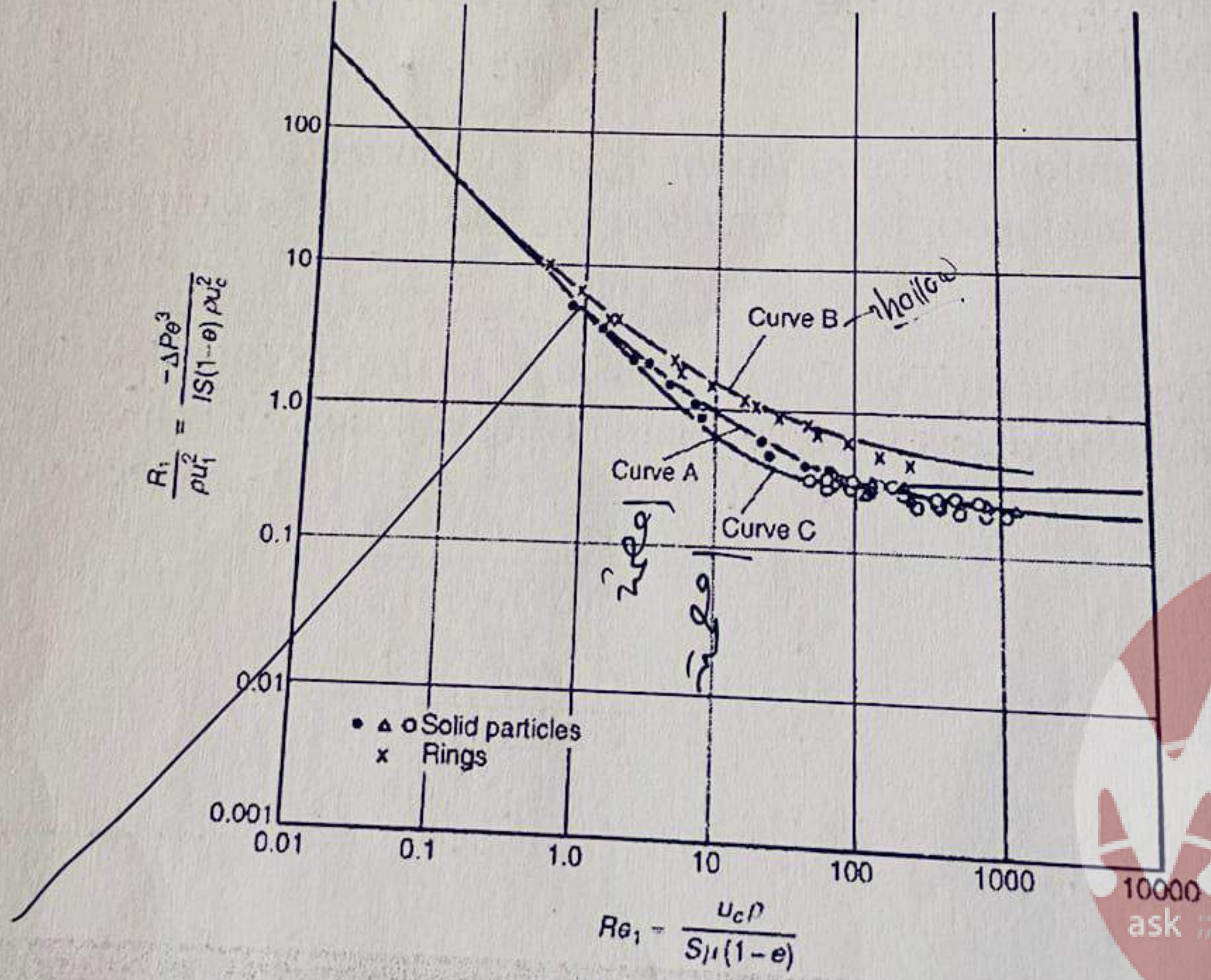
$$R_1 = \frac{e}{S(1-e)}\frac{(-\Delta P)}{l}$$

Thus

$$\frac{R_1}{\rho u_1^2} = \frac{e^3}{S(1-e)}\frac{(-\Delta P)}{l}\frac{1}{\rho u_c^2}$$

Carman found that when $R_1/\rho u_1^2$ was plotted against Re_1 using logarithmic coordi his data for the flow through randomly packed beds of solid particles could be corre approximately by a single curve (curve A, Figure 4.1), whose general equation is:

$$\frac{R_1}{\rho u_1^2} = 5Re_1^{-1} + 0.4Re_1^{-0.1}$$



From equation 4.16 it can be seen that for values of Re_1 less than about 2, the secon term is small and, approximately:

$$\frac{R_1}{\rho u_1^2} = 5Re_1^{-1} \tag*{(4.18}$$

$$u_c = \frac{1}{5}\left(\frac{1}{1-e}\right)\left(\frac{\rho u_c^2}{S\mu}\right)\left(\frac{R_1}{\rho u_1^2}\right)$$

$$\frac{R_1}{\rho u_1^2} = 5\left(\frac{S(1-e)\mu}{u_c\rho}\right)$$

$$= 5Re_1^{-1}$$

As the value of Re_1 increases from about 2 to 100, the second term in equation 4.16 becomes more significant and the slope of the plot gradually changes from -1.0 to about $-\frac{1}{4}$. Above Re_1 of 100 the plot is approximately linear. The change from complete streamline flow to complete turbulent flow is very gradual because flow conditions are not the same in all the pores. Thus, the flow starts to become turbulent in the larger pores, and subsequently in successively smaller pores as the value of Re_1 increases.

Rings, which as described later are often used in industrial packed columns, tend to deviate from the generalised curve A on Figure 4.1 particularly at high values of Re_1.

SAWISTOWSKI(9) compared the results obtained for flow of fluids through beds of hollow packings (discussed later) and has noted that equation 4.16 gives a consistently low result for these materials. He proposed:

$$\frac{R_1}{\rho u_1^2} = 5Re_1^{-1} + Re_1^{-0.1} \tag{4.19}$$

4.17

fluid

This equation is plotted as curve B in Figure 4.1.

Ergun semi-empirical correlation

For flow through ring packings which as described later are often used in industrial packed columns, ERGUN[(10)] obtained a good semi-empirical correlation for pressure drop as follows:

$$\frac{-\Delta P}{l} = 150\frac{(1-e)^2}{e^3}\frac{\mu u_c}{d^2} + 1.75\frac{(1-e)}{e^3}\frac{\rho u_c^2}{d} \quad (4.20)$$

③

V.I.P

Writing $d = 6/S$ (from equation 4.3):

$$\frac{-\Delta P}{Sl\rho u_c^2}\frac{e^3}{1-e} = 4.17\frac{\mu S(1-e)}{\rho u_c} + 0.29 \ .$$

or:

$$\frac{R_1}{\rho u_1^2} = 4.17 Re_1^{-1} + 0.29 \quad (4.21)$$

This equation is plotted as curve C in Figure 4.1. The form of equation 4.21 is somewhat similar to that of equations 4.16 and 4.17, in that the first term represents viscous losses which are most significant at low velocities and the second term represents kinetic energy losses which become more significant at high velocities. The equation is thus applicable over a wide range of velocities and was found by Ergun to correlate experimental data well for values of $Re_1/(1-e)$ from 1 to over 2000.

Dependence of K`` on bed structure

Tortuosity

CARMAN(1) has shown that:

$$K'' = \left(\frac{l'}{l}\right)^2 \times K_0 \tag{4.22}$$

where (l'/l) is the tortuosity and is a measure of the fluid path length through the bed compared with the actual depth of the bed,

K_0 is a factor which depends on the shape of the cross-section of a channel through which fluid is passing.

Non-spherical particles

☆ to exam

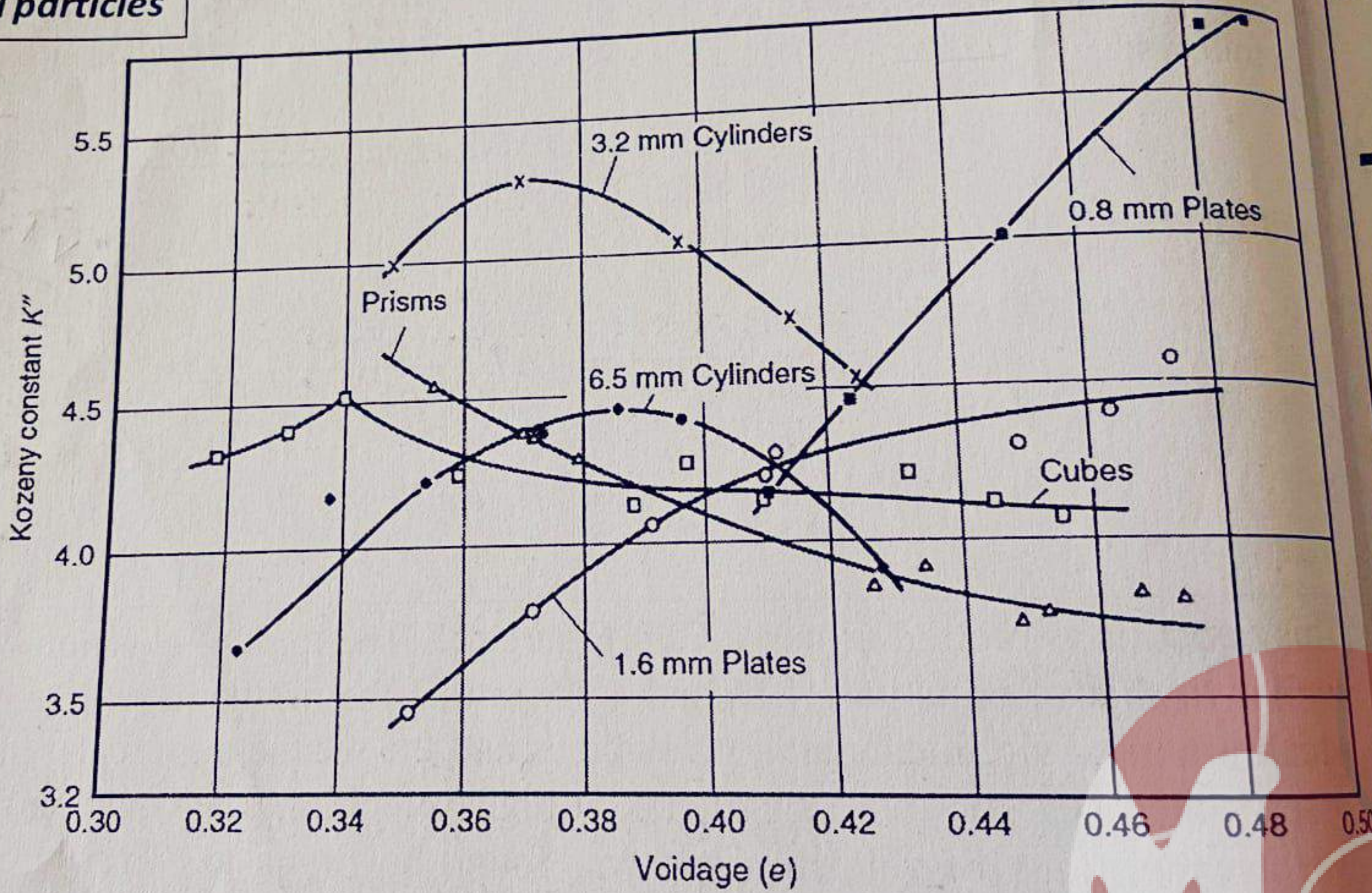


Figure 4.2. Variation of Kozeny's constant K'' with voidage for various shapes

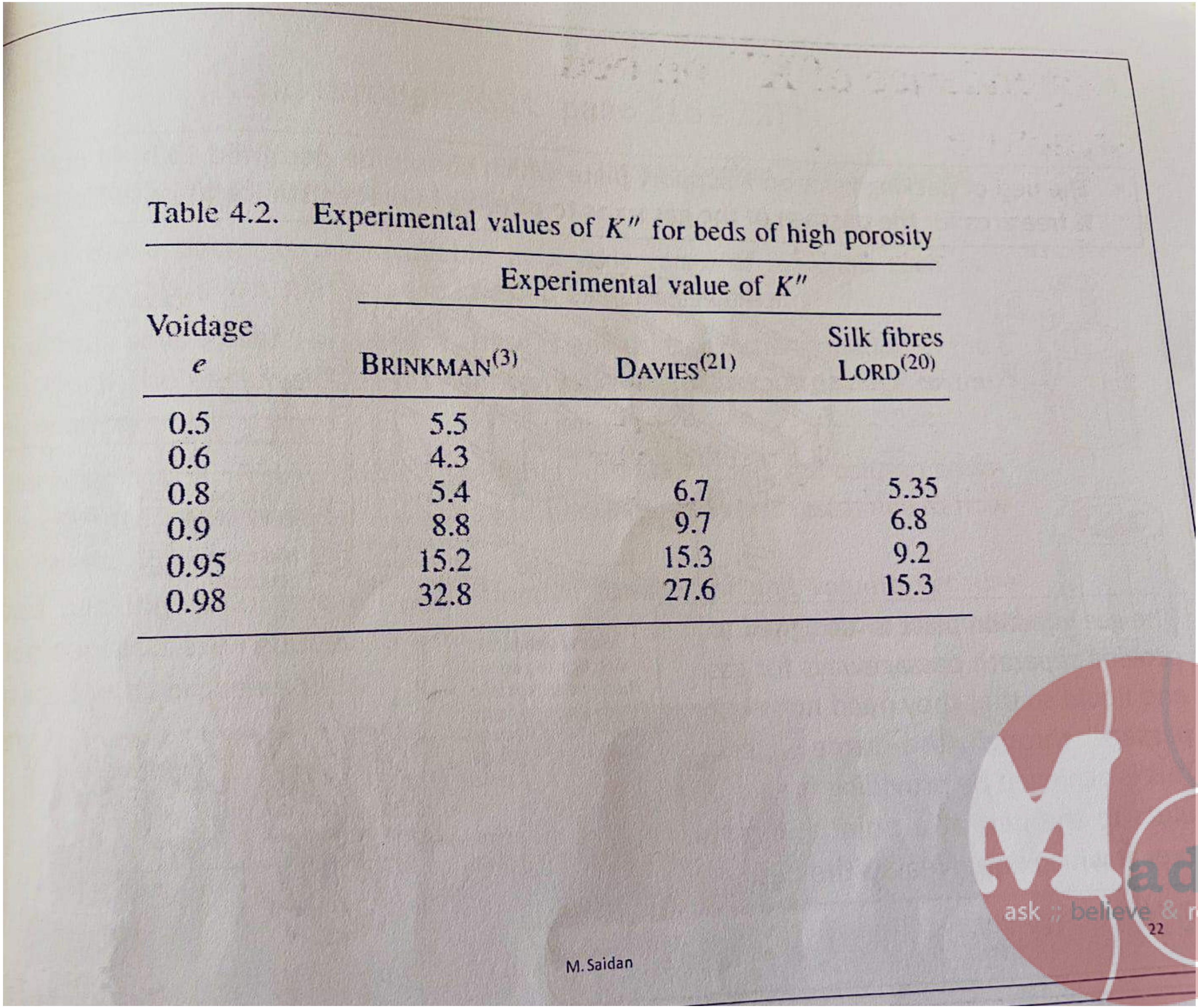
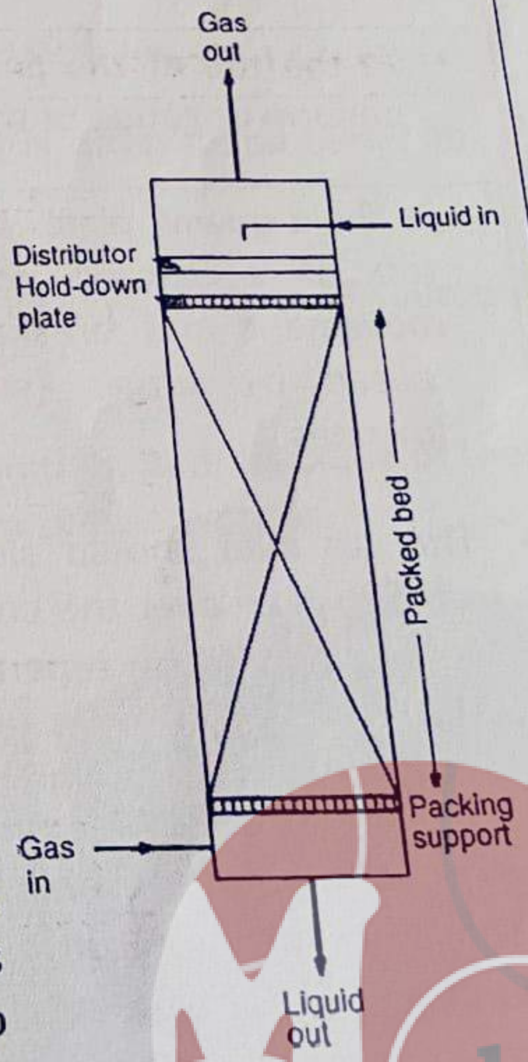


Table 4.2. Experimental values of K'' for beds of high porosity

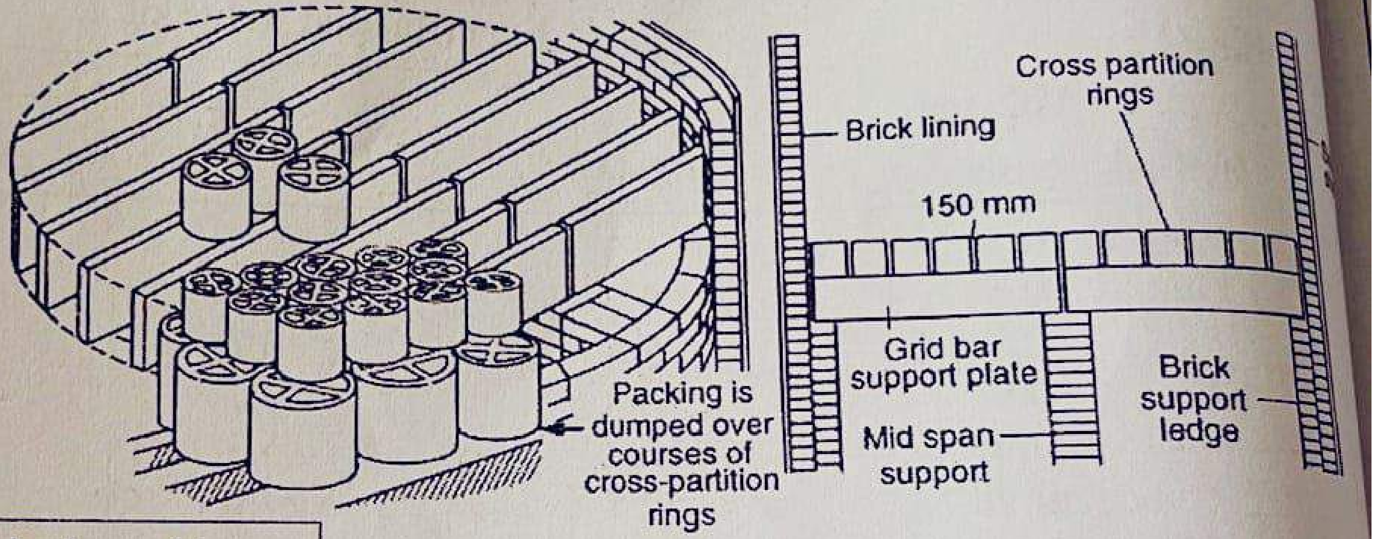
Voidage e	Experimental value of K''		
	BRINKMAN(3)	DAVIES(21)	Silk fibres LORD(20)
0.5	5.5		
0.6	4.3		
0.8	5.4	6.7	5.35
0.9	8.8	9.7	6.8
0.95	15.2	15.3	9.2
0.98	32.8	27.6	15.3

Packed Columns

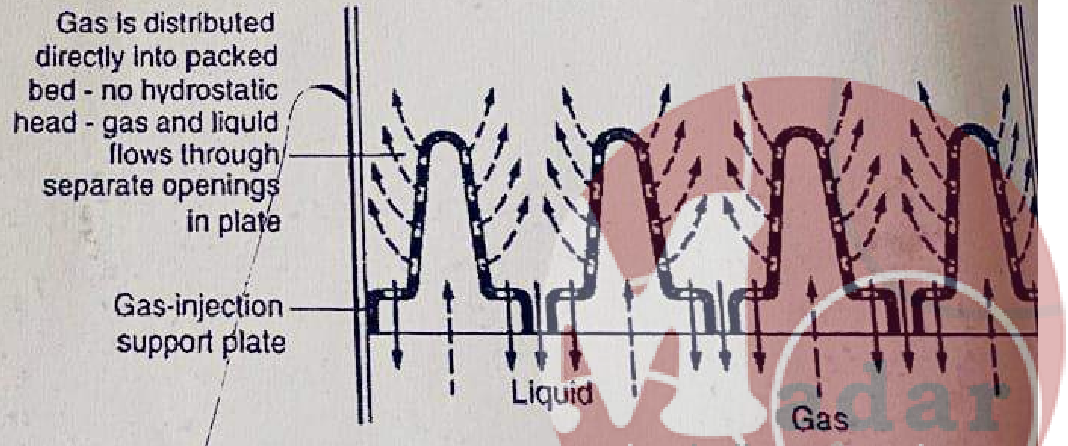
- Packed columns consist of shaped particles contained within a column, their behavior will in many ways be similar to that of packed beds which have already been considered.
- Packed towers are used for bringing two phases in contact with one another and there will be strong interaction between the fluids.
- Normally one of the fluids (liquid) will preferentially wet the packing and will flow as a film over its surface; the second fluid (gas) then passes through the remaining volume of the column.
- An example of the liquid–gas system is an absorption process where a soluble gas is scrubbed from a mixture of gases by means of a liquid.
- In the construction of packed towers, the shell of the column may be constructed from metal, ceramics, glass, or plastics material. The column should be mounted truly vertically to help uniform liquid distribution.



- The bed of packing rests on a support plate which should be designed to have at least 75 % free area for the passage of the gas so as to offer as low a resistance as possible.



The gas injection plate is designed to provide separate passageways for gas and liquid so that they need not vie for passage through the same opening. This is achieved by providing the gas inlets to the bed at a point above the level at which liquid leaves the bed.



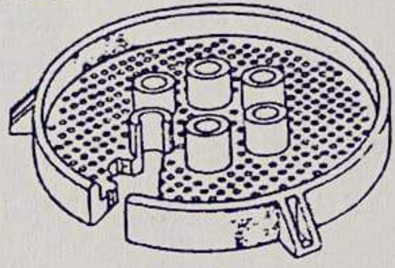
Types of liquid distributor

- At the top of the packed bed a liquid distributor of suitable design provides for the uniform irrigation of the packing

✓ A "hold-down" plate is often placed at the top of a packed column to minimize movement and breakage of the packing caused by surges (sudden increase) in flowrates.

✓ The gas inlet should also be designed for uniform flow over the cross-section and the gas exit should be separate from the liquid inlet

➢ Columns for both absorption and distillation vary in diameter from about 25 mm for small laboratory purposes to over 4.5 m for large industrial operations; these industrial columns may be 30 m or more in height.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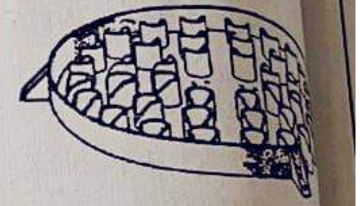
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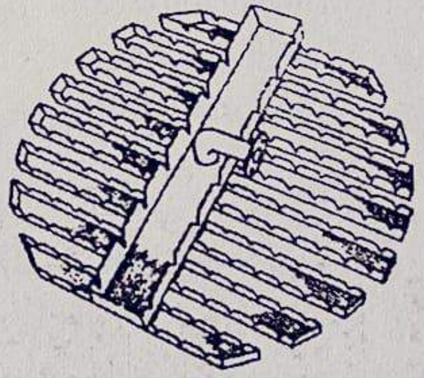
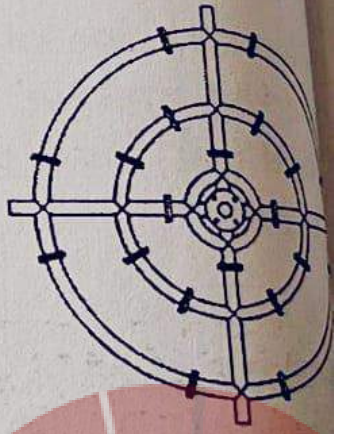
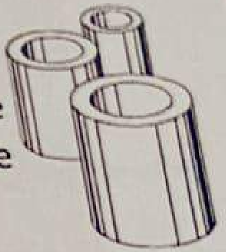

(c)


(d)

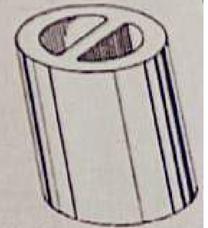
Packing

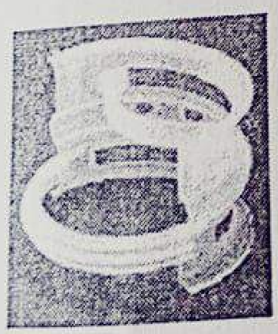
(Read through R&C page 216 - 221)

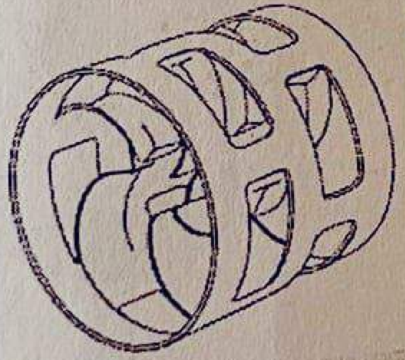
- Packings can be divided into four main classes—broken solids, shaped packings, grids, and structured packings.
- Most of these packings are available in a wide range of materials such as ceramics, metals, glass, plastics, carbon, and sometimes rubber.
- Non-porous solid should be used if there is any risk of crystal formation in the pores when the packing dries, as this can give rise to serious damage to the packing elements.

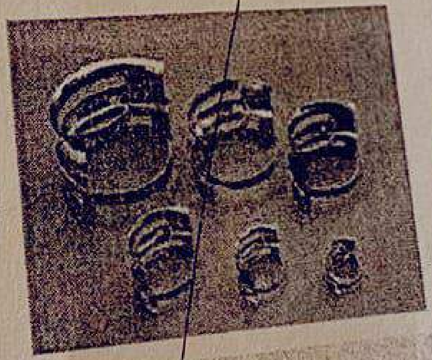


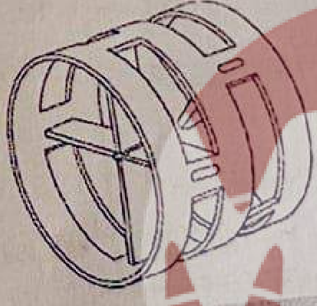
- Channeling, that is non-uniform distribution of liquid across the column cross-section, is much less marked with shaped packings, and their resistance to flow is much less.
- Shaped packings also give a more effective surface per unit volume because surface contacts are reduced to a minimum and the film flow is much improved compared with broken solids.









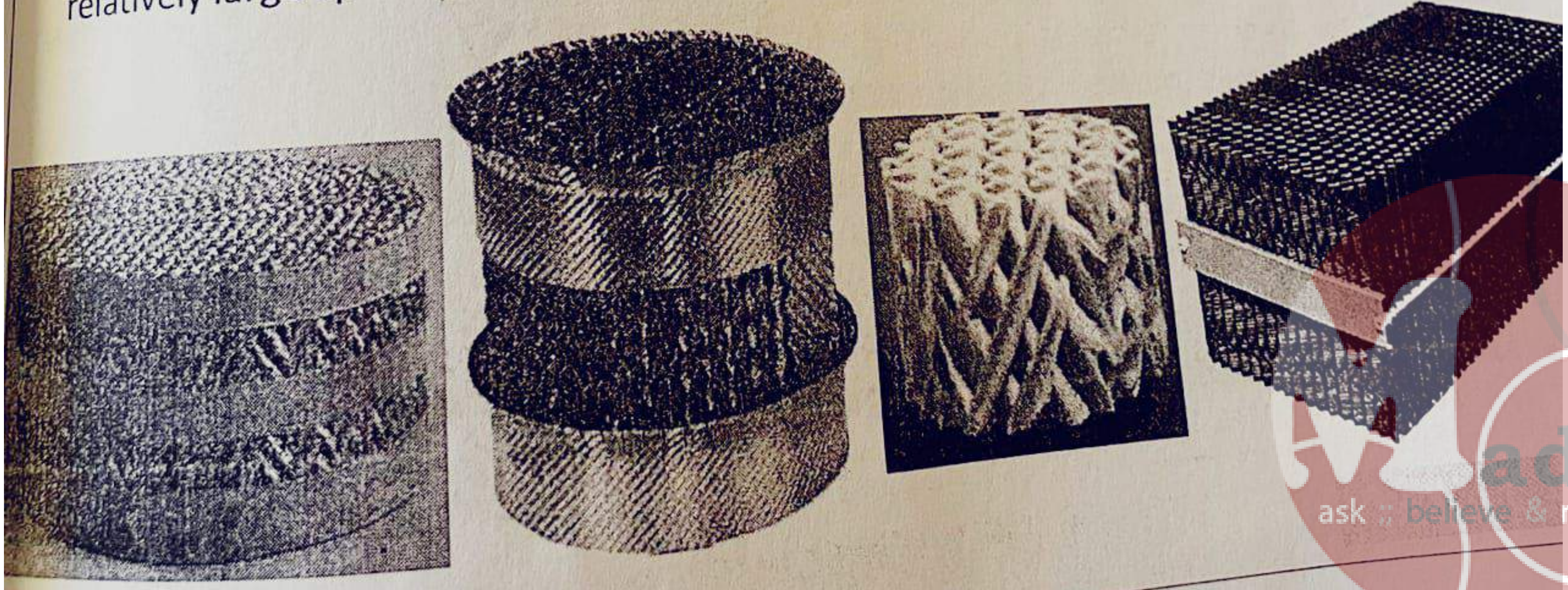


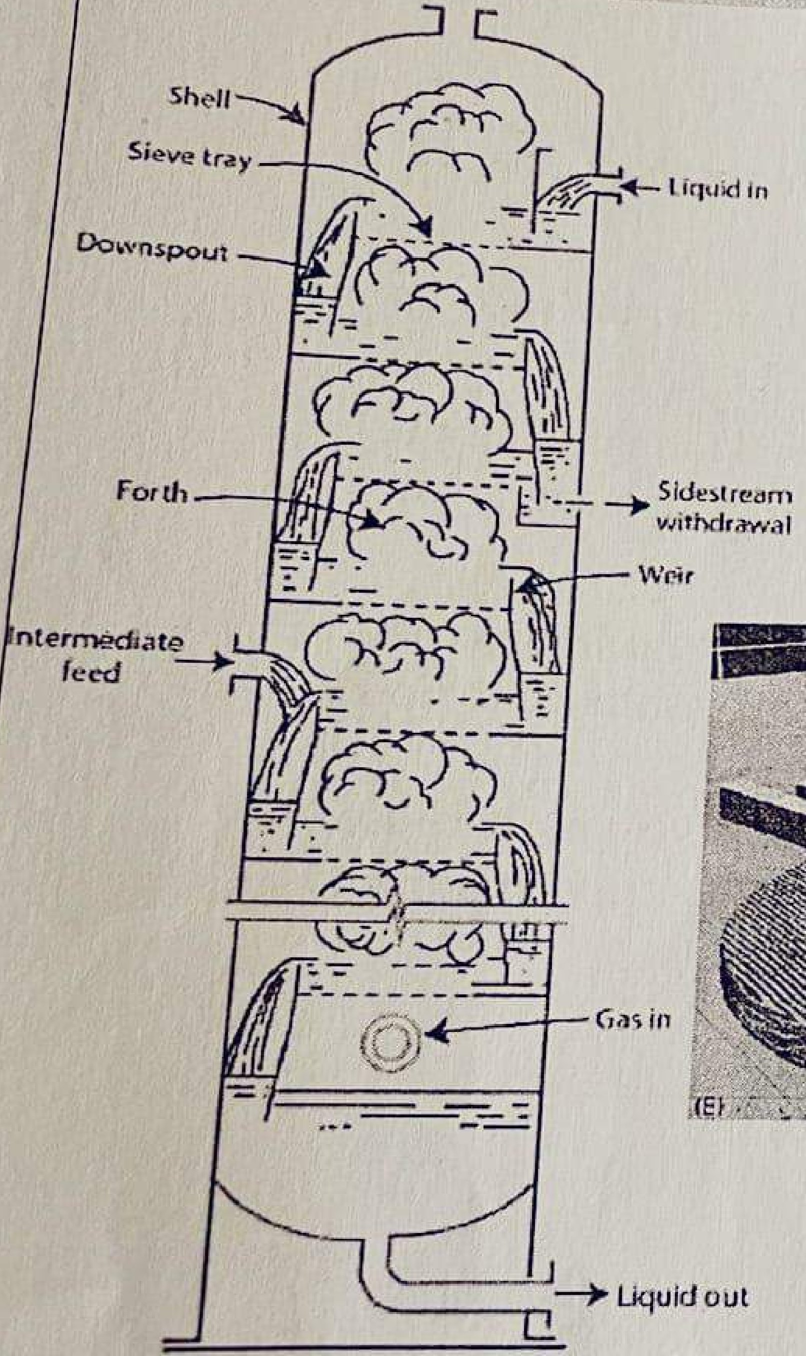
Packing

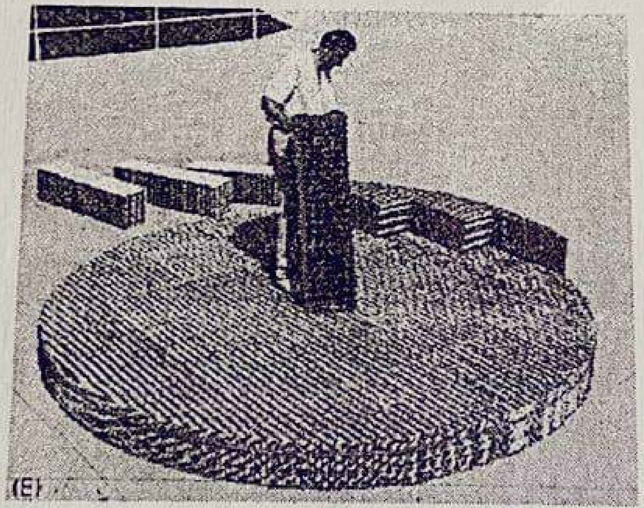
Table 4.3. Design data for various packings

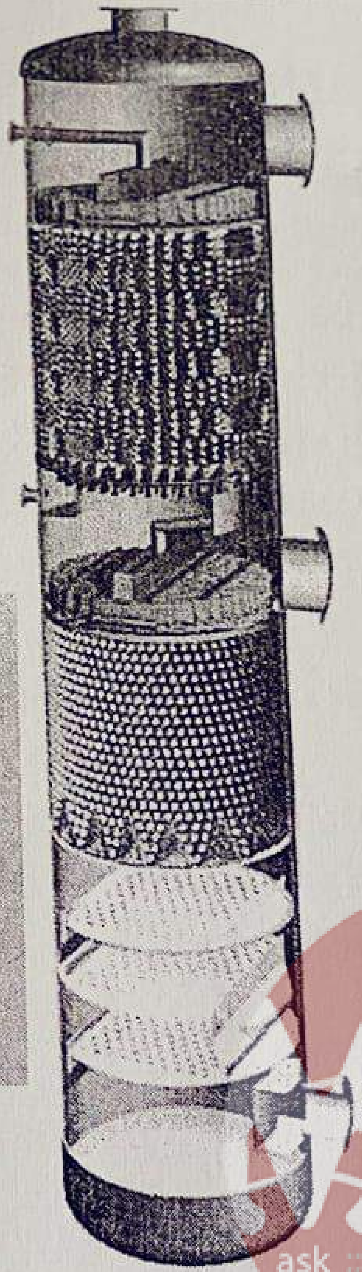
S

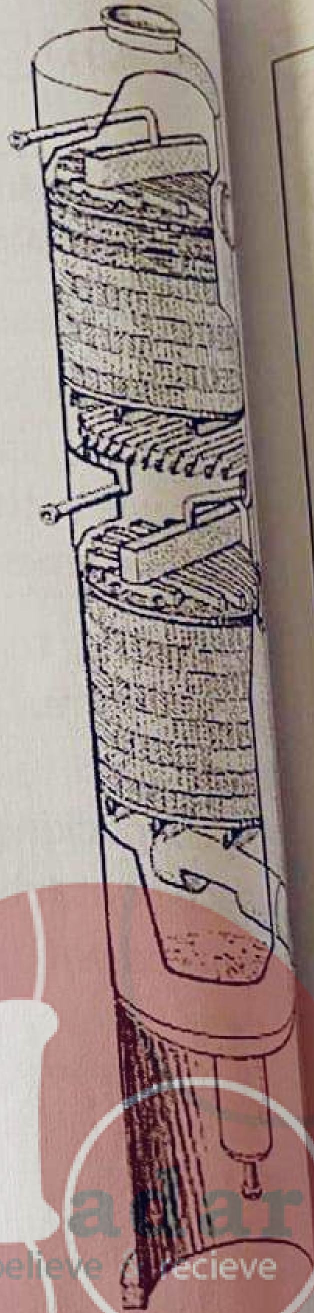
- The voidage obtainable with these packings varies from about 0.45 to 0.95
- To obtain high and uniform voidage and to prevent breakage, it is often found better to dump the packings into a tower full of liquid.
- Grid packings, which are relatively easy to fabricate, are usually used in columns of square section, and frequently in cooling towers.
- They may be made from wood, plastics, carbon, or ceramic materials, and, because of the relatively large spaces between the individual grids, they give low pressure drops.




Shell
Sieve tray
Liquid in
Downspout
Forth
Sidestream withdrawal
Weir
Intermediate feed
Gas in
Liquid out


(E)

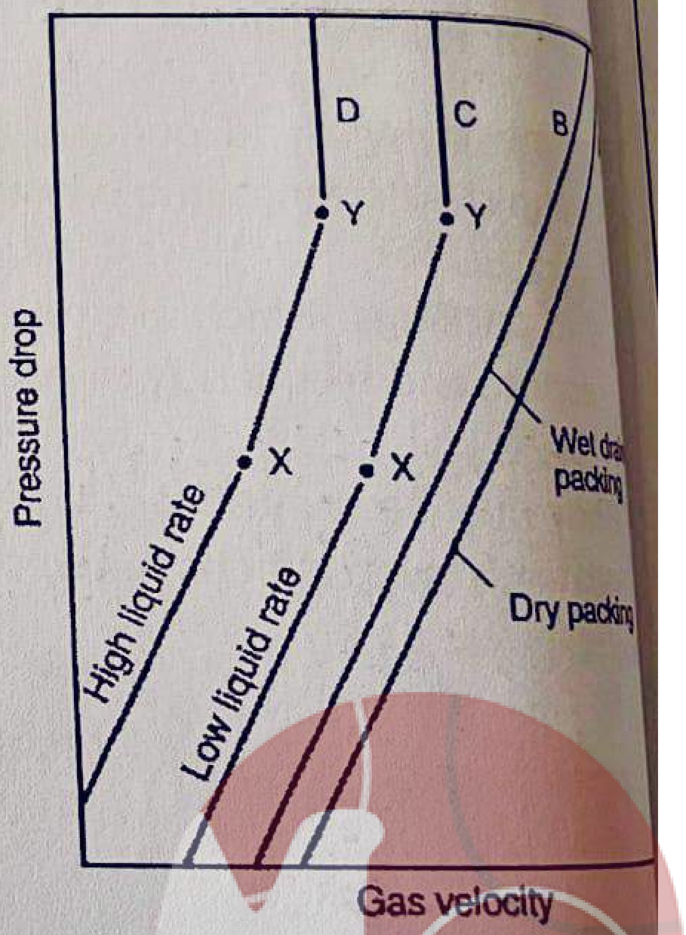




Fluid flow in packed columns

Pressure drop

- The drop in pressure arising from the flow of a single phase through granular beds is considered and the same general form of approach is usefully adopted for the flow of two fluids through packed columns.



Loading (X) and flooding (Y) points

Hold-up

Read through R&C pages 222-228