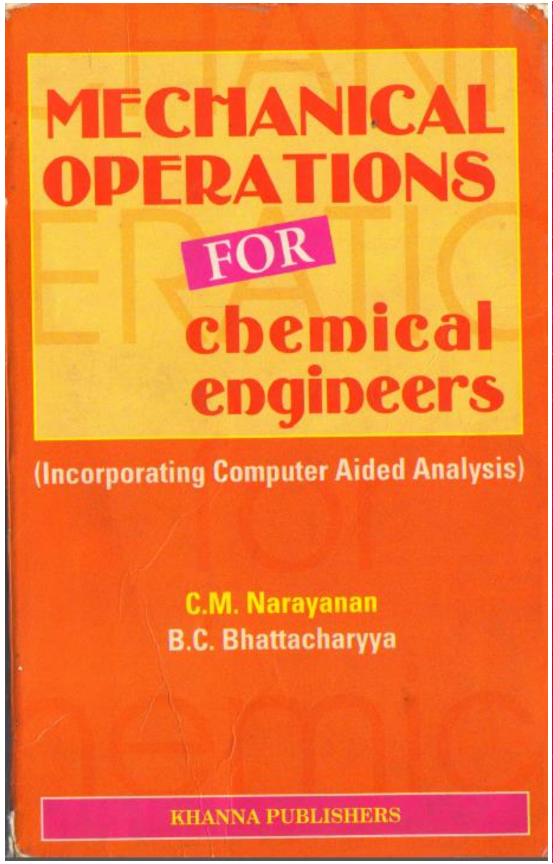
Course Distribution

- Particulate solid handling and their properties
  - Particle characterization (defining a particle/distribution)
    - Particle size and shape
    - Particle size investigation
      - Size measurement of fine particles
        - Defining a fine particles
        - Measurement
      - Sieving
    - Industrial screening equipment
  - Size Reduction
    - Primary/Coarse size reduction
    - Intermediate size reduction
    - Fine size reduction
  - Separation
    - Classification
    - Solid-Liquid separation
      - Dynamics of particle in liquid medium
      - Sedimentation
      - Flotation
    - Solid-Gas separation
      - Dynamics of particle in gas medium
      - Miscellaneous methods
      - Fluidization
  - Storage, Handling and Transport of Solids
    - Storage of solids
    - Transport of solids


SIEVING

Books


MECHANICAL OPERATIONS
FOR
chemical engineers
(Incorporating Computer Aided Analysis)
C.M. Narayanan
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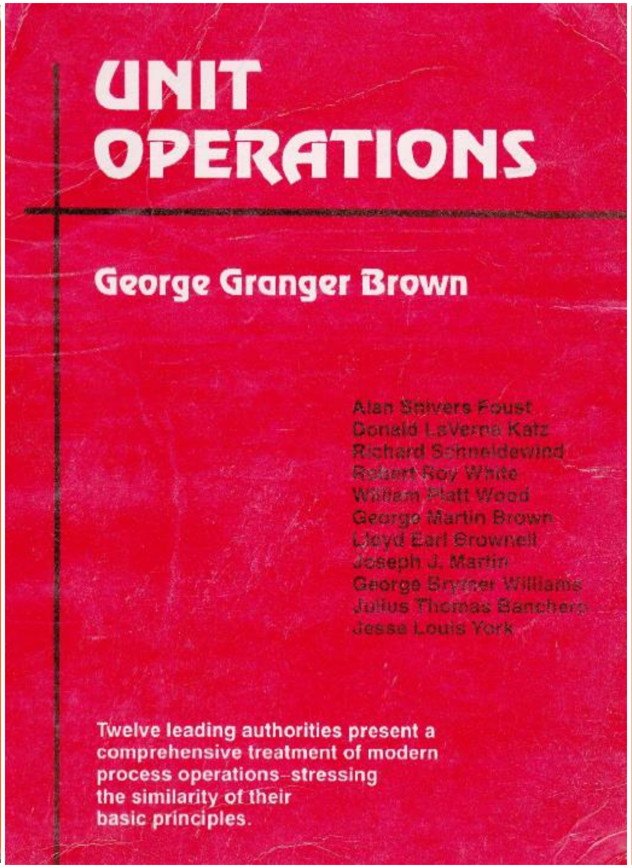
KHANNA PUBLISHERS


UNIT OPERATIONS
George Granger Brown
Alan Shivers Foust
Donald LaVerne Katz
Richard Schneidewind
Robert Roy White
William Platt Wood
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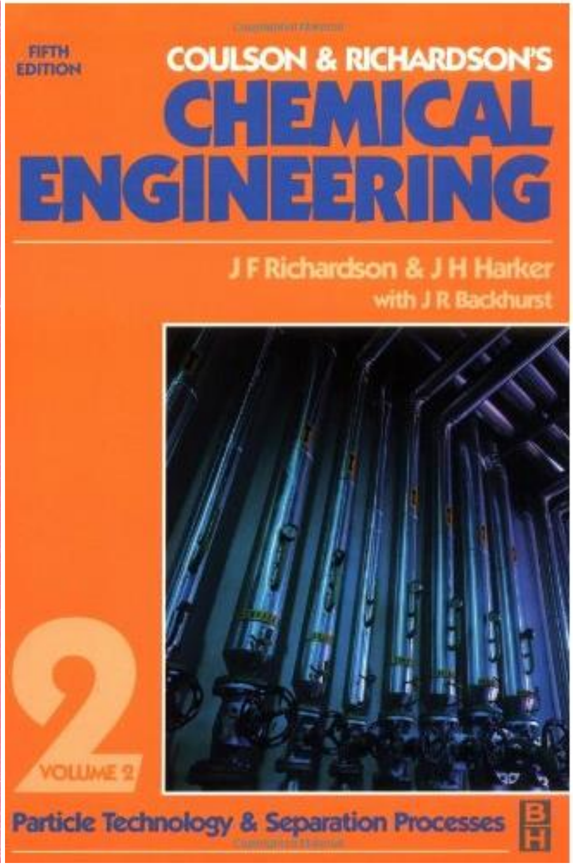
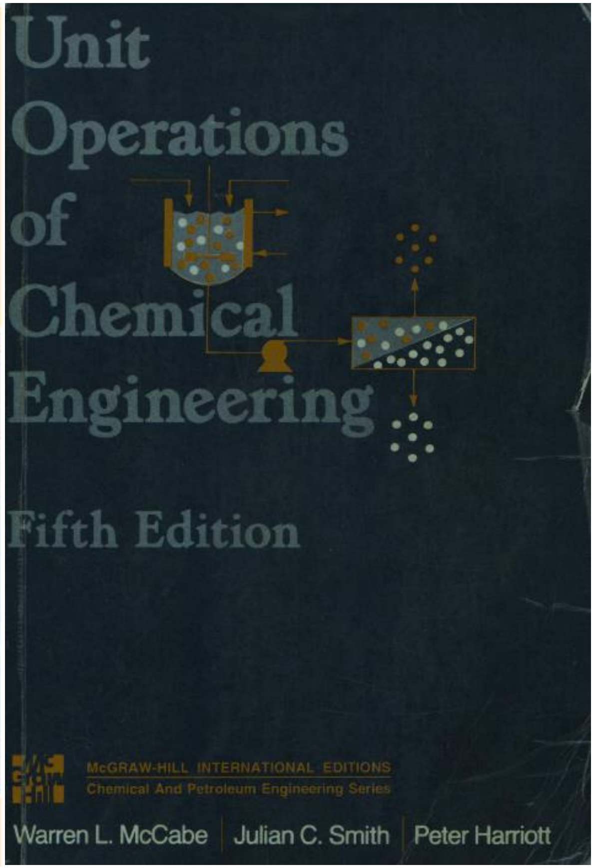
Lloyd Earl Brownell
Joseph J. Martin
George Brymer Williams
Julius Thomas Banchero
Jesse Louis York
Twelve leading authorities present a comprehensive treatment of modern process operations–stressing the similarity of their basic principles.


FIFTH EDITION
COULSON & RICHARDSON'S
CHEMICAL ENGINEERING
J F Richardson & J H Harker
with J R Backhurst
2
VOLUME 2
Particle Technology & Separation Processes
B H


Unit Operations of Chemical Engineering
Fifth Edition
McGRAW-HILL INTERNATIONAL EDITIONS
Chemical And Petroleum Engineering Series
Warren L. McCabe
Julian C. Smith
Peter Harriott

MEASUREMENT OF PARTICLES AND SIEVE ANALYSIS

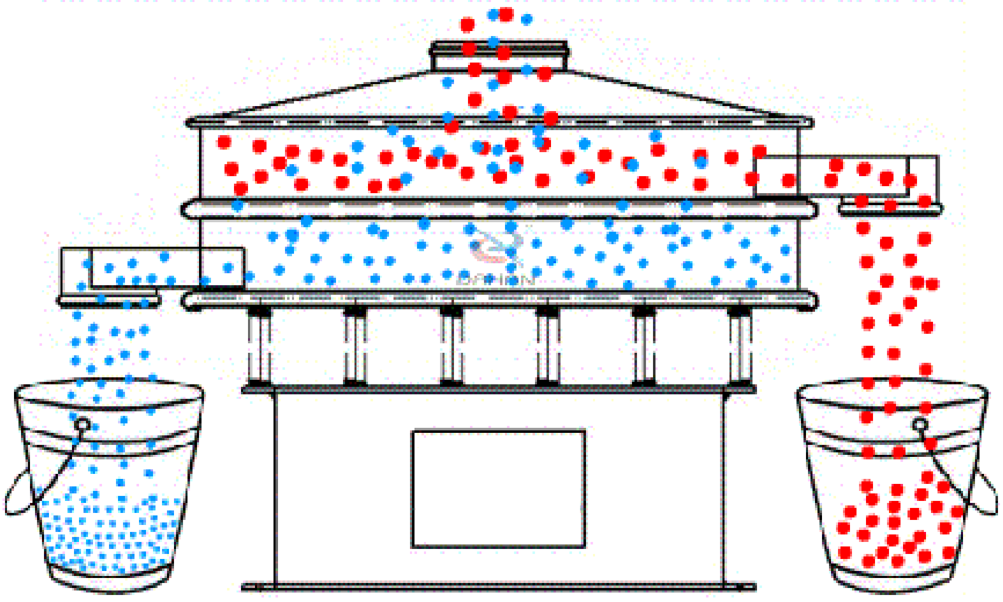
What is the difference between sieve and industrial screen?

- The difference between them is that screening is a continuous operation while sieving is a batch action.

- Sieve wire is usually of small diameter whereas a screen will have relatively large wire thickness.

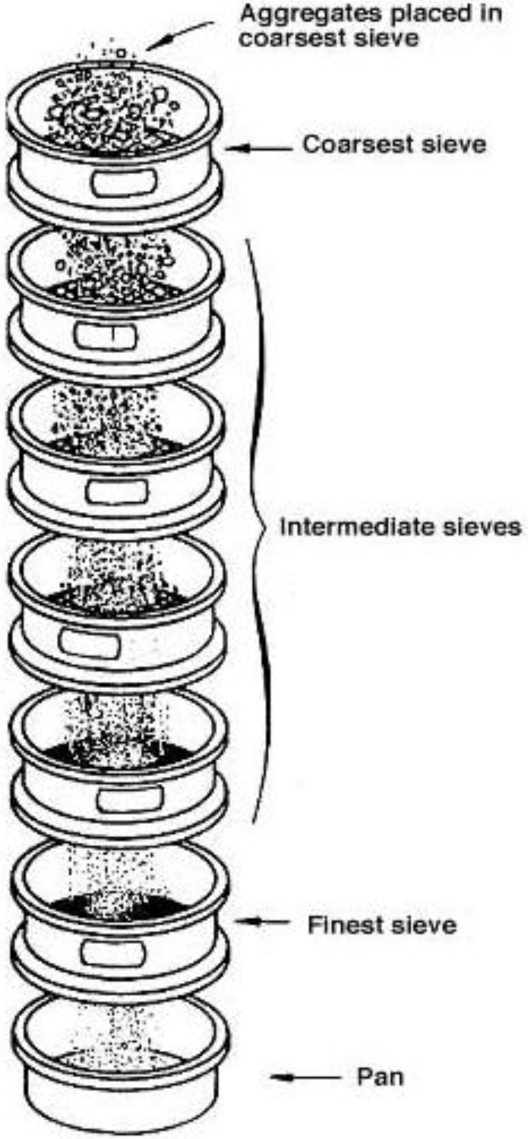
- Sieves are used for light duty fine separations and screens are used for heavy duty and last longer

Industrial screens



Industrial vibrating screens

Sieves



Aggregates placed in coarsest sieve
Coarsest sieve
Intermediate sieves
Finest sieve
Pan

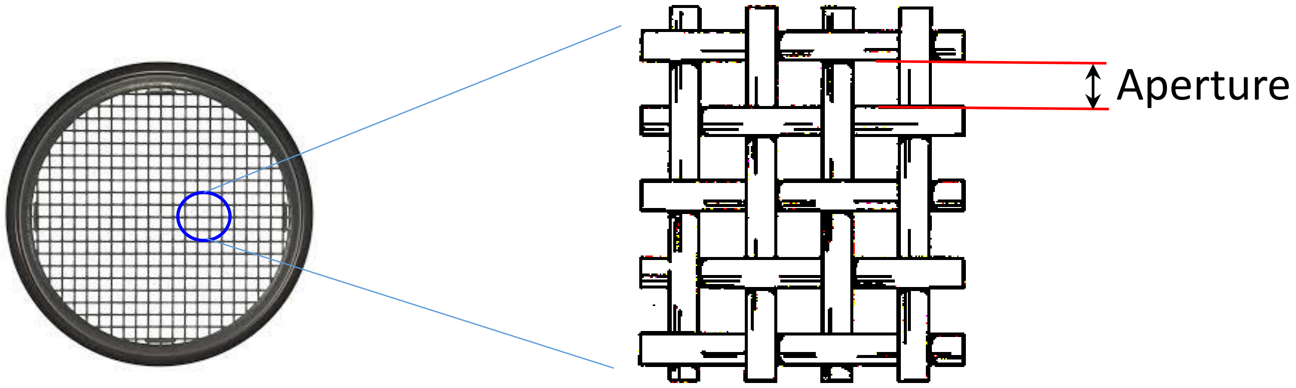
- Undoubtedly, the easiest and most rapid method for obtaining the particle size analysis is by sieving.
- Restricted to powders having the greater proportion coarser than 40 microns.
- For fine powders the method is not generally used because of the high cost of producing sieves.

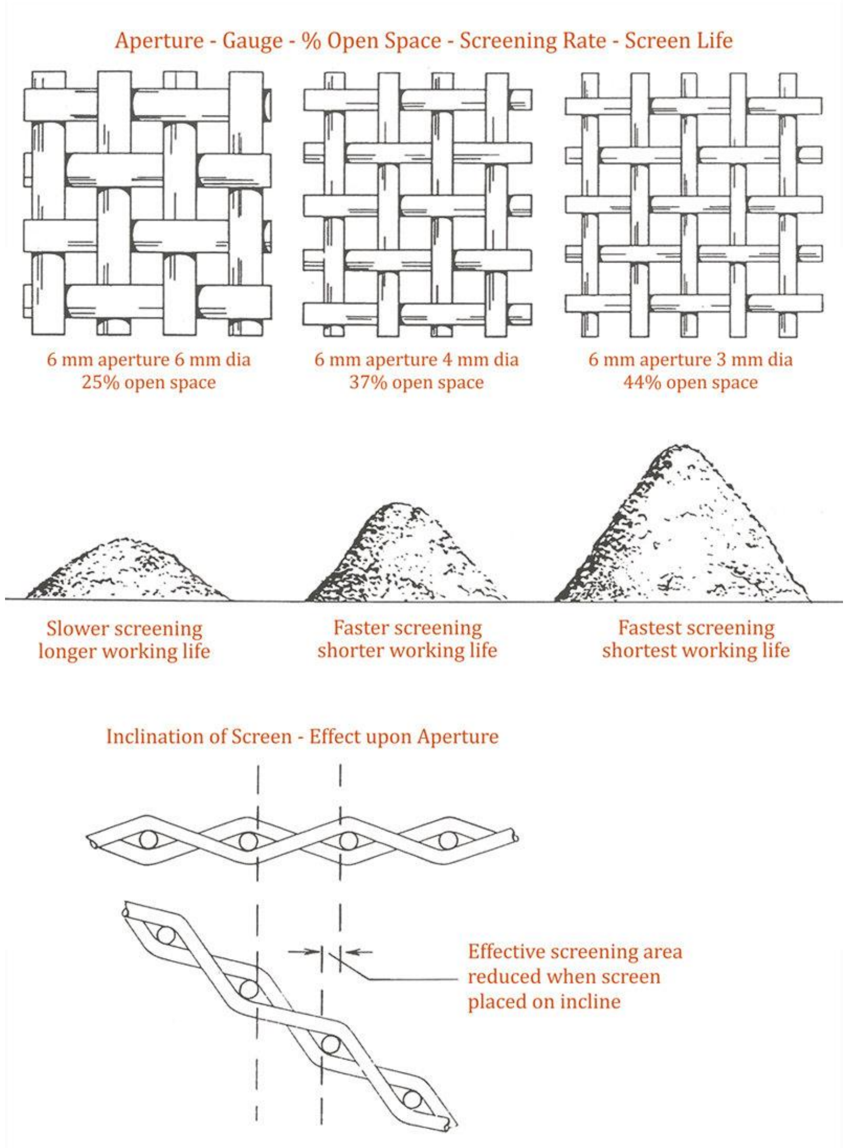
Types of sieves: A variety of sieve aperture ranges are currently being used, the most popular being the

- German Standard DIN 1171 (1934)
- American standard (ASTM standard E 11-61, American Tyler Series)
- French Series AFNOR
- Russian standard Gost 35821-50,
- Institute of Mines and Metallurgy standard and the British standard (BSS).
- Indian standerd screens (ISS)

Aperture:

The size of the square opening (the space between the individual wires) is called the aperture size of the screen.





Mesh Number:

- For (German, American and British standard)
  - Indicates the number of apertures per linear lengh.

    Example: A screen having 10 squre opening per inch may be called 10 mesh screen
- For Indian standard screen (ISS)
  - The mesh number is equal to its aperture size expressed to the nearesd deca-micron (0.01 mm)

    Example: A screen number 50 will have approximately 500 microns aperture width.

Standard screen interval

- The area of opening of any one screen in the series is exactly twice that of the opening in the next smaller screen
- Sometimes intermediate screens with interval $(2)^{\frac{1}{4}}$ is also used.

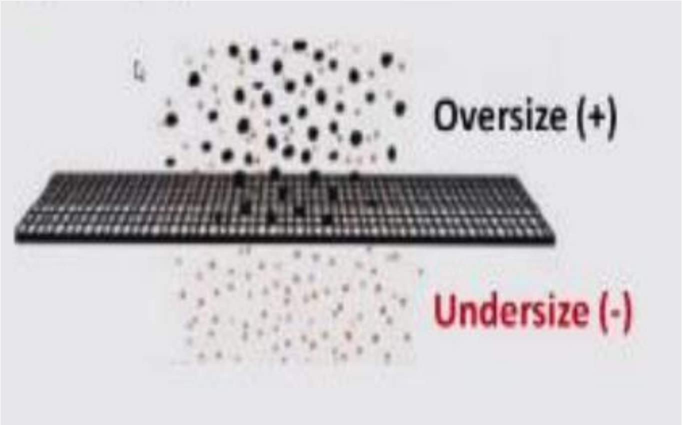
Material:

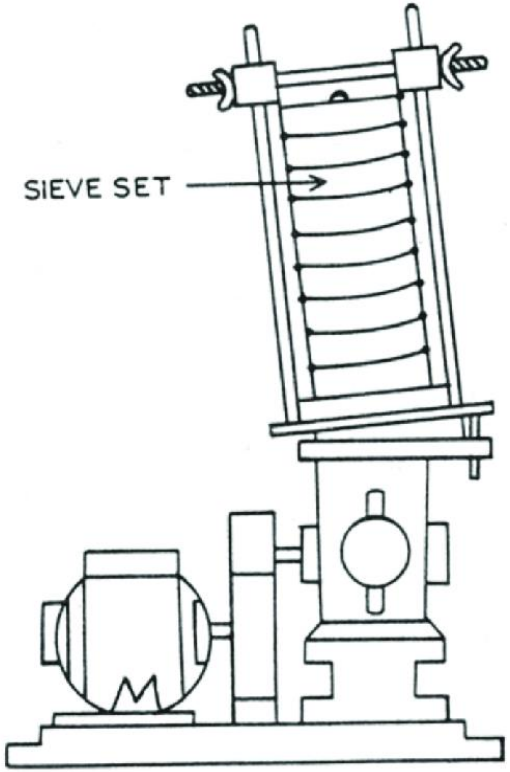
Usually made of phosphor bronze wires. Brass or mild steel wires are used sometimes.

Indian Standard Test Sieves

Sieve Designation Number	Sieve Opening or Width of Aperture		Permissible Variation in Width of Aperture: Average opening		Permissible Variation in Width of Aperture: Maximum opening		Wire Diameter			Equivalent Mesh Number of Other Standard Screens		
	mm	*inch*	*Microns*	*Percent*	*Microns*	*Percent*	*mm*	*inch*	*SWG*	*ASTM*	*BSS*	*Tyler*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
570	5.660	0.2230	± 170	± 3.0	+ 566	+ 10	2.184	0.086	13.5	3.5	—	3.5
480	4.760	0.1870	± 143	± 3.0	+ 476	+ 10	2.032	0.080	14	4	3/16"	4
400	4.000	0.1570	± 120	± 3.0	+ 400	+ 10	1.829	0.072	15	5	—	5
340	3.353	0.1320	± 108	± 3.2	+ 370	+ 11	1.727	0.068	15.5	6	5	6
320	3.180	0.1252	± 102	± 3.2	+ 350	+ 11	1.829	0.072	15	—	1/8"	—
280	2.818	0.1109	± 97	± 3.4	+ 309	+ 11	1.422	0.056	17	7	6	7
240	2.399	0.0945	± 91	± 3.8	+ 263	+ 11	1.219	0.048	18	8	7	8
200	2.032	0.0800	± 93	± 4.6	+ 244	+ 12	1.118	0.044	18.5	10	8	9
170	1.676	0.0659	± 55	± 3.3	+ 201	+ 12	0.864	0.034	20.5	12	10	—
160	1.600	0.0630	± 54	± 3.4	+ 192	+ 12	0.965	0.038	19.5	—	1/16"	10
140	1.405	0.0553	± 48	± 3.4	+ 168	+ 12	0.711	0.028	22	14	12	12
120	1.201	0.0473	± 46	± 3.8	+ 156	+ 13	0.610	0.024	23	16	14	14
100	1.000	0.0394	± 50	± 5.0	+ 150	+ 15	0.584	0.023	23.5	18	16	16
85	0.842	0.0332	± 44	± 5.2	+ 126	+ 15	0.559	0.022	24	20	18	20
80	0.790	0.0311	± 38	± 4.8	+ 111	+ 14	0.533	0.021	24.5	—	1/32"	—
70	0.708	0.0279	± 38	± 5.4	+ 106	+ 15	0.457	0.018	26	25	22	24

- A set of standard screens is arranged serially in a stack, with the smallest mesh at the bottom and largest at the top. An analysis is conducted by placing the sample on the top screen and shaking the stack mechanically for a definite period.
- The particles retained on each screen are removed and weighed, and masses of the individual screen increments are converted to mass fraction or mass percentage of the total sample. Any particles that pass the finest screen are caught in a pan at the bottom of the stack.
- **The materials that passes through the screen is called the minus (-) material or undersize and the material that is retained on the screen is called the plus (+) material or the oversize. It is designated as (-42+48) or (42/48) in Tyler series.**
- **The average size of the particles in a specific fraction will be the arithmetic average of the aperture size of the screens involved.**





Schematic showing a sieve set and mechanical shaking

Sieve Analysis

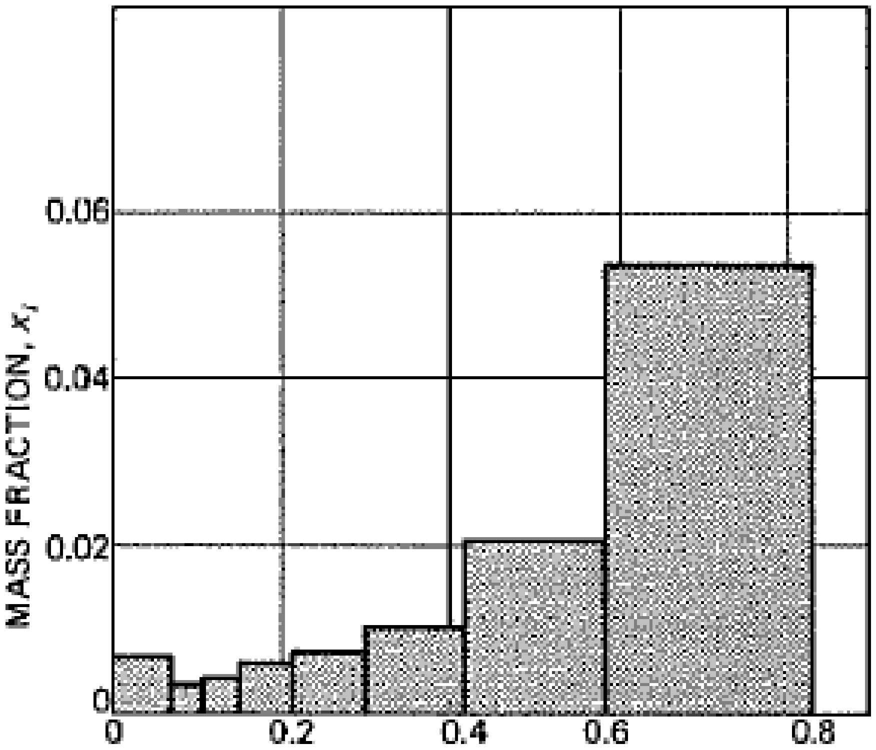
- **Differencial Analysis**
  - The results of a screen analysis are tabulated to show the mass fraction of each screen increment as a function of the mesh size range of the increment.
  - Since the particles on any one screen are passed by the screen immediately ahead of it, two numbers are needed to 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 notation 14/20 means, through 14 mesh and on 20 mesh. An analysis tabulated in this manner is called a *"differential analysis"*. A typical differential analysis is shown in table below.

- **Cumulative Analysis**
  - The second type of screen analysis is the cumulative analysis. A cumulative analysis is obtained from a differential analysis by adding cumulatively, the individual differential increments, starting with that retained on the largest mesh and tabulating or plotting the cumulative sums against the mesh dimensions of the retaining screen of the last to be added.
  - The cumulative analysis is a relation between Φ and D_{p_i}, where D_{p_i} is the mesh size of screen i. the quantity Φ is the mass fraction of the sample that consists of particles smaller than D_{p_i}. The value of Φ for the entire sample is, of course, unity.

$$\Phi = x_1 + x_2 + \ldots\ldots + x_n = \sum x_i \qquad \ldots..(10)$$

Differential Screen Analysis

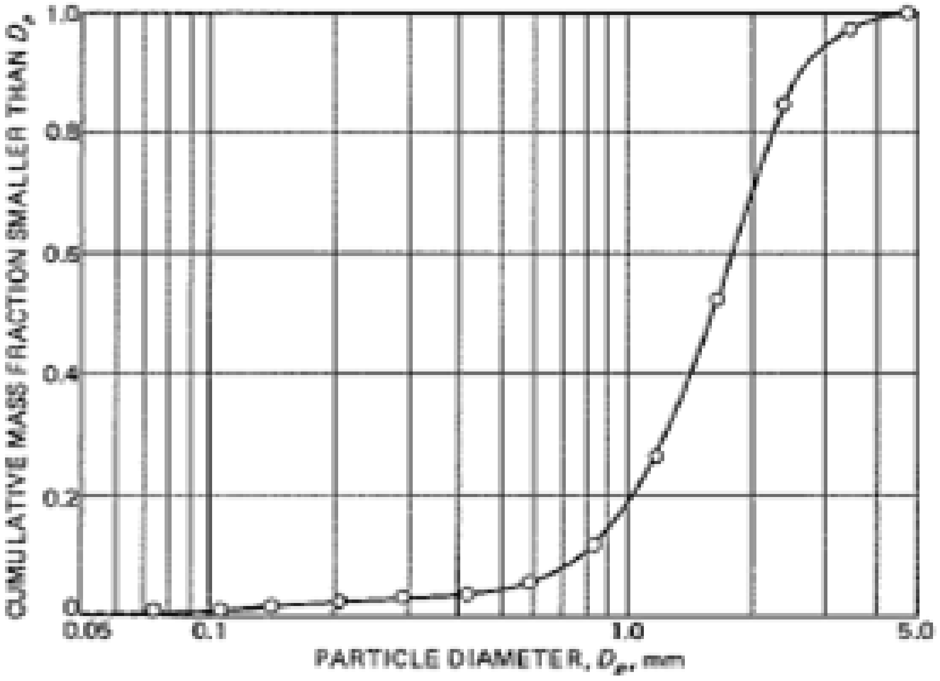
Mesh	Screen Opening D_{pi}, mm	Mass Fraction Retained, x_i,	Average Particle Diameter in Increment, $\bar{D}_{pi}$, mm
4	4.699	0.0000	–
6	3.327	0.0251	4.013
8	2.362	0.1250	2.85
10	1.651	0.3207	2.007
14	1.168	0.2570	1.409
20	0.833	0.1590	1.001
28	0.589	0.0538	0.711
35	0.417	0.0210	0.503
48	0.295	0.0102	0.356
65	0.208	0.0077	0.252
100	0.147	0.0058	0.178
150	0.104	0.0041	0.126
200	0.074	0.0031	0.089
Pan	–	0.0075	0.037



Differential Screen Analysis, direct plot from Table 28.2, McCabe Smith

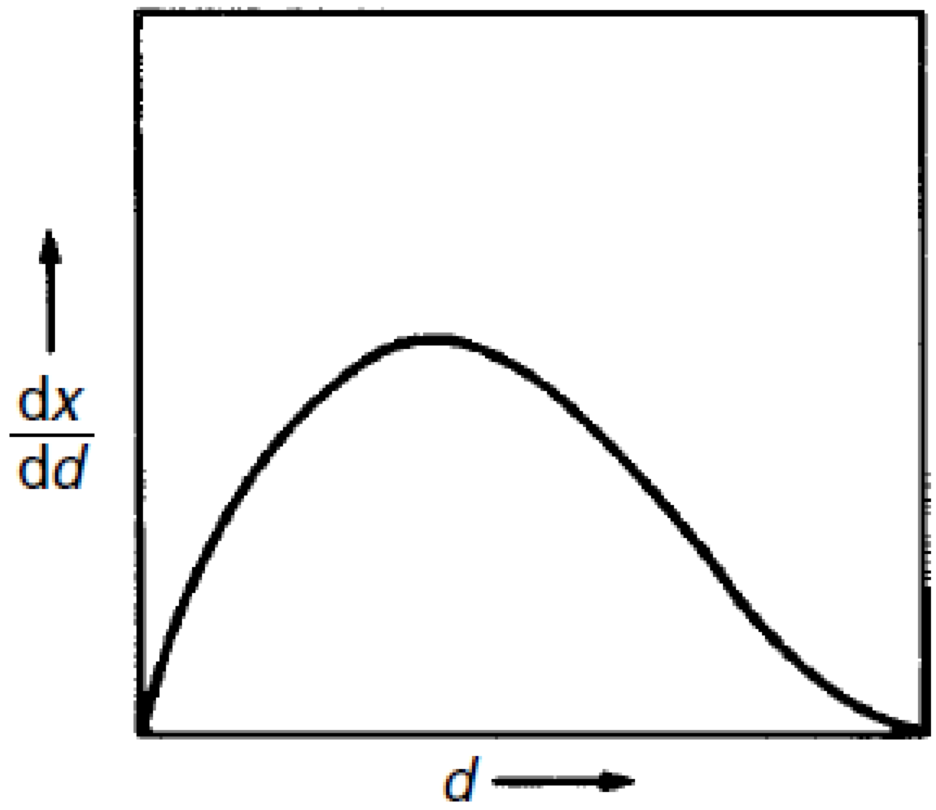
Cumulative Screen Analysis

Mesh	Screen Opening D_{pi}, mm	Mass Fraction Retained, x_i,	Average Particle Diameter in Increment, $\bar{D}_{pi}$, mm	Cumulative fraction smaller than D_{pi}, Φ_i
4	4.699	0.0000	–	1.0000
6	3.327	0.0251	4.013	0.9749
8	2.362	0.1250	2.85	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



Size frequency curve

- The most frequently occurring size is 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.



- The mentioned size distribution is incomplete as the size distribution of the particles below 0.074 mm is not known.

- For estimating the size distribution of such a small particle we can use **Gaudin-Schumann size distribution law**.

According to this law, for very fine particles, a log-log plot of mass fraction x versus average particle (D_{pi} *or* d_{avg}) size shall give a straight line

$$\ln(x) = m\ln(d_{avg}) + \ln B \qquad \text{.....(11)}$$

Where, *m* and B are constant

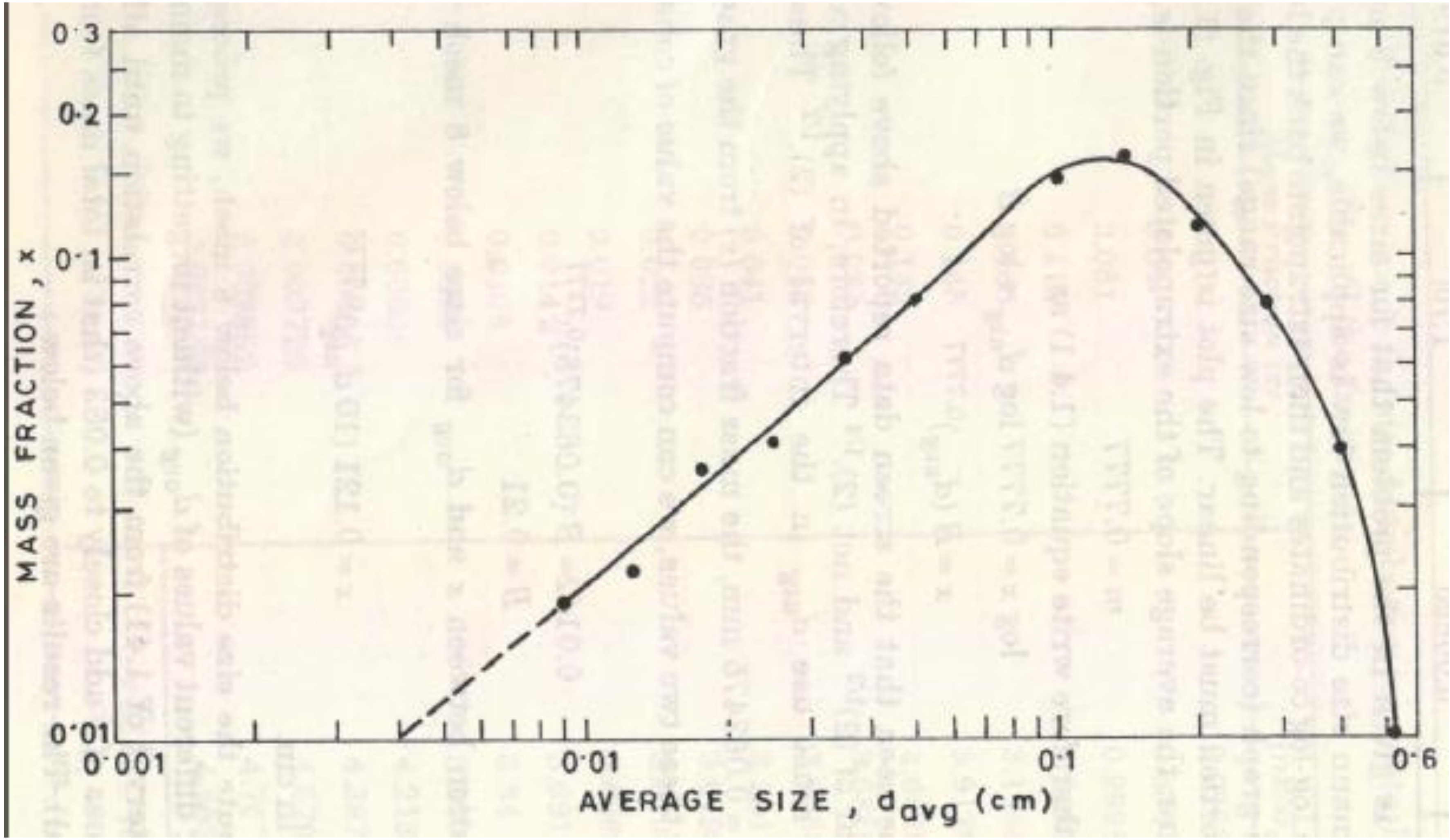
N.B: d_{avg} is the screen size of the particles with screen interval of $(2)^{\frac{1}{4}}$. It is therefore essential that while applying the above equation the values of d_{avg} must confirm to the screen interval employed for the test screens.

Problem 1

Estimate the specific surface and sauter diameter of a sample of galena (specific gravity = 7.43) having the screen analysis below :

Mesh	*Mass fraction*
– 570 + 480	0.01
– 480 + 340	0.04
– 340 + 240	0.081
– 240 + 160	0.115
– 160 + 120	0.160
– 120 + 85	0.148
– 85 + 60	0.132
– 60 + 40	0.081
– 40 + 30	0.062
– 30 + 20	0.041
– 20 + 15	0.036
– 15 + 10	0.022
– 10 + 8	0.019
– 8	0.053

Assume Gaudin-Schumann distribution is valid for sizes below 8 mesh.



Log-log plot of mass fraction vs average particle size

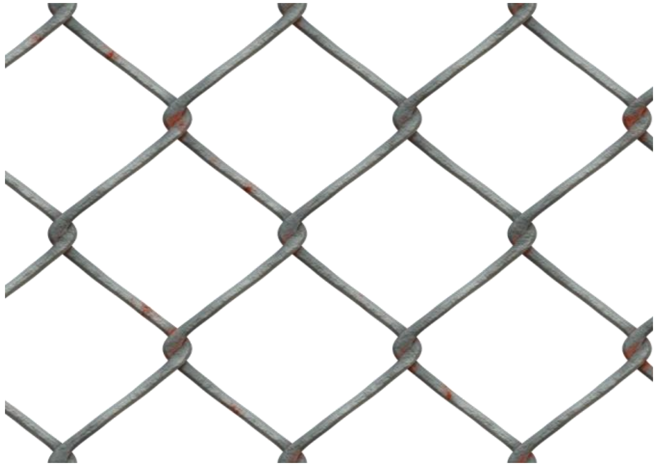
Sieve set

Sieving errors: The possibility for a particle to pass through an aperture depends on the following factors :

1) The particles size distribution of the powder
2) The number of particles on the sieve
3) The physical properties of the particle like surface area, specific gravity *etc.*
4) The method of shaking the sieves
5) The dimensions and shape of the particles
6) Geometry of the sieving surface i.e. open area / Total area

The **sieve distribution** given by sieving operation depends also on the following variables:

1) Duration of sieving
2) Presence of “near mesh particles”
3) Variation of sieve aperture
4) Errors of observation and experiment
5) Errors of sampling
6) Effect of different equipment and operation



Enlarged view of mesh

Screen Effectiveness

- Screen effectiveness/efficiency mostly depends on two aspects

  1. Recovery of desired product (Represents the ability of the screen to separate all particles of the desired size)
  2. Rejection of Undesired material (Separated product must contain minimal amount of particles having sizes other than the desire size)

The general method of classifying screen effectiveness *(E_c)* is

$$E_c = (Recovery)(Rejection) \qquad .....(12)$$

$$Recovery = \frac{Desired\ material\ in\ the\ product}{Desired\ material\ in\ the\ feed} = \frac{Py_p}{Fy_F} \qquad .....(13)$$

Where, y_p and y_F are the mass fraction of the desired particle in the product and feed respectively

F is the feed rate (kg/s) and P is the product rate

$$\textbf{\textit{Rejection}} = \frac{\textbf{\textit{Undesired material in the reject}}}{\textbf{\textit{Undesired material in the feed}}} = \frac{R(1-y_R)}{F(1-y_F)} \qquad .....(14)$$

Substituting (13) and (14) in equation (12) we get

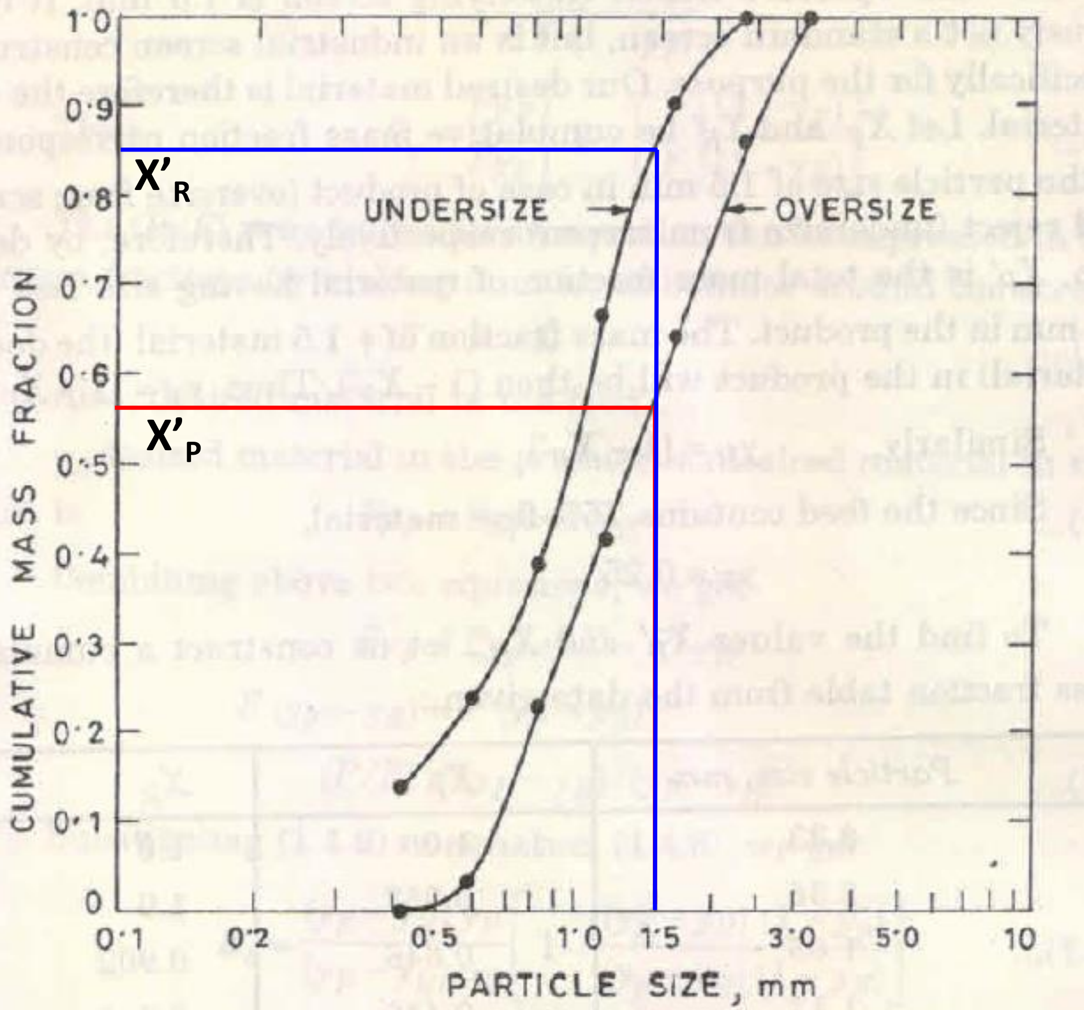
$$\boldsymbol{E_c} = \frac{(y_F - y_R)y_p}{(y_p - y_R)y_F}\left[1 - \frac{(y_F - y_R)(1-y_p)}{(y_p - y_R)(1-y_F)}\right] \qquad .....(15)$$

Problem 2:

Anthracite coal from a pulverization unit has been found to contain an excess of fine material (75% by weight). In order to remove these fines, it is screened using a 1.5 mm screen. Estimate the effectiveness of the screen from the following data :

	Mass fraction	
Particle size, mm	*Oversize from Screen*	*Undersize from Screen*
3.33	0.143	0.00
2.36	0.211	0.098
1.65	0.230	0.234
1.17	0.186	0.277
0.83	0.196	0.149
0.59	0.034	0.101
0.42	0.00	0.141

Particle size, mm	X_P	X_R
3.33	1.0	1.0
2.36	0.857	1.0
1.65	0.646	0.902
1.17	0.416	0.668
0.83	0.230	0.391
0.59	0.034	0.242
0.42	0.0	0.141



Plots of Cumulative Mass Fraction Versus Particle Size on Semi-log Coordinates.

Problem 3:

Table salt is being fed to a vibrating screen at the rate of 150 kg/hr. The desired product is – 30 + 20 mesh fraction. A 30 mesh and a 20 mesh screen are therefore used (double deck), the feed being introduced on the 30 mesh screen. During the operation, it was observed that the average proportion of oversize (from 30 mesh screen) : oversize (from 20 mesh screen) : undersize (from 20 mesh screen) is 2 : 1.5 : 1. Calculate the effectiveness of the screener from the following data :

Mesh	Mass fraction			
	Feed	Oversize from 30 Mesh Screen	Oversize from 20 Mesh Screen	Undersize from 20 Mesh Screen
– 85 + 60	0.097	0.197	0.026	0.0005
– 60 + 40	0.186	0.389	0.039	0.0009
– 40 + 30	0.258	0.337	0.322	0.0036
– 30 + 20	0.281	0.066	0.526	0.3490
– 20 + 15	0.091	0.005	0.061	0.2990
– 15 + 10	0.087	0.006	0.026	0.3470

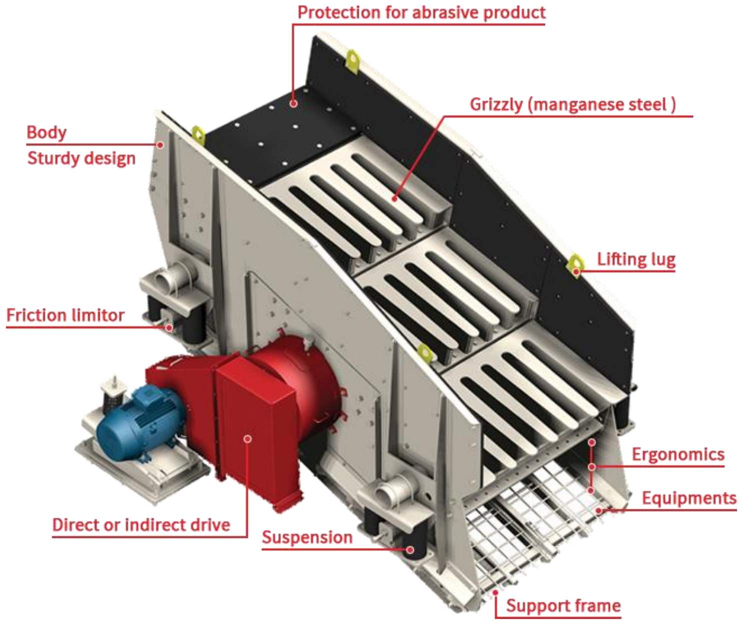
Problem 4:

A quartz mixture having the screen analysis shown in Table is screened through a standard 10-mesh screen. The cumulative screen analysis of overflow and underflow are given in Table . Calculate the mass ratios of the overflow and underflow to feed and the overall effectiveness of the screen.

		Cumulative fraction smaller than D_p		
Mesh	D_p, mm	Feed	Overflow	Underflow
4	4.699	0	0	
6	3.327	0.025	0.071	
8	2.362	0.15	0.43	0
10	1.651	0.47	0.85	0.195
14	1.168	0.73	0.97	0.58
20	0.833	0.885	0.99	0.83
28	0.589	0.94	1.00	0.91
35	0.417	0.96		0.94
65	0.208	0.98		0.975
Pan		1.00		1.00

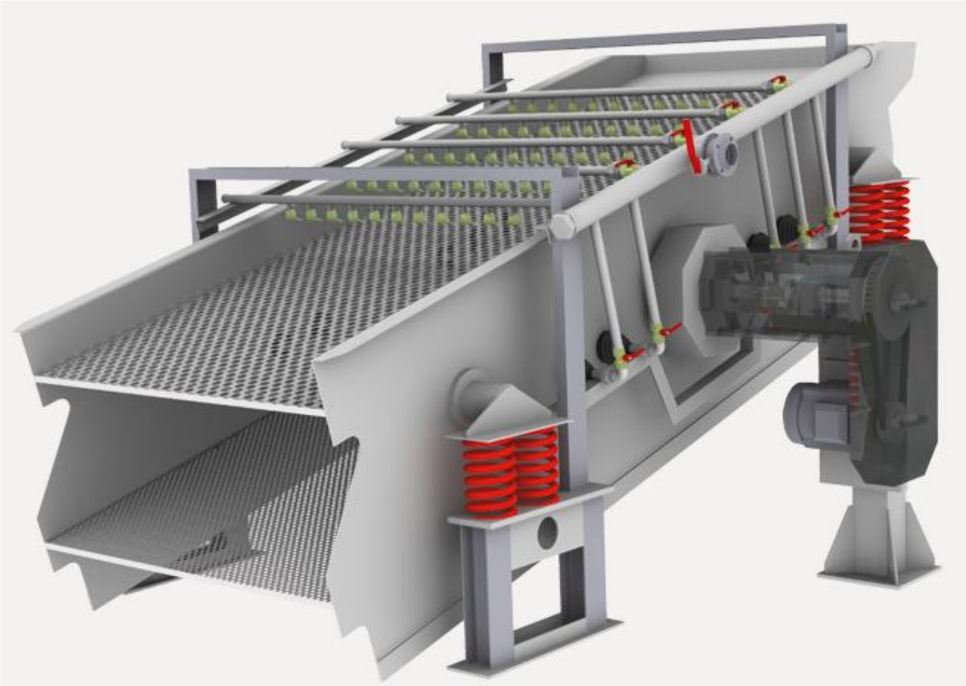
Industrial screening equipment

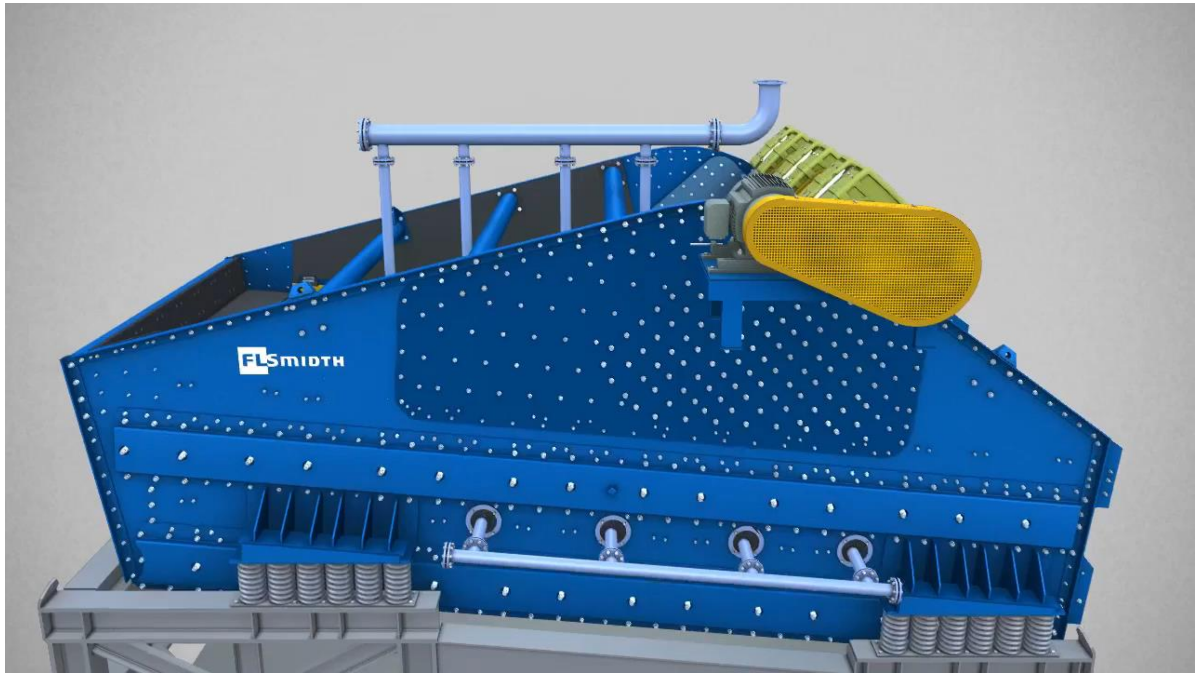
Grizzlies



Used to screen large sizes of rocks of 25mm and above

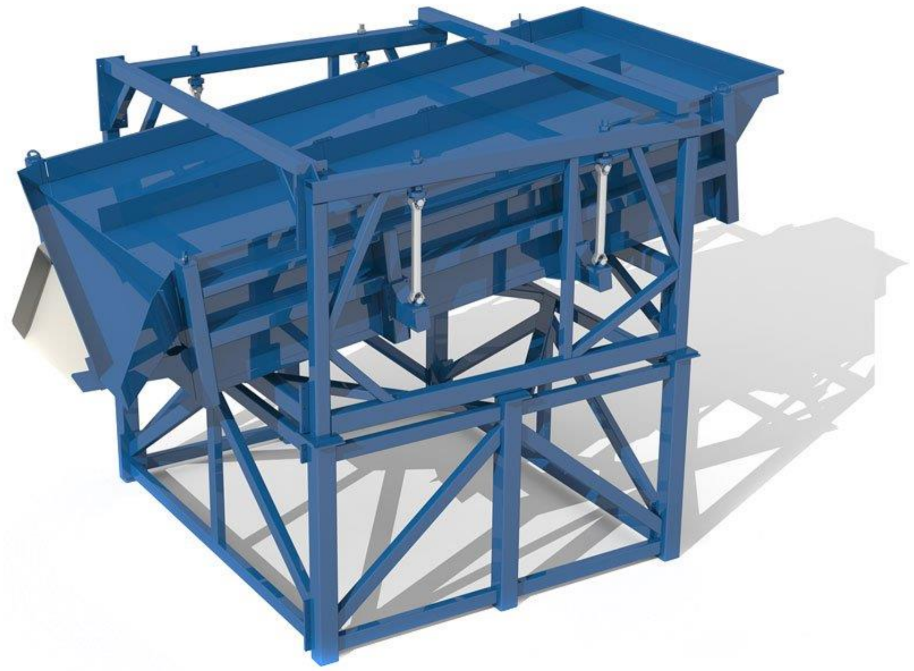
<u>Vibrating screens</u> (most popular)





- The frequency or speed of vibration can vary from 1500 to 7200 per minute.
- Can handle a wide verity of feed from 480 mesh to 4 mesh.

Oscillatory screens



Relatively low speed oscillations (300 to 400 per minute)

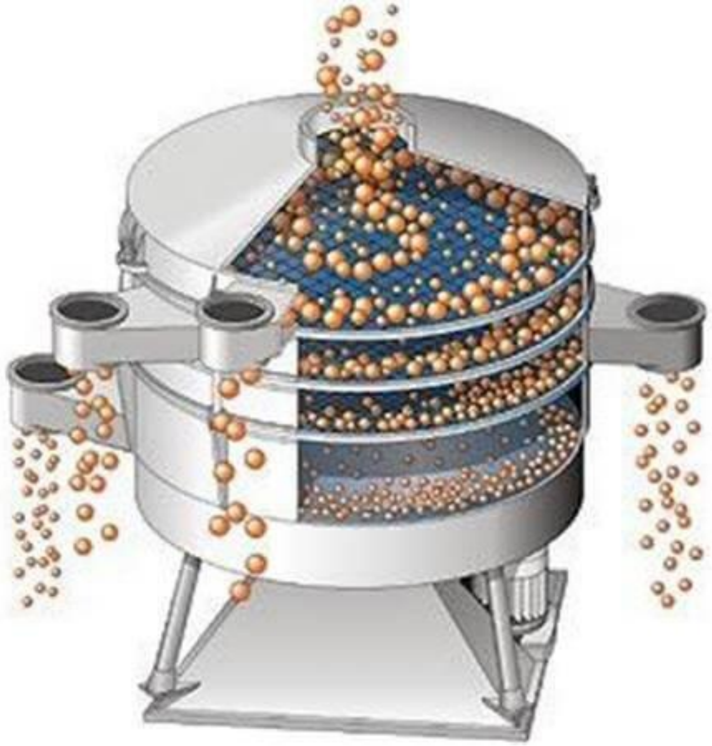
Mostly used for batch screening of coarse material coarse material of 5 to 15 mm and fine.

Reciprocating screens

The speed varies from 500 to 600 per minute

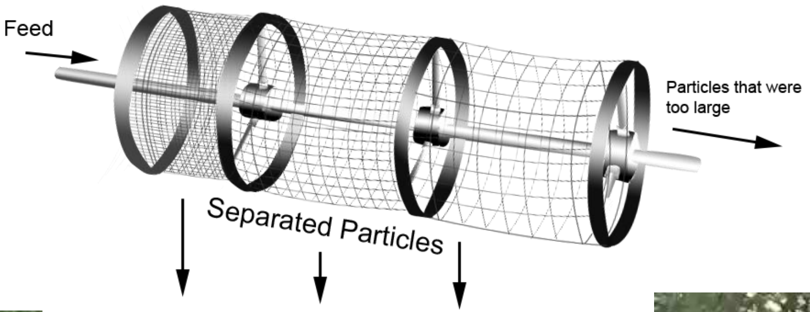
Used for handling dry chemical, light metal powders, powered food and granulr materials

Gyratory screens



Oscillations in circular or near circular orbits.

Trommel



- Relatively low capacity and low efficiency.
- Very efficient for coarser size
- Rotation speed around 15-20 rpm.