Mechanical Operation (NCH-302) Third Semester Chemical Engg.

UNIT : 1.

INTRODUCTION :-

Mechanical - Physical Separation Processes :- The separation of mixtures into their components is frequently necessary in chemical engg. practice. Various separation methods are classified in following heads :-

① Mechanical Separation
↓
applicable to heterogeneous mixt. not to homogeneous solⁿ. Techniques are based on physical diff. b/w the particles such as size, shape or composition.

② Molecular Separation (involves phase change or transfer of material from one phase to another. eg: Distillation.

* Size affects - surface per unit vol.
  - rate of settling of particle in fluid

* Shape - regular (eg. spherical, cubical)
  - irregular (eg. piece of broken glass

* composition determines density.

The mechanical methods of separation may be grouped into 2 general classes :-

- those whose mechanism is controlled by fluid mechanics such as classification, sedimentation, etc. and

those whose mechanism is not described ~~controlled~~ by fluid mech such as screening.

Mechanical - Physical Sep. Process may be studied under the following heads:-

1. Mechanical Size Reduction & Sepⁿ:- In this solid particles are broken mechanically into smaller particles and separated acc. to size.

2. Settling and Sedimentation:- The particles are sep. from fluid by gravitational forces acting on the various size and density particles.

3. Centrifugal Sepⁿ:- The particles are sep. from the fluid by centrifugal forces acting on the various size and density particles.

4. Filtration:- In solid-liq. sep. when the proportion of solid is relatively small, it is often used. In this fluid is caused to flow through small pores which block the passage of the large solid particles.

* Unit operation include physical steps of prep. reactants, separating and purifying the products, recycling unconverted reactants and controlling the energy transfer in and out of reactor.

Particle Technology :- Individual solid particles are characterized by their size, shape and density.

Particle Shape :- The shape of a particle is expressed in terms of sphericity, Φ_s which is independent of size of particle. For a spherical particle $\Phi_s = 1$ and for non-spherical it is defined by relation :-

$$\Phi_s = \frac{\text{Surface Ar. of the sphere of eq. dia } D_p}{\text{Actual surface area of particle}}$$

if S_p = Surface area of 1 particle. πD_p^2

V_p = Volume of one particle. $\left(\frac{4}{3}\pi r^3\right) = \frac{\pi}{6} D_p^3$

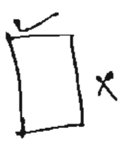
D_p = eq. diameter. (dia of sphere of = vol.)

From - (a)

$$\Phi_s = \frac{\pi D_p^2}{S_p} = \frac{6 V_p}{D_p \cdot S_p} \quad \text{--- (1)}$$

$$\left[\begin{array}{l} V_p = \frac{\pi}{6} D_p^3 \\ D_p^2 = \frac{6 V_p}{\pi D_p} \end{array}\right] \text{-(a)}$$

Particle Size :- The second largest dimension is called size.



* Coarse particles in terms of inchs, or mm
* Fine particles in terms of screen size.
* Very fine particles in μm or nm

Mixed Particle Sizes and Size Analysis :-

Let vol. of one particle = V_p

Total mass of sample = m

density " particles be ρ_p

Total vol. of particles $= \frac{m}{\rho_p}$.

No. of particles in the sample $= N = \frac{m/\rho_p}{V_p}$

$$\boxed{N = \frac{m}{\rho_p \cdot V_p}} \quad \frac{kg}{\frac{kg}{m^3} \times m^3} = \text{no u}$$

— (2)

Total S.A. of the particles = A.

from eqn (1) and (2)

$= N \cdot S_p$

$$\boxed{A = \frac{6m}{\Phi_s \cdot \rho_p \cdot D_p}} \quad \left\{ \frac{m}{\rho_p V_p} \times \frac{6V_p}{D_p \times \Phi_s} \right\}$$

Specific S.A. $A_w = \frac{6}{\Phi_s \cdot \rho_p} \sum_{i=1}^{n} \frac{x_i}{D_{pi}}$

Avg. particle size (i) $\bar{D}_s = \frac{6}{\Phi_s \cdot \rho_p \cdot A_w}$

vol. surface mean dia

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

(ii) Arithmetic mean dia $\bar{D}_N$

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

N_T is no. of particle in entire sample.

(iii) Mass mean diameter $\bar{D}_w$:- $\bar{D}_w = \sum_{i=1}^{n} x_i \bar{D}_{pi}$

(iv) Vol. mean dia $\bar{D}_v = \left[\frac{1}{\sum_{i=1}^{n} \left(\frac{x_i}{\bar{D}_{pi}^3} \right)} \right]^{1/3}$.

No. of particles in the mixture. Nw

$V_p = a D_p^3$

$(V_p \propto D_p^3)$

a = vol. shape factor and it depends on geometry of solids.

a = 0.5236 for sphere.

= .785 " short cy.

a = 1 " cube.

Assuming a is independent of size.

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

Numericals! - * Sphericity & * size analysis.

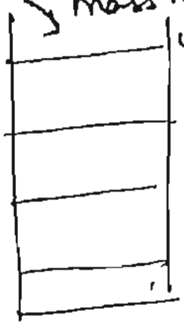
Screen Analysis :- is a method to sep. particles acc. to their sizes. Screens are identified in the terms of mesh no.

Mesh no. = no. of sq. openings in per linear inch.

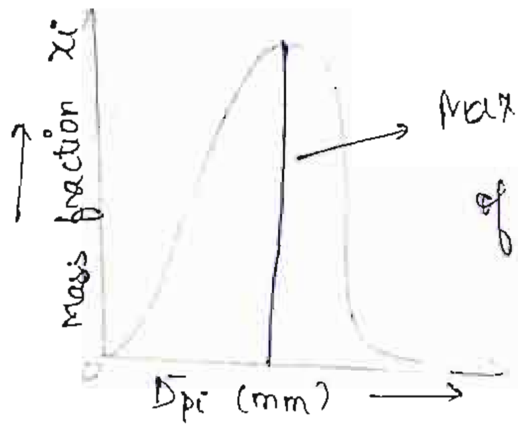
* The area of the opening in any one screen in exactly the twice that of the opening in the next smaller screen. i.e. $\frac{A_1}{A_2} = \frac{2}{1}$

* The ratio of the actual mesh dimension of any screen to that of next smaller is $\sqrt{2} = 1.41$ i.e. $\frac{D_1}{D_2} = \frac{\sqrt{2}}{1}$ and $\frac{D_{p\,n-1}}{D_{p\,n}} = \frac{(2)^{1/4}}{1} = \frac{1.89}{1}$

① Differential Screen Analysis.



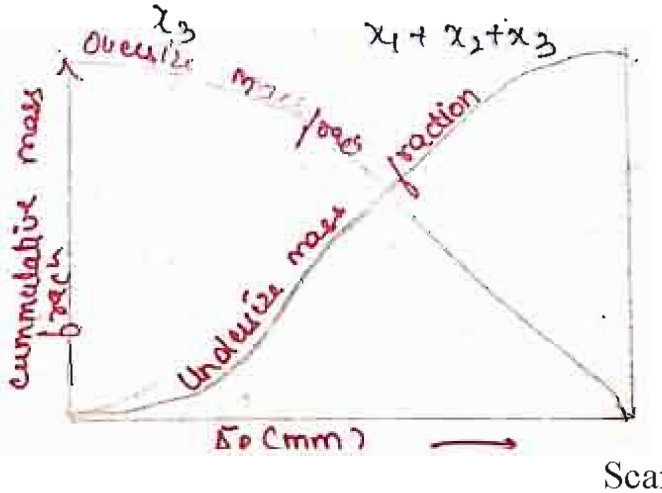
Mesh No.	Mass retained	x_i	D_{pi}	$\bar{D}_{pi}$
4	0	0	D_{p1}	—
6	m_1	m_1/m	D_{p2}	$D_{p1}+D_{p2}/2$
8	m_2	m_2/m	D_{p3}	$D_{p2}+D_{p3}/2$
10	m_3	m_3/m	D_{p4}	$D_{p3}+D_{p4}/2$
⋮	⋮	⋮	⋮	



* Numericals.

② Cummulative Screen Analysis :-

Mesh No.	$\bar{D}_p$	x_i	Cummulative oversize	Fraction undersize
4	—	0	0	1
6	$\bar{D}_{p1}$	x_1	x_1	$1-x_1$
8	$\bar{D}_{p2}$	x_2	x_1+x_2	$1-x_1-x_2$
10	$\bar{D}_{p3}$	x_3	$x_1+x_2+x_3$	$1-x_1-x_2-x_3$
⋮				



Screening:-

1) It is a method of Sep. particles acc. to size alone.

2) Material that remains on screening surface is oversize and material that passes through it is undersize.

3) Industrial screens are made from woven wire, silk cloth, metal bars etc.

4) Sep. b/w 4-mesh to 48 mesh (fine screening)
if >48 called (ultrafine Screening)

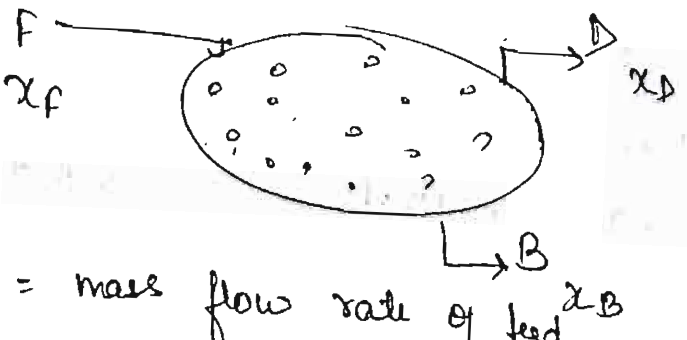
Objectives:-

1) To remove fines from material before entering to reduc^n equipment.

2) To remove fines or degradation from a finished product.

3) To scalp out oversize material.

Material Balance On Screen :-



Here F = mass flow rate of feed
D = " " " " overflow
B = " " " " underflow.

x_F = mass fraction of material A in feed

x_D = " " " " " overflow

x_B = " " " " " underflow.

M.B:

$$F = D + B \quad \text{—} \quad (1)$$

For material A :-

$$F \cdot x_F = D \cdot x_D + B \cdot x_B \quad \text{—} \quad (2)$$

By (1) and (2)

eliminating B :=

$$\frac{D}{F} = \frac{x_F - x_B}{x_D - x_B} \quad \text{—} \quad (3)$$

and elimination D:=

$$\frac{B}{F} = \frac{x_D - x_F}{x_D - x_B} \quad \text{—} \quad (4)$$

Screen Effectiveness :- Screen efficiency is a measure of the success of a screen in closely sep. two materials A and B. If the screen functioned perfectly, all of material A would be in the overflow and all of material B would be in the underflow.

Screen efficiency based on the oversize :-

$$E_A = \frac{\text{oversize material in the overflow}}{\text{Amt. of oversize material entering with feed}}$$

$$= \frac{D \cdot x_D}{F \cdot x_F}$$

on undersize :- $E_B = \dfrac{B(1-x_B)}{F(1-x_F)}$.

Overall Efficiency :-

$$E = E_A \cdot E_B.$$

$$= \frac{D \cdot B\, x_D(1-x_B)}{F^2\, x_F\,(1-x_F)}.$$

$$= \frac{(x_F - x_B)\cdot(x_D - x_F)\,x_D(1-x_B)}{(x_D - x_B)^2 \cdot (1-x_F)\cdot x_F}.$$

Major Screening Equipments :-

Screens

Grizzly	Gyratory	Vibratory.
* Consists of ∥ bars sep. by spacers at some predetermined opening.	* They are box like machines, which contain several decks screens one above other held in a box or casing.	* used when large capacity and high efficiency required.
* Bars are made of Mn steel to reduce wear.	* Coarest screen is at the top and finest at the bottom.	Adv :-
* Used before primary crushing to remove fines from ore.	* The mix of particles is dropped on the top screen.	* Accuracy of sizing
→ Stationary: → no power, → least exp., → little maint. ; → flat	* Screen and casing are gyrated to shift the particles thru openings.	* increased capacity per unit area.
		* Saving in installation space and weights.
		* low maintenance cost.
		* highest screen efficiency.

Qu. A quartz mix. having the screen analysis is screened through a standard 10 mesh screen. The cummulative screen analysis of overflow and underflow are given below

Mesh	Dpi (mm)	Screen Analysis feed	overflow	underflow
4	4.699	.046	0	
6	3.327	.025	.025	
8	2.362	.15	.025+.15	
10	1.651	.47	.85	.195
14	1.168	.73	.97	.58
20	.833	.885	.99	.83

Calc. the ratio D/F, B/F and over all screen effectiveness.

Sol: For mesh screen 10.

$x_F = .47$, $x_D = .85$, $x_B = .195$

$$\frac{D}{F} = \frac{x_F - x_B}{x_D - x_B} = 0.41$$

and $$\frac{B}{F} = \frac{x_D - x_F}{x_D - x_B} = .58$$

$x_f = .45$
$x_D = .87$
$x_B = .195$

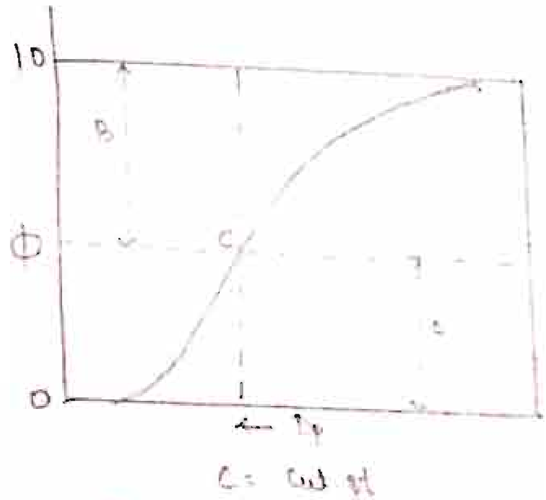
$$E = \frac{(x_F - x_B)(x_D - x_F)\ x_D(1 - x_B)}{(x_D - x_B)^2\ (1 - x_F)\ x_F}$$

$= .669$

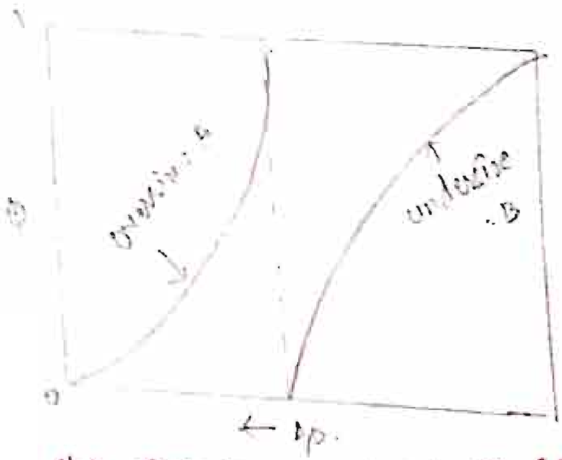
Ideal And Actual Screens :-

An **ideal screen** is one which sharply separates the feed mixture in such a way that the smallest particle in the overflow is just larger than the largest particle in the underflow.

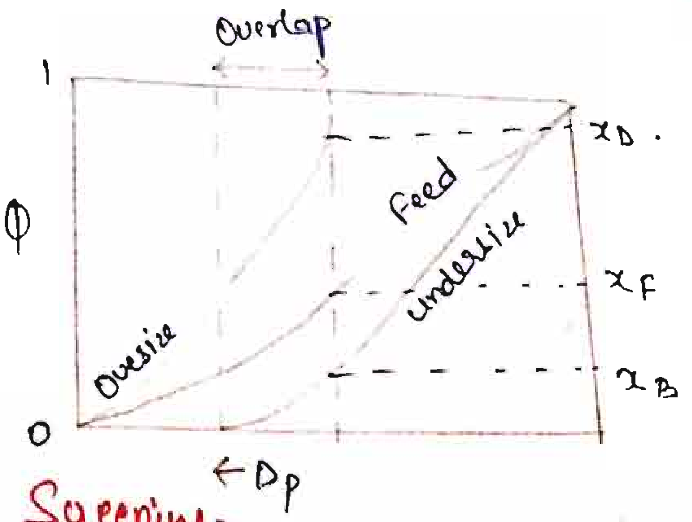
* The ideal sep. defines a cut diameter D_{pc} (a typical particle dimension) which makes the pt. of sep. b/w the undersize and oversize fractions and is nearly equal to the mesh opening of the screen.



(a) Ideal Screening



(b) Screen analysis of ideal Screening.



(c) Actual Screening.

Comparison of Ideal Screens And Actual Screens :

Ideal Screen	Actual Screen
1. Yields sharp seperation.	1. Does not yield sharp sep.
2. Efficiency of screen is 100%	2. Efficiency of screen is less than 100%
3. Such screens do not found in practice reality.	3. Such screens are available in practice.

PARTICLE SHAPE :-

The shape of the particle is expressed in terms of Sphericity ϕ_s

$$\phi_s = \frac{\text{Surface area of the sphere of equivalent diameter } D_p}{\text{Actual surface area of Particle}}$$

If, $S_p \rightarrow$ Surface area of one particle
$v_p \rightarrow$ Volume of one particle
$D_p \rightarrow$ Equivalent diameter of one particle

Volume of sphere $v_p = \frac{\pi D_p^3}{6}$

and $S_p = \pi D_p^2$

$$\therefore \phi_s = \frac{\pi D_p^2}{S_p} = \frac{6 v_p}{D_p \cdot S_p}$$

$$\boxed{\phi_s = \frac{6 v_p}{D_p \cdot S_p}}$$

NOTE:- $\boxed{\phi_s = 1}$ for Spheres
ϕ_s is 0 to 1 for other Particle shapes.

If N are no. of particles in the sample

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

where m = total mass of sample.
ρ_p = Density of the particles.

→ Total surface area of the particles, A

$N S_p$

i.e, $A = N S_p$

$$A = \frac{m}{\rho_p v_p} \cdot \frac{6 v_p}{\phi_s D_p}$$

$$A = \frac{6m}{\phi_s \rho_p D_p}$$

Specific surface area (total surface area per unit mass of particles)

$$A_w = \frac{6}{\phi_s \cdot \rho_p} \sum_{i=1}^{n} \frac{x_i}{\bar{D}_{pi}}$$

where, x_i = mass fraction in a given increment

n = number of increments

$\bar{D}_{pi}$ = Average particle diameter, taken as airthmetic average of smallest and largest particle diameter in increment.

AVERAGE PARTICLE SIZE

→ Volume surface mean diameter

$$\bar{D}_s = \frac{6}{\phi_s \rho_p A_w} = \frac{1}{\sum_{i=1}^{n} \left(\frac{x_i}{\bar{D}_{pi}}\right)}$$

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Mass Mean diameter;

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

→ Volume mean diameter:

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

→ Number of particles in the mixture,

$$N_w = \frac{m}{\rho_p v_p} = \frac{m}{\rho_p a D_p^3}$$

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

$$\boxed{N_w = \frac{1}{a \rho_p \bar{D}_V^3}}$$

a = Volume shape factor.

SCREENING

A method to separate particles according to their size. Screens are identified in terms of Mesh number.

Mesh number = Number of square openings in per linear inch.

Sieves are made of woven wire screen or metal bars.

Screen Analysis :-

A set of standard screens is arranged serially in a stack in such a way that the coarsest of the screens is at the top and finest of the screens is at the bottom. The material retained on each screen is removed and weighed. For reporting the screen analysis, the amount of material retained on each screen is expressed as the weight fractions of the sample.

The results of a screen analysis can be reported in a tabular form to show the weight fraction of the material retained on each screen as a function of the mesh size. As the particles retained on any one screen are passed through the screen immediately above it, two numbers are needed to specify the size, one for the screen through which the fraction passes and other for the screen on which that fraction is retained.

10/14 means material passes through 10 mesh and
-10 +14 retained on 14 mesh.

An analysis reported in a tabular form in this manner is called a differential analysis.

On the basis of size.

* Screening.

On the basis of specific gravity

* Tabling
* Jigging

On the basis of electrical prop.

* electrostatic ppt sep.

On the basis of magnetic prop.

* Magnetic sep.

On the diff. of surface prop.

* Froth flotation process.

On the basis of centrifugal force

* Centrifugal separators.

⇒ On the basis of terminal falling/settling velocities.

* Gravity settling tank. } classifier.
* Cone Classifier }

Crushing → prim / sec

Grinders → intermediate

Ultrafine grinders → fine particles.

Cutting Mills → define shape and size

→ physical change

→ chemical change

P adsorption ✓

Chemisorption.

Numericals: Sphericity.

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Calc. the eq. dia and sphericity of following particles :-

(i) a β conical solid of dia 2mm and height 5mm

(ii) Cubical particle of size 2cm.

Soln (i) $\phi_s = \frac{6V_p}{D_p \cdot S_p}$

vol. of particle (V_p) $= \frac{1}{3} \pi r^2 h = \frac{5}{3}\pi = 5.23 mm^3$

S.A. of particle $S_p = \pi r(r+l) = 16.01 mm^2$ 19.15 mm^2.

Now for eq. Dia.

~~Vol~~ $V_p = \frac{\pi}{6} D_p^3$

$\Rightarrow D_p = 2.154$.

$\therefore \phi_s = \frac{6 \times 5.23}{2.154 \times 19.15}$ = ~~.7758~~ ~~.9089~~ = (.91) Ans .76

(ii) $V_p = (2)^3 = 8 \ cm^3$

$S_p = 6a^2 = 24 \ cm^2$

Now for $D_p \Rightarrow V_p = \frac{\pi D_p^3}{6}$

$D_p = 2.4$ cm

$\phi_s = \frac{6 \times 8}{24 \times 2.4} = .83$ Ans.

Q find the sphericity of

(i) Cylinder of 1mm dia & 3mm length

(ii) Cube of dimension 'a' m.

Sol:

(i) $V_p = \pi r^2 h = 3.14 (.5)^2 \times (3)$ 2.355 mm^3

$S_p = 2\pi r (r+h)$

$= 2 \times 3.14 \times .5 (.5+3)$

$= 10.99\ mm^2$

Now for D_p.

$V_p = \frac{\pi}{6} D_p^3$

$2.355 = \frac{\pi}{6} \times D_p^3$

$D_p^3 = 4.5$

$D_p = 1.64$ mm.

$\frac{\pi D_p^2}{S_p} = \frac{6 V_p}{D_p S_p}$

$V_p = \frac{\pi}{6} D_p^3$

$D_p \cdot D_p^2 = \frac{3 V_p}{\pi} \cdot \frac{1}{D_p}$

Now $\phi_s = \frac{6 V_p}{S_p \cdot D_p} = \frac{6 \times 2.355}{10.99 \times 1.64}$

$\phi_s = .78$

(ii) $V_p = a^3$ $\quad S_p = a^2$

Now, $V_p = \frac{\pi}{6} D_p^3 \Rightarrow a^3 = \frac{\pi}{6} D_p^3 \Rightarrow$

$D_p^3 = \frac{6a^3}{\pi}$

$\phi_s = \frac{6 \times a^3}{a^2 \times (6)^{1/3} a} \times (\pi)^{1/3} = (6)^{1-\frac{1}{3}} \cdot (\pi)^{1/3}$

$= (6)^{\frac{2}{3}} \cdot (\pi)^{1/3}$ $= 0.805$

Calc. the mean diameter of material of the following distribution :-

Commulative mass (m)	Actual mass	Dp (μm)	x_i	$\bar{D}_{pi}$	$\frac{x_i}{\bar{D}_{pi}}$	$x_i \bar{D}_{pi}$
0	0	50	—	—	—	—
60	60	75	60/360 = .16	62.5	.00256	
150	90	100	.25	87.5	.0028	
270	120	125	.33	112.5	.0029	
330	60	150	.166	137.5	.0012	
360	30	175	.08	162.5	.0004	

now

$$\bar{D}_s = \frac{1}{\sum_{i=1}^{N} \frac{x_i}{\bar{D}_{pi}}} = \frac{1}{.0102} = 98.03 \ \mu m$$

$$\bar{D}_w = \sum x_i \bar{D}_{pi} = 105.682 \ \mu m$$

$$\bar{D}_v = \left[\frac{1}{\sum \frac{x_i}{\bar{D}_{pi}^3}} \right]^{1/3} = 90.038 \ \mu m$$

Scanned by CamScanner

Q Data below were obtained on the operation of mesh (sq.) screen at a coal mine. The screening was done to sep. a very fine from fine coal stream so that it would be reprocessed. Calc.

(a) Recovery & rejection of each size fraction.
(b) Screen effectiveness.

Size	Feed (gm) 131 tons/hr.	Overflow (gm)	Underflow (gm) 98 tons/hr.
$+\frac{1}{4}$ inch	3825	2905	11.3
$\frac{1}{4} \times 6$ mesh	1006	767	78
6 x 14 mesh	750	405	6.9
14 x 28 mesh	303	117	8.6
28 x 48 "	219	68	3.0
48 x 0 "	807	278	62.1
	6910	4540	1699

Sol:

$$\text{Recovery} = \frac{D \cdot x_D}{F \cdot x_F} \quad x_D \to \frac{767}{4540}, \quad x_F \to \frac{1006}{6910}$$

$$= \frac{.168 \times 767}{1006 \times .145}$$

$$= 0.87$$

$$\text{Rejection} = \frac{B(1-x_B)}{F(1-x_F)}$$

$$\to 1 - \frac{(1-x_D)D}{(1-x_F)F}$$

$$= \frac{78 \times (1-.459)}{1006 \times (1-.145)}$$

$$= .25 \quad .049$$

$$\text{Effectiveness} = .87 \times .25 = ~~.217~~ \quad .04$$

Q. Calc. the specific surface (A_w) in cm^2/gm of pyrite having the screen analysis below. Specific gravity of pyrite is 5 gm/cm³. $\Phi_s = .7$

Mesh	% retained	aperture (mm)	x_i	$\bar{D}_{pi}$ (cm)
-3, +4	0	6.680 / 4.699	—	.056
-4 +6	4.0	4.699 / 3.327	.04	.040
-6 +8	7.2	3.327 / 2.362	.072	.028
-8 +10	12.0	2.362 / 1.651	.12	.020
-10 +14	17.6	1.651 / 1.168	.176	.014
-14 +20	15.4	1.168 / .833	.154	.010
-20 +28	12	.833 / .589	.120	.007
-28 +35	10	.589 / .417	.100	.005
-35 +48	7.2	.417 / .295	.072	.003
-48 +65	6	.295 / .208	.060	.002
-65 +100	3.8	.208 / .147	.038	.0017
-100 +150	2.8	.147 / .104	.028	.0012
-150 +200	2.0	.104 / .0674	.020	.0008

$$\Rightarrow A_w = \frac{6}{\Phi_s \rho_p} \sum_{i=1}^{n} \frac{x_i}{\bar{D}_{pi}}$$

$\Phi_s = .7 \qquad \rho_p = 5$

$$A_w = \frac{6}{.7 \times 5} \times \_\_\_ =$$

Q Data below were obtained on the operation of a 6 mesh screen at a coal mine. The screening was done to sep. a very fine from fine coal stream so that it would be reprocessed.

Calculate:-

(a) Recovery & rejection (b) screen effectiveness.

Size	Feed (gm) 131 tons/hr.	Overflow (gm)	Underflow (gm) 98 tons/hr.
+1/4 inch	3825	2905	11.3
$\frac{1}{4}$ x 6 mesh	1006	767	78
6 X 14 mesh	750	405	6.9
14 X 28 mesh	303	117	8.6
28 X 48 "	219	68	3.0
48 X 0 "	807	278	62.1
	Σ 6910	Σ 4540	Σ 169.9

⇒ Recovery ! $= \frac{x_p P}{x_f F} = \frac{.168 \times 767}{.145 \times 1006} = .87$

Rejection $= 1 - \left[\left(1 - \frac{x_p}{x_f}\right)\frac{P}{F}\right] = .25$

(b) Effectiveness = Rec. X Rejection

= .87 X .25

= .217. Ans