MANUAL

MECHANICAL OPERATIONS LABORATORY

B.E. Chemical Engineering

Department of Chemical Engineering

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CONTENTS

Experiment No: 1

JAW CRUSHER

Aim: - To determine the crushing law constants and to verify the laws by conducting experiment on jaw crusher.

Apparatus: - Jaw crusher, sieve set, sieve shaker, weighing balance, brush, etc. .

Theory: - Crushers are slow speed machines for coarse reduction of large quantities of solids. Coarse feed is used in jaw crusher. Jaw crusher crushes lumps and other hard materials using compression force. In a jaw crusher feed is admitted between two jaws set to from a 'V' open at the top. One jaw, the fixed or the anvil jaw is nearly vertical and does not move. The other jaw swinging jaw reciprocates in a horizontal plane. It makes an angle of 20^0 to 30^0 to the anvil jaw. It is driven by an eccentric so that it applies great compression force to lumps caught between the jaws. The jaw opening is 10mm at the bottom. There are two types, namely Blake jaw crusher(swinging jaw pivoted at the top) and the Dodge jaw crusher(swinging jaw pivoted at the bottom).

Following laws have been proposed to calculate the energy requirement in crushing,

1. **Rittinger's law: -** $E = K_R (1/D_P - 1/D_F)$
   Where K_R = Rittenger's constant
   D_P = Diameter of the product
   D_F = Diameter of the feed.
   Rittinger's law is applicable mainly to that part of the process where new surface is being created and holds most accurately for fine grinding where increase in surface per unit mass of material is large. This law states that the work required in crushing is proportional to the new surface created. K_R value is usually determined by the drop weight test.. Rittinger's law is best applicable to coarse and intermediate size reduction.

2. **Kick's Law: -** $E = K_K \ln(D_F/D_P)$
   K_K = Kick's Constant
   D_P =Diameter of the product
   D_F = Diameter of the feed
   Kick's law states that the energy necessary for crushing a material is same for the same reduction ratio irrespective of original size. It means that required energy is proportional to the logarithm of the ratio of feed size to product size. This is the limitation of this law too. Kick's law can be applied without much serious error to coarse crushing where the feed size is quite large and the reduction ratio is quite low.

3. **Bond's Law: -**
   $E = K_B (1/\sqrt{D_P} - 1/\sqrt{D_F})$
   K_B = Bond's constant
   D_P = Diameter of the product
   D_F = Diameter of the feed .

   Work required to obtain a particle of size of D_P from very large feed is proportional to the square – root of surface to volume ratio of the product.

4. **Work Index: -** Work index is denoted by W_I. W_I is defined as the gross energy in kilowatt-hour per ton of feed needed to reduce a very large feed to such a size that 80% of

the product passes through a 100-micron screen and this definition leads to relation which gives $W_I = \sqrt{(100 \times 10^{-3})}\ K_B = 0.3162\ K_B$

Procedure: -

1. About 1 kg of sample of approximately the same size and shape is taken.
2. The feed size is found by taking three representative stones by water displacement method. Known volume (say 500 mL) of water is taken in a measuring cylinder and stones are placed in it. The volume of displaced water is noted.
3. The time t_2 taken for 5 revolutions of the energy meter disc without load as (N_i) is found.
4. The sample is fed one by one to the jaw crusher, the stopwatch is started simultaneously. The time t_1, and the number of revolutions (N) of the energy meter disc are recorded when all the material is crushed.
5. Sampling for screen analysis: Representative product of about 500 g by **cone and quarter method** is obtained. Crushed sample is mixed well and put together to form a cone. The cone is divided into four equal parts (quarted) and two of them are considered. Once again quartered and two of them are considered. **or**
   Representative product of about 500 g by **random sampling method** is obtained. Crushed sample is mixed well and about 500 g is taken randomly for analysis.
6. The sample product is transferred on to the top screen of the given sieve set and shaken for about five minutes. The sample weights retained on each screen are recorded.
7. One more sample of 500 g is obtained from the remaining 1.5 kg and the step no. 6 is repeated.

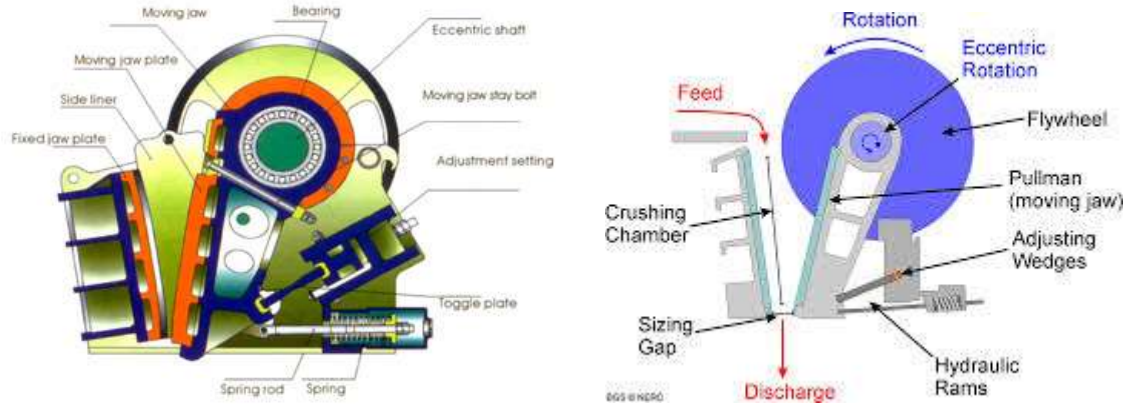


Fig: Jaw crusher

Energy meter constant =150 rev/kwh

Tabular column: Observations

Sl. No.	Weight of sample taken, W	Time required to crush the material		No. of revolutions of energy meter with load(N)
		With load t_1, s	Without load t_2,s for N_i= 5	
1				
2				

Tabular Column 2: Observations and calculations

Sl. No.	Mesh No. (BSS)	Aperture size D_{pi}	Average particle size (D_{Pave})	Weight of material retained, W_i	Weight fraction $w_i = W_i / W$	$w_i/(D_{Pave})$	Cumulative weight fraction (x_i)
01	5	3					
02	8	1.875					
03	18	0.833					
04	25	0.6					
05	30	0.5					
06	44	0.3409					
07	85	0.1763					
08	100	0.15					
09	Pan	0.0					
				$\Sigma W_i = W$		$\Sigma x_i / \bar{d}p$	

Tabular Column 3:

Sl. No.	Mesh No. (BSS)	Aperture size Dp_i	Average particle size (D_{Pave})	Weight of material retained W_i	Weight fraction $w_i = W_i / W$	$w_i/(D_{Pave})$	Cumulative weight fraction (x_i)
01	5	3					
02	8	1.875					
03	18	0.833					
04	25	0.6					
05	30	0.5					
06	44	0.3409					
07	85	0.1763					
08	100	0.15					
09	Pan	0.0					
				$\Sigma W_i = W$		$\Sigma x_i / \bar{d}p$	

Specimen Calculations:

Feed particle diameter by volume displacement method

Note: Assuming that the particles are spherical in shape.

Volume of water displaced by three stones=3 times the volume of sphere

$=3 \times 4/3 \pi R_F^3 =$ - m^3

$R_F =$ mm

$D_F =$ mm

$E = (1/\mathbf{m}) [N - N_i (t_1/t_2)] / ECF$ J/kg

m = mass of sample crushed in kg
ECF = 150 Rev/kw h
ECF = 150/1000*3600, rev/w s
= 150/1000*3600, rev/J=$4.17*10^{-5}$ rev/J
Unit of E becomes rev/rev kg/J = J/kg
D_p from Analytical method:
$D_P = 1/ \Sigma(w_i/D_{Pave})$ (to be obtained from the table)
D_P = Volume surface mean diameter.
D_P from the graphical method :
Draw a graph of $(1/D_{Pave})$ Vs Cumulative weight fraction (x_i). The inverse of area under the curve from 0-1 of x_i gives the D_P

Cumulative weight fraction (x_i)	w_1	$w_1+ w_2$	$w_1+w_2+ w_3$	weight fraction

Kicks law: $K_K= E/ \ln(D_F/D_P)$ J/kg

Rittingers law: $K_R = E/(1/D_P - 1/D_F)$ J/kg mm

Bonds law:- Since the percentage of sample product passing through 100µm mesh is very less, the Bonds is not verified.
W_I for granite is 15.13 .

Verification of the laws: Find the ratios of law constants (K_{R1}/K_{R2}) and (K_{K1}/K_{K2}). The ratio closure to One (1) represents the valid law.

Find the reduction ratio (D_F/D_P) for both the trials and check whether they are same or not. If reduction ratio is same Kicks law is valid.

Result:-
I trial: Rittenger's law constant K_{R1} = _____

Kick's law constant K_{K1} = _____

Reduction ratio(D_F/D_P) is _____

II trial: Rittenger's law constant K_{R2} = _____

Kick's law constant K_{K2} = _____

Valid law for jaw crusher operation is_____

Reduction ratio(D_F/D_P) is _____

Note: State whether Rittenger's or Kick's law is valid.
Compare reduction ratio of two trials. If reduction ratio is same, report as "Kick's law is valid".

Experiment No: 2

I.C.I SEDIMENTATION

Aim: To determine the particle size of given sample in sub-sieve range using ICI sedimentation technique and also to plot the cumulative distribution curve.

Apparatus: ICI (Imperial Chemical Industries) setup, six graduated beakers (50ml), stopwatch, weighing balance, measuring jar, hot air oven and six filter papers.

Theory: The particle size in the sub-sieve range can be determined by using several techniques such as ICI sedimentation, Beaker decantation etc. These methods depend on fact that terminal settling velocity of particle in a fluid increases with size.

Sedimentation methods are of two main types. In the first, the sample is abstracted from selecting a suspension at a fixed horizontal level at an interval of time, each sample of suspension with the exception of particles larger than a critical size, all of which will have settled below level of sampling point. In the second, the particles settle on a immersed sedimentation balance pan, which is continuously weighed. The largest particles will be deposited preferentially and consequently the rate of increase of weight will fall off progressively as particles settle out. Sedimentation methods must be carried out at concentrations which are sufficiently low for interactive effects between particles to be negligible so that their terminal falling velocities can be taken as equal to those of isolated particles.

Procedure:

1. The terminal settling velocities using Stoke's equation of different size of particles and also the time of settling are calculated using height of settling. All the particles are assumed to be present at the top surface initially.
2. Six number of filter papers are numbered, dried and then weighed.
3. Six graduated beakers of 50 mL capacity are taken and numbered.
4. 1g of sample is taken and the slurry is prepared with about 3ml of water.
5. The reservoir is filled with water up to the brim by keeping valve2 open while all other valves are kept closed.
6. Valve 2 is closed and valve1 is opened. Water is added up to 18 cm.
7. The slurry is transferred to the sedimentation tube and made up to the mark to known height by adding water.
8. Valve 4 is opened and air is blown gently into the sedimentation tube by opening valve1 till the slurry concentration becomes uniform.
9. Stopwatch is started and the particles are allowed to settle for calculated time.
10. About 20 mL of sample is collected by opening the valve3 carefully.
11. Water is added up to the mark and air is blown using valve 4 .

12. The procedure (steps 8, 9,10 and 11) is repeated to collect the particles of other size samples at corresponding calculated time.
13. The collected samples are filtered and dried to know the mass of the particles.

Observations:

Density of the sample = $\rho_{s,}$ = 2560 kg/m^3

Density of water = $\rho_{w,}$ = 1000 kg/m^3

Viscosity of water = μ_w, = 0.98 x 10^{-3} Ns/m^2

Acceleration due to gravity = g = 9.81 m/s^2

Height of setting = 27 cm

Particle Size: 120, 120/√2, 60, 60/√2, 30, 30/√2µm respectively

Table: Observations

Sl. No.	Particle size, D_p µm	Terminal velocity $U_{t,,}$ m/s	Time θ , s	Weight retained W_i , g	Weight fraction; $w_i = W_i/W$
1.	120				
2.	120/√2				
3.	60				
4.	60/√2				
5.	30				
6.	30/√2				
				$\sum W_i=W$	

Table:Observations and calculations

Sl No	Size µm	Size Range µm	Average Particle Size – $D_{p\ avg}$, µm	Cumulative Wt fraction , x_i	1 - x_i	$w_i/ D_{p\ avg}$
1.	120	240/√2- 120	(240/√2+120)/2	w_1		
2.	120/√2	120 - 120/√2	(120 + 120/√2)2	$w_1+ w_2$		
3.	60	120/√2 – 60		$w_1+w_2+ w_3$		

Sl No	Size µm	Size Range µm	Average Particle Size – $D_{p\ avg}$, µm	Cumulative Wt fraction , x_i	$1 - x_i$	$w_i / D_{p\ avg}$
1.	120	240/√2- 120				
2.	120/√2	120 - 120/√2				
3.	60	120/√2 – 60				
4.	60/√2	60 - 60/√2				
5.	30	60/√2 – 30				
6.	30/√2	30 - 30/√2				
				$\sum = 1$	$\sum = 1$	$\sum w_i / D_{pavg}$

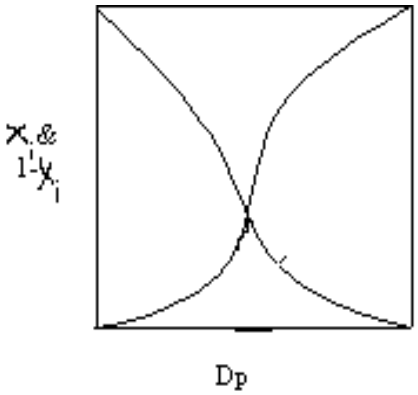
Specimen calculations*:*

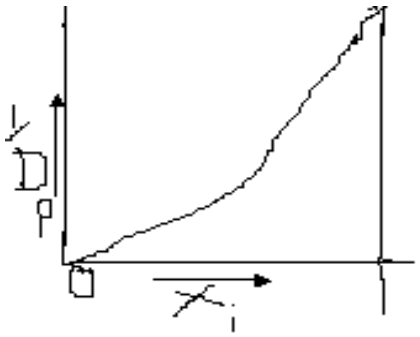
1. Terminal settling velocity $U_t = [g\ D_p^2\ (\rho_s - \rho_w)] / 18\mu_w$ = _____ m / s
2. Level/Height of the slurry in the sedimentation tube, H = _____m
3. Time = t = H / U_t = _____ s
4. Volume surface mean diameter of sample, $D_P = 1/\sum w_i/D_{p\ aveg}$

Graph: Draw the graph and find the area under the curve.

Inverse of area under the curve = Average particle size of the sample (X –axis range 0-1)
Variable on X-axis is cumulative weight fraction
Variable on Y-axis is $1/ D_{p\ aveg,}$
$D_{p\ avg}$ of sample = 1/Area under the curve

Frequency distribution curves:





RESULT: The average particle size of the sample

1. Analytically: $D_{p,\ sample}$
2. Graphically : $D_{p,sample}$
3. Frequency distribution curves are plotted.

Experiment No: 3

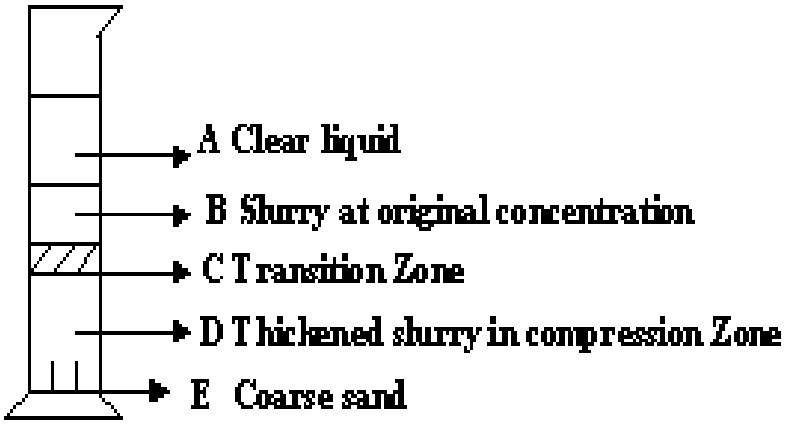
BATCH SEDIMENTATION

Aim: To determine the minimum cross sectional area of a continuous thickener required to handle 150tons/day of dry solids from initial concentration of 4% to give an underflow concentration of 50% by conducting a batch sedimentation test.

Apparatus: 1litre measuring cylinder, plastic beaker, stirrer, weighing balance, stop watch.

Sample Used: $CaCO_3$ (laboratory Grade)

Theory*:* In the operation of thickeners the basic assumption is that the material to be settled consists of flocs sufficiently uniform in size and shape so that they settle at uniform velocities under conditions of hindered settling in the initial stages. The process of settling is best described by batch settling tests in glass cylinders.



Application of Batch Settling Test to Design a Continuous Thickener: The capacity of a continuous thickener is determined by the fact that the solids initially present in the feed must be able to settle through all zones of slurry concentration from that of the initial feed to that of the underflow. If the area provided is not sufficient, the solids will build up through the settling zone and into the classification zones until finally some solids are discharged in the overflow. It was assumed that the settling rate was a function only of the solid concentration expressed as volume of solids per unit volume of slurry. This method is based on the mathematical analysis of batch settling presented by Kynch, which showed that the settling rate and the concentration of the zone that limits capacity can be determined by from the single batch settling test.

L_o = Feed rate, m^3/s

L_u = under flow rate, m^3/s

C_o = Slurry feed concentration, kg/ m^3

C_u = under flow concentration, kg/ m^3

Writing the material balance for solids/unit time: $L_o C_o = L_u C_u$

$L_u = L_o C_o/Cu$

Now writing the overflow liquid balance: $L_o (1-C_o) – Lu (1-C_u) = V$

Where V is the overflow volume per unit time.

Substituting for L_u: $L_o (1-C_o) – L_o C_o/C_u (1-C_u) = L_o C_o(1/C_o – 1/C_u)$

If the cross sectional area of the thickener is denoted by S, $V/S = L_o S_o/S (1/C_o – 1/C_u)$

The term V/S denotes the upward liquid velocity in the clarification zone of the thickener. When the thickener is operated at capacity the lowest settling rate encountered must be equal to or greater than this value, otherwise some solids will leave in the overflow.

Thus V/S is replaced by v.

$L_o C_o = L_L C_L$

$v = L_L C_L/S(1/C_L – 1/C_u)$

$S = L_L C_L /(v/(1/C_L-1/C_u))$

Here $C_L L_L$ = solids handling capacity, kg/s is given.

v = settling velocity which is calculated by batch sedimentation test. The minimum value of $v/[(1/ C_L)-(1/ C_u)]$ is used to calculate the thickener area.

Where C_L = Limiting layer concentration, kg/m^3

Procedure:

1. Prepare 4 % $CaCO_3$ slurry in a measuring jar using one litre water and 40 g of $CaCO_3$.
2. Keep the measuring jar against a bright background to see the interface clearly.
3. The slurry is stirred vertically for uniform concentration and the initial height of slurry Z_o is noted down.
4. As soon as the agitation is stopped, the stop watch is started and the time is noted as solid –liquid interface moves down by every 1cm.
5. After some height (about 15cm), the time is noted down for every half cm decrease in the interface height.
6. The experiment is continued for about 1hour and till no more settling is observed.
7. A graph of the interface Z vs. settling time θ is plotted.
8. 6 tangents are drawn and Z_i, $Z_{L,}$ and θ_L are noted.
9. C_L Vs v_L graph and as well as graph of $v_L/(1/C_L- 1/C_U)$ Vs v_L are plotted.
10. Extra data of C_L and v_L from the second graph to get the shape of third graph (to confirm the minimum value by increase in y-axis value) are obtained.

Observations & Calculations:

1. Initial height of the slurry ,Z_o = _____cm
2. Density of $CaCO_3$ = 2560 kg/m^3

Table:Observations

Height of the interface Z , cm	Time θ, s

Specimen calculations:

Plot a graph of Z Vs θ.

Z_i = point where tangent drawn from selected point at Z vs θ curve meets Y-axis.
θ_L = point where vertical line drawn from selected point curve meets X-axis.
Z_L = point where horizontal line drawn from selected point curve meets Y-axis.
C_o = initial concentration of slurry, kg/m^3
C_u = underflow concentration of slurry, kg/m^3
$C_L L_L$ = (150*1000)/(24*3600) kg/s

1. Initial concentration of $CaCO_3$ = C_o, kg/m^3 =

   Sample wt./{(sample wt./ sample density)+(water wt./water density)},

Minimum cross sectional area of the thickener = $S = \dfrac{C_L L_L}{Y \min} \quad \dfrac{C_L L_L}{\left[\dfrac{V_L}{1/C_L - 1/C_u}\right]_{\min}}$

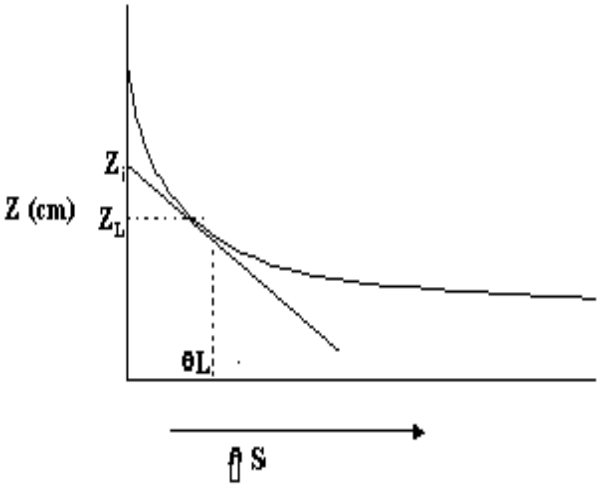
Table 2:Observations

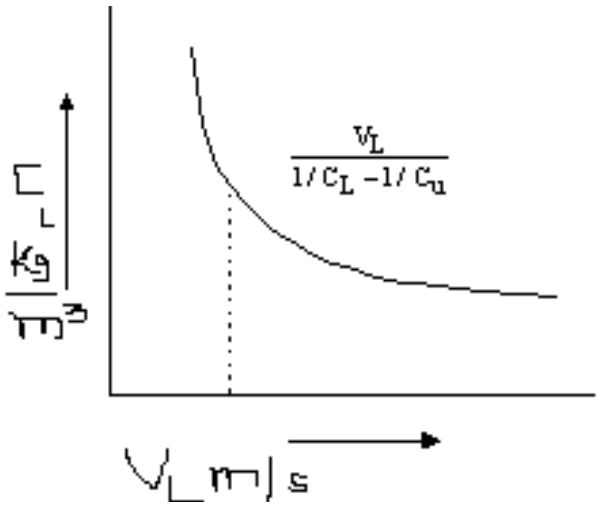
Sl. No	Z_L m	Z_i m	θ_L s	$v_L=(Z_i-Z_L)/\theta_L$ m/sec	$C_{L=}(Z_oC_o)/Z_i$ kg/m^3

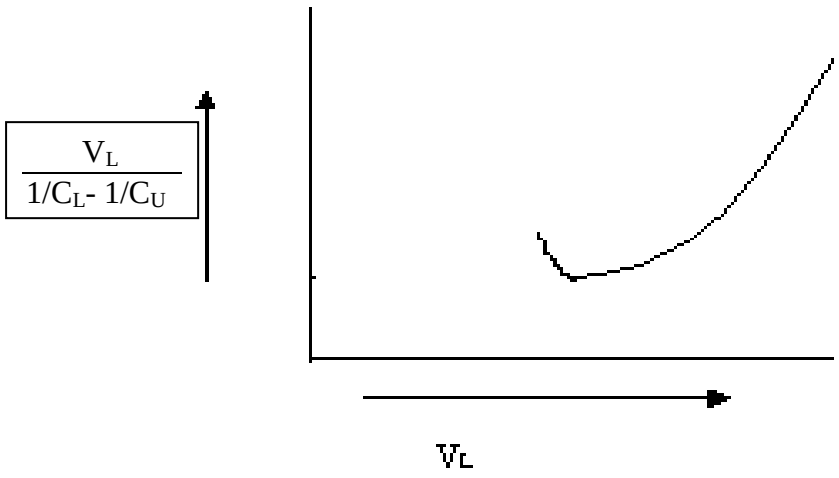
Table 3: Calculations

Sl. No.	v_L m/s	C_L kg/m^3	$v_L/[(1/C_L)-(1/C_u)]$ kg/m^2 s

Graphs: C_L versus v_L and $\dfrac{V_L}{1/C_L - 1/C_U}$ Versus v_L







Result: The area of thickener = _____m^2

Experiment No: 4

PLATE & FRAME FILTER PRESS

Aim: To determine the specific cake resistance (α) and filter medium resistance (R_m) by carrying out an experiment using plate & frame filter press with 4% by weight of $CaCO_3$ slurry.

Apparatus: Filter press, stopwatch, bucket, stirrer, weighing balance, two watch glasses.

Theory: Filtration is the removal of solid particles from a fluid by passing the fluid through a filtering medium or septum on which the solids are deposited. Often the feed is modified by pretreatment to increase the filtration rate as by heating, re-crystallization or adding a filter aid such as cellulose or diatomaceous earth.

The process may be continuous or discontinuous depending upon whether the discharge of filtered solids is steady or interrupted. In discontinuous filtration the flow of fluid through the device is continuous, but it must be interrupted periodically to permit discharge of the accumulated solids. In continuous filters the discharge of both solids and fluids is interrupted as long as the equipment is in operation.

Plate & Frame Filter Press: the plate and frame filter press represents a more satisfactory and more versatile type of filter. This press is made up of plates with very slightly raised edges and hollow frames, assembled alternately. In assembling this press a filter cloth is thrown over each plate but not over the frame. The filter cloth has holes that register with the connections on the plates and frames, so that when the press is assembled these openings form a continuous channel through the whole length of the press and register with the corresponding connections on the fixed head. The channel shown opens only into the interior of the frames and has no opening on the plates, and at the bottom of the plates holes are cored that connect the faces of the plates to the outlet cock. As the material to be filtered is pumped through the feed channel, it first fills all the frames. As the feed pump continues to supply material and builds up pressure the filtrate passes through the cloth, runs down the face of the plate and passes out through the discharge cock. When the press is filled it is opened and dumped. In such a press the cake cannot be washed and therefore is discharged containing a certain amount of the filtrate with whatever valuable or undesirable material it may contain. Each plate discharges a visible stream of filtrate into the collecting launder and therefore if any cloth breaks or runs cloudy, that plate can be shut off without spoiling the whole batch. If the filtrate is hot or volatile or if for any other reason the open discharge is not desired a channel like the feed channel can be supplied to take this discharge.

Constant Rate & Constant Pressure Filtration: If an initial high pressure is maintained, the first particles caught will be compacted on to a tight mass that fills the pores of the cloth and results in the low rate of filtration throughout the cycle. If the initial pressure is low, the initial layer of precipitate will be more open. Rate of filtration will be higher and the cake can be easily separated from the cloth. As time passes the cake resistance increases and the

pressure is increased until the maximum pressure is reached. As soon as the clothes are well coated with cake and the filtrate is clear, the pressure is increased at constant pressure.
The filter medium resistance may vary with the pressure drop since the higher liquid velocity caused by a large pressure drop may add particles of solids into the filter medium.

Procedure:

1. 4% $CaCO_3$ slurry by mixing 160 g $CaCO_3$ in 4litres of water is prepared in a bucket..
2. Two dry, empty watch glasses are weighed.
3. The compressor is switched on.
4. The filter clothes are wet, placed over the frame and tightened by means of ram.
5. Slurry is agitated for uniform concentration.
6. The drain valve is closed. The compressed air flow rate is adjusted till the pressure is constant at 0.5 kg/cm^2 using the vent cock.
7. The slurry is transferred into the tank by opening the inlet valve and vent cock.
8. The initial level of filtrate (water) in filtrate receiver is noted. The slurry outlet valve is opened to begin the filtration and the stopwatch is started simultaneously.
9. The time (cumulative) for the filtrate rise in the receiver for every 1cm is noted.
10. After the completion of filtration, a sample of cake is taken on the watch glass.
11. The wet cake is weighed, dried and weighed again to note the dry cake weight.
12. The above steps are repeated with an increased pressure of about 1.0 kg/cm^2 with fresh slurry.

Observations:

1. Dimensions of the filtrate receiver(tank) = $13 \times 10^{-2} * 13 \times 10^{-2}$ m^2
2. Diameter of the plate $=d_2 = 12.5 \times 10^{-2}$ m.
3. Pressure applied, $\Delta p = 0.5$ $kg/cm^2 \times 9.81 \times 10^4 = 49.050 \times 10^3$ N/m^2
4. Viscosity of the filtrate μ $= 0.98 \times 10^{-3}$ Ns/m^2
5. Density of sample $= 2560$ kg/m^3
6. Density of water (ρ) $= 1000$ kg/m^3
7. Initial concentration of $CaCO_3 = C_s$, kg/m^3 =
8. Sample wt./{(sample wt./ sample density)+(water wt./water density)},

Table: Obervations

SL. No.	Filtration pressure drop, Δp (kg/cm^2)	Weight of watch glass W_1(g)	Weight of wet cake + watch glass W_2(g)	Weight of dry cake + watch glass W_3(g)	Weight of wet cake (W_2-W_1) m_f (g)	Weight of dry cake (W_3-W_1) m_c(g)

Table: Observations and Calculations

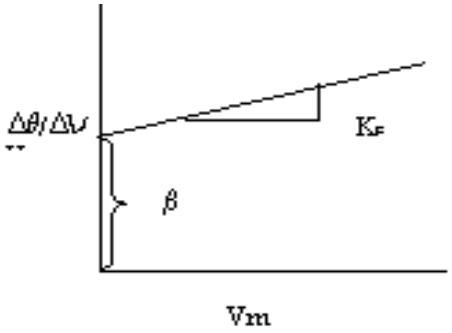
Sl No.	Filtrate level L (m)	Filtrate volume V , m^3	$\Delta V = V_2 - V_1$ m^3	$V_m = \frac{V_1 + V_2}{2}$ m^3	θ s	$\Delta\theta = \theta_2 - \theta_1$ s	$\Delta\theta/\Delta V$ s/m^3
	0	0			0		

Specimen Calculations:

1. Cross sectional area of the filtrate tank, Cylindrical A= 13 x 10^{-2} *13 x 10^{-2} m^2
2. Volume of the filtrate collected V = A x L= _____m^3
3. Cross sectional area of the plate = $A_f = \pi d_2^2/4$ = _____m^2
4. Weight of watch glass W_1 = _____g
5. Weight of wet cake + watch glass W_2 = _____g
6. Weight of wet cake $(W_2-W_1) = m_f$ = _____g
7. Weight of dry cake + watch glass W_3 = _____g
8. Weight of dry cake $(W_3-W_1) = m_c$ = _____g
9. Concentration of solids per unit volume of filtrate = $C^* = \dfrac{C_S}{1-\left\{\left(\dfrac{m_f}{m_C}-1\right)\dfrac{C_s}{\rho}\right\}}$

   C* = _____kg/m^3
10. Specific cake resistance = $\alpha = \dfrac{K_C * A_f^{\,2} * \Delta p}{C^* \mu}$ = _____ m/kg.
11. Filter medium resistance $R_m = \dfrac{\beta * A_f * \Delta p}{\mu}$ = _____/m

Graph



Results from the graph: Filtration pressure = 0.5 kg/cm^2

k_c = _____s/m^6

β = _____s/m^3

For the pressure of 1.0 kg/cm^2

k_c = _____s/m^6

β = _____s/m^3

Results: Filtration pressure = 0.5 kg/cm^2

Specific cake resistance α = _____m/kg

Filter medium resistance R_m = _____/m.

For the pressure of 1.0 kg/cm^2

Specific cake resistance α = _____m/kg

Filter medium resistance R_m = _____/m.

Experiment No: 5

AIR PERMEABILITY

Aim: - To determine the specific surface area of the given sample by conducting an experiment using air permeability technique.

Apparatus: - Stop watch, Measuring jar, Air permeability apparatus, Plunge, Beakers, weighing balance and Granite Powder (sample).

Theory: -Air permeability methods depend on the fact that at low flow rates the flow through a packed bed is directly proportional to the pressure difference the proportionality constant being proportional to the square of the specific surface (Surface to volume ratio) of the powder. From this method it is possible to obtain the diameter of the sphere with the same specific surface area of the powder. The reliability of the method is dependent upon the care with which the sample of powder is packed. The method is strictly only suitable for beds of uniformly packed particle and it is not a suitable method for measuring the size distribution of particle in the sub sieve range. In the apparatus air or another suitable gas flows through the bed contained in a cell and the pressure drop across the bed and the flow rate of air through the bed are obtained. If the diameters of the particle are below about 5 micron meter then slip will occur and this must be allowed for. This method is successfully used for measurement of surface area of cement, pigment, fine metal powders, pulverized coal and fine fibers.

Kozeny Carmann equation is used for the flow of fluids through bed of solids.

$$S_W^2 = \Delta P \in^3 \Phi_S / L*(1-\in)^2 * k\, \mu V \rho_s^2$$

Where S_w = specific surface area of sample (m^2/kg)

ΔP = pressure drop across bed (N/m^2)

L = Bed height (m)

$\in$ = Porosity of the bed

μ= viscosity of air (kg/m s)

V= velocity of air (m/s)

ρ_s = density of particle (kg/m^3)

Φs = Shape factor =1(for sphere)

k , the constant = 4.6

Procedure:

1. The tank is filled about $3/4^{th}$ of the total height with water which is indicated by the level indicator.
2. 6 g of the given sample is weighed and transferred into the sample holder. The graduated plunger is used for leveling and to measure the height of the bed.
3. The system is checked for air tightness by opening the bottom valve and while the top air valve is closed (no water should flow if the setup is air tight).

4. The tap at the bottom is opened so as to attain a certain flow rate. The manometer reading is taken when the liquid levels in the two tubes become steady.
5. The volume of water collected for 60 s is noted down.
6. Similarly the volume of water collected for different flow rates for 60seconds are noted.
7. The above steps are repeated for 8 g of sample being taken in the sample holder.

Tabular Column

Table : Observations and Calculations (6g of the sample)

Sl. No	Manometer reading, (cm)			ΔH m	Pressure drop, ΔP (N/m^2)	Water volume V, m^3	Time , s	Superficial velocity, v (m/s)	Porosity ∈	Specific surface area, S_w (m^2/kg)
	LHS	RHS	R_m							

Avg S_w=-------- m^2/kg

Table 2: Observations and Calculations (8g of sample)

Sl. No	Manometer reading, (cm)			ΔH m	Pressure drop, ΔP (N/m^2)	Water volume V, m^3	Time, s	Superficial velocity, v (m/s)	Porosity ∈	Specific surface area, S_w (m^2/kg)
	LHS	RHS	R_m							
										Avg S_w = --- m^2/kg

Specimen calculation: -

1. Height of the bed, L = _____ m.
2. Diameter of the bed, d = 3.4 x 10^{-2} m.
3. Cross sectional area of the bed, $A_B = \frac{\pi d^2}{4}$ = _____m^2
4. Manometer reading, R_m = _____m.
5. Pressure drop, $\Delta P = \rho g \Delta H$ = _____N/m^2
6. $\Delta H = R_m \{(\rho_m - \rho_f)/ \rho_f\}$ = m

7. Superficial velocity, $\bar{v} = V/\theta A_d$ = _____m/s

A_D = Cross sectional area of drain pipe, m^2 $= \pi D^2/4$

D = Diameter of the drain pipe = 6.35 mm

V= Volume of water collected in m^3

θ = Time of collection in seconds

8. Volume of the bed, $V_B = A_B \times L$ = _____m^3

9. Volume of particles, $V_p = \frac{amount\ of\ sample\ taken}{\rho_s}$ = _____m^3,

Where ρ_s is the density of the sample.

10. Porosity, $\in$ = $(V_B - V_p)/V_B$ or $\{1/\rho_B - 1/\rho_S\}/(1/\rho_B)$

ρ_B = Density of Bed.

ρ_B = Mass of sample taken/A_B * L

ρ_s = 2660 kg/m^3, Density of sample

11. $Sw = \frac{\left[\in^3 \times \Delta P\right]^{1/2}}{\left[4.6(1-\in)^2\ L{\rho_s}^2\ v\mu\right]^{1/2}}$ = _____m^2/kg

Viscosity of air=18.36 x 10^{-6} N-s/m^2
Density of air =1.129 kg/m^3

Result:

The specific surface area of the particles of the 6g sample is found to be S_w = _____ m^2/kg for porosity of ----

The specific surface area of the particles of the 8g sample is found to be S_w = _____ m^2/kg for porosity of ----

Experiment No: 6

SCREEN EFFECTIVENESS

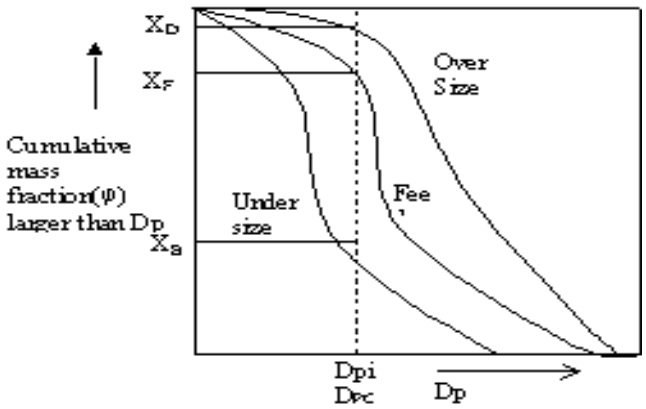
Aim: - To find the particle size distribution of a given sample and effectiveness of given screen.

Apparatus: - Sieve shaker, sieve set, balance & weights.

Theory: - Screening is a method of separating particles according to size alone. In industrial screening the solids are dropped on or thrown against, a screening surface. The undersize or fines pass through the screen openings; oversize, or tails do not. A single screen can make but a single separation in to two fractions. They are called unsized fractions, because although either the upper or lower limit of the particle sizes they contain is known, the other limit is unknown.

Comparison of ideal and actual screens: The objective of a screen is to accept a feed containing a mixture of particles of various sizes and separates it into two fractions, as under flow that is passed through the screen and an overflow that is rejected by the screen. Either one or both of these streams may be a product and in the following discussion no distinction is made between the over flow and under flow streams from the stand point of one's being desirable and other undesirable. An ideal screen would sharply separate the feed mixture in such a way that the smallest particle in the overflow would be just larger than the largest particle in the underflow. Such an ideal separation defines cut point diameter D_{pc} which marks the point of separation between the fractions, usually D_{pc} is chosen to be equal to the mesh opening of the screen.

Actual screens do not give a perfect separation about the cut point diameter instead the cumulative screen analysis of the under flow and over flow are like those shown in figure below. The closest separation is obtained with spherical particles on standard testing screens but even here there is an overlap between the smallest particle in the overflow and largest ones in the underflow. The overlap is especially pronounced when the particles are needle like or fibrous or where the particles tend to aggregate into clusters that act as large particles. Some long thin particles may strike the screen surface endwise and pass through easily while other particles of the same size and shape may strike the screen sidewise and be retained. Commercial screens usually give poorer separation than testing screens of the same mesh opening operating on the same mixture.



Mesh Opening (mm) – x axis
Cumulative mass fraction (range: 0-1)larger than D_p

Material balance over the screen: The equations are useful in calculating the ratio of feed, over size, and under size from the screen analysis of the three streams and knowledge of the desired cut diameter.

Let F= mass flow rate of feed
D=mass flow rate of over flow
B= mass flow rate of under flow
x_F = mass fraction of material A in feed
x_D= mass fraction of material A in overflow
x_B= mass fraction of material A in underflow
The mass fraction of material B in the feed, overflow and underflow are, 1- x_F, 1-x_D, & 1- x_B.

Since the total material feed to the screen must leave either as underflow or overflow.

$$F = D + B \quad \ldots i$$

The material A in the feed must also leave in those two streams and ___

$$F x_F = D x_D + B x_B \quad \ldots ii$$

Elimination of B from equation 1 and 2 gives: $D/F = (x_F - x_B)/(x_D - x_B)$ …iii

Elimination of D gives: $B/F = (x_D - x_F)/(x_D - x_B)$ …iv

The screen effectiveness or efficiency of a screen is a measure of the success of a screen in closely separating materials A and B. If the screen functioned perfectly all of materials A would be in the over flow and all of material B would be in the under flow. A common measure of screen effectiveness is the ratio of oversize material A that is actually in the over flow to the amount of A entering with the feed. These quantities are D x_D and F_{XF} respectively thus: $E_A = (D_{XD})/(F_{XF})$ ….v

Where E_A is the screen effectiveness based on the oversize. Similarly E_B is the screen effectiveness based on the undersize material is given by:

$E_B = B(1-x_B)/F(1-x_F)$ …vi

A combined effectiveness can be defined as the product of the two individual ratios. If this product is denoted E,

$E = E_A * E_B$

$E = D B x_D(1-x_B)/F^2 x_F(1-x_F)$ ….vii

Substituting D/F and B/F equations and into the above equation vii gives

$$E = (x_F - x_B)(x_D - x_F)\, x_D (1-x_B)/(x_D - x_B)^2 (1-x_F)\, x_F \quad \text{....viii}$$

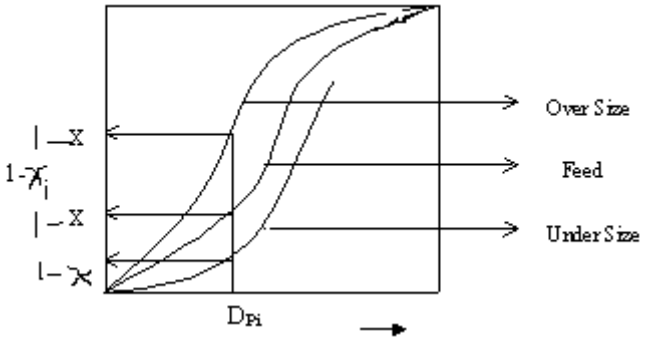
Procedure:

Sampling for screen analysis: Representative product of about 300 g by **cone and quarter method** is obtained. Given sample is mixed well and put together to form a cone. The cone is divided into four equal parts and two of them are considered. Once again quartered and two of them are considered. This quartering procedure is repeated to obtain about 300g. **OR**

Representative product of about 300g is obtained **by random sampling method**. Crushed sample is mixed well and about 300g is taken randomly for analysis.

1. 300g of sample is weighed.
2. The sieve set is arranged such that the largest mesh number is at the bottom and lowest mesh number is at the top.
3. The sample is transferred on to the top mesh and closed with lid.
4. **Feed analysis**: The sieve set is shaken in a sieve shaker (gyratory or rotap) for 5minutes and the weights retained in each mesh are found.
5. Separation of the sample as **oversize and undersize**: The same sample is taken in a particular mesh number (say 100) of which the effectiveness is to be determined. The sieve is shaken manually or using the mechanical shaker for about 5 minutes and the weight retained on the mesh are noted as oversize and the material screened through the mesh as under size.
6. **Over size and the under size analysis**: Oversize and undersize material is screened separately. Oversize and undersize material is screened using specified set of sieves for 5 minutes in a sieve shaker. The weights retained in each mesh are recorded for both oversize and undersize.

Graph:



Mesh opening D_P : x-axis

Cumulative mass fraction (Range: 0-1) smaller than D_P : y- axis

Specimen calculations: $E = (x_F - x_B)(x_D - x_F)\, x_D (1-x_B) / (x_D - x_B)^2 (1-x_F)\, x_F$

Where x_F =Cumulative mass fraction of the feed

x_D = Cumulative mass fraction of over size.

x_B = Cumulative mass fraction of under size.

Table: Observations and calculations of feed analysis

Sl. No	Mesh. No (BSS)	Aperture Size D_{pi} mm	Weight/Mass Retained in g, W_i	Weight/Mass Fraction = W_i/W	Cumulative Weight/Mass Fraction larger than D_{Pi} (x_i)	Cumulative weight fraction smaller than D_{Pi} $1-x_i$
01	25	0.6			w_1	
02	44	0.351			$w_1+ w_2$	
03	60	0.251			$w_1+w_2+ w_3$	
04	100	0.151				
05	150	0.104				
06	170	0.089				
07	200	0.076				
08	Pan	0.0				
			$\sum W_i= W$			

Table: Observations and calculations of oversize analysis

Sl. No	Mesh. No (BSS)	Aperture Size D_{pi} mm	Weight Retained, g W_i	Weight/Mass Fraction = Wi/W	Cumulative Weight/Mass Fraction larger than D_{Pi} (x_i)	Cumulative weight fraction smaller than D_{Pi} $1-x_i$
01	18	0.842			w_1	
02	25	0.6			$w_1+ w_2$	
03	52	0.296			$w_1+w_2+ w_3$	
04	72	0.211				
05	100	0.152				
06	120	0.124				
07	170	0.089				
08	Pan	0.0				
			$\sum W_i= W$			

Table: Observations and Calculations of undersize analysis

Sl. No	Mesh. No (BSS)	Aperture Size D_{pi} mm	Weight Retained , g W_i	Weight/Mass Fraction = Wi/W	Cumulative Weight/Mass Fraction larger than D_{Pi} (x_i)	Cumulative weight fraction smaller than D_{Pi} $1-x_i$
01	72	0.211			w_1	
02	85	0.178			$w_1+ w_2$	
03	100	0.152			$w_1+w_2+ w_3$	
04	120	0.124				
05	150	0.104				
06	170	0.089				
07	200	0.076				
08	Pan	0.0				
			$\sum W_i= W$			

Result: The efficiency or effectiveness of the given screen (Mesh No. =100) is:_____

Experiment No: 7

DROP WEIGHT CRUSHER

Aim: - To determine the Rittinger's law constant Kr & Kick's law constant K_K by carrying out crushing operation in a drop weight crusher and to verify the laws of crushing.

Apparatus: - Drop weight crusher, sieve set, weighing balance, and screen shaker.

Theory: - The crushing operation is carried out to effect the size reduction. During size reduction new surface area is created. Since a unit area of a solid has a definite amount of surface energy the creation of new surface requires work to be done which is supplied by the release of energy when the particles break. The basic law of crushing and its energy is given as $dE/dL = -CL^P$ ….(.i)

Where L is the size of the particle .By giving 3 different values to P we get 3 different laws. When P= - 2 , Rittinger's law results

$E = P/W = K_R [1/D_P – 1/D_F]$ ….(ii)

P= power required.

W = Mass of materials crushed.

Where K_R =Rittinger's law constant

D_P =product size. m

D_F =feed size. m

E = energy required, J,Where P= -1 we get Kick's law i.e.

$E = P/W = K_K [\ln D_F / D_P]$

Where K_K =Kick's law constant

When P = -3/2, Bond's law constant can be obtained

$E = P/W = K_B (1/\sqrt{Dp} – 1/\sqrt{D_F})$ ..(iii)

K_B= Bond's law constant.

Work Index: -It is the energy required for material to crush from a very large size feed to a product such that 80% passes through a 100 micron mesh. We have work index

$W_I = K_B\sqrt{100} \times 10^{-3}$ kW h/t

Energy required E =m g h n ….(iv)

m = mass of bob

h = height through which bob has fallen

n = number of times the bob has fallen down

g = acceleration due to gravity

Procedure: -

1. The feed sample is prepared by screening sample through 8 and 10 mesh. Collect the sample, which is retained on 10 mesh and passes through 8 mesh.
2. About 70 g of this sample is weighed and placed in a crushing zone in a drop weight crusher.
3. Bob (weight) is dropped from a known height about 40times. The product is mixed using spatula after every 5 drops for uniform mixing.
4. Sample after the crushing is subjected to screen analysis and weight retained on each mesh is noted. From the data, average size of product is determined.
5. The experiment is repeated for the same product about 20 more drops. (total 30 + 20 = 50 drops)
6. The weight of the bob is noted.
7. The height through which the bob has fallen is noted.
8. Using the data, energy and the law constants are determined.

Data:

Weight of crusher = 1 kg
Weight of Feed = 70 g
Height of fall = 1 m
Size of feed = 1.854 mm

Table: 1

Sl. No.	Mesh No. BSS	Aperture Size D_{pi} mm	Average aperture size $\overline{D_{pi}}$,mm	Weight retained (W_i)	
				40 drops	80 drops
01	8	2.032			
02	10	1.676			
02	18	0.833			
03	25	0.592			
04	44	0.351			
05	72	0.211			
06	100	0.151			
07	120	0.124			
08	150	0.104			
09	Pan	0.0			
				$\sum W_i = W$	$\sum W_i = W$

Table 2:Calculations

Weight fraction $w_i = W_i / W$		Cumulative weight fraction, x_i		$w_i / D_{Pi\ ave}$	
40	80	40	80	40	80
				$\Sigma(w_i / D_{Pi\ ave})$	$\Sigma(w_i / D_{Pi\ ave})$

Specimen Calculations:

E =m g h n/ W = _____ J/kg

Mass of the bob (weight), m = _____ kg

Height of the column from where the bob is dropped, h = _____m

Weight of the sample taken (Run-1), n = 40 = _____ g

Weight of the sample taken (Run-2), n = 80 = _____ g

Feed size, D_F = - 8 # + 10 # {(2.032+1.676)/2 = 1.854 = 1.854 mm

Where g = acceleration due to gravity = 9.81 m/s^2

Cumulative weight fraction, x_i	w_1	$w_1 + w_2$	$w_1 + w_2 + w_3$

Volume surface mean diameter of the sample, $D_p = 1 / \Sigma(w_i / D_{Pi\ ave})$

Rittinger's law: $E = K_R [1/D_P - 1/D_F]$ = _____ J/kg.
So, $K_R = E/[1/D_P - 1/D_F]$ J m /kg.

Kick's law: $E = K_K \ln [D_F / D_P]$ = _____ J/kg

So, $K_K = E/ \ln[D_F / D_P]$ = J/kg

Verification of the laws : Find the ratios of law constants (K_{R1}/ K_{R2}) and (K_{K1}/K_{K2}). The ratio closure to one represents the valid law.

Result: - For n=50

K_R =Rittinger's law constant for, = _____ J m /kg

K_K =Kick's law constant for, = _____J/kg

For n=70

K_R = Rittinger's law constant for, = _____ J m /kg

K_K =Kick's law constant for, = _____J/kg

The valid law for drop weight crusher =

Reduction ratios are =

Experiment No: 8

AIR ELUTRIATION

Aim: - To determine the average particle size differentially and cumulatively and frequency distribution curves.

Apparatus: Elutriator setup, weighing balance, sample collecting bottles.

Sample Used: Granite powder

Theory: - Materials can be separated by means of an elutriator, which consists of a vertical tube in which fluid is passed at a controlled velocity. The particles are introduced through a side tube for continuous operations or sample holder is attached for batch operations. The smaller particles are carried over in the fluid stream while the larger particles settle against the upward current. Further sized fractions can be corrected if the over flow from the first tube is passed vertically upwards through a second tube of the greater cross section. Any number of such tubes can be arranged in series. Other fractions can also be collected by changing the fluid velocity with the same set up.

Cyclones are used primarily for the separation of solids from fluids and utilize the centrifugal force to effect the separation. Such a separation depends not only on the particle size but also on the particle density so that the cyclones may be used to effect a separation on the basis of particle size or particle density or both.

The apparatus consists of a short vertical cylinder closed by a flat or dished plate on top and by a conical bottom. The air with its load of solid is introduced tangentially at the top of the cylindrical portion. Centrifugal force throws the solid particles out against the wall and they drop into the hopper. Terminal velocity is given by

$$U_t = \frac{g\, D_P^2(\rho_s - \rho_{air})}{18\,\mu} \quad m/s$$

Where D_p = diameter of the particle in m

ρ = Density of the sample, kg/m^3

ρ_{air} = Density of elutriating air, kg/m^3

μ. = Viscosity of air, Ns/m^2

Procedure: -

1. The density of air at room temperature is determined using ideal gas law and viscosity of air is found from Chemical Engineer's handbook Perry.
2. Using Stoke's equation the terminal settling velocities of different ranges of particles are determined and the corresponding manometer readings to be maintained are noted down from the given calibration chart.

Assumption: Sizes greater than 1μm are to be assumed. Since this method should not be used for sub sieve range. The size range with the difference of square root of 2 starting from 60μm to 240 μm.

3. Exactly 2g of the sample is weighed and put into the sample holder.
4. The flow rate of air is adjusted using manometer and maintained constant for about 5 minutes so that all particles between say $30\sqrt{2}$-60μ size are elutriated.
5. The fraction of the sample in the previously weighed bottle is collected from the cyclone separator.
6. The collected sample is weighed.
7. The procedure is repeated for different flow rates so that all particles between the next size fractions are elutriated into different bottles.

Experimental set up:

Observations:

1. Ambient temperature = _____ ^{0} C
2. Density of air at ambient temperature, ρ_{air} = _____kg/m^3

   Density of ρ_{air} = PM/RT

   P = Atmospheric pressure = 1.0133 x 10^5 N/m^2

   M = Molecular weight of air = 29

   R = Gas constant = 8314 J/ k mol, k

   T = Ambient temperature in, k
3. Viscosity of air at ambient temperature, μ = _____Ns/m^2

   (Approximately = 18 x 10^{-6} N s/m^2)
4. Density of granite sample, ρ_s = 2660 kg/m^3
5. Diameter of Elutriator tube, D_e = 2.8 cm

Table 1:

Sl. No	Particle size, D_p(μm)	Terminal settling velocity, U_t m/s	Flow rate, $Q = U_t/\{A_e)$ m^3/s	Manometer reading, R_m ,cm
01	30			
02	$30\sqrt{2}$			
03	60			
04	$60\sqrt{2}$			
05	120			
06	$120\sqrt{2}$			

Table 2:Calculations

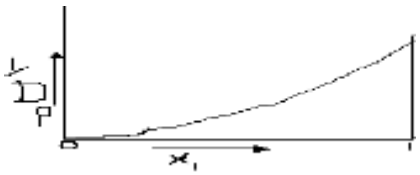
Sl. No	Size range (μ)	Average size (D_{Pave}) (μ)	Weight Retained, g , W_i	Weight fraction $w_i = W_i/W$	$w_i/(D_{Pave})$	Cumulative Wt fraction (x_i), larger than D_P	Cumulative Wt fraction ($1- x_i$), smaller than D_P
01	15√2-30					w_1	1.0
02	30-30√2					$w_1+ w_2$	
03	30√2-60					$w_1+w_2+ w_3$	
04	60-60√2						
05	60√2-120						
06	120-120√2					1.0	0.0
			$\sum W_i=W$		$\sum w_i/(D_{pave})$		

Specimen Calculations:

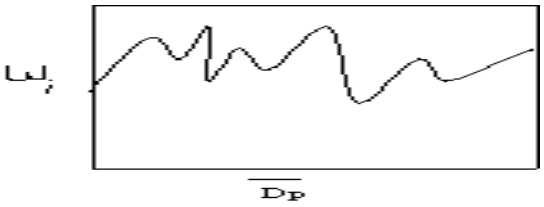
1. $U_t = g D_p^2(\rho_s- \rho_{air})/18\mu$ = _____m/s
2. Area, $A_e = \pi D_e^2/4$ = _____m^2
3. Volumetric flow rate of air through elutriator tube, $Q= U_t *A$ = _____m^3/s
4. Average sample size, $D_{p\ Sample} = 1/ \sum w_i/D_p$

The average sample size by cumulative analysis :

Graph: Draw the graph of $1/D_{p\ ave}$ Vs x_i and find the area under the curve.



Sample $D_{p\ avg}$ = 1/area under the curve
Y- Axis range 0-1
To plot frequency distribution curve using mass fraction and particle size



Result: - The average size of the sample:
Differentially
Cumulatively

Experiment No: 9

BEAKER DECANTATION

Aim: To determine the average particle size of the given powdered sample by beaker decantation method and also to plot the particle size distribution curves.

Sample used: $CaCO_3$ (commercial grade).

Apparatus: 6 (1liter capacity) beakers, stopwatch, 6 filter papers, 6 funnels, stirrer, weighing balance etc.

Theory: When size separations are to be carried out on particles too small to screen effectively(less than 50μm) or where very large tonnages are to be handled, methods involving the differences in the rates of settling of particles of different sizes and of different materials are used. For example two particles of different settling rates in water are placed in an upward flowing water stream. If the velocity of the water is adjusted so that it lies between the settling rate of two particles, the slower particle will be carried upward, the faster particle will move downward against the water stream and separation is thereby attained.

Another method would be to send a slow stream of water horizontally through a tank of water. If the two particles are carried into the box by the entering water, they will both start to settle. Each will be carried horizontally at substantially the same rate, but the faster settling particle will reach the bottom of the tank before the slower settling particle and will be found nearer the entrance end of the tank than its slower companion. Such classification methods are not very simple. The settling rate of the particle depends on its shape also. Water velocities in any one c/s of the classifying device are not uniform. Hence such processes do not give fractions having all the particles in a relatively small size range but rather fractions having a mixture of sizes with the average size smaller in one fraction and larger in the other.

Procedure:

1. The terminal settling velocities using Stoke's equation of different ranges of particles and also the time of settling are calculated using height of settling All the particles are assumed to be at the top surface initially.
2. Six equal size filter papers are cut, numbered, dried and then weighed.
3. Six beakers of equal size and shape are taken and are numbered.
4. Water is taken up to the mark in the first beaker i.e. 12 cm from the bottom.
5. A known amount of sample (2 g) is added to the beaker and stirred vertically in order to minimize centrifugal action.
6. The stirrer is removed from the water suspension and simultaneously the stopwatch is started.
7. This homogeneous suspension is allowed to settle for predetermined time (corresponding to the terminal settling velocity of largest size particle).
8. Water from the first beaker is carefully decanted into the second beaker leaving about 1cm of water in the beaker, which corresponds to the settled particles.

9. Fresh water is added to the second beaker to make up to the mark (12cm), stirred well, and again allowed to settle for the calculated time to the next larger particle size.
10. This is continued till the last beaker, the water in the last beaker is discarded leaving 1cm in the bottom for collection of particles. The particles remaining in each beaker is weighed after filtering and drying.
11. Weight of the empty filter paper is subtracted.

Observations & Data

1. Density of solids = ρ_S = 2560 kg/m^3
2. Density of water = ρ_f = 1000 kg/m^3.
3. Viscosity of water = μ_f = 0.98 x 10^{-3} Ns/m^2
4. Acceleration due to gravity = g = 9.81 m/s^2
5. Particle size 60, 60/√2, 30, 30/√2, 15, 15/√2 μm respectively
6. Weight of the sample taken= 2 g
7. Height of settling=12 cm

Specimen Calculations:

1. Terminal velocity, $U_t = \frac{g D_p^2 (\rho_s - \rho_f)}{18 \mu_f}$ = _____m/s

2. Time, $\theta = H / U_t$ = _____s

Method of calculating cumulative weight fraction

Cumulative weight fraction, x_i	Sample weight, w_1, w_2	$w_1 + w_2$	$w_1 + w_2 + w_3$

3. Average particle size of sample, $D_{p\,avg} = 1/\sum w_i/D_{P\,aveg}$ = _____μm

Table 1:

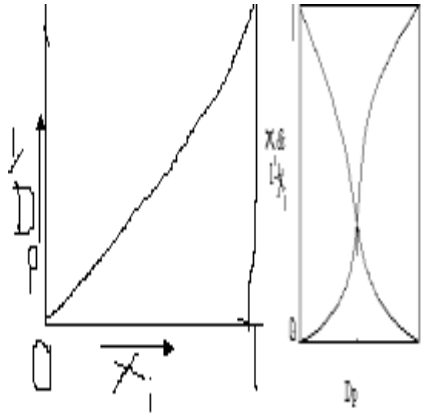
Sl. No.	Particle size, D_p(μm)	Terminal velocity, U_t, m/s	Height H m	Time θ	Weight of Empty Filter paper in g	Weight of sample (alone), W_i, g
01	60					
02	60/√2					
03	30					
04	30/√2					
05	15					
06	15/√2					

Table 2:

Sl. No.	Size range (μm)	Average size, (m) $D_{P\ ave}$	Weight of sample W_i	Weight fraction, $w_i = W_i/W$	w_i/D_{Pave}	Cumulative wt fraction x_i, larger than D_p	Cumulative weight fraction $(1- x_i)$ smaller than D_P
01	$60\sqrt{2} – 60$						
02	$60 – 60/\sqrt{2}$						
03	$60/\sqrt{2} – 30$						
04	$30 – 30/\sqrt{2}$						
05	$30/\sqrt{2} – 15$						
06	$15 – 15/\sqrt{2}$						
			$\sum W_i = W$		$\sum w_i/D_{Pave}$		

Particle size distribution of sample: Draw the graph and find the area under the curve
$D_{p\ avg}$ = 1/area under the curve

Nature of Graph:



Result:

1. Average particle size, calculated = _____μm

2. Particle size distribution curve is plotted

Experiment No: 10

LEAF FILTER

Aim: To determine the specific cake resistance (α) and filter medium resistance (R_m) by filtering $CaCO_3$ slurry in a vacuum leaf filter apparatus.

Apparatus: Leaf filter setup, stopwatch, water, bucket (to prepare the slurry), two watch glasses, weighing balance, hot air oven.

Sample: $CaCO_3$(Commercial Grade)

Theory: - Filter is a device that separates solids from fluids through a membrane called filter medium. This is done by applying pressure difference between slurry inlet and filtrate outlet. In this case vacuum is created with the help of a vacuum pump, so that filtrate is forced through the equipment. During filtration the solids form the solid bed of particles and stick to the lower part of the leaf filter. Two types of resistances are offered by the filtration unit.(1) the resistance of the cake (2) the resistance of the filterer medium. Filter press although it is well adapted for many purposes, it is not so economical for handling the large quantities of sludge or for efficient washing with a small amount of wash water, because of the channeling that always takes place in a washing press. Thus leaf filters were introduced which require less labor. But the first cost of this filter is higher and the filters are somewhat more complicated. Flow rate dt/dv is given by the following formula

$dt/dv = K_p V_{ave} + \beta$

$K_p = C \alpha \mu / A^2 (\Delta p)$

$\beta = R_m \mu / A (\Delta p)$

$C = C_s / \{1-(m_f/m_s - 1) C_s / \rho\}$

Note: After integration the equation becomes $t/v = (K_p/2) V + \beta$

Where
- C = concentration of filtrate, kg/m^3
- C_s = concentration of slurry, kg/m^3
- ρ = Density of water, kg/m^3
- μ = viscosity of filtrate, kg /m s
- A = Area of filter , m^2
- Δp = pressure difference across filter medium, N/m^2
- m_f = weight of wet cake, g
- m_s = weight of dry cake, g
- α = Specific cake resistance m/kg
- R_m = Filter medium resistance in /m

Procedure:

1. 4 litre of 4 % $CaCO_3$ slurry is prepared by weighing 160g $CaCO_3$ powder in 4 litre of water
2. Two dry empty watch glasses are weighed.
3. 5litre of this slurry is transferred to the slurry tank and the slurry in the slurry tank is mixed by switching on the stirrer.
4. The pressure is adjusted to the required value by placing the leaf in water taken in a bucket.
5. The filter cloth is placed on to the leaf and the leaf is kept in the tank, thus equipment is set to filter the slurry.
6. The pressure of 100mm Hg is set on the pressure gauge and maintained constant throughout the experiment.
7. The rise in the filtrate level is observed as soon as the vacuum pump is switched on.
8. The time taken for every 2 cm rise in the filtrate level is recorded (cumulated time).
9. Leaf is lifted from the tank to collect a small quantity of the cake on a previously weighed watch glass. The vacuum pump is switched off. The weight of wet cake is noted. The cake is dried and the dry weight is noted.
10. Repeat the above steps by preparing the fresh slurry for 200 mm Hg pressure.

Observations:

1. Diameter of the filtrate tank = d_1 = 0.08 m
2. Diameter of the leaf =d_2 = 0.105 m
3. Pressure ΔH = 100 mm Hg or 100 x 10^{-3} m Hg
4. Pressure applied $\Delta p = \rho_{Hg}\, g\, \Delta H$ = 13600 x 9.81x100x10^{-3} Hg
   =13.341x 10^3 N/m^2
5. Viscosity of the filtrate, μ = 0.98 x 10^{-3} Ns/m^2(Assuming as that of water)
6. Density of sample = 2560 kg/m^3
7. Density of water = 1000 kg/m^3
8. Initial concentration of $CaCO_3$ = Cs, kg/m^3 =

   Sample wt./{sample wt./ sample density+ water wt./water density},

Table 1: Observations and Calculations

SL No.	Filtration pressure drop, Δp (mm Hg)	Weight of watch glass W_1(g)	Weight of wet cake + watch glass W_2(g)	Weight of dry cake + watch glass W_3(g)	Weight of wet cake (W_2-W_1) (g)	Weight of dry cake (W_3-W_1) (g)

Table: Sample calculations

Sl No.	Filtrate level L (m)	Volume of filtrate collected V, (m^3)	$\Delta V = V_2 - V_1$ (m^3)	$V_m = \frac{V_1 + V_2}{2}$ m^3	θ s	$\Delta\theta = \theta_2 - \theta_1$ (s)	$\Delta\theta/\Delta V$ s/m^3
	0	0	$5.026*10^{-05}$				
	1	$5.026*10^{-5}$	$5.026*10^{-5}$	$2.5133*10^{-5}$			
	2	$10.026*10^{-5}$	$5.026*10^{-03}$	$7.54*10^{-5}$			
	3	$15.026*10^{-5}$	$5.026*10^{-03}$	$12.513*10^{-5}$			
	4	$20.026*10^{-5}$	$5.026*10^{-03}$	$17.5*10^{-5}$			

Table: observations and Calculations

Sl No.	Filtrate level L (m)	Volume of filtrate collected V, (m^3)	$\Delta V = V_2 - V_1$ (m^3)	$V_m = \frac{V_1 + V_2}{2}$ m^3	θ s	$\Delta\theta = \theta_2 - \theta_1$ (s)	$\Delta\theta/\Delta V$ s/m^3

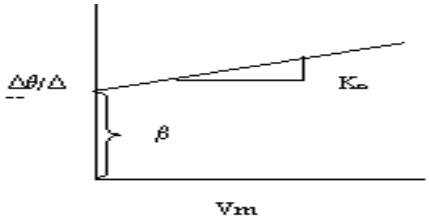
Specimen Calculations:

1. Cross sectional area of the filtrate tank A= $\pi d_1^2/4$ $5.026*10^{-3}$ m^2
2. Volume of the filtrate collected V = A x L = _____m^3
3. Cross sectional area of the leaf = $A_f = \pi d_2^2/4$ = $8.659*10^{-3}$ m^2
4. Weight of watch glass, W_1= _____g
5. Weight of wet cake + watch glass W_2= _____g
6. Weight of wet cake (W_2-W_1)= m_f = _____g
7. Weight of dry cake + watch glass , W_3= _____g
8. Weight of dry cake (W_3-W_1) = m_c = _____g

9. Concentration of solids per unit volume of filtrate = $C^* = \dfrac{C_S}{1-\left\{\left(\dfrac{m_f}{m_C}-1\right)\dfrac{C_s}{\rho H_2 o}\right\}}$

C* = _____kg/m^3

Plot a graph of $\Delta\theta/\Delta V$ Vs V_m



From graph: k_c = _____s/m^6

β = _____s/m^3

10.

Specific cake resistance = $\alpha = \dfrac{K_C * A_f{}^2 * \Delta p}{C * \mu}$ = _____ m/kg

11. Filter medium resistance $R_m = \dfrac{\beta * A_f * \Delta p}{\mu}$ = _____/m

Result: **Pressure = 100 mmHg**

Specific cake resistance, α = _____m/kg

Filter medium resistance, R_m = _____/m

Pressure = 200 mmHg

Specific cake resistance, α = _____m/kg

Filter medium resistance, R_m = _____/m