Rajiv Gandhi University of Knowledge Technologies

Department of Chemical Engineering

Mechanical Unit Operations Lab

(CH2802)

Course Objectives:

- To enable the students to develop a sound working knowledge on different types of crushing equipments and separation characteristics of different mechanical operation separators

List of Experiments:

S.No	Name of the experiment
1.	Ball mill
2.	Cyclone separator
3.	Froth floatation
4.	Gyratory sieve shaker
5.	Jaw crusher
6.	Plate and frame filter press
7.	Sedimentation studies apparatus

Course Outcomes:

By the end of this course, the student should be able to:

- Design a mixed tank, calculate its power requirements and scale-up the design.
- Understand and apply the basic methods of characterization of particles and bulk solids, e.g. Average particle size, settling velocity.
- Describe the operation of filter processes and types of filters used to perform solid-liquid separations, and calculate their power requirements.

BALL MILL (MO-104)

(VARIABLE SPEED)

Foreword

Welcome to the fast growing family of K.C. product owners. We appreciate your interest in us and thank you for buying our product.

You have chosen the finest quality product in the market which is produced using latest techniques and has underwent strict quality control tests. It is a product that we are proud to build and you are proud to own it.

Our products are easy to understand and operate. They are excellent for students who are trying to gain practical knowledge through experiments.

However your comfort and safety are important to us, so we want you have an understanding of proper procedure to use the equipment. For the purpose, we urge you to read and follow the step-by-step operating instructions and safety precautions in this manual. It will ensure that your favourite product delivers reliable, superior performance year after year.

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Contents

BALL MILL

(VARIABLE SPEEDS)

1. OBJECTIVE:

To study the operation of a ball mill.

2. AIM:

2.1 To calculate the efficiency of a ball mill for grinding a material of known work index (W_i).

2.2 To study the effect of RPM on the power consumption of ball mill.

2.3 To calculate the critical speed ($n_{c)}$ of ball mill.

3. INTRODUCTION:

Generally the ball mills are known as the secondary size reduction equipment. The ball mill is made in a great many types and sizes and can be used on a greater variety of soft materials than any other type of machine. The feed must be non-abrasive with a hardness of 1.5 or less. A ball mill consists of a cylindrical shell slowly turning about a horizontal axis and filled to about 1/4th of its volume with solid grinding medium (i.e. metallic balls etc.). When the ball mill is rotated, the grinding elements (balls) are carried to the side of the shell nearly to the top, from where; they fall on the particles under gravity. In a ball mill most of the size reduction is done by impact. The energy expanded in lifting the grinding units are utilizes in reducing the size of the particles. Ball mill can accept a feed size of 12mm or less and deliver a product size in the range of 50μm. The speed of ball mill varies between 60 to 70 RPM. As the product size become fines, the capacity of a mill reduces the energy requirement increases.

4. THEORY:

A ball mill consists of a cylindrical shell slowly turning about a horizontal axis and filled with solid grinding medium (metallic balls, wooden balls or rubber balls). In ball mill most of the size reduction is done by impact.

CRITICAL SPEED OF A BALL MILL (n_c):

$$n_c = \frac{1}{2\pi} \times \sqrt{\frac{g}{R-r}}$$ ------------- (1)

Where n_c is critical rotational speed, R is radius of the ball mill and r is radius of the ball.

For effective operation of the mill, the mill should be operate at 65 to 80 % of critical speed. As the product size becomes finer, the capacity of a mill reduces and the energy requirement increases. As the speed of the mill exceeds n_c (i.e. mill is centrifuging the size reduction capacity decreases.)

BOND CRUSHING LAW AND WORK INDEX:

A more realistic method of estimating the power required for crushing and grinding is

$$\frac{P}{m} = \frac{K_b}{\sqrt{D_p}}$$ ------------- (2)

Where K_b is a constant which depends on the type of machine and on the material being crushed, D_p is in millimeters, P in kilowatts and m in tons per hour.

W_i is defined as the gross energy requirements in kilo watt hours per ton of feed

needed to reduce a very large feed. This definition leads to a relation between K_b and W_i.

$$K_b = 0.3162 * W_i$$ ------------- (3)

If 80 percent of the feed passes a mesh size of D_{pa} mm and 80 percent of the product a mesh of D_{pb} mm, it follows from eq (1) & (2).

$$\frac{P}{m} = 0.3162 \times W_i \left(\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right)$$

$$P = m \times 0.3162 \times W_i \left(\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right)$$ -------------- (4)

5. DESCRIPTION:

The present laboratory ball mill consist a shell is fabricated from thick steel. It contain balls. A revolution counter is provided to find the number of turns. A guard is provided on gear for safety purposes. An opening and tightening arrangement is provided in the centre of the shell to feed and to take off the material. Power is given by HP motor coupled with horizontal gearbox. Drive is provided to vary the RPM. A RPM indicator with proximity switch is provided in the set-up.

6. Utilities Required:

6.1 Electricity Supply: Single phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Floor Area Required 1.5 m x 1 m.

6.3 Raw material for feed (size 5-8 mm).

6.4 Set of sieves with sieve shaker for analysis.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Prepare a uniform sized material for feed using sieve shaker (5mm to 8mm approx).

7.1.2 Fill the shell with the balls provided.

7.1.3 Ensure that all switches given on the panel are at OFF position.

7.1.4 Now switch ON the main power supply.

7.1.5 Set the revolution counter to zero position.

7.1.6 Switch ON the MCB and then starter to run the machine.

7.1.7 Run the machine at no load condition by determining the time for 10 or 20 pulses on the energy meter.

7.1.8 Switch OFF the starter and then MCB.

7.1.9 Fill the Feed in the ball mill.

7.1.10 Switch ON the MCB and then starter to run the machine.

7.1.11 Run the machine at loaded condition by determining the time for 10 or 20 pulses on the energy meter.

7.1.12 Repeat the experiment for different RPM.

7.2 Closing Procedure:

7.2.1 When experiment is over switch OFF the power supply.

8. Observation & Calculation:

8.1 Data:

Radius of the ball r	= 0.011 m
Radius of the ball mill R	= 0.1375 m
Acceleration due to gravity g	= 9.81 m/sec^2
Energy meter constant EMC	= 3200 Pulses/kWh

Work Indexes Of Some Common Minerals

Material	Work Index (W_i)
Bauxite (sp.gr =2.20)	8.78
Cement climker (sp.gr =3.15)	13.45
Coal (sp.gr =1.40)	13.00
Coke (sp.gr =1.31)	15.13
Gravel (sp.gr =2.66)	16.06
Gypsum rock (sp.gr =2.69)	6.73
Lime stone (sp.gr =2.66)	12.74
Quartz (sp.gr =2.65)	13.57

Observations:

W_f = _____ kg

t_c = _____ sec

D_{pa} = _____ mm

D_{pb} = _____ mm

8.2 OBSERVATION TABLE:

P_1	t_{p1} (sec)	P_2	t_{p2} (sec)

8.3 CALCULATIONS:

$$P_{NL} = \frac{P_1 \times 3600}{t_{p1} \times EMC} \text{ (kW)}$$

$$P_L = \frac{P_2 \times 3600}{t_{p2} \times EMC} \text{ (kW)}$$

$$P_{act} = P_L - P_{NL} \text{ (kW)}$$

$$m = \frac{W_f}{t_c} \times \frac{3600}{1000} \text{ (tons/h)}$$

$$K_b = 0.3162 \times W_i \text{ (kWh/tons)}$$

$$P_{cal} = m \times K_b \times \left[\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right] \text{ (kW)}$$

$$\eta = \frac{P_{act}}{P_{cal}} \times 100 \text{ (\%)}$$

$$n_c = \frac{1}{2\pi} \times \sqrt{\frac{g}{R - r}} \times 60 \text{ (RPM)}$$

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
D_{pa}	Average feed size	mm	Measured
D_{pb}	Average product size	mm	Measured
EMC	Energy meter constant	Pulses/kWh	Given
g	Acceleration due to gravity	m/sec^2	Given
K_b	Bond's constant	kWh/tons	Calculated

m	Feed rate	tons/h	Calculated
n_c	Critical speed of ball mill	RPM	Calculated
P_1	Number of pulses counted at no load condition	*	Measured
P_2	Number of pulses counted at loaded condition	*	Measured
P_{act}	Actual power required for crushing	kW	Calculated
P_{cal}	Calculated power required for crushing	kW	Calculated
P_L	Power consume by machine at loaded condition	kW	Calculated
P_{NL}	Power consume by machine at no load condition	kW	Calculated
R	Radius of the ball mill	m	Given
r	Radius of the ball	m	Given
t_c	Time for crushing	sec	Measured
t_{p1}	Time for P_1 pulses	sec	Measured
t_{p2}	Time for P_2 pulses	sec	Measured
W_f	Weight of feed taken	kg	Measured
W_i	Work index of material	kWh/tons	Given
η	Crushing efficiency	%	Calculated

* Symbols are unit less.

10. Precaution & Maintenance Instructions:

10.1 Never run the apparatus if power supply is less than 180 volts and more than 230 volts.

10.2 Revolution counter should be zero before start.

10.3 Coupling fixing pin should be fixed after attached the ball mill coupling.

10.4 Don't attach or detach the coupling during the experiment.

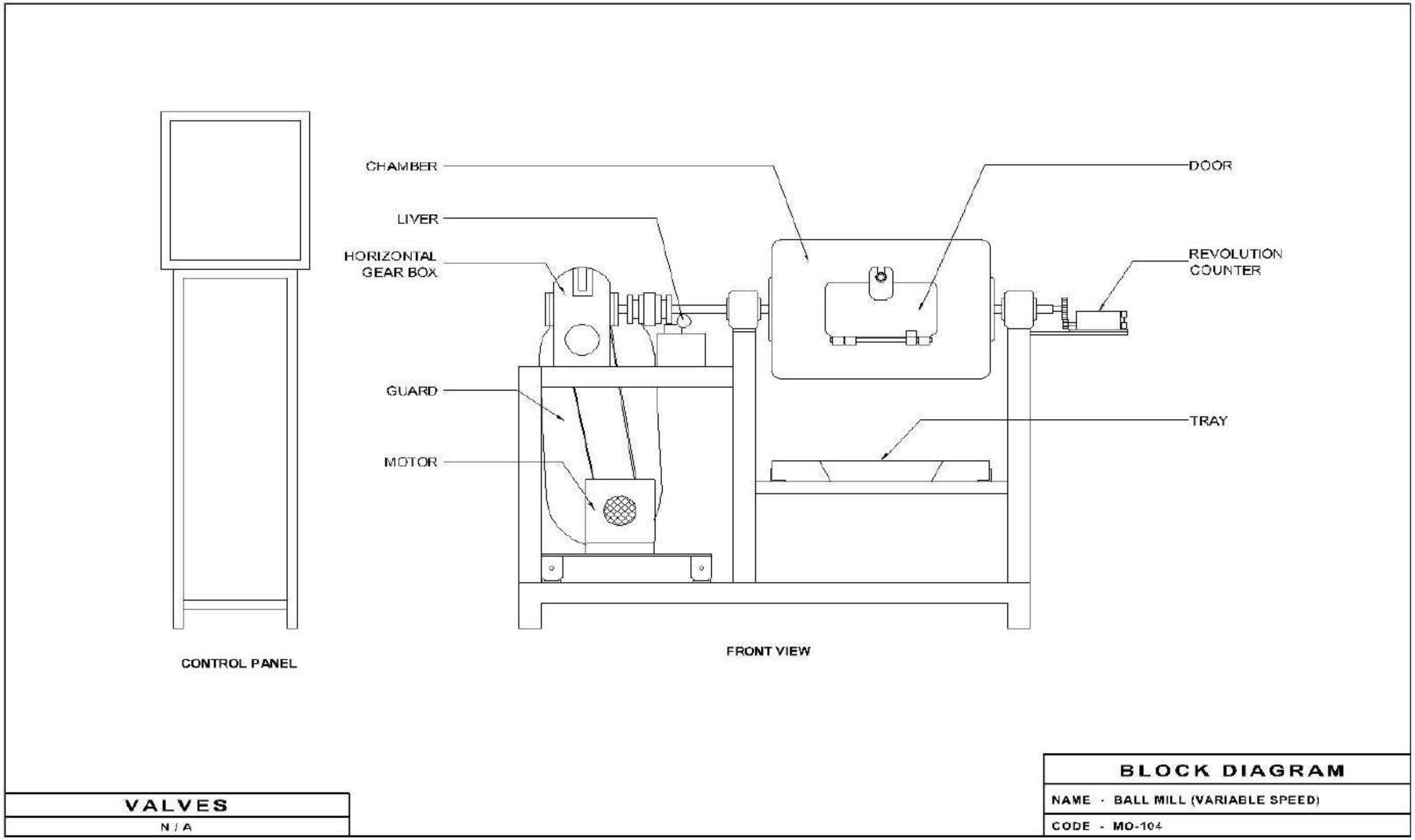
11. Troubleshooting:

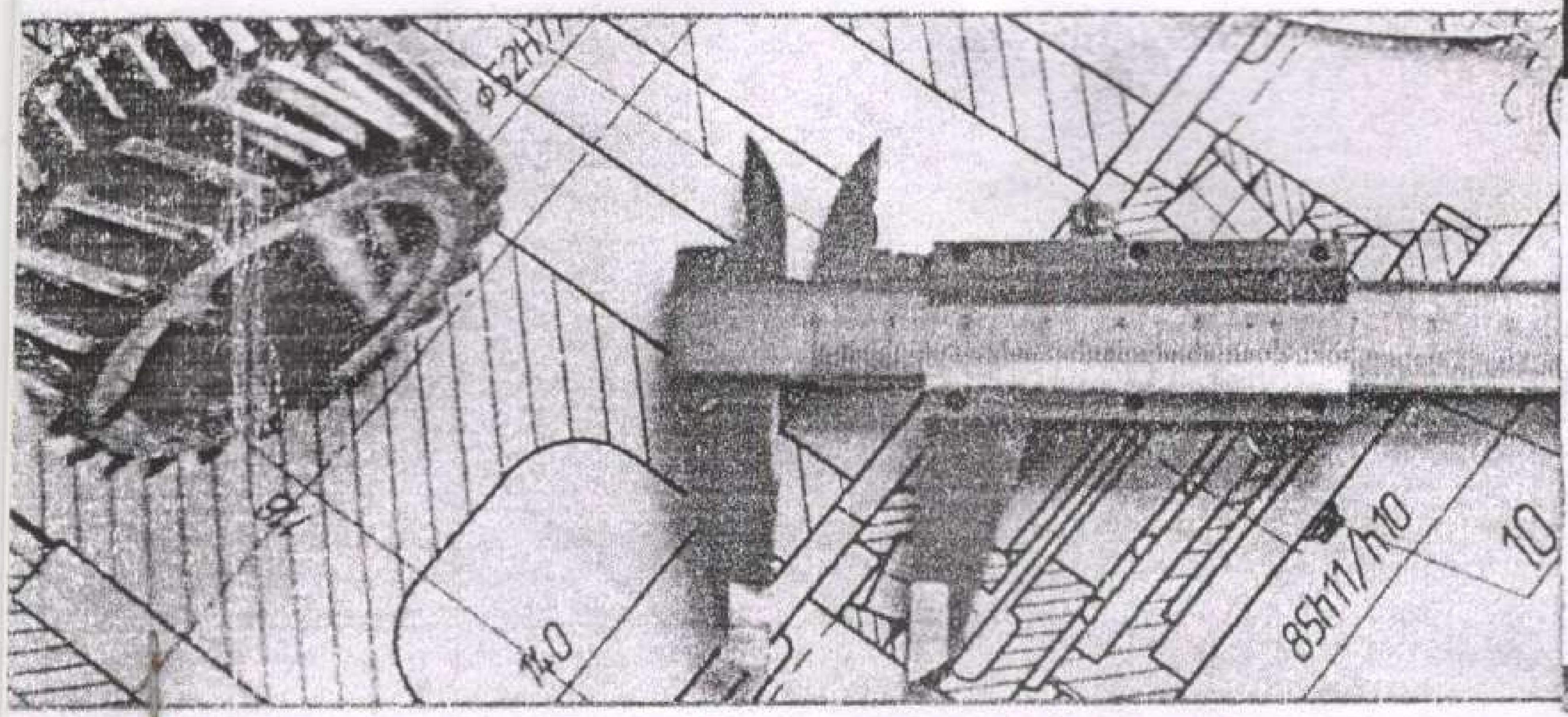
11.1 If the motor is not working check the electric connection.

12. References:

12.1 McCabe, Warren L. Smith, Julian C. Harriott, Peter (2005). *Unit Operations of Chemical Engineering.* 7th Ed. NY: McGraw-Hill. pp 985-986, 992-993.

13. Block Diagram:





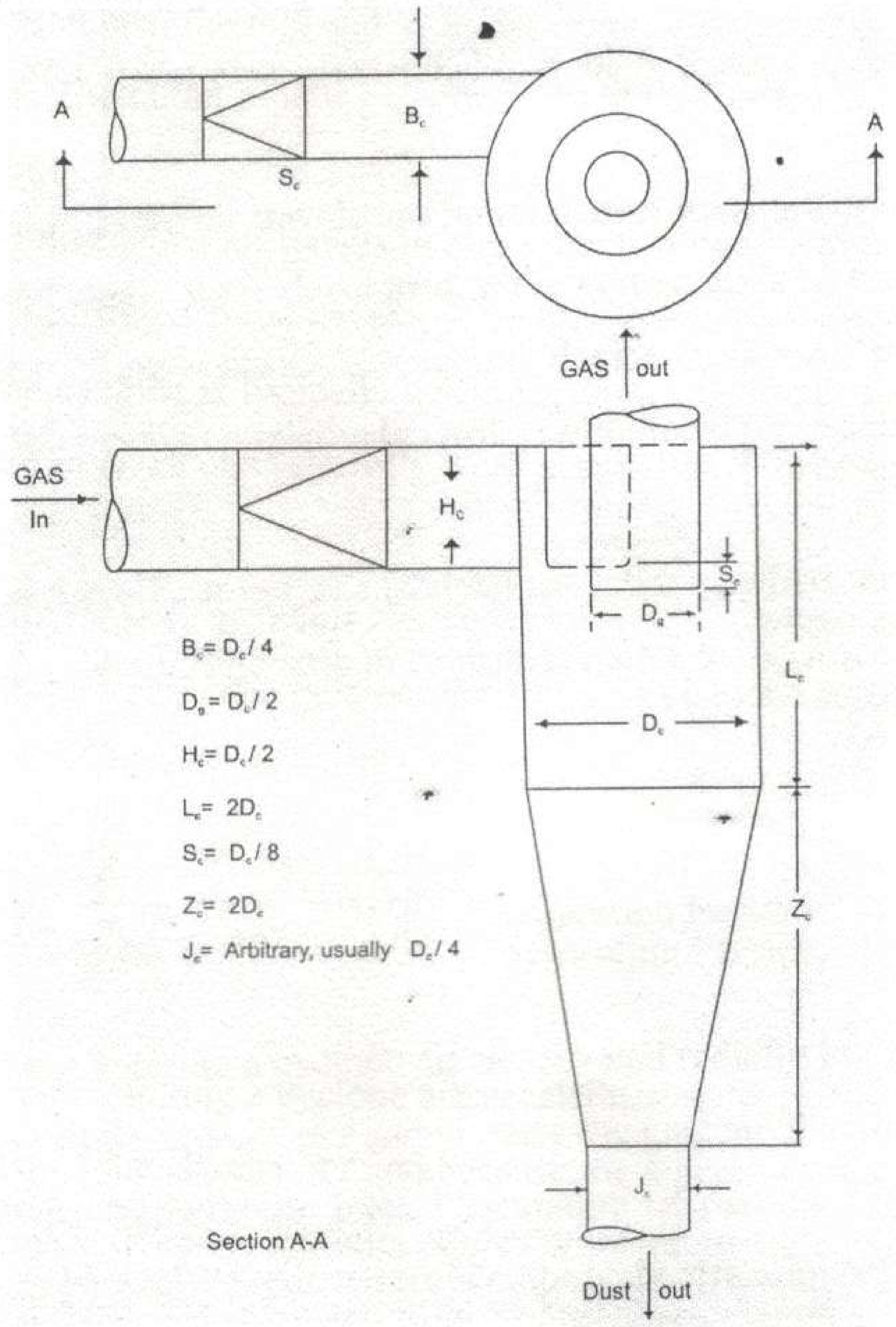
(8) **Lab manual**:- CYCLONE SEPARTOR : APP

EXPERIMENT

a) To study the performance of a given Cyclone (eff. Vs dp).

b) To study the effect of inlet gas velocity on overall efficiency.

c) To study the effect of solid concentration of ΔP.



Section A-A

THEORY:

Cyclonė is the most widely used Centrifugal Separation Equipment for separating dust or mist from gases.

Most centrifugal separators for removing particles from gas streams contain no moving parts. They are typified by the cyclone separators. It consists of a vertical cylinder with a conical bottom, a tangential inlet near the top, and an outlet for dust at the bottoms of the cone. The inlet is usually rectangular. The outlet pipe is extended into the cylinder to prevent short circuiting of air from inlet to outlet.

The incoming dust laden air travels in a spiral path around and down the cylindrical body of the cyclone. The centrifugal force developed in the vertex tends to settle down into the cone and are collected. The cyclone is basically a settling device in which a strong centrifugal force, acting radially, is used in place of a relatively weak gravitational force acting vertically.

The centrifugal force F_c at radius r is equal to $\frac{mu^2_{tan}}{r_c}$, where m is the mass of particle and u_{tan} is its tangential velocity. The ratio of centrifugal force to the force of gravity is then

$$\frac{F_c}{F_g} = \frac{mu^2_{tan}/r}{mg} = \frac{u^2_{tan}}{rg} = \text{Separation Factor}$$

The dust particles entering a cyclone are accelerated radially but the force on the particle is not constant because of the change in r and because the tangential velocity in the vertex varies with r and with distance bellows the inlet. Calculation of particle trajectory is difficult and efficiency of cyclone is generally predicted from empirical correlations.

The lower efficiency of larger cyclone is mainly a result of the decrease of the centrifugal force. For a given air flow rate and inlet velocity, how ever, moderate increase in cyclone diameter and length improve the collection efficiency, because the increase in surface area of sets the decreased centrifugal force. Higher and lower efficiency would be expected for larger and smaller units at the same flow rate and inlet velocity.

The decrease in efficiency with decreasing particle size is actually more gradual than the predicted by simple theories. For smaller particles the radial velocity and the collection efficiency should be a function of D_p^2 , but agglomeration of the fines may occur to raise the efficiency for these particles. Because of the particle size effect, the uncollected leaving the gas has much smaller average size than the entering dust, which may be important in setting emission limits. Also, the overall efficiency is a function of particle size distribution of the feed and can not be predicted just from the average size.

The collection efficiency of a cyclone increases with particle density and decreases as the gas temperature is increased because of the increase in the gas velocity. The efficiency is quit dependent on the flow rate because of the u^2_{tan} term in above equation. The cyclone is one of the few separation devices that work batter in full load than at the partial load. Some times two identical cyclones are used in series to get more complete solids removal, but the efficiency of the second unit is less than that of the first, because the feed to second unit has a much lower average particle size.

The pressure drop in a cyclone is proportional to the gas density and the square of the inlet velocity; it does not depend on the density of the solid particles. The pressure drop actually decreases with increasing particle concentration.

CORRELATIONS:

Inlet Gas Velocity $\mu_t = \dfrac{Q}{H_c \times B_c}$, ft/sec

μ_t lies between 50-90 ft./sec.

Number of turns $N_a = (L_c + Z_c / 2)/ H_c$

Natural Length, l $= 2.3\ D_c\ (D_c^2 / H_c\ B_c)^{1/3}$

Pressure loss (Inches of water)

DP $= 0.003\ \rho_r u^2_r N_H$ (DP< 10" water)

ρr = lb / ft³ (Fluid Density)

u_r = ft/ sec.

N_H = $16\ (H_c B_c / D_c^2)$ = No. of Intel Velocity heads. (Usually lies between 5-8)

$\Delta P_{at\ c} = \Delta P_{at\ c=0}\ [1-0.013\ c^{1/2}]$

c = grains /ft³

Collection Efficiency $[\eta_i]$ % = $[W_i \text{ (collected)} / W_i \text{ (feed)}] \times 100$

Of i^{th}. Particle

Over all efficiency η % = $\sum w_i \eta_i$

PROCEDURE:

1. Prepare feed stock of cement dust or fine sand or fly ash with constant average particle size. Size: 50μm, 40μm, 20μm, 10μm, 8μm, 6μm, 4μm, and 2μm. Prepare about 200gms each.

2. Run the Cyclone with pure air at fixed $\dot{\mu}_r$ (between 50-90 ft / sec.) by adjusting the blower valve.

3. Measure the ΔP across the Cyclone inlet and out let in terms of inches of water. i.e. $\Delta P_{c=0}$.

4. Now feed the dust particles of one particle size (say 50 m) 200gms (W_{io}) at a constant rate.

5. Collect the solid at the solid outlet of the Cyclone.

6. Measure the weight of collected (W_{ic}) and the Pressure Drop. ΔP_i.

7. Calculate the collection efficiency $\eta_i = \frac{W_{ic}}{W_{io}} \times 100$

8. Repeat steps 4 to 7 for all sizes of solid particles.

Change the Air Inlet Velocity and repeat step 3 to 7 for a particular solid say 6 or 4 m.

RECORDS & CALCULATIONS:

- Note al the dimensions of the given Cyclone (D_c = 130mm)
- At ambient condition note the density and velocity of air.
- Note the average particle size and the particle

Particle Size µm	W_{io} gms	W_{ic} gms	$\eta_i = (W_{ic} / W_{io}) \times 100$	W_i	ΔP in N/m	Conc. of Particles gms/cm^3
50						
40						
20						
10						
08						
06						

$\eta_T = \sum W_i \eta_i$

- Plot Log of dp Vs Grade Efficiency

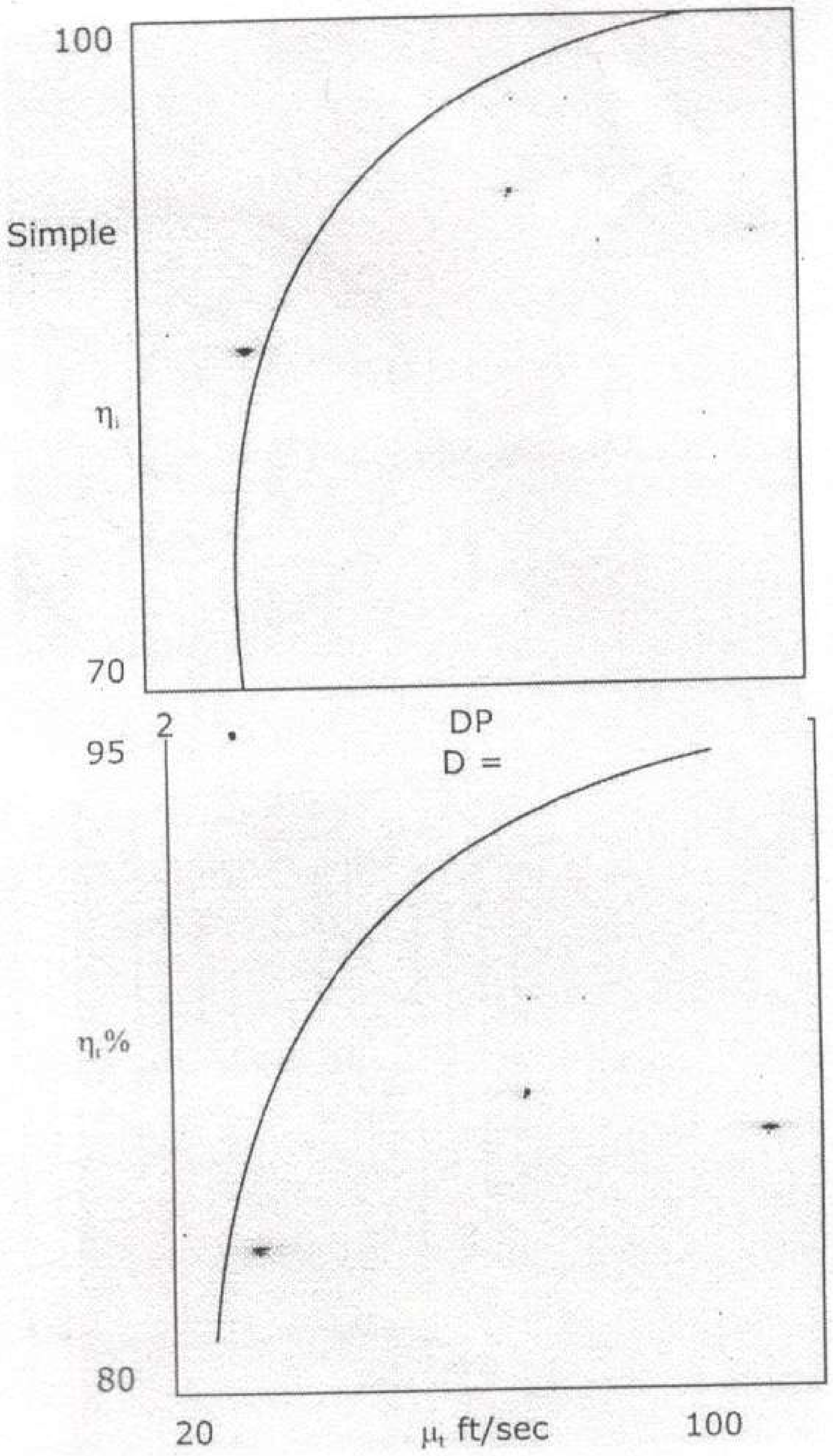
- Plot Inlet Gas Velocity (μ_t) Vs η_T on simple graph .

  .Plot

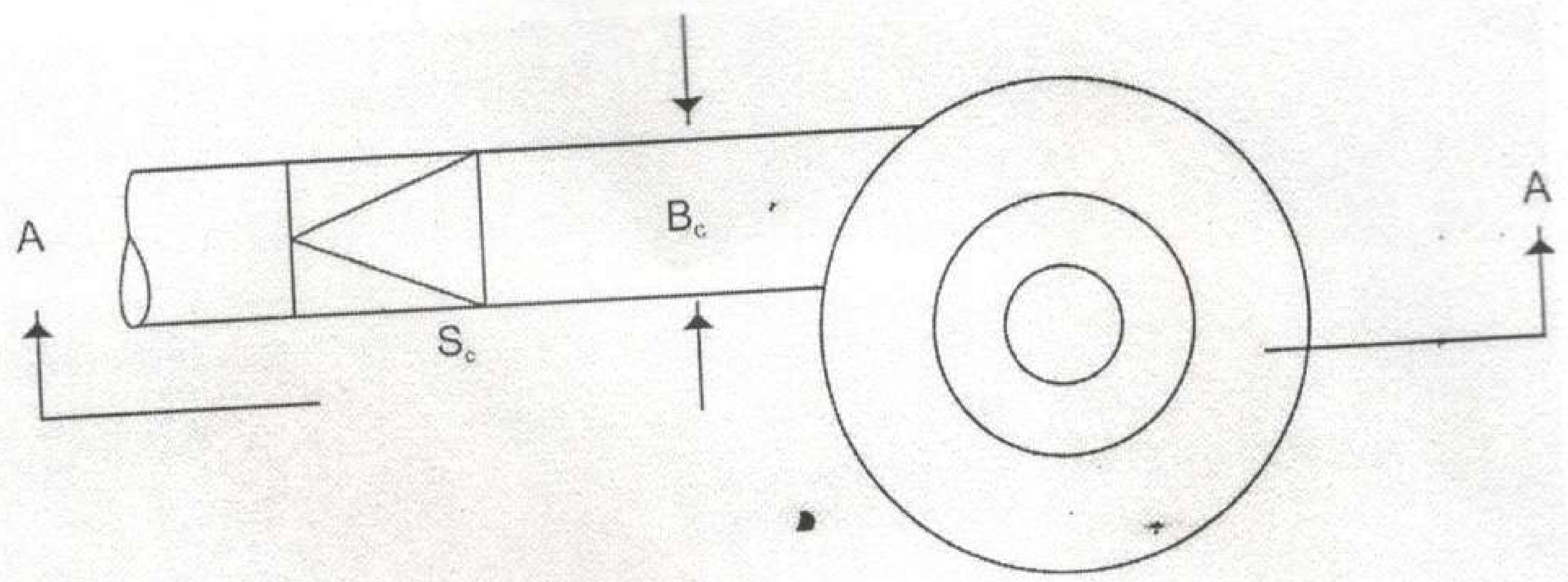
  $$\frac{\Delta P_c}{\Delta P_{c=0}} \text{ Vs } \sqrt{c}$$

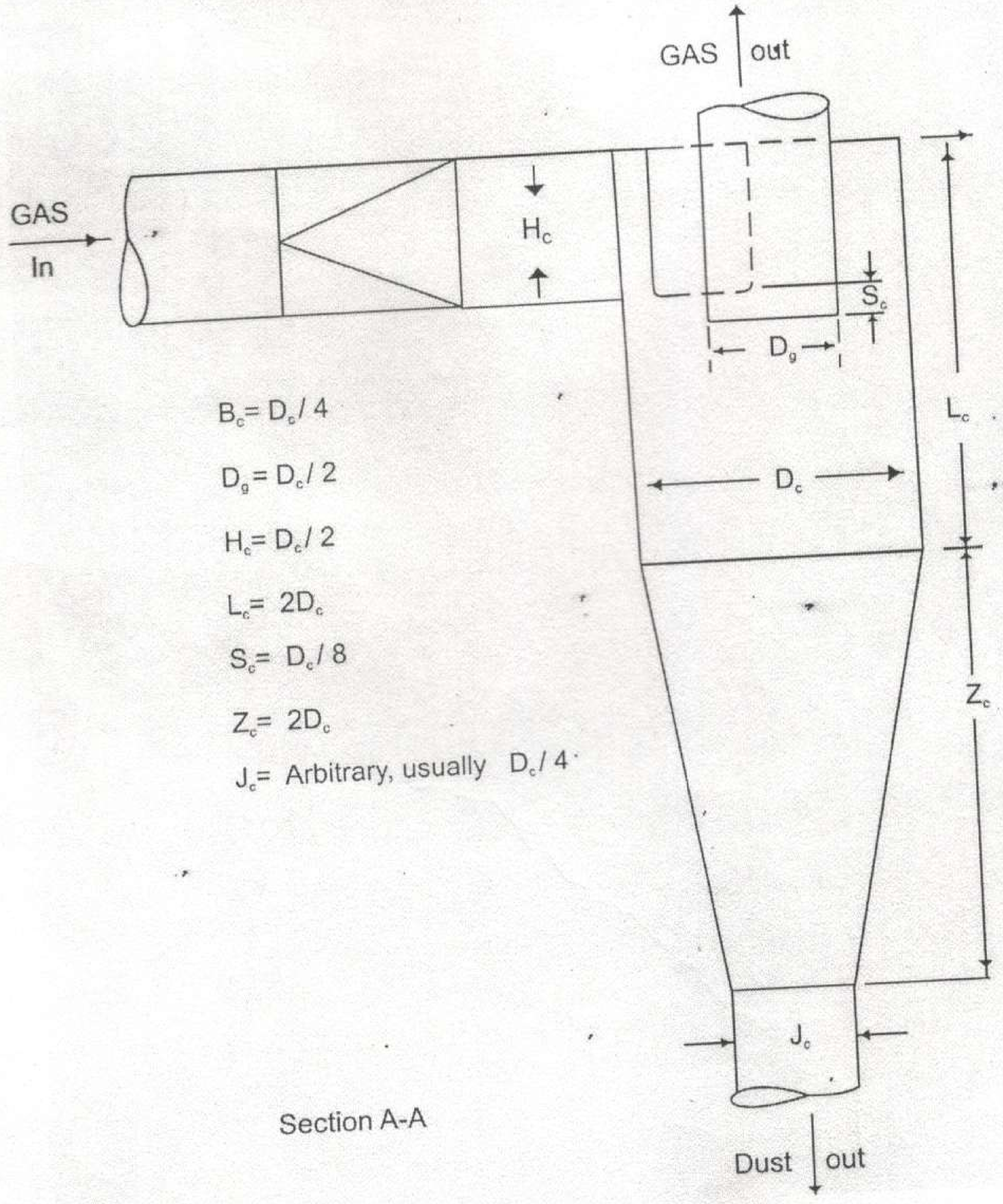
  and verify that

  $$\frac{\Delta P_c}{\Delta P_{c=0}} = 1\text{-}0.013\sqrt{c}$$



Discuss the results.





$B_c = D_c/4$

$D_g = D_c/2$

$H_c = D_c/2$

$L_c = 2D_c$

$S_c = D_c/8$

$Z_c = 2D_c$

J_c = Arbitrary, usually $D_c/4$

Section A-A

Engineering Growth Connection

FROTH FLOATATION CELL

(MO-124)

Foreword

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FROTH FLOTATION CELL

1. OBJECTIVE:

To study the working principle of froth flotation cell.

2. AIM:

To calculate the percentage recovery of coal in froth flotation cell from coal-sand mixture.

3. INTRODUCTION:

Froth flotation cells are used for the separation of lighter density particles from higher density particle, by depending upon their surface tension properties. i.e. cohesion & adhesion properties. A flotation cell is the equipment in which the material is actually separated or floated from the residual tailings. It consist a vessel or tank provided with a feed at one end, an overflow for froth removal, and a discharge for tailings at the opposite end, with a provision for introducing air for froth formation and agitation.

4. THEORY:

Flotation is an operation in which the separation of one of the constituents is carried out by using a method which depends on the differences in surface tension properties of materials involved. This method consists of suspending of mixture of finely divided solids in water which is aerated so that air bubbles tend to adhere preferentially to one of the constituents - the one which is difficult to wet and its effective apparent density is reduced to such an extent that it rises to the surface in the form of a froth, and the one which more readily absorbs, water phase becomes surrounded by water and sinks. If a suitable frothing agent is added to liquid, the particles will be held in the surface by means of a stable froth until they can be discharged. Froth flotation is widely used in the metallurgical industries where, generally, the ore is difficult to wet and the residual earth is readily wetted.

5. DESCRIPTION:

Froth flotation cell consists of an agitated vessel open at the top. In the chamber, an impeller coupled to a shaft is fixed in a stationary diffuser. Agitator is provided with air passage. Motor is given for drive the apparatus. The collector coated mineral particles adhere to the rising bubbles and are carried to the top of the cell to be removed in the froth product tank. Valve is provided for draining purpose.

6. UTILITIES REQUIRED:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection

6.2 Compressed Air Supply: @ 1 CMH at 2 kg/cm^2.

6.3 Water Supply (Initial fill).

6.4 Floor Drain Required.

6.5 Floor Area Required: 1.5 m x 1 m.

6.6 Electronics Weighing Balance :capacity 2 kg, least count 1 gm.

6.7 Oven for drying of product.

6.8 Chemicals:-

Coal	:	100 gm
Sand	:	900 gm
Pine oil	:	10 ml
Kerosene	:	10 ml

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE:

7.1.1 Take known weight of coal (100 gm) and sand (900 gm) and note down the weight of coal

7.1.2 Prepare feed mixture of above material.

7.1.3 Prepare mixture of pine oil and kerosene in desired ratio.

7.1.4 Close the valve V_1.

7.1.5 Put the feed mixture in flotation cell and pour water till it does not come out of the flotation cell.

7.1.6 Connect the compressed air supply.

7.1.7 Switch ON the stirrer.

7.1.8 Switch ON the power supply.

7.1.9 Add mixture of pine oil and kerosene in the flotation cell.

7.1.10 Wait till coal obtained on the surface of solution.

7.1.11 Collect the coal with the help of metallic strip.

7.1.12 Filter it using filter cloth.

7.1.13 Dry it and weigh.

7.1.14 Note down the weight of coal.

7.1.15 Repeat the experiment for different mixture ratio of pine oil and kerosene.

7.2 Closing Procedure:

7.2.1 When experiment is over stop the stirrer.

7.2.2 Switch OFF the power supply.

7.2.3 Stop the compressed air supply.

7.2.4 Drain the water from vessel by open the valve V_1.

8. Observation & Calculation:

8.1 Observation Table:

S.No.	P (ml)	K (ml)	W_F (gm)	W_P (gm)

8.2 Calculations:

$$R = \frac{W_P}{W_F} \times 100 \ (\%)$$

S.No.	R (%)

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
K	Volume of kerosene	ml	Measured
P	Volume of pine oil	ml	Measured
R	Percentage recovery of coal	%	Calculated
W_F	Weight of coal in feed	gm	Measured
W_P	Weight of coal obtained after froth flotation	gm	Measured

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 180 volts and more than 230 volts.

10.2 Close the drain valve properly.

10.3 Collect the product regularly in the collector.

10.4 Speed of the stirrer should not be high.

11. TROUBLESHOOTING:

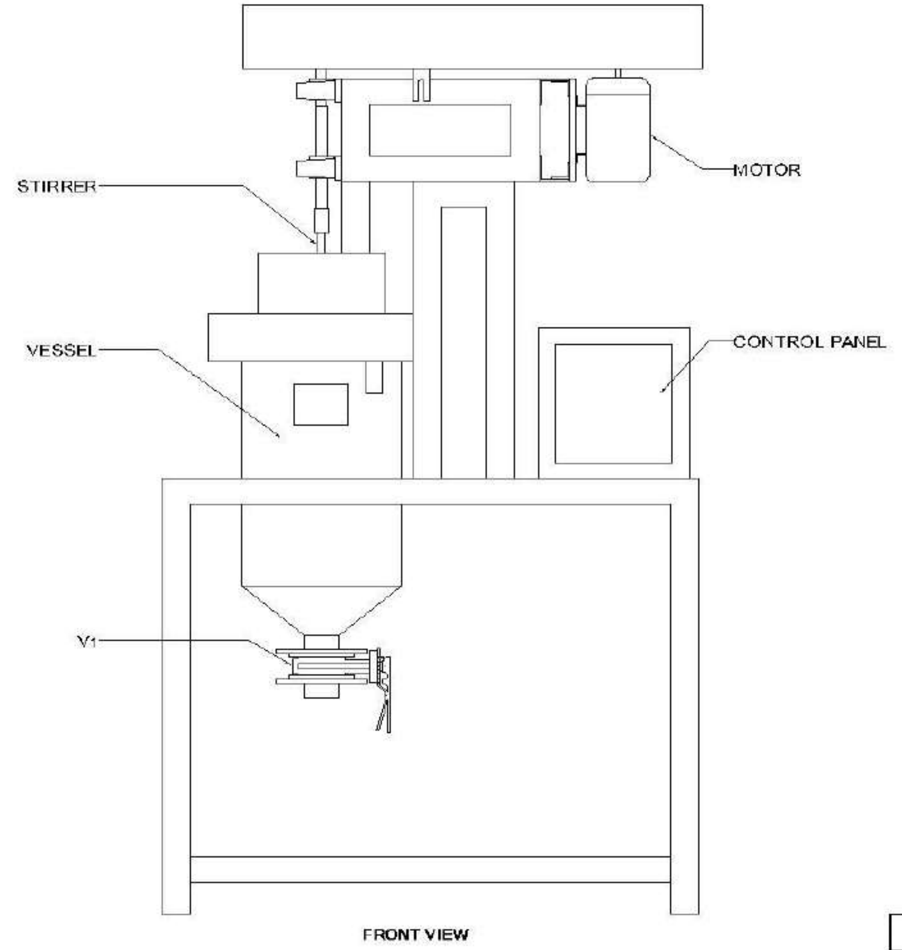
11.1 If the pump gets jam open the back cover of pump and rotate the shaft manually.

12. REFERENCES:

12.1 Coulson, J M & Richardson, J F (1991). *Chemical Engineering Vol-2.* 4th Ed. ND: Asian Books Pvt. Ltd. pp 47-51.

12.2 Brown, George Granger (1995). *Unit Operations.* 1st Ed. ND: CBS Publishers & Distributors. pp 99-103.

13. Block Diagram:



VALVES	
1.	V1 - DRAIN VALVE OF VESSEL

BLOCK DIAGRAM
NAME - FROTH FLOTATION CELL
CODE - MO-124

Engineering Growth Connectio

GYRATORY SIEVE SHAKER (MO-115)

Foreword

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K.C. Engineers Pvt. Lt

Contents

GYRATORY SIEVE SHAKER

1. OBJECTIVE:

To study the operation of gyratory sieve shaker.

2. AIM:

2.1 To demonstrate the gyratory sieve shaker.

2.2 To report the screening analysis.

3. INTRODUCTION:

Gyratory sieve shaker contain several decks of screens, one above the other, held in box or casing. The coarsest screen is at the top and the finest at the bottom, wit suitable discharge ducts to permit removal of the several fractions. The mixture c particles is dropped on the top screen. Screens and casing are gyrated to shift th particles through the screen openings.

4. THEORY:

Standard screens are used to measure the size of particles in the size range between 3 0.0015 inch (76 mm to 38 μm). Testing sieves are made of woven wires screens, th dimensions of which are carefully standardized. The openings are square. Each scree is identified in meshes per inch. The ratio of the actual mesh dimension of any screen t that of the next smaller screen is, then 1.41. In making an analysis a set of standar screens are arranged serially in a stack, with the smallest mesh at the bottom and th largest at the top. The sample is placed on the top screen and the stack shake mechanically for a definite period of time, perhaps 20 min. The particles retained o each screen are removed and weighed and the masses of the individual scree increments are converted to mass fractions or mass percentages of the total sampl Any particles that pass the finest screen are caught in a pan at the bottom of the stack. As a control on the raw materials or on the finished products dry sieve analysis is carrie out regularly in a number of industries. This can be used for ores, refractory materia mineral aggregates, pigments, powdered coal, soap, cement, roofing materials, plast moulding powders, metal powders and in the pharmaceutical industry in short, whereve sieving is applied.

5. Description:

The set-up consists of series of seven sieves with different size opening. They arranged vertically from top to bottom in decreasing size opening. The whole sieves are held in a casing inclined at an angle between 16° and 30° with horizontal. The sieve shaker is driven by FHP motor through a reduction gear box. The whole mechanism runs in an oil bath. A time switch from 0 to 60 minutes is provided to run the set up for particular time interval.

6. Utilities Required:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Floor Area Required 2 m x 1 m.

6.3 Electronics Weighing Balance capacity 2 kg, least count 1 gm.

6.4 Raw material for analysis.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Prepare a feed mixture of different size particles.

7.1.2 Note down the weight of feed mixture.

7.1.3 Arrange the sieves vertically from top to bottom with decreasing opening size of screens.

7.1.4 Tighten the adjustment screw with lid properly.

7.1.5 Fill the upper sieve with feed mixture.

7.1.6 Set the timer to run the machine, for particular time interval (30-60 min.).

7.1.7 Switch ON the power supply.

7.1.8 After the completion of screening weigh all the samples of each screen properly and note down their weight.

7.2 Closing Procedure:

7.2.1 When experiment is over switch OFF the power supply.

7.2.2 Remove the materials from screens properly.

7.2.3 Remove the arrangement, separate the sieves.

8. Observation & Calculation:

8.1 Data:

S.No	Screen openings of sieves S_{oi} (mm)
	0

In experiment the last sieve must be pan and screen opening of pan will be always zero.

8.2 Observations:

M = ______ gm

Observation Table:

S.No	M_i (gm)

8.3 Calculations:

$$D_{pi} = \frac{S_{o(i-1)} + S_{oi}}{2} \text{ (mm)} \quad \text{[Where i = 2,3....]}$$

$$m_i = \frac{M_i}{M} \quad \text{[Where i = 1,2....]}$$

CALCULATION TABLE:1		
S.No	**D_{pi} (mm)**	**m_i**
	*	

* Symbols represent not applicable quantity.

$$C_{p1} = \sum m_i$$

$$C_{pi} = C_{p(i-1)} - m_i \qquad \text{[Where i = 2,3....]}$$

CALCULATION TABLE:2					
S.No	**S_{oi} (mm)**	**M_i (gm)**	**m_i**	**D_{pi} (mm)**	**C_{pi}**
				*	

* Symbols represent not applicable quantity.

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
C_{p1}	Cumulative mass fraction of sample of first screen	*	Calculated
C_{pi}	Cumulative mass fraction of sample of screen i	*	Calculated
D_{pi}	Average particle diameter of screen i	mm	Calculated
M	Total mass of feed sample	gm	Measured
M_i	Mass of sample after screening of screen i	gm	Measured
m_j	Mass fraction of sample after screening of screen i	*	Calculated
S_{oi}	Screen opening of sieve i	mm	Given
i	Value of S.No	*	Given

* Symbols represent unitless quantity.

10. Precaution & Maintenance Instructions:

10.1 Never run the apparatus if power supply is less than 180 volts and more than 230 volts.

10.2 Always use the specified size feed.

10.3 Gearbox should be filled with oil up to the mark on rod with bolt.

11. Troubleshooting:

11.1 Proper cleaning and oiling of the set up is necessary.

12. References:

12.1 Brown, George Granger (1995). *Unit Operations*. 1st Ed. ND: CBS Publishers & Distributors. pp 10-13, 15, 18-19.

12.2 McCabe, Warren L. Smith, Julian C. Harriott, Peter (2005). *Unit Operations of Chemical Engineering*. 7th Ed. NY: McGraw-Hill. pp 971-972, 1000-1005.

Engineering Growth Connection

JAW CRUSHER

(MO-101)

Foreword

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Contents

JAW CRUSHER

1. OBJECTIVE:

To study the operation of jaw crusher.

2. AIM:

To determine the efficiency of the crusher for crushing a material of known work index (W_i).

3. INTRODUCTION:

Jaw crushers do the heavy work of breaking large pieces of solid material into small lumps. The jaw crusher is widely used in industry for coarse reduction of large quantities of solids. They operate by compression and can break large lumps of very hard materials, as in the primary and secondary reduction of rocks and ores. They are very common in industry and have a wide application.

4. THEORY:

In a jaw crusher feed of known size distribution is admitted between the two jaws, set to form a V open at the top. It is driven by an eccentric so that a great compressive force is applied to lumps of solids caught between the jaws. Large lumps caught between the upper parts of the jaw are broken, drop into narrower space below and are re-crushed the next time the jaws close. The most common type of jaw crusher is the blake crusher. In this machine an eccentric drives a pitman connected to two toggles, one of which is pinned to the frame and the other to the swinging jaw. The pivot point is at the top of the movable jaw or above the top of the jaws on the centerline of the jaw opening. The greatest amount of motion is at the bottom of the V, which means that there is little tendency for a crusher of this kind to choke.

BOND CRUSHING LAW AND WORK INDEX:

A more realistic method of estimating the power required for crushing and grinding is

$$\frac{P}{m} = \frac{K_b}{\sqrt{D_p}} \qquad \text{---------------- (1)}$$

Where K_b is a constant which depends on the type of machine and on the material being crushed, D_p is particle size in millimeters, P is power in kilowatts and m is mass flow rate in tons per hour.

W_i is defined as the gross energy requirements in kilo watt hours per ton of feed

needed to reduce a very large feed. This definition leads to a relation between K_b and W_i.

$$K_b = 0.3162 * W_i \qquad \text{--------------- (2)}$$

If 80 percent of the feed passes a mesh size of D_{pa} mm and 80 percent of the product a mesh of D_{pb} mm, it follows from eq (1) & (2).

$$\frac{P}{m} = 0.3162 \times W_i \left(\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right)$$

$$P = m \times 0.3162 \times W_i \left(\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right) \qquad \text{--------------- (3)}$$

5. Description:

The set-up is a blake jaw crusher, contains two jaws of hard steel with one jaw stationary and other is moving. A hopper is provided at the top for feeding material. The opening of the jaw is adjustable. The motor is coupled to the machine through triple `V' belt drive. A handle is provided.

6. Utilities Required:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection

6.2 Floor Area Required: 1m x 1m.

6.3 Raw material for feed (max size 50 mm)

6.4 Set of sieves with sieve shaker for analysis.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Prepare a suitable feedstock of a solid material.

7.1.2 Measure its size distribution.

7.1.3 Fix the opening of jaws.

7.1.4 Switch ON the power supply.

7.1.5 Start the machine with no load condition and record the time taken for 10-20 pulses of energy meter.

7.1.6 Start feeding the solid material by hopper at a constant rate.

7.1.7 Again record the time taken for 10-20 pulses of energy meter.

7.1.8 Repeat the experiment for different opening of jaws.

7.2 Closing Procedure:

7.2.1 When experiment is over switch OFF the power supply.

8. Observation & Calculation:

8.1 Data:

Energy meter constant EMC	= 3200 Pulses/kWh

Work Indexes Of Some Common Minerals

Material	Work Index (W_i)
Bauxite (sp.gr =2.20)	8.78
Cement climker (sp.gr =3.15)	13.45
Coal (sp.gr =1.40)	13.00
Coke (sp.gr =1.31)	15.13
Gravel (sp.gr =2.66)	16.06
Gypsum rock (sp.gr =2.69)	6.73
Lime stone (sp.gr =2.66)	12.74
Quartz (sp.gr =2.65)	13.57

Observations:

W_f = _____ kg

t_c = _____ sec

D_{pa} = _____ mm

D_{pb} = ______ mm

8.2 Observation Table:

P_1	t_{p1} (sec)	P_2	t_{p2} (sec)

8.3 Calculations:

$$P_{NL} = \frac{P_1 \times 3600}{t_{p1} \times EMC} \text{ (kW)}$$

$$P_L = \frac{P_2 \times 3600}{t_{p2} \times EMC} \text{ (kW)}$$

$$P_{act} = P_L - P_{NL} \text{ (kW)}$$

$$m = \frac{W_f}{t_c} \times \frac{3600}{1000} \text{ (tons/h)}$$

$$K_b = 0.3162 \times W_i \text{ (kWh/tons)}$$

$$P_{cal} = m \times K_b \times \left[\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right] \text{ (kW)}$$

$$\eta = \frac{P_{act}}{P_{cal}} \times 100 \text{ (\%)}$$

9. Nomenclature:

Nom	Column Heading	Units	Type
D_{pa}	Average feed size	mm	Measured
D_{pb}	Average product size	mm	Measured
EMC	Energy meter constant	Pulses/kWh	Given
K_b	Bond's constant	kWh/tons	Calculated
m	Feed rate	tons/ h	Calculated
P_1	Number of pulses counted at no load condition	*	Measured

P_2	Number of pulses counted at loaded condition	*	Measured
P_{act}	Actual power required for crushing	kW	Calculated
P_{cal}	Calculated power required for crushing	kW	Calculated
P_L	Power consume by machine at loaded condition	kW	Calculated
P_{NL}	Power consume by machine at no load condition	kW	Calculated
t_c	Time for crushing	sec	Measured
t_{p1}	Time for P_1 pulses	sec	Measured
t_{p2}	Time for P_2 pulses	sec	Measured
W_f	Weight of feed taken	kg	Measured
W_i	Work index of material	kWh/tons	Given
η	Crushing efficiency	%	Calculated

* Symbols are unit less.

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Never run the apparatus if power supply is less than 180 volts and more than 230 volts.

11. TROUBLESHOOTING:

11.1 If electric panel is not showing the input on the mains light, check the main supply.

12. REFERENCES:

12.1 McCabe, Warren L. Smith, Julian C. Harriott, Peter (2005). *Unit Operations of Chemical Engineering.* 7th Ed. NY: McGraw-Hill. pp 985-986, 988.

12.2 Brown, George Granger (1995). *Unit Operations.* 1st Ed. ND: CBS Publishers & Distributors. pp 27-28.

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13. Block Diagram:

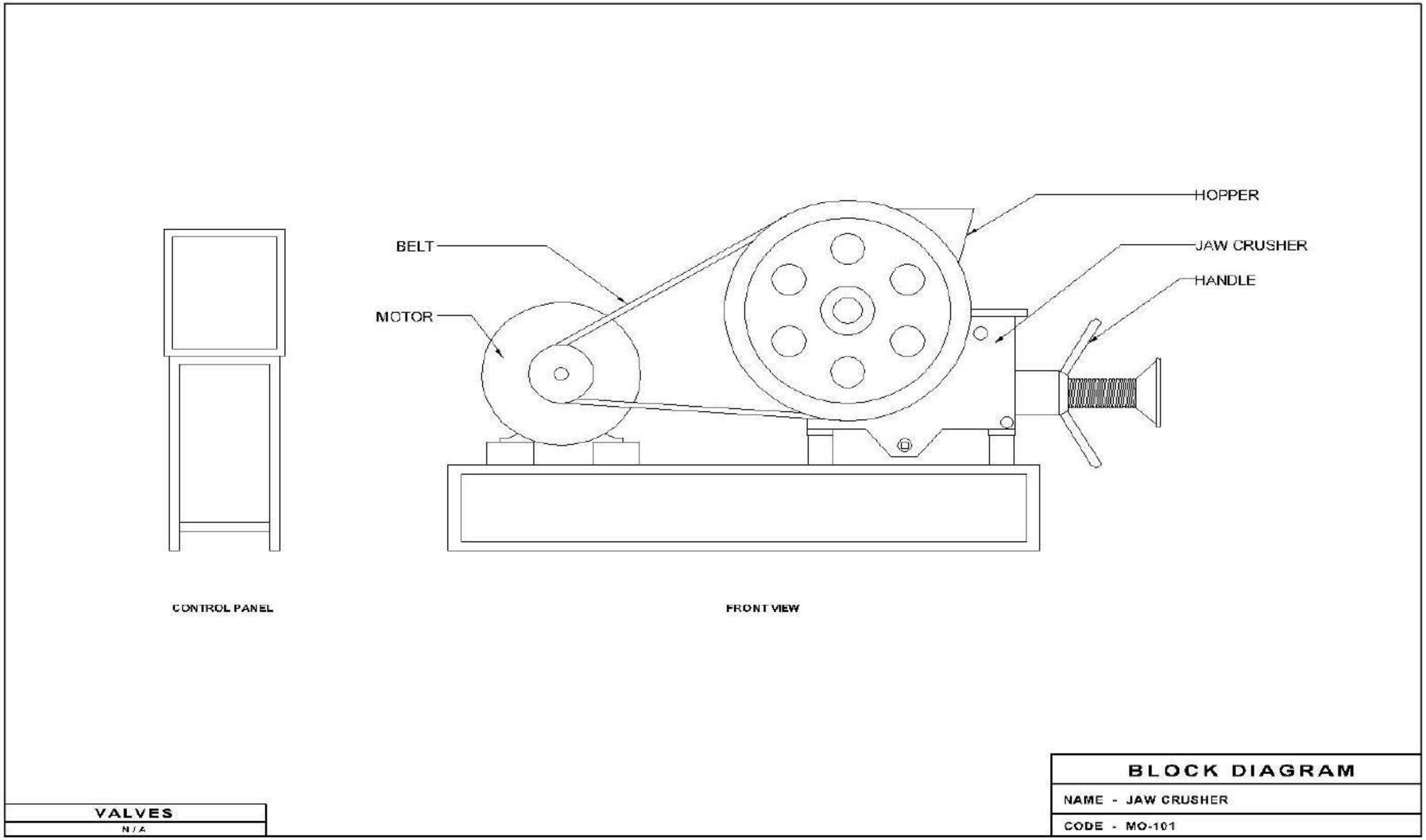

PLATE & FRAME FILTER

PRESS (MO-131)

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Contents

PLATE & FRAME FILTER PRESS

1. OBJECTIVE:

To study the operation of plate and frame filter press.

2. AIM:

2.1 To calculate the specific cake resistance (α).

2.2 To calculate the medium resistance (R).

3. INTRODUCTION:

The separation of solids from a suspension in a liquid by means of porous medium or screen which retains the solids and allow the liquid to pass is termed filtration. In general the pores of the medium will be larger than the particles which are to be removed, and the filter will work efficiently only after an initial deposit has been trapped in the medium. Filtration is essentially a mechanical operation and is less demanding in energy than evaporation or drying. The most suitable filter for any given operation is the one which will fulfill the requirements at minimum overall cost. The most important factors in filter selection are the specific resistance of filter cake, the quantity to be filtered and the solid concentration.

4. THEORY:

Filtration involves the separation of solids from liquids by passing a suspension through a permeable medium, which retains the particles.

FOR INCOMPRESSIBLE CAKE:

The basic filtration equation is:

$$\frac{dt}{dV} = \frac{\mu}{A\Delta P}\left(\frac{\alpha c V}{A} + R\right) \qquad \text{--------- (1)}$$

$$\frac{dt}{dV} = \frac{\mu \alpha c V}{A^2 \Delta P} + \frac{\mu R}{A \Delta P} \qquad \text{----------(2)}$$

Integrate the above equation for t = 0 to t and V = 0 to V

$$\int_0^t dt = \frac{\mu \alpha c}{A^2 \Delta P} \int_0^V V dV + \frac{\mu R}{A \Delta P} \int_0^V dV$$ ----------(3)

$$t = \frac{\mu \alpha c}{A^2 \Delta P} \left[\frac{V^2}{2} \right] + \frac{\mu R}{A \Delta P} [V]$$ ----------(4)

Let $a_1 = \frac{\mu \alpha c}{A^2 \Delta P}, t = \frac{R\mu}{A \Delta P}$

Put these value in equation (2)

$$t = \frac{a_1 V^2}{2} + b_1 V$$

$$t = V\left(\frac{a_1}{2} + b_1\right)$$ ----------(5)

Put $\frac{a_1}{2} = a$, $b_1 = b$

Put these value in equation (5)

$$\frac{t}{V} = aV + b$$

Plot a graph of t/V vs V and find slope “a” and intercept “b”.

α *and* R can be calculated as :

$$\alpha = \frac{A^2 \Delta P a}{\mu C}$$

$$R = \frac{A \Delta P b}{\mu}$$

5. DESCRIPTION:

The set up consists of 7 plates and 6 frames. Frames are covered with filter cloth. Feed is fed by gear pump at the top in slurry tank, and filtrate collected from the outlet valve. After removing cake washing and cleaning can be done by water provided by water tank. Inlet and outlet pressures are measured by pressure gauges. Rate of filtrate removals is measured by measuring tank provided.

6. Utilities Required:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Water Supply (Initial fill).

6.3 Floor Drain Required.

6.4 $CaCO_3$: 10 kg.

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Prepare feed solution by mixing 4 kg of calcium carbonate in 40 liter of water.

7.1.2 Note down the weight of feed and volume of water.

7.1.3 Close all the valves V_1-V_6.

7.1.4 Ensure that switches given on the panel are at OFF position.

7.1.5 Fix the plate and frames on the press.

7.1.6 Fill water in the water tank.

7.1.7 Filter the prepared solution and fed it in the feed tank.

7.1.8 Switch ON the power supply.

7.1.9 Switch ON the agitator of the feed tank.

7.1.10 Connect the outlet of the filter press to the filtrate tank.

7.1.11 Open the valve V_1.

7.1.12 Start the pump and allow feed to enter the press by open the valve V_2 and by pass valve V_3 and keep close the valve V_4.

7.1.13 Note down the inlet slurry pressure and outlet slurry pressure and keep it constant.

7.1.14 Collect filtrate in the receiver by open the valve V_4 and record the weight of filtrate collected and time.

7.1.15 Run the filtration till there is appreciable fall in rate of filtrate collection.

7.1.16 Repeat the experiment for different pressure drop.

7.2 Closing Procedure:

7.2.1 When experiment is over switch OFF the agitator.

7.2.2 Switch OFF the pump.

7.2.3 Stop the supply of slurry by closing the valve V_1.

7.2.4 Drain the slurry tank by open the valve V_6.

7.2.5 Open the valve V_4 and V_5 for circulation of water (Washing is necessary).

7.2.6 Switch OFF the power supply.

8. Observation & Calculation:

8.1 Data:

Number of frame N_F	= 6
Area of filtrate tank A_c	= 0.0398 m^2
Area of one frame A_{F1}	= 0.04 m^2
Viscosity of the filtrate μ	= $9.03*10^{-5}$ $N\text{-sec}/m^2$

Observations:

P_i = ______ kg/cm^2

P_o = ______ kg/cm^2

M = ______ kg

V_1 = ______ Lit

8.2 Observation Table:

S.No	t (sec)	h (cm)

8.3 CALCULATIONS:

$$V = \frac{A_c \times h}{100} \text{ (m}^3\text{)}$$

CALCULATIONS TABLE:			
S.No.	**t (sec)**	**V (m^3)**	**t/V (sec/m^3)**

Plot the graph of t/v vs v and find slope "a" and intercept "b".

$a =$ _______(sec/m^6)

$b =$ _______(sec/m^3)

$$A = 2 \times N_F \times A_{F1} \text{ (m}^2\text{)}$$

$$\Delta P = (P_i - P_o) \times 98066.5 \text{ (N/m}^2\text{)}$$

$$C = \frac{m}{V_1} \times 1000 \text{ (kg/m}^3\text{)}$$

$$\alpha = \frac{A^2 \times \Delta P \times a}{\mu \times c} \text{ (m/kg)}$$

$$R = \frac{A \times \Delta P \times b}{\mu} \text{ (m}^{-1}\text{)}$$

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A	Total filtration area	m^2	Calculated
A_c	Area of filtrate tank	m^2	Given
A_{F1}	Area of one frame	m^2	Given
a	Slope of the graph t/V vs V	sec/m^6	Calculated
b	Intercept of the graph t/V vs V	sec/m^3	Calculated
C	Concentration of the slurry	kg/m^3	Calculated

h	Height of filtrate collected in time t	cm	Measured
m	Mass of $CaCO_3$ in feed	kg	Measured
N_f	Number of frame	*	Given
ΔP	Pressure drop	kg/cm^2	Calculated
P_i	Inlet pressure	kg/cm^2	Measured
P_o	Outlet pressure	kg/cm^2	Measured
R	Medium resistance	m^{-1}	Calculated
t	Time to collect filtrate	sec	Measured
V	Volume of filtrate collected in time t	m^3	Calculated
V_1	Volume of liquid in feed	Lit	Measured
α	Specific cake resistance	m/kg	Calculated
μ	Viscosity of the filtrate	$N\text{-}sec/m^2$	Given

* Symbols represent unitless quantity.

10. Precaution & Maintenance Instructions:

10.1 Cleaning of plates and frames and its clothes is must.

10.2 For proper cleaning circulation of water is necessary (for this operation open the valve V_4 & V_5).

10.3 Feed slurry is filtered before feeding it into the tank.

10.4 Plates & frames should be properly tightened.

11. Troubleshooting:

11.1 If the slurry is leakage more than enough detached the plate and frame, arrange it properly and tight it again.

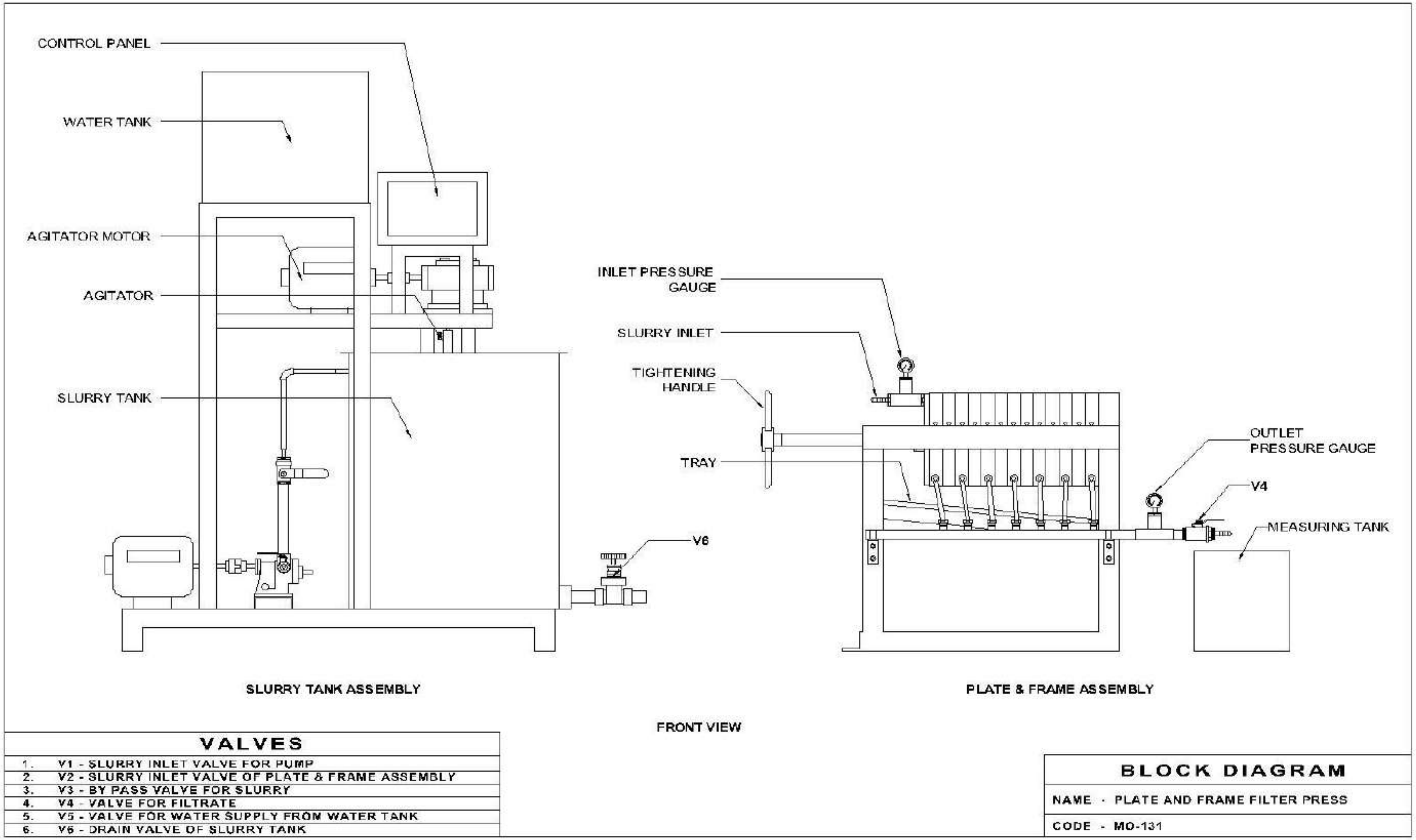
11.2 If the slurry is not coming properly, then check the holes of the cloths and frames are matching or not, if not arrange it accordingly.

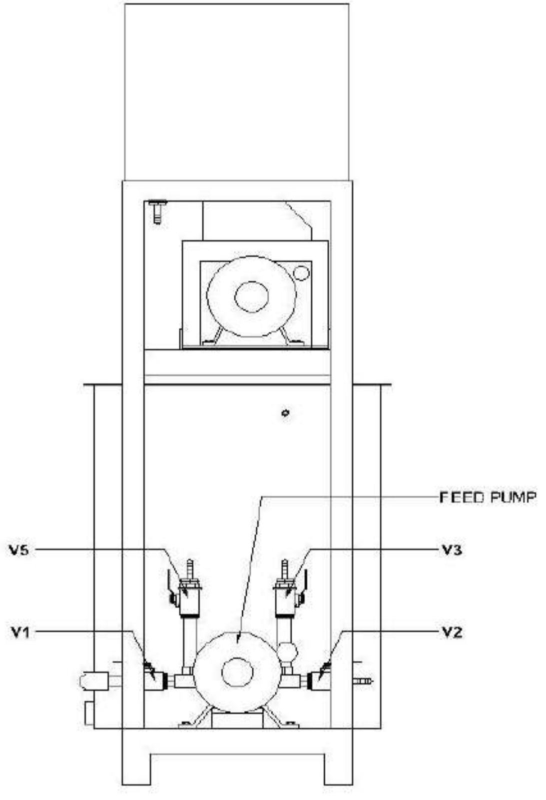
12. References:

12.1 Brown, George Granger (1995). *Unit Operations.* 1st Ed. ND: CBS Publishers & Distributors. pp 231-233.

12.2 McCabe, Warren L. Smith, Julian C. Harriott, Peter (2005). *Unit Operations of Chemical Engineering.* 7th Ed. NY: McGraw-Hill. pp 1008-1010, 1019-1025.

13. Block Diagram:





SLURRY TANK ASSEMBLY

SIDE VIEW

VALVES	
1.	V1 - SLURRY INLET VALVE FOR PUMP
2.	V2 - SLURRY INLET VALVE OF PLATE & FRAME ASSEMBLY
3.	V3 - BY PASS VALVE FOR SLURRY
4.	V4 - VALVE FOR FILTRATE
5.	V5 - VALVE FOR WATER SUPPLY FROM WATER TANK
6.	V6 - DRAIN VALVE OF SLURRY TANK

BLOCK DIAGRAM
NAME - PLATE AND FRAME FILTER PRESS
CODE - MO-131

SEDIMENTATION STUDIES

APPARATUS (EBE-106)

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Contents

SEDIMENTATION STUDIES APPARATUS

1. OBJECTIVE:

To study the batch sedimentation process.

2. AIM:

2.1 To determine the effect of initial concentration and initial suspension height on the sedimentation rates.

2.2 To show the effect of flocculating agent.

2.3 To show the effect of particle size distribution.

3. INTRODUCTION:

Sedimentation is the process of letting suspended material settle by gravity. Suspended material may be partials, such as clay or silts, originally present in the source water. More commonly suspended material or floc is created from material in the water and the chemical used in coagulation or in the other treatment process, such as lime softening. Sedimentation is accomplished by decreasing the velocity of the water being treated to a point below which the particle will no longer remain in suspension. When the velocity no longer supports the transport of the particles, gravity will remove them from the flow. Some of the more comman types of factors to consider are:

The size and type of particles to be removed have a significant effect on the operation of the sedimentation tank. Because of their density, sand or silt can be removed very easily. In contrast colloidal material, small particles that stay in suspension and make the water seem cloudy, will not settle until the material is coagulated and flocculated by the addition of a chemical, such as an iron salt or almunium sulphate.

The shape of the particle also affects its settling characteristics.

4. THEORY:

For any batch sedimentation experiment, on slurry of known concentration, the height of a liquid-solid interface is obtained as a function of time. Slopes of this curve at any point of time represent settling velocities of the suspension at that time and are characteristics of specific solid concentration.

At the beginning of a batch sedimentation process, the solid is uniformly distributed in the liquid. The total depth of suspension is maximum but after a short while the solid have settled to give a zone of clear liquid. After some times it is divided into three zone, clear liquid zone, partial dense zone and dense zone. Earlier dense zone increases then decreases.

In the present experimental set-up record the height with respect to time and plot the graph between them to show the various effects.

5. DESCRIPTION:

The set up consists of five cylinder made of borosilicate glass. The cylinders are mounted on vertical back-panel, which is illuminated from behind. Measuring scale are provided for each of the cylinders.

6. UTILITIES REQUIRED:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Laboratory glass ware:-

Graduated cylinders (2 Lit)	:	5 Nos.
Stop watch	:	1 No.

6.3 Chemicals:-

$CaCO_3$	:	2 kg
Distilled water	:	10 Lit

7. EXPERIMENTAL PROCEDURE:

7.1 STARTING PROCEDURE (FOR CASE-1):

7.1.1 Prepare five different slurry solutions.

7.1.2 Fill the solution in cylinders.

7.1.3 For first three cylinders, take (50,100,150) gm $CaCO_3$ in 2 liter water and note down the initial height, which is same.

7.1.4 For second two cylinders, take (100,100) gm $CaCO_3$ in 2 liter water and note down the initial height which is different.

7.1.5 Connect the electric supply.

7.1.6 Switch ON the light.

7.1.7 Stir the solution of cylinder-1 until a uniform solution is achieved. Record the initial time.

7.1.8 Start the stop watch and record the height of clear liquid interface at every 5 minute interval.

7.1.9 Also note down the time.

7.1.10 Repeat the above steps for all remaining cylinders.

7.1.11 Record the final height and time for each cylinder.

7.2 Closing Procedure (For Case-1):

7.2.1 When experiment is over switch OFF the light.

7.2.2 Switch OFF the power supply.

7.2.3 Clean all the cylinders.

7.3 Starting Procedure (For Case-2):

7.3.1 Prepare five slurry solutions, take 100 gm $CaCO_3$ in 2 liter water for each cylinder with different amount of flocculants (5,10,15,20,25) ml and note down the initial height, which is same.

7.3.2 Fill the solution in cylinders.

7.3.3 Connect the electric supply.

7.3.4 Switch ON the light.

7.3.5 Stir the solution of cylinder-1 until a uniform solution is achieved. Record the initial time.

7.3.6 Start the stop watch and record the height of clear liquid interface at every 5 minute interval.

7.3.7 Also note down the time.

7.3.8 Repeat the above steps for all remaining cylinders.

7.3.9 Record the final height and time for each cylinder.

7.4 Closing Procedure (For Case-2):

7.4.1 When experiment is over switch OFF the light.

7.4.2 Switch OFF the power supply.

7.4.3 Clean all the cylinders.

7.5 Starting Procedure (For Case-3):

7.5.1 Take five different size of calcium carbonate and note down the size of it.

7.5.2 Prepare slurry solution by mixing known amount of sodium carbonate with 2 liter of water.

7.5.3 Fill the solution in cylinders.

7.5.4 Connect the electric supply.

7.5.5 Switch ON the light.

7.5.6 Stir the solution of cylinder-1 until a uniform solution is achieved. Record the initial time.

7.5.7 Start the stop watch and record the height of clear liquid interface at every 5 minute interval.

7.5.8 Also note down the time.

7.5.9 Repeat the above steps for all remaining cylinders.

7.5.10 Record the final height and time for each cylinder.

7.6 Closing Procedure (For Case-3):

7.6.1 When experiment is over switch OFF the light.

7.6.2 Switch OFF the power supply.

7.6.3 Clean all the cylinders.

8. Observation & Calculation:

8.1 Data:

Initial concentration of solution C_o = __________ kg/m^3

8.2.a Observation Table (For Case-1):

S.No	Cylinder-1		Cylinder-2		Cylinder-3		Cylinder-4		Cylinder-5	
	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)

8.2.b Observation Table (For Case-2):

S.No	Cylinder-1		Cylinder-2		Cylinder-3		Cylinder-4		Cylinder-5	
	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)

8.2.c Observation Table (For Case-3):

D_p (mm)	Cylinder-1		Cylinder-2		Cylinder-3		Cylinder-4		Cylinder-5	
	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)	θ (sec)	Z (cm)

8.3 Calculations:

(For Case-1):

Plot the graph of Z vs θ for cylinder- 1, 2 & 3.

Plot the graph of Z vs θ for cylinder- 4 & 5.

(For Case-2):

Plot the graph of Z vs θ for cylinder- 1, 2, 3, 4 & 5.

(For Case-3):

$Z_O =$ ______(cm)   [Initial height of Z]

$$C = \frac{C_O Z_O}{Z} \text{ (kg/m}^3\text{)}$$

Calculation Table (For Case-3):					
D_p (mm)	Cylinder-1	Cylinder-2	Cylinder-3	Cylinder-4	Cylinder-5
	C (kg/m^3)	C (kg/m^3)	C (kg/m^3)	C (kg/m^3)	C (kg/m^3)

Plot the graph of D_p vs C for cylinder- 1, 2, 3, 4 & 5.

9. Nomenclature:

Nom	Column Heading	Units	Type
C	Concentration of sediment at any time θ	kg/m^3	Calculated
C_o	Initial concentration of sediment	kg/m^3	Given
D_p	Size of solid particles	mm	Measured
Z	Height of suspension clear liquid interface	cm	Measured
Z_o	Initial height of suspension clear liquid interface	cm	Calculated
θ	Time of settling	sec	Measured

10. Precaution & Maintenance Instructions:

10.1 Keep apparatus free from dust.

10.2 Always drain the cylinders after use.

11. TROUBLESHOOTING:

11.1 If light is not showing ON then check the mains.

12. REFERENCES:

12.1 Coulson, J M & Richardson, J F (1991). *Chemical Engineering Vol-2.* 4th Ed. ND: Asian Books Pvt. Ltd. pp 174-188.

13. Block Diagram: