GAS-SOLID FLUIDIZATION IN TAPERED-VESSELS

A DISSERTATION
submitted in partial fulfilment of the
requirements for the award of the Degree of
MASTER OF ENGINEERING
in
CHEMICAL ENGINEERING
(PLANT & EQIUPMENT DESIGN)

by

BHUPAL SHARMA

DEPARTMENT OF CHEMICAL ENGINEERING
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C E R T I F I C A T E

CERTIFIED that the thesis entitled "GAS-SOLID FLUIDIZATION IN TAPERED VESSELS" which is being submitted by Shri Bhupal Sharma in partial fulfilment of the requirements for the award of the Degree of MASTER OF ENGINEERING IN CHEMICAL ENGINEERING (Plant and Equipment Design) at the University of Roorkee, Roorkee is a record of candidate's own work carried out by him under the supervision and guidance of the undersigned. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.

This is further certified that he has worked for a period of more than four and a half months for preparing this thesis at this University.

N. Gopal Krishna

(N.Gopal Krishna)
Professor and Head

May 23, 1974.

Department of Chemical Engineering
University of Roorkee,
Roorkee.

A B S T R A C T

Studies in gas-solid fluidization have been conducted in tapered vessels with circular cross-section. Materials fluidized include glass beads, crushed bauxite and calcite of different particle sizes. Tapered vessels of cone angles vary from 10^{o} to 90^{o} (Gas solid contact was found to be more efficient with larger particle sizes and smaller cone angles (10^{o} to 30^{o})). For smaller size of particles and larger cone angles the fluidization is limited to a central core with layers of particles remaining stationary near the walls. Slugging is more predominant in smaller angles cones. While in larger angle cones it is completely absent.

Pressure drop data were obtained in the fixed bed region, at the onset of fluidization and in the expanded bed zone. Pressure peak which is characteristic of tapered vessels has been observed and correlated in terms of dimensionless groups like $(R_{ep})_{mf}$, (D/D_o) and $(\tan\alpha/2)$ The correlation obtained by curve fitting is

$$\left(\frac{\Delta\pi}{\Delta P_{net}}\right) = 3.48 \times 10^{-2} \, (D/D_o)^{0.497} \left(\tan\frac{\alpha}{2}\right)^{-0.08} \left(R_{ep_{mf}}\right)^{0.426}$$

The experimental and theoretical pressure drops, have been calculated using computer and it was found that nearly 90% data vary between the range of ± 35 %. The coefficient of variation for all the data on glass beads, bauxite and calcite comes out to be 43.49.

ACKNOWLEDGEMENTS

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C O N T E N T S

CONTENTS (Contd..)

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NOMENCLATURE

A	$(\mu/g_c\ \bar{d}p^2)\ \frac{(1-\epsilon)^2}{\epsilon^3}$
B	$\left(\frac{\rho_f}{g_c\ \bar{d}p}\right)(1-\epsilon)/\epsilon^3$
dp	particle dia., Cms.
D	Bed dia at top of packed section, Cm.
D_o	Bed dia at distributor, Cm.
g	Acceleration due to gravity
g_c	Gravitational constant
ΔP	Pressure drop across the bed.
R	Radial distance from the apex of the cone to the top of bed, Cm.
R_o	Radial distance from the apex of the cone to the distributer, Cm.
U	Avg. fluid velocity at the top of tapered bed, cm/sec.
U_o	Average fluid velocity at the distributor based on empty crosssection cm/sec.
W_{net}	Buoyant weight of material in the bed, gms.
α	Apex angle degrees.
ϵ	Bed porosity
ρ_b	Fluid density , gm/cm^3
μ	Fluid viscosity, poise.
K	Proportionality coefficient with relation $\Delta P = K.\ W_f H_{sta}$.

W_b Superficial fluid velocity M/sec.

H_{sta} Height of stationary bed

Y_{sta} Bulk density of stationary bed

$\Delta\pi$ Pressure peak

$\acute{W}_{ls}$ Superficial fluid velocity of minimum fluidization, m/sec.

CHAPTER - ONE

INTRODUCTION

Fluidization is the operation by which fine solids are transformed into a fluid like state 'Through contact with a gas or liquid.'

Phenomenon of fluidization can be explained by passing a fluid upward through a bed of fine particles. At a low flow rate, fluid merely percolates through the void spaces between stationary particles. This is a fixed bed.

With an increase in flow rate, particles move apart and a few are seen to vibrate and move about in restricted regions. This is the expanded bed.

At a still higher velocity a point is reached, when the particles are all just suspended in the upward flowing gas or liquid. At this point the frictional force between a particle and fluid counterbalances the weight of the particle, the verticle component of the compressive force between adjacent particles disappears, and the pressure drop through any section of the bed about equals the weight of fluid and particles in that section. The bed is considered to be just fluidized and is referred to as an incipiently fluidized bed or a bed at minimum fluidization.

In liquid-solid systems an increase in flow rate above minimum fluidization usually results in a smooth, progressive expansion of the bed. Gross flow instabilities are damped and remain small, and large scale bubbling or heterogeneity is not observed under normal conditions. A bed such as this is called a particulately fluidized bed, a homogeneously fluidized bed, or simply a liquid fluidized bed.

Gas solid systems generally behave in quite a different manner. With an increase in flow rate beyond minimum fluidization, large instabilities with bubbling and channeling of gas are observed. At higher flow rates agitation becomes more vigorous. In addition the bed does not expand much beyond its volume at minimum fluidization. Such a bed is called an aggregative fluidized bed, a heterogeneously fluidized bed, a bubbling fluidized bed, or simply a gas fluidized bed.

Both gas and liquid fluidized beds are considered to be dense-phase fluidized beds as long as there is fairly clearly defined upper limit or surface to the bed. However, at a sufficiently high fluid flow rate the terminal velocity of solids is exceeded, the upper surface of the bed disappears, entrainment becomes appreciable, and solids are carried out of the bed with the fluid stream. In this state we have a disperse, dilute- or lean-phase fluidized bed with pneumatic transport of solids.

Although the properties of solid and fluid alone will determine whether smooth or bubbling fluidization occurs, many factors influence the rate of solid mixing, the size of bubbles, and the extent of heterogeneity in the bed. These factors include bed geometry, gas flow rate, type of gas distributor and vessel internals such as screens, baffles, and heat exchangers. As an example slugging, a phenomenon strongly affected by the vessel geometry.

ADVANTAGES AND DISADVANTAGES OF FLUIDIZATION FOR INDUSTRIAL OPERATIONS

The fluidized bed has both desirable and undesirable characteristics . These can be brought out as follows.

Advantages of Fluidized Beds

1. The smooth, liquid like flow of particles allows continuously automatically controlled operations with ease of handling.
2. The rapid mixing of solids leads to nearly isothermal conditions through out the reactor or vessel, hence the operation can be controlled simply and reliably.
3. The circulation of solids between two fluidized beds makes it possible to transport the vast quantities of heat produced or needed in large reactors.
4. It is suited to large scale operations.

5. Heat and mass transfer rates between gas and particles are high when compared with other modes of contacting.

6. The rate of heat transfer between a fluidized bed and an immersed object is high, hence heat exchangers within fluidized beds require relatively small surface areas.

<u>Disadvantages of Fluidized beds</u>

1. The difficult-to-describe flow of gas, with its large deviations from plug flow and the bypassing of solids by bubbles, represents an inefficient contacting system.

2. Friable solids are pulverized and entrained by the gas, they then must be replaced.

3. Erosion of pipes and vessels from abrasion by particles can be serious.

4. For non catalytic operations at high temperatures. The agglomeration and sintering of fine particles can necessitate a lowering in temperature of operation, reducing the reaction rate considerably.

CHAPTER - TWO

LITERATURE REVIEW

2.1 FLUIDIZATION IN CYLINDRICAL VESSELS WITH CONSTANT AREA OF CROSS SECTION

When a fine granular material is dumped into a vessel, the resulting bed has a definite bulk density. This bulk density depends on the size and shape of the particles. When the wall of the vessel is tapped during the dumping operation, the bed packs some what more densely than under quiet conditions. If fluid is now admitted at a very low rate into the bottom of this bed a small pressure drop is indicated by the manometer. As the rate of fluid flow is gradually increased, the pressure drop rises to a point of equilibrium at which the weight of the bed in the fluid stream equals the fluid pressure drop across the column multiplied by the cross-sectional area of the vessel. As the rate of fluid flow increases further, the bed begins to expand. This expansion increases the percentage of voids in the bed sufficiently to keep the pressure drop, essentially constant, despite the accelerated flow rate. At a certain fluid velocity the bed will have expand to such a density that the individual particles will become disengaged sufficiently from each other to permit internal motion of particles in the bed. This internal motion is induced by the fluid moving through the interstices of the bed and indicates the beginning of fluidization. Just like the bulk density which results from dumping the material into the vessel, this limiting bed density at which fluidization begins depends also on the size and the shape of the particles of the bed and has been termed "maximum fluid density". The fraction voids associated with this condition have been called a"minimum fluid voidage". This concept is important in connection with the onset of fluidization.

An additional increase in fluid rate expands the bed further and intensifies the motion of particles. The particle movement is, however, not an entirely random one. In fact it appears that a fluidized bed resembles somewhat a column of liquid which is heated from the bottom, with the result that coordinated convection currents are generated throughout the fluid body. For much higher rates of fluid flow, the state of agitation increases still further, and the position of the top of the bed fluctuates considerably. For very high flow rates, large bubbles usually force their way upward through the bed. In small diameter fluidization equipment, these bubbles coalesce and form a gas slug which may extend over the entire cross section of the unit. This condition is called slugging. For a slugging bed, however the manometer fluctuates considerably between rather wide limits. These fluctuations of the pressure drop were found to be a fair indication of the slugging behaviour of the bed.

Another phenomenon which interferes with smooth fluidization is known as 'channeling', which describes the flow of fluid through channels in the bed caused by the gas flow. It appeared that channeling depends chiefly on the following four factors.

1. moisture in the bed,
2, diameter of the reactor
3. Rate of fluid flow through beds of small particles.
4. Diameter of particles in the fluidized bed.

If a bed is moist, the particles will tend to clump together, and any gas flow through the bed takes place through channels between the lumps.With narrow fluidization equipment chenneling was observed chiefly near the wall of the vessel. The resistance offered to fluid flow in a narrow tube appears smaller near the wall than through the centre of the tube. For larger apparatus, this small wall effect is reduced, so that channeling through the bed is improved. For high rates of fluid flow, channeling is virtually nonexistent, whereas for low flows channeling can be very pronounced. The explanation is the at high fluid rates, the agitation of the bed is more intense than at low flows, this agitation apparently destroys the channels as soon as they are formed. It was also observed that fine materials have a greater tendency to ohannel than large particles.

The reason why fine particles channel more readily than coarse materials is not understood. The answer to this question is further obscured by the observation that fine materials appear in much more intense state of agitation than coarse particles, this intense state should prevent channeling. Apparently for fine materials, it is possible to have channeling despite the high degree of internal particles movement.

2.2 COMPARISON BETWEEN FLUIDIZATION IN STRAIGHT TUBE AND CONICAL VESSEL

The main disadvantage of fluidization in straight tubes is of attraction of particles. Due to attrition particles become smaller and smaller in size. As the cross-sectional area of tube is smae throughout its length, therefore, linear velocity will also be same throughout the entire section. Thus a flow rate, fixed for a particular size of particles, will cause entrainment of smaller particles formed due to attrition . And the reactions like cracking or reforming are carried out, in the fluidized beds, the solid used is generally the costly catalyst. So it is very important to avoid attrition and hence the transportation of costly catalysts from the reactor of fluidizing column. This difficulty may be overcome in conical (tapered) vessels. Fluid is entered through the lower cross section. As we go upwards, cross section of the conical vessel will be increasing , consequently linear velocity will decrease. Thus we can have a check on entrainment of particles by using tapered vessels.

Another advantage of tapered vessels is that two types of particles can be fluidized simultaneously. In this case the smaller particles are retained at the upper surface while the larger particles at the bottom.

2.3 FLUIDIZATION IN TAPERED OR CONICAL VESSEL

When fluidization occurs in a conical apparatus tapering downward, there is a considerable pressure peak at the limit of stability. This peak is much larger than at the onset of fluidization in an apparatus with a constant corss-section and is due to the conical form of the bed. In some experiments the pressure drop before the onset of fluidization was two to three times greater than the value established after the limit of stability. This phenomenon was explained by the observation that in conical apparatus the bed passes into the fluidized state only after fluidization of the upper portions. Since at this time the gas velocities in the lower and middle parts of the bed are considerably greater than the critical fluidization velocities, the pressure drop in the stationary bed portions increases rapidly compared with that at the limit of stability in a cylindrical bed of the same height. Immediately beyond the limit of stability the pressure drop falls to approximately the usual theoretical value, equal to the product of the bed density and its height, regardless of the bed configuration, in the same way that the hydrostatic pressure on the bottom of a vessel does not depend on its shape.

As the fluid velocity is further increased the pressure drop does not remain constant but, in contrast to the cylindrical bed, begins to fall. Gel'perin et al, noted, this is because in a conical apparatus, as the porosity increases, the bed height increases more slowly than its volume, so that the quantity $H(1-\varepsilon)$ decreases. A similar movement of the lower limit of a conical fluidized bed occurs as the fluid velocity increases.

2.4 FIXED BED PRESSURE DROP AND PRESSURE PEAK IN CONICAL VESSELS

Correlations for determination of the point of incipient fluidization in cylindrical beds usually require knowledge of the pressure drop through cylindrical fixed beds of particles. In attempting to apply the same method to tapered or conical beds, a lack of information is noted in the literature on pressure drop through fixed beds of particles in vessels of this type. This situation was some what surprising in view of the useful properties of and increasing interest in this type of equipment(1-2).

Gel'perin, at al(4) have derived for the pressure drop through conical fixed beds the following equation

$$\Delta P = k\ UD\ ((D/D_o)-1)\ /\ (2\ \tan \alpha\ /2) \qquad (1)$$

The coefficient k is given by

$$k = \underline{c}\ \mu\ /\ 2\ dp^2 \qquad (2)$$

Equation (1) and (2) are valid for laminar flow, the value of the constant C was not given.

Baskakov and Gelprin (5) presented the following equation.

$$\Delta P = C_1 A\ (R_o/R)\ (R-R_o)\ U_o + C_2 B(R_o/3R^2)(R^3-R_o^3)U_o^2 \qquad (3)$$

The coefficients C_1 and C_2 were given the values proposed by Ergun(3) : $C_1 = 150$, $C_2 = 1.75$

Various corelations for the determination of incipient fluidization in tapered or conical vessels have been proposed. The first is due to Gelprin et al (4) and its basic assumption is that the bed will start to expand at the flow rate at which the velocity at the top of the bed based on empty cross section reaches the value of the incipient fluidization velocity characteristic of the particular particle-fluid system in cylindrical vessels.

Baskakov and Gelprin (5) assumed that the bed begins to expand at the moment when the resistance to the flow becomes equal to the 'net weight' of particles in the container. Net weight is discussed further below. According to Baskakov and Galperin incipient fluidization velocity is then obtained by solving the following equation for U_o.

$$W_{net} = (\pi \sin^2(\alpha/2)) \left[C_1 A R_o^2 (R-R_o)U_o + C_2 B(\frac{R_o^3}{R}) (R-R_o)U_o^2 \right] \quad (4)$$

Baskakov and Galperins(5) assumption is not identical with the assumption made by Gelperin et al except in the case of cylindrical beds. Equation (4) was not tested by Baskakov and Galperin against experimental data. The coefficients C_1 and C_2 were again given the Ergun values.

Farkas and Koloini (6) however found out for liquid fluidized beds that the Ergun constants 150 and 1.75 should not be used for conical or tapered fixed beds, even where the apex angle is small. They shaw that C_1 and C_2 depend strongly on the geometry of the bed (Conical half-conical, two dimensional) . The main reason for that was that the flow distribution in the packed bed is certainly influenced by the bed form and is most probably not the same as in cylindrical beds.

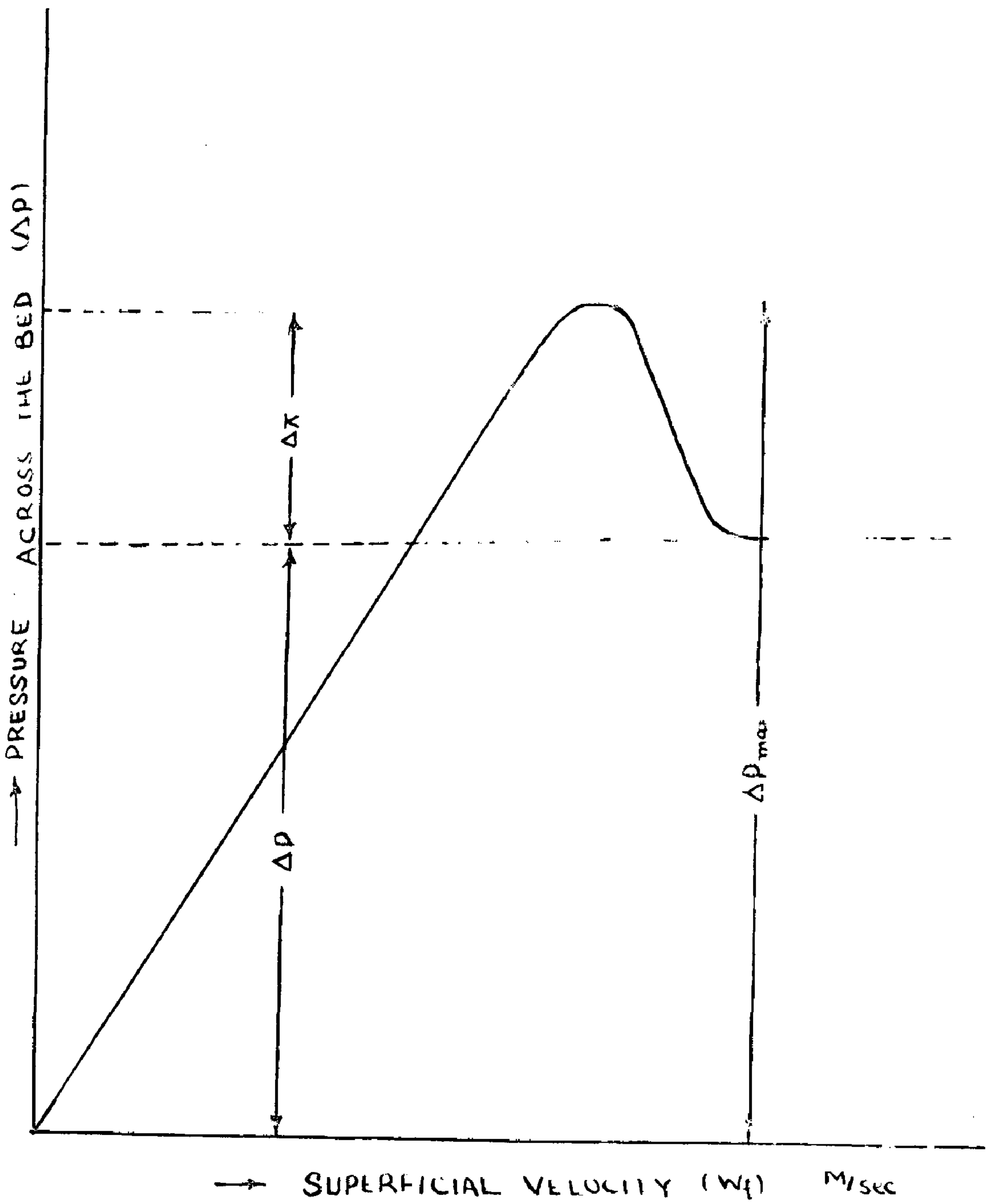


FIG. 2.1 VARIATION OF ΔP WITH SUPERFICIAL VELOCITY

In conical or tapered vessel as the upflow of fluid through a fixed bed of particles is increased from zero, a compacting effect is noted. The explanation appears to be that the particles near the bottom of the bed can experience a substantial upward drag force, due to the relatively large velocity of fluid near the bottom of the bed. This upward drag force can be larger than the force of gravity on the particles. At the same time, the velocity near the top of the conical bed is still relatively small. So the force of gravity on particles near the top of the bed is larger than the upward drag force exerted on them by the fluid. The resultant force on particles near the top is downward.

In deriving a theoretical formula for the pressure peak $\Delta\pi$ (Fig. 2.1) Gelprin et al made the assumption that the fluidizing gas was uniformly distributed over the bed cross section at every height in the bed and that the motion of the gas in the bed was laminar. They arrived at the expression

$$\Delta\pi_{\text{theoretical.}} = \frac{D_o}{2\tan\frac{\alpha}{2}}\left(\frac{D}{D_o}-1\right)\left(\frac{K.\,W_{\ell s.}\,D}{D_o} - Y_{sta}\right) \quad (5)$$

Considering that the assumption of uniform distribution of the gas over the conical bed, made in the derivation of equation (5) is far from fulfilled in practice, the authors have not proposed this as a design equation, but only as a basis for choosing the type of emperical formula. For this purpose they proposed

$$\Delta\pi = f\,(D/D_o,\ \tan\frac{\alpha}{2}) \qquad (6)$$

It follows from eqn (5) that $\Delta\pi$ can vary even when D/D_o and α are unchanged due to difference in the value of K. It is also probable that the emperical formula

$$\Delta\pi_{exp.} = 2.53\,(\frac{D}{D_o})^{2.55}\ (\tan\alpha/2)^{-1.19} \qquad (7)$$

which was proposed by these authors, and confirmed by them over the ranges $\alpha = 10\text{-}60^o$ and $D/D_o = 1.3 - 6.77$ is valid only within the conditions under which the experiments were carried out (with sand only).

In their experiments on fluidization in conical beds, Gel'perin et al(4) observed that the free surface of the bed assume a concave shape, the surface of the material in the peripheral stagnant zone is higher than in the fluidized core. They attribute this to the fact that in a conical apparatus the pressure drop is smaller than the calculated from the bulk density and bed height at the walls. Obviously it is possible to form gas channels lower down in the central part of the bed.

CHAPTER - THREE

EXPERIMENTAL SETUP AND PROCEDURE

3.1 EXPERIMENTAL SET UP

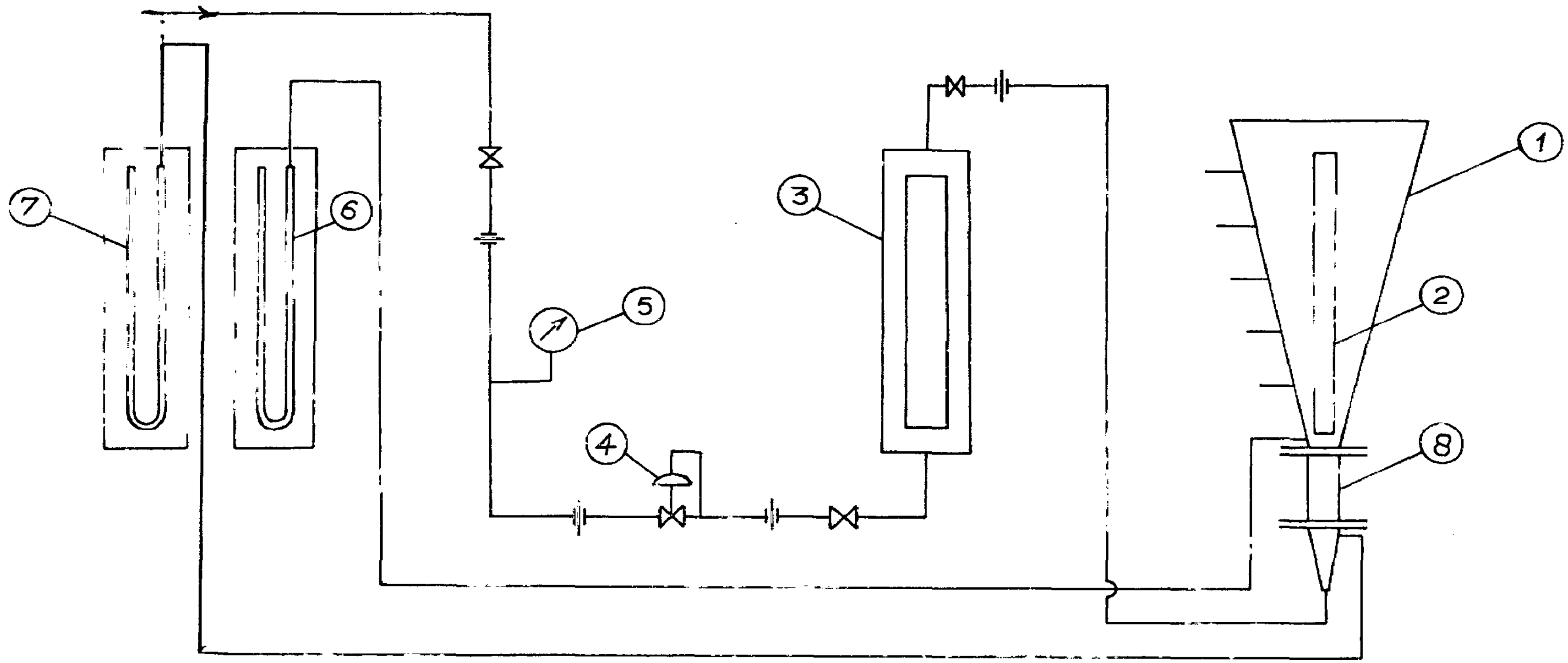
The experimental set up used for the study of the fluidization in tapered vessels consists mainly of fluidizing column , rotameter, manometers. The air inlet cone and calming section are used to get uniform distribution of air while entering the column. The schematic diagram of the experimental set up is shown in Fig. 3.1 and the fig. 3.2 by photograph.

3.1.1 OVERALL SETUP OF THE EQUIPMENTS

Compressed air at 100 atmospheres is taken from the surge tank of the compressor. It is regulated with the help of a pressure regulator employed in the air line going to the equipment to get constant supply of air to the column. This is passed through the rotameter for the measurement purpose and then fed to the fluidizing column. On the panel board manometers are provided for the pressure measurement. The calming section is fitted at the bottom of the column with the grid plate in between. The calming section is followed by the air inlet cone which receives the air from the outlet of the rotameter. The whole set up is shown in the schematic diagram Fig. 3.1

3.1.2 CALMING SECTION AND AIR INLET CONE

The calming section has been provided at the bottom portion of the tapered column to have a proper and



1 FLUIDIZING COLUMN
2. PERSPEX SLIT
3. ROTAMETER
4. PRESSURE REGULATOR
5. PRESSURE GAUGE
6. MANOMETER (for ΔP across bed)
7. MANOMETER (for ΔP across other section)
8. CALMING SECTION

FIG. 3.1 SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP

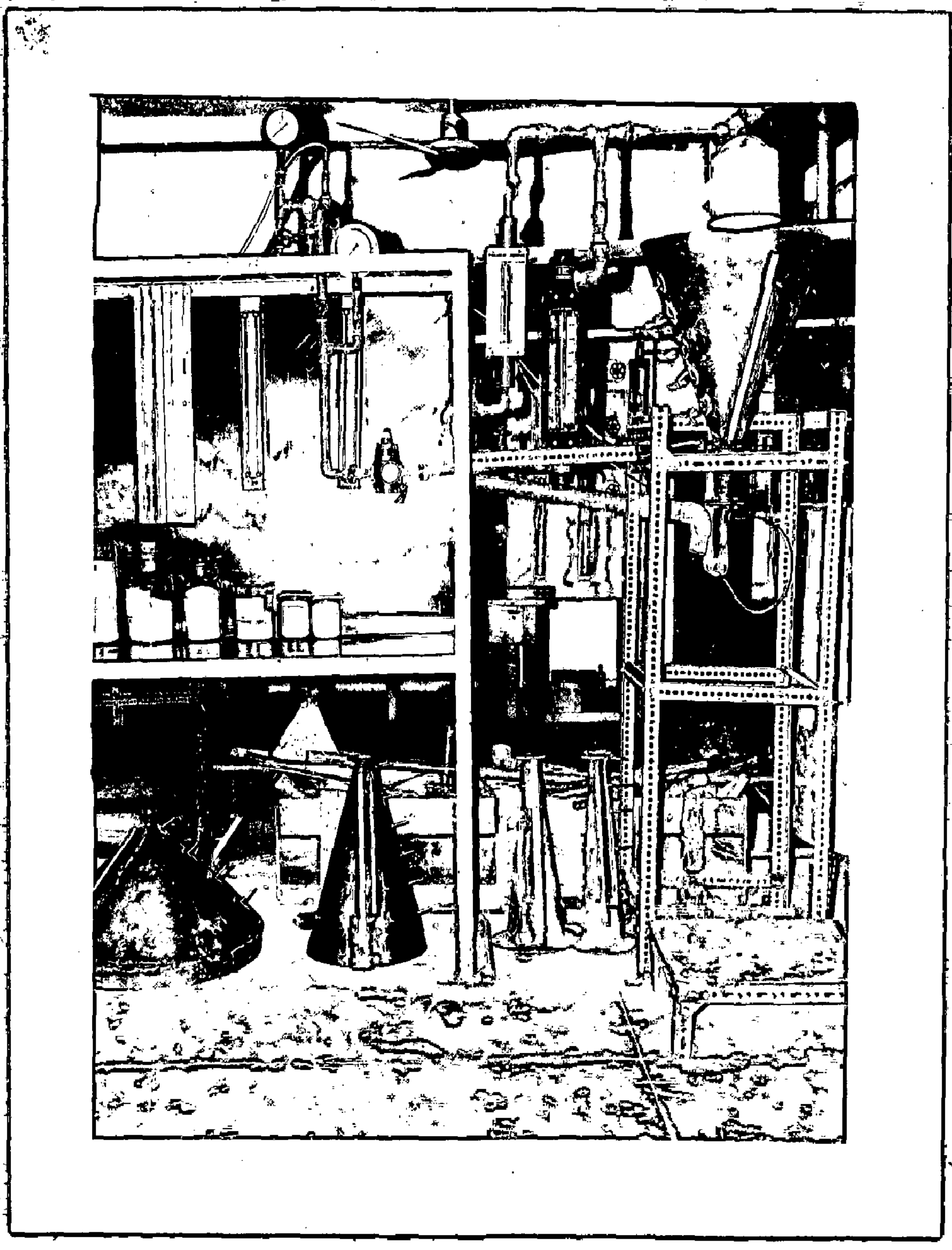


FIG.3.2- EXPERIMENTAL SETUP

uniform distribution of air. This part is simple in the construction. The packing of Raschig rings has been filled in a section of 4.0 cm. diameter to check the channeling of the inlet air. The 10 cms. diameter flanges have been welded at both sides of this section for its further fittings. The calming section has been shown in the Fig. 3.3 with a height of 10 cms.

The air inlet cone is a conical section with 1/2" bottom diameter and 4.0 cms top diameter. The total height of conical section is 10 cms. For the line fittings, 1/2" mild steel socket is welded at the bottom part and a 10 cms. diameter flange at the top portion. Four holes with 3/8" diameter have been drilled in the flange at 7.ω cm. pitch circle diameter. Wire mesh is provided to support the Raschig rings at the junction of the air inlet cone and calming section. Both air inlet cone and calming section are shown in Fig. 3.3.

3.1.3 DISTRIBUTOR OR GRID PLATE

The quality of bubbling fluidization is strongly influenced by the type of gas distributor used. For few air inlet openings the bed density fluctuates appreciably at all flow rates ₵ 20 to 50% of mean value), though more severely at high flow rates the bed density varies with height and gas channeling becomes severe. For many air inlet openings the fluctuation in bed density is negligible at low air flow rates

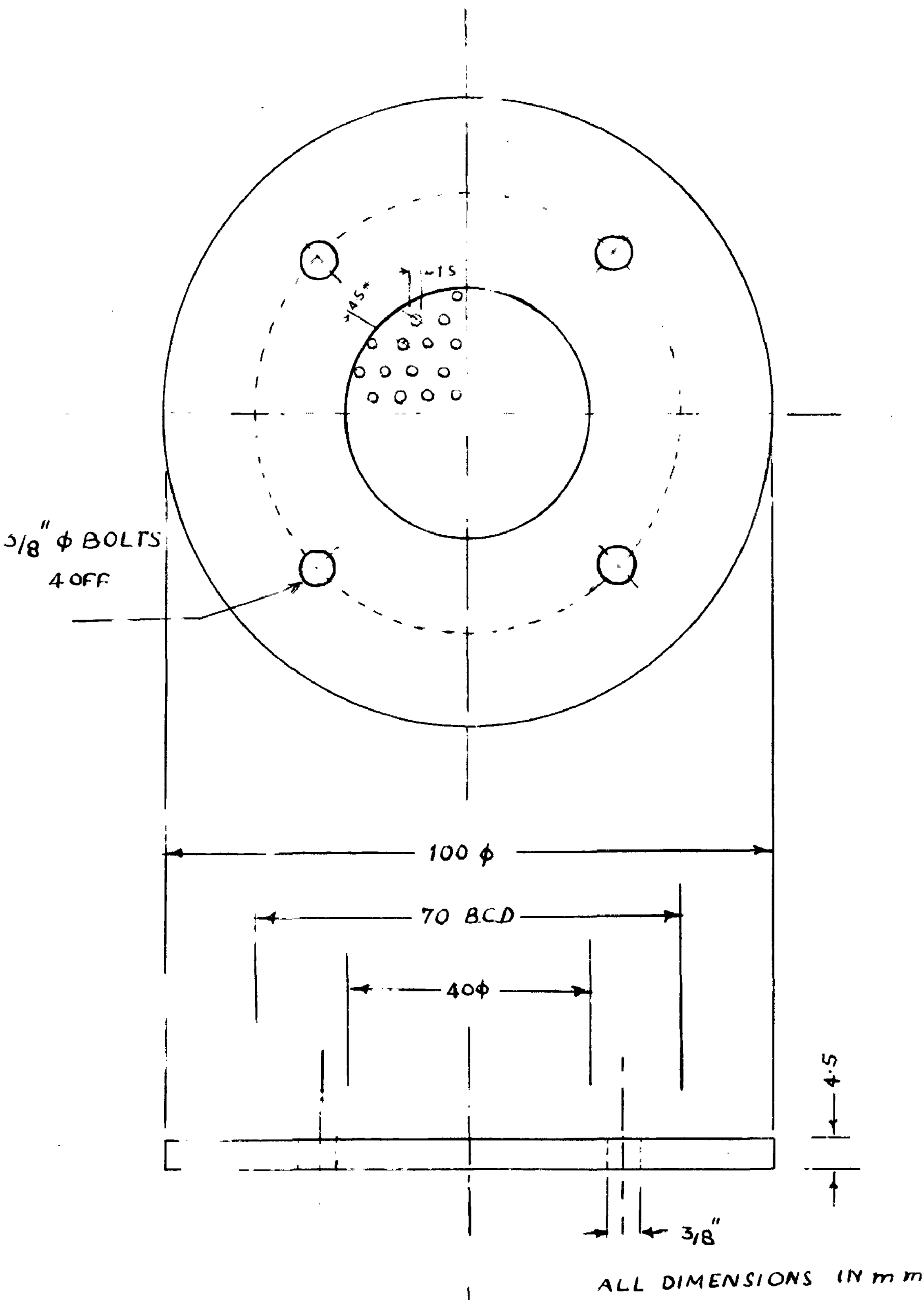


FIG.34 - DETAILS OF GRID PLATE

but again becomes appreciable at high flow rates. Bed density is more uniform throughout, bubbles are smaller, and air-solid contacting is more intimate with less channeling of air.

Contacting is superior when density consolidated porous media or plates with many small orifices are used. Depending upon the above criteria a grid plate of aluminium has been chosen. As shown in the Fig. 3.4 the holes are drilled in an area of 4.0 cms. diameter. The thickness of the plate is 3/16" . The total diameter of the plate is 10.0 cms . The details of the plate are as follows

Material	Aluminium
Thickness	3/16 inches
holes size	1.5 mm ø
Pitch	4.5 mm.

3.1.4 FLOW MEASUREMENT DEVICE

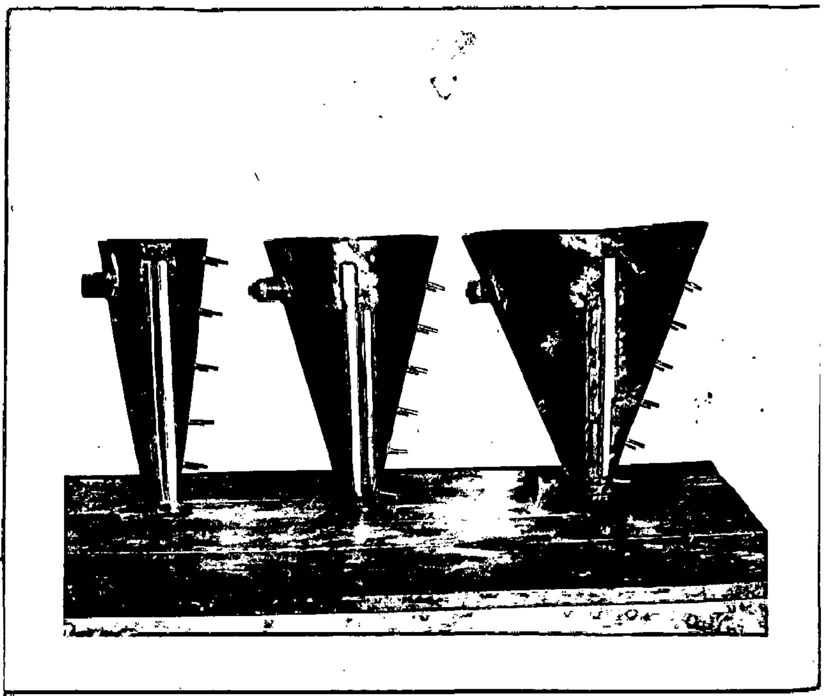
Air flow rate is measured with the help of rotameter. The rotameter gives the flow rate in litres per hour. Such a rotameter is to be used which can cover smaller as well as higher flow rates of air in case of the lighter and heavier particles. The lighter particles and the smaller bed heights need only lesser flow rates while the heavier particles and larger bed heights require higher air flow rates. So to cover the total range of fluidization rotameter of the range 0- 35000 NPLH is used.

3.1.5 PRESSURE MEASUREMENT DEVICES

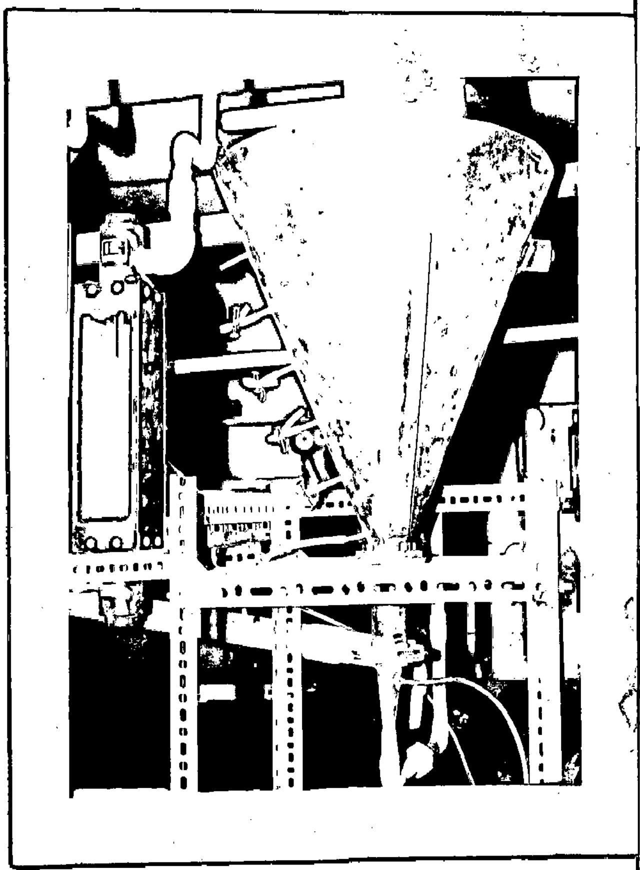
The pressure is measured by simple device of manometers. The pressure of the inlet air is very less of the order of 1.0 to 1.5 atmos-phere. So we use only the water manometers. One tube of the manometer is fixed with the pressure taping of the air inlet cone and the other is open to autmosphere. Second manometer is connected inbetween the lowest taping of the column and the atmosphere. One end of the manometers are open to atmosphere because pressure in the column above the bed is atmospheric.

3.1.6 TAPERED COLUMNS

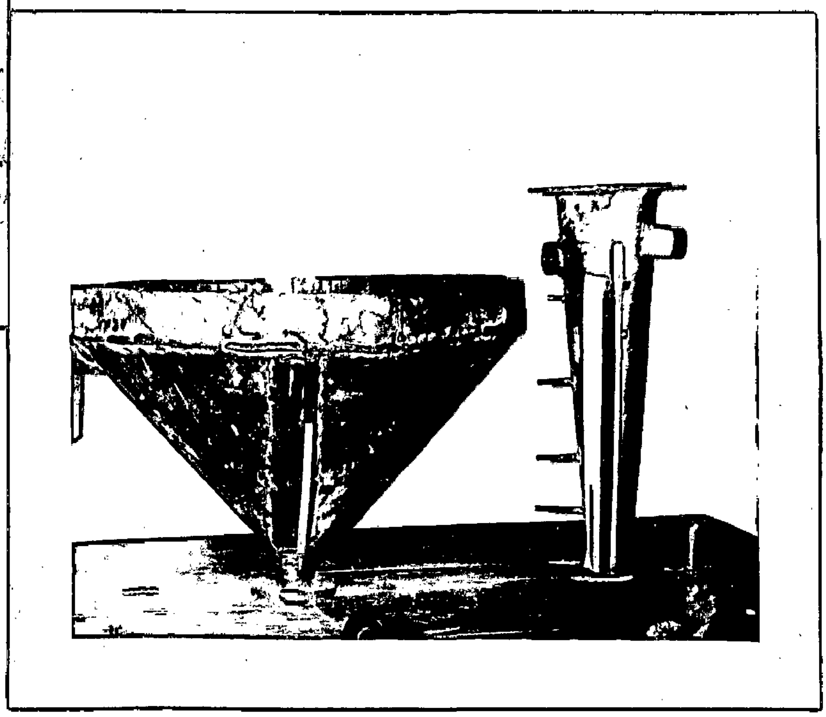
The tapered column is the main part of the apparatus. The taper angles of the columns taken for the experiment are 10, 15, 20 , 30 , 45 and 90 ^{o}. Thus in all six columns have been studied. The bottom diameter of the columns have been chosen arbitrarily to be 4.0 cms. This diameter equals the diameter of the calming section. Bottom diameter of all the columns is taken same because only single calming section and air inlet cone will serve for all. For convenience of the experimental work the height of first five columns is taken as 50.0 cm. while for 90^{o} it is less. On the basis of the above measurements the other details of the columns have been fixed and are summarized in the following table.



15° 20° 30°



45°



90° 10°

FIG.3.5- FLUIDIZING COLUMNS

Table 3.1

S.No.	Taper Angle (Degrees)	Material of construction (M.S.Plate) size inch	Height of column cms	Bottom diameter cms	Top diameter cms
1	10	1/4	50	4	12.4
2	15	1/4	50	4	16.8
3	20	1/4	50	4	21.6
4	30	1/4	50	4	32.4
5	45	1/4	50	4	48.4
6	90	1/4	21	4	46.0

The 10 cms flange is welded at the bottom of the columns for the necessary fittings. Pressure tapings have been provided at the different heights of the columns, for measuring the pressure. To see the fluidization in the tapered columns the transparent perspex slit of 1" width has been fixed in the columns. Areldite has been put to fix the slit and to check the leakage. Photographs of the columns is shown in Fig. 3.5

3.2 EXPERIMENTAL PROCEDURE

The experimental procedure can well be explained on the basis of the schematic diagram of the experimental set up. Shown in fig. 3.1 The procedure can be explained schematically according to the layout of the different equipments in the setup.

3.2.1 OPERATING PROCEDURE

The air drawn from a compressor is stored in a surge tank at the required pressure. From the surge tank air is supplied to the fluidizing column at a uniform pressure and at the same time the flucuations caused by the compressor are eliminated competely. The air is fed to the main equipment through a pressure regulator which gives us the constant air supply at the exit. This air from the pressure regulator is passed through the rotameter, where the air flow rate in litres per hour is measured. This measured air is then fed to the main fluidizing column through the conical inlet cone . In between the air inlet cone and the main column the calming section has been provided which ensures the proper distribution of the air in the column. The Raschig ring packing have been provided in the calming section. At the top of the calming section the grid plate and a wire cloth are fixed. Thus before passing through the column the air is properly distributed. This air fluidizes the material filled in the column. The pressure difference for the bed is measured with the help of manometer. The air at the exit is let to go as such in the atmosphere.

3.2.2 PERFORMANCE OF MANOMETERS

The operation takes place at the atmospheric pressure and the operating pressure in the fluidizing column is of the order of 1 to 1.4 atmospheres. So we use the water manometer

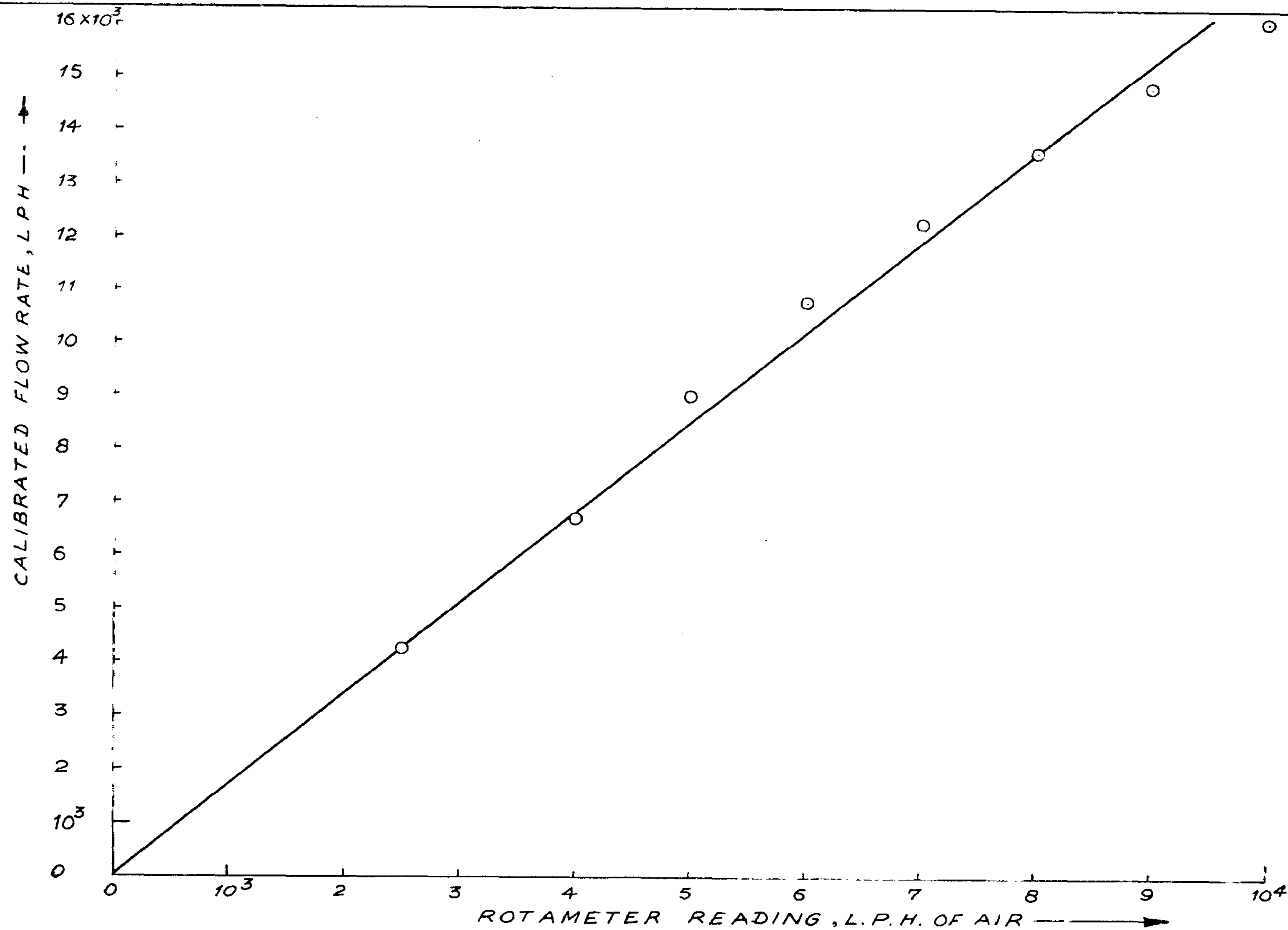


FIG. 3.6 CALIBRATION OF ROTAMETER

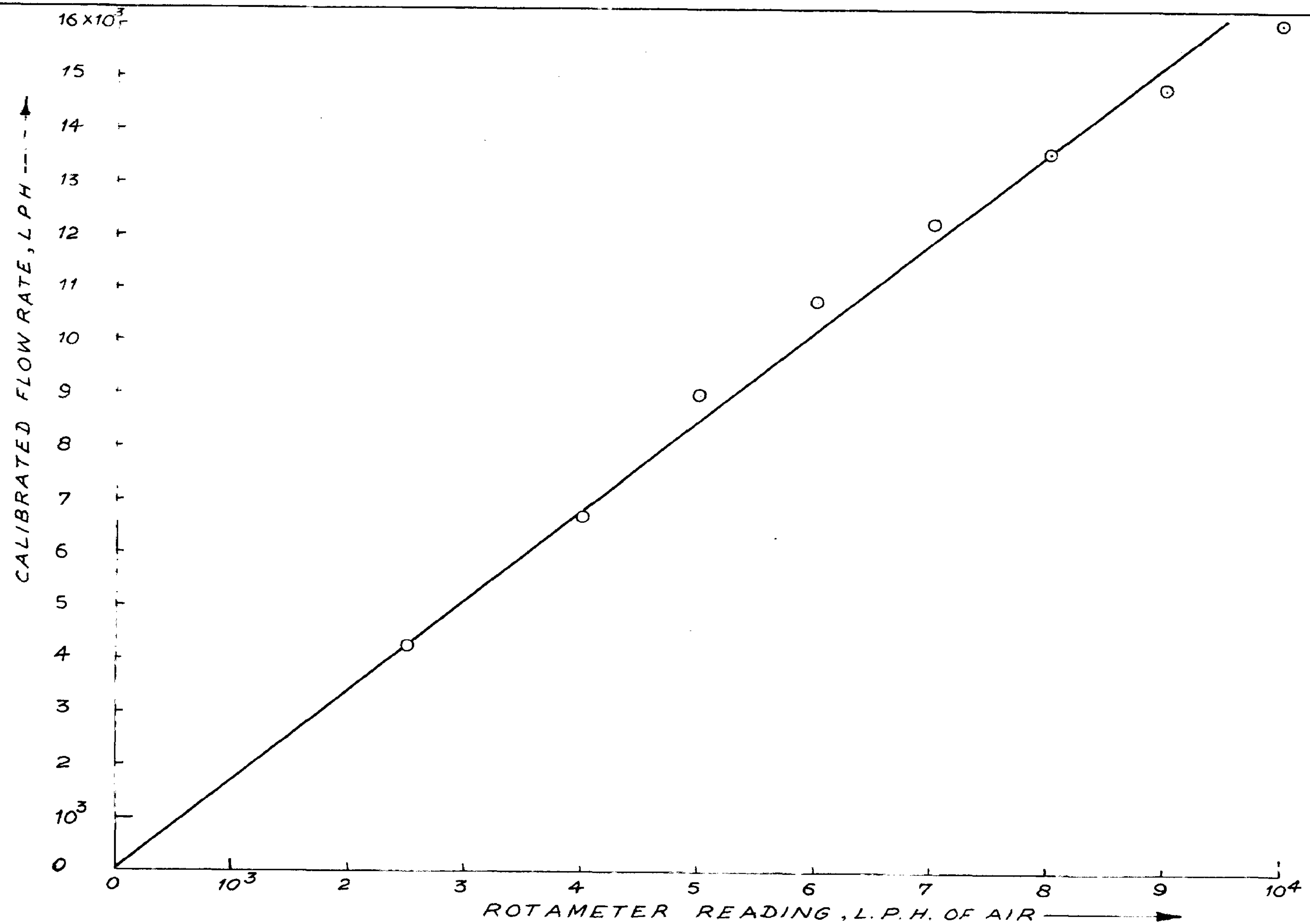


FIG. 3.6 CALIBRATION OF ROTAMETER

These water manometers indicate very small pressure drops to a greater accuracy . The pressure difference is directly measured as the difference of cms of water.

$$\Delta P \text{ (Cm. of water)} = \Delta P \text{ (gms/cm}^2\text{)}$$

Thus we directly get the pressure difference in gms/cm^2.

3.2.3 CALIBRATION OF ROTAMETER

The rotameter is calibrated with the help of gas flow meter. We first pass the air at different flow rates through the rotameter which indicates the flow in litres per hour. The same air from the rotameter exit is allowed to pass through the gas flow meter. The gas flow meter gives its own readings according to the air flow rate. Sufficient data have been taken at different flow rates and the rotameter is thus calibrated using standard gas flow meter. The calibration curve is shown in Fig. 3.6.

CHAPTER - FOUR

RESULT AND DISCUSSION

The pressure drop and air flow rate data have been obtained for different materials like glass beads, bauxite and calcite in different tapered vessels. The size range of the materials used, vary from -16 to +40 mesh size. These data are tabulated in Table A-1 to Table A-62 and some important plots have been drawn, to study the effect of different parameters.

4.1 EFFECT OF BED HEIGHT

For the same material and particle size, pressure drop, pressure peak and air flow rate at onset of fluidization have been found to increase with bed height.

Pressure drop increase is justified by the fact that at onset of fluidization, it is equal to the net weight of particles in the bed. So with increase in bed weight it will increase. Higher value of pressure peak and air flow rate is due to increased degree of interlocking between the adjacent particles. So to fluidize these particles, greater air flow rate is required. After the pressure peak value, pressure drop suddenly falls to minimum value. With further increase in air flow rate pressure drop falls gradually. Fig. 4.1 shows this effect for glass beads, fig. 4.2 to 4.4 for calcite and Fig. 4.5 for bauxite. Fig. 4.6 shows the same effect for another cone angle.

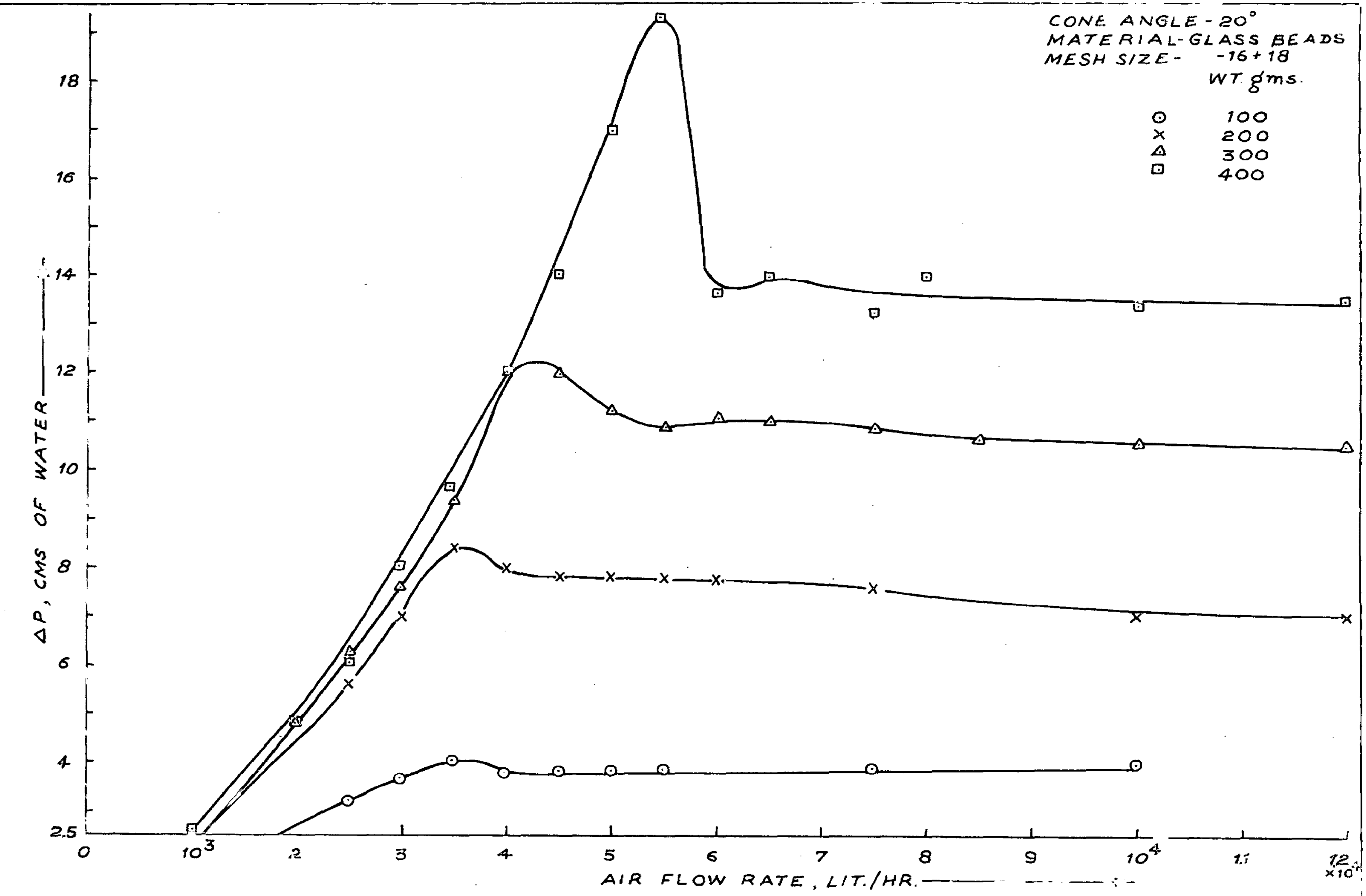


FIG. 4.1 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT BED HEIGHTS OF GLASS BEADS

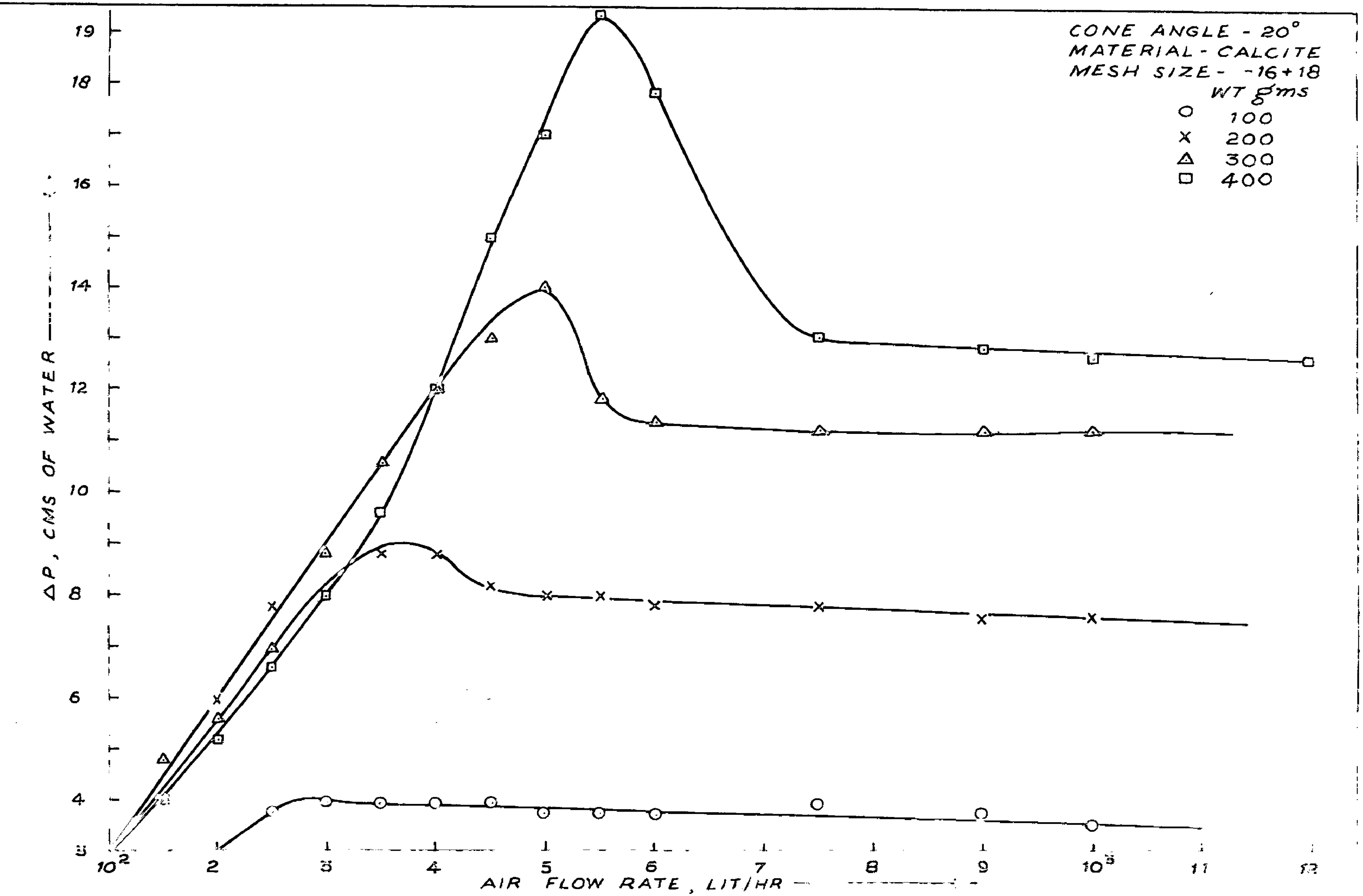


FIG. 4.2 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT BED HEIGHTS OF CALCITE

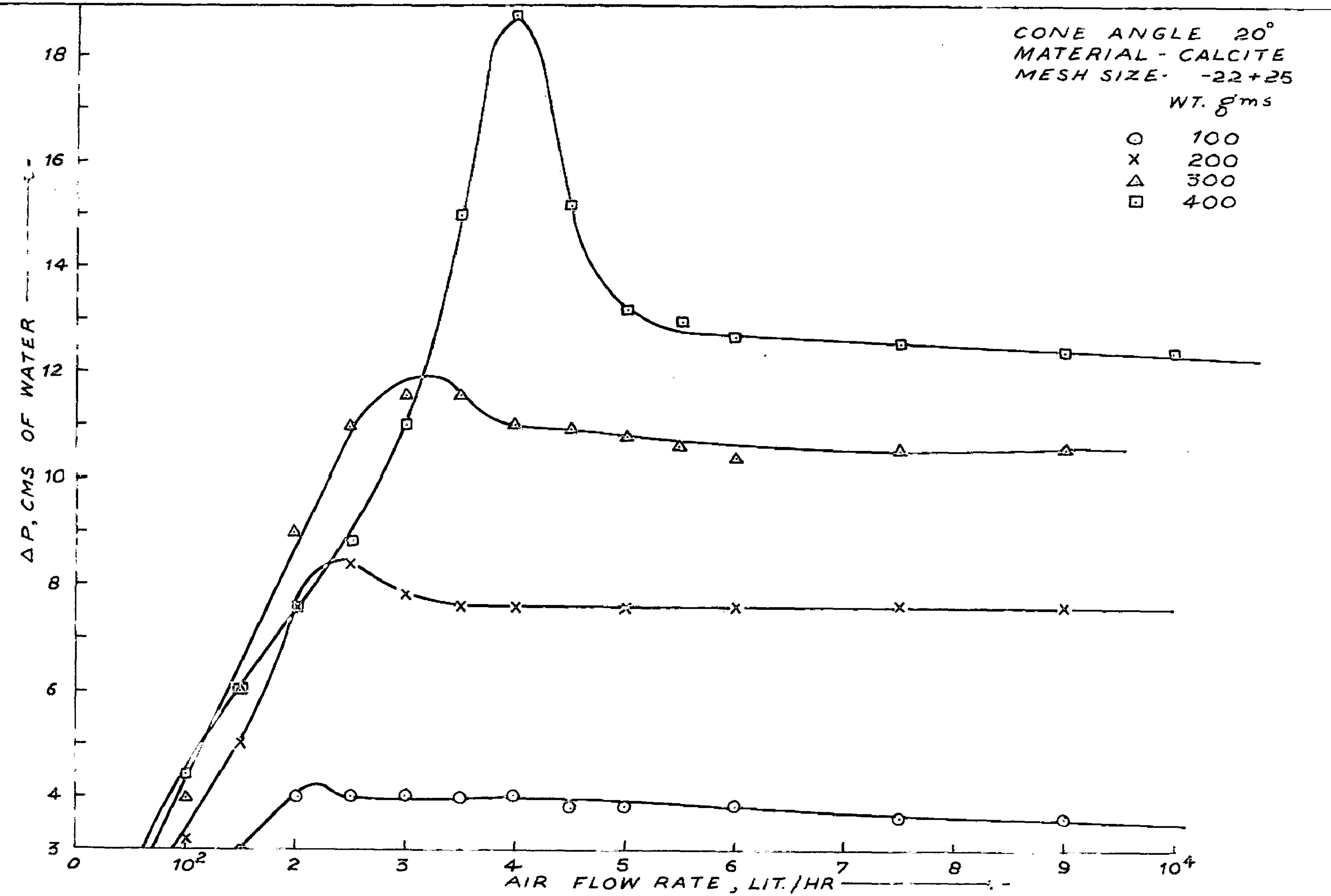


FIG.4.3 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT BED HEIGHTS OF CALCITE

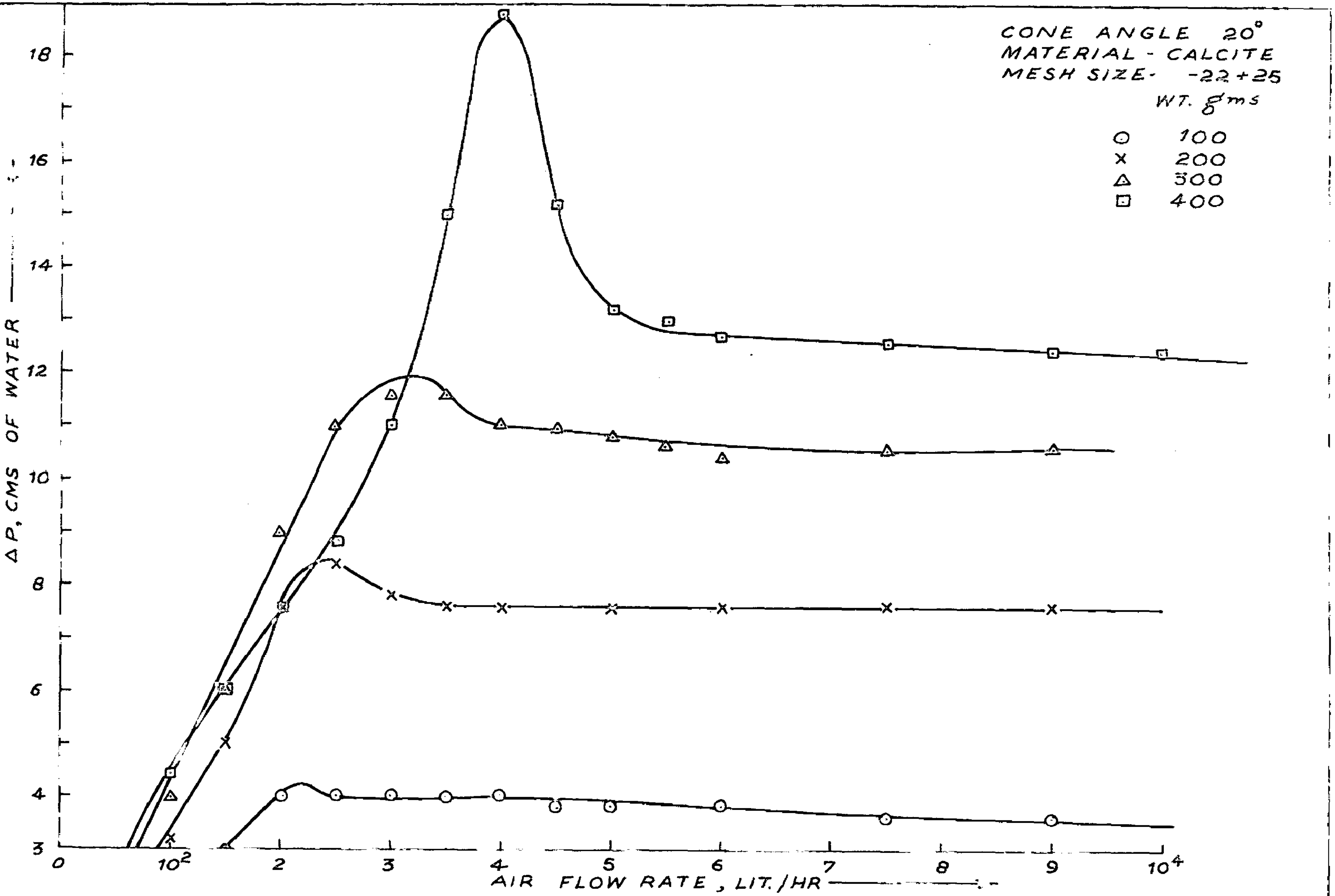


FIG.4.3 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT BED HEIGHTS OF CALCITE

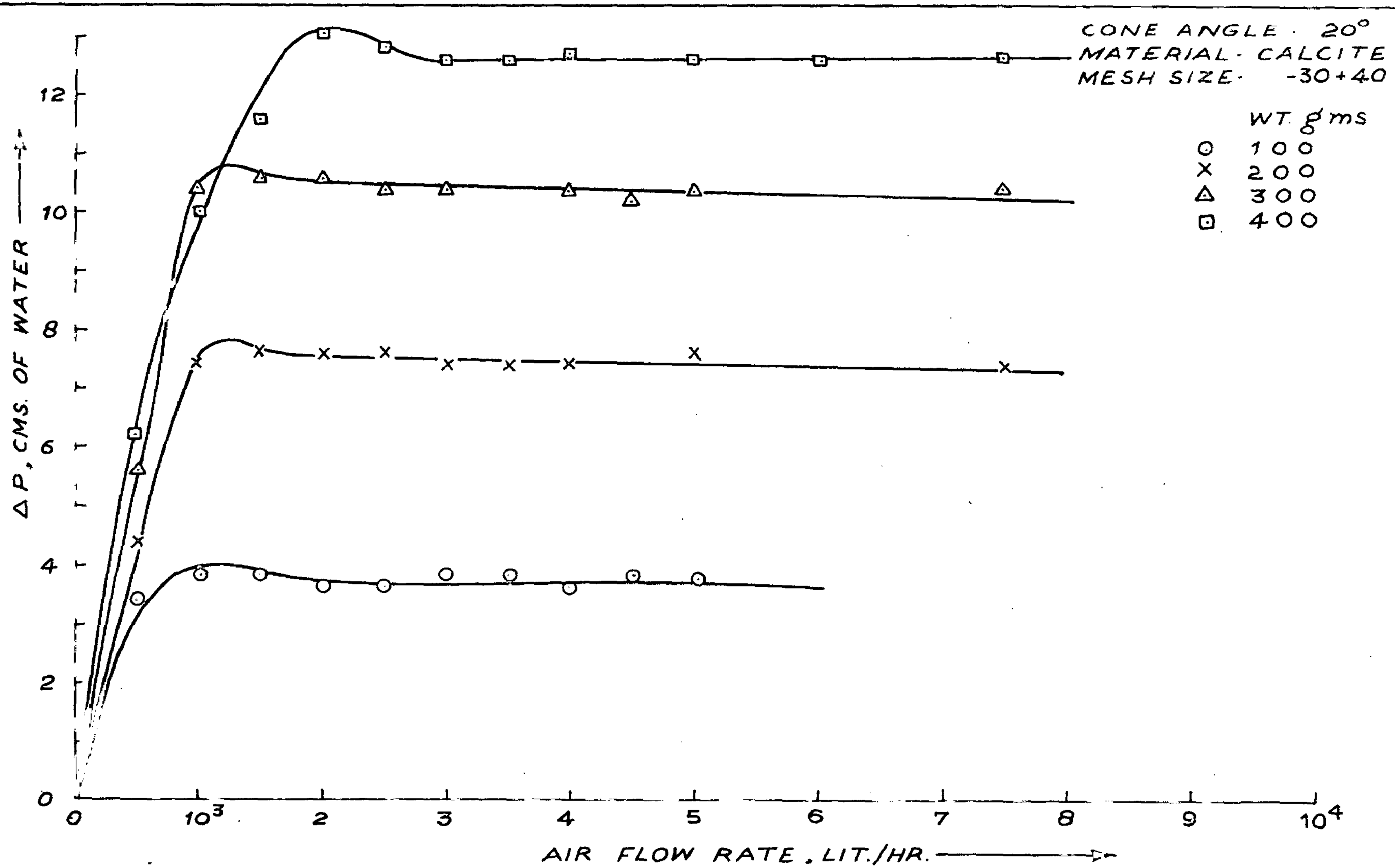


FIG. 4.4. VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT BED HEIGHTS OF CALCITE

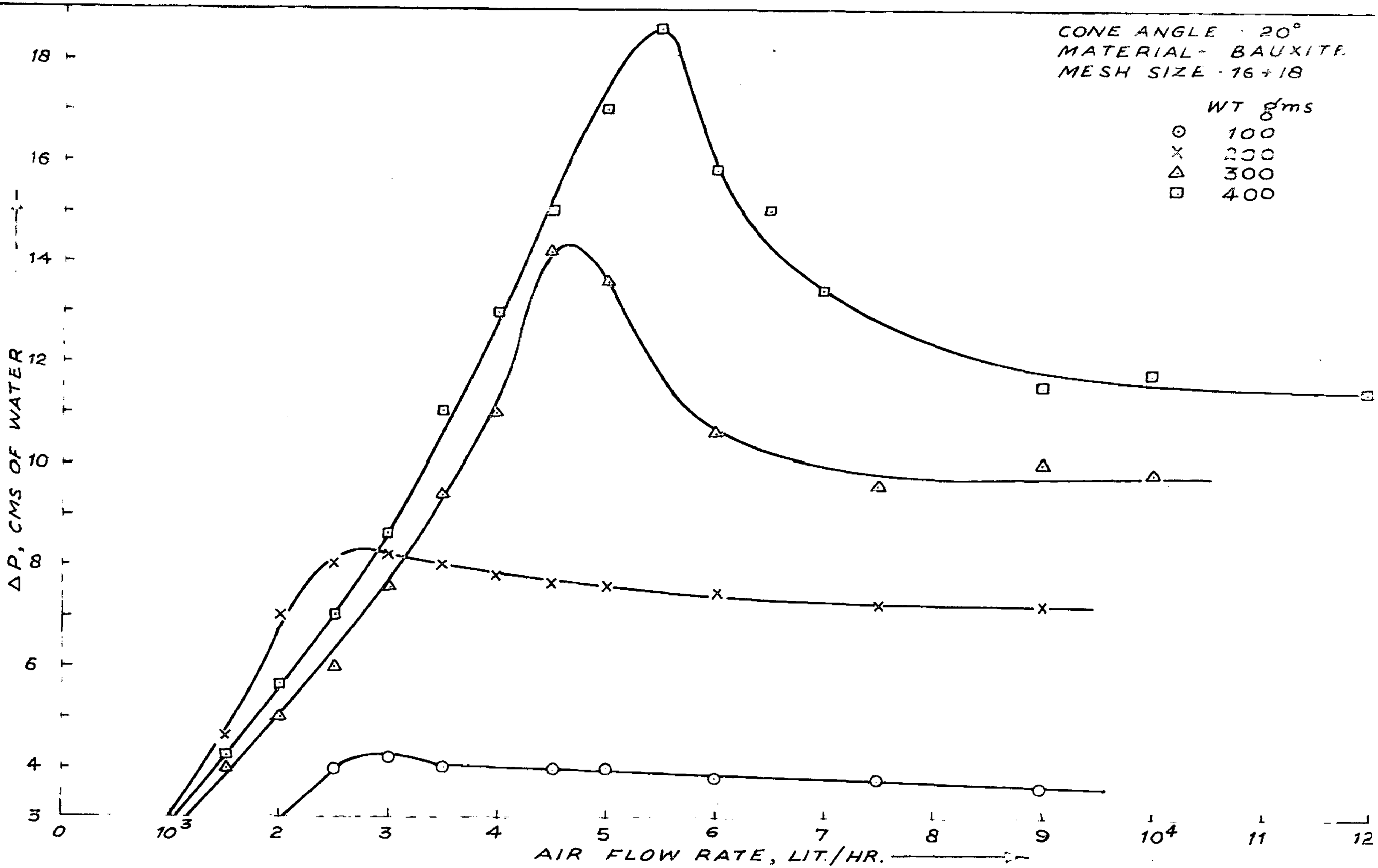


FIG. 4.3 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT BED HEIGHTS OF BAUXITE

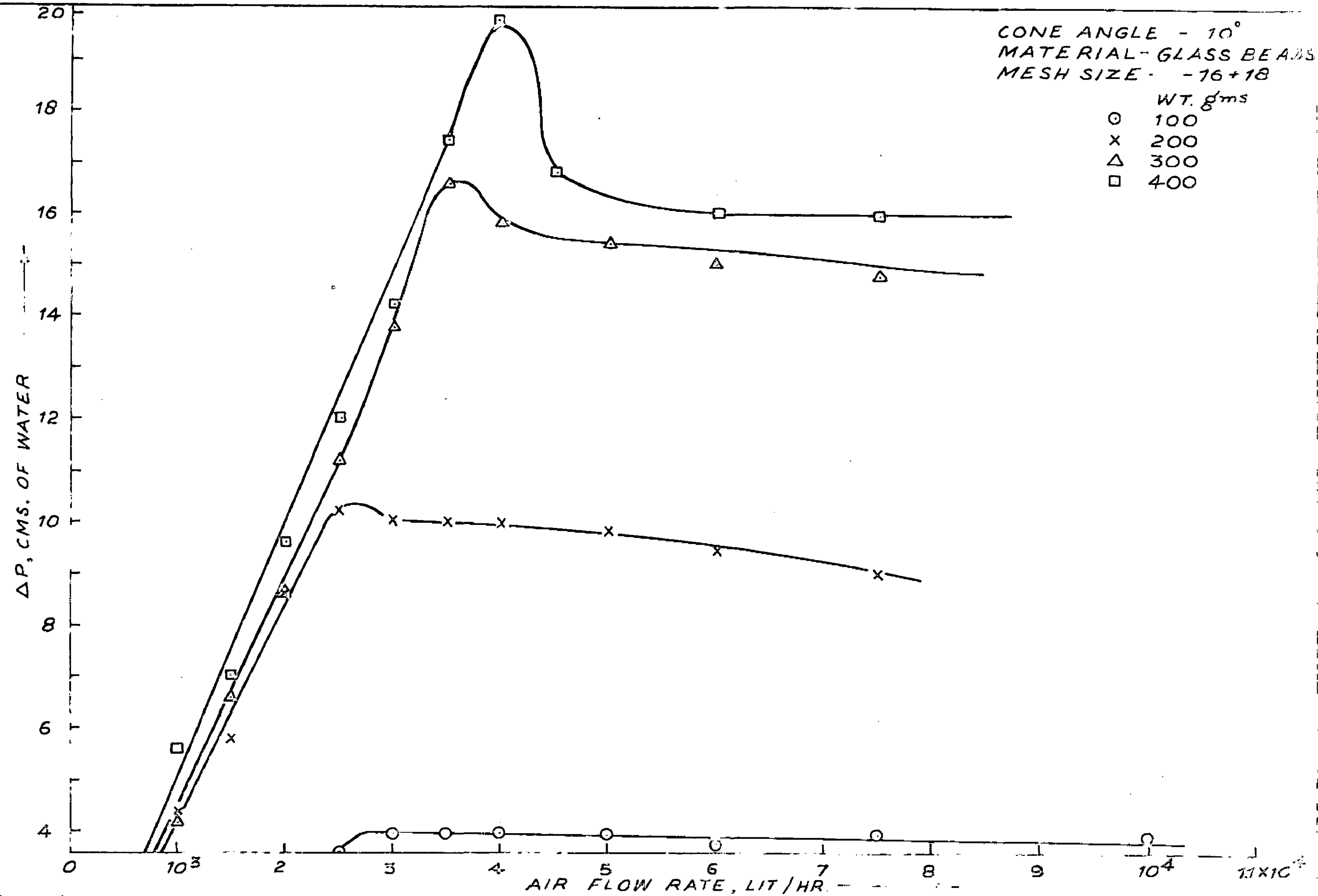


FIG. 4.6 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT BED HEIGHTS OF GLASS BEADS

4.2 EFFECT OF PARTICLE SIZE

For the same material and bed weight, pressure peak value increases with particles size. Increased value of pressure peak is because of increased degree of interlocking between particles as particle size increases. Like pressure peak, pressure drop and air flow rate at onset of fluidization also increase with particle size. Fig. 4.7 shows these effects for Calcite in 10° cone, Fig. 4.8 for glass beads in 15°cone, Fig. 4.9 for Bauxite in 20° cone and fig. 4.10 for glass beads in 45°cone.

4.3 EFFECT OF SHAPE FACTOR

From Fig. 4.11 and 4.12 , it is found that pressure peak value is more for non spherical particles than for spherical ones. Pressure peak in calcite and bauxite are quite high as compared to glass beads.

Pressure drop at onset of fluidization shows an increase with particle density. The higher value of pressure peak in non spherical particles is due to better interlocking characteristics.

4.4 EFFECT OF CONE ANGLE

For 300 gms of glass beads, bauxite and calcite, curves (Fig. 4.13-4.14) with different cone angles have been drawn.

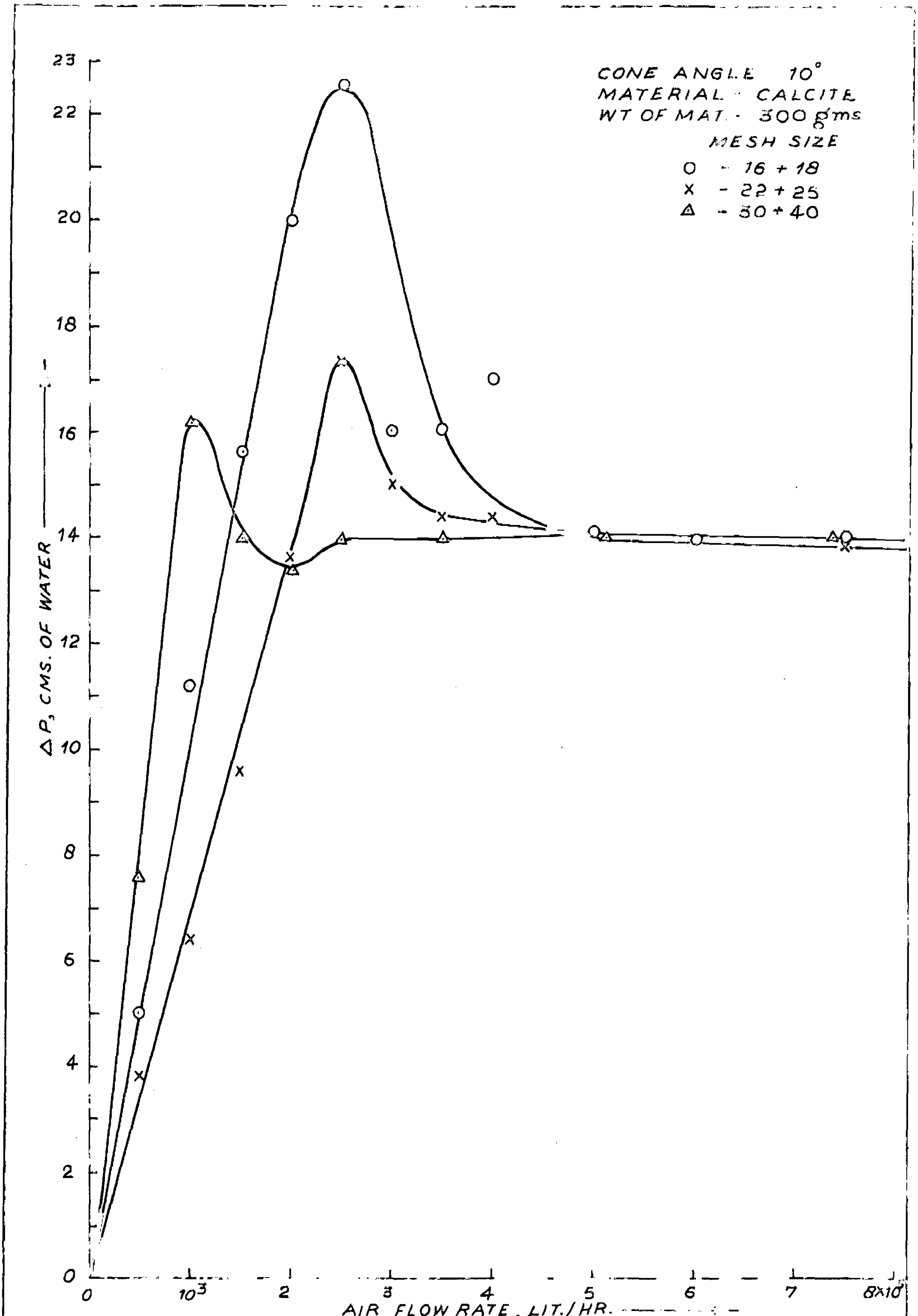


FIG. 4.7 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT SIZES OF CRUSHED PARTICLES IN 10° CONE

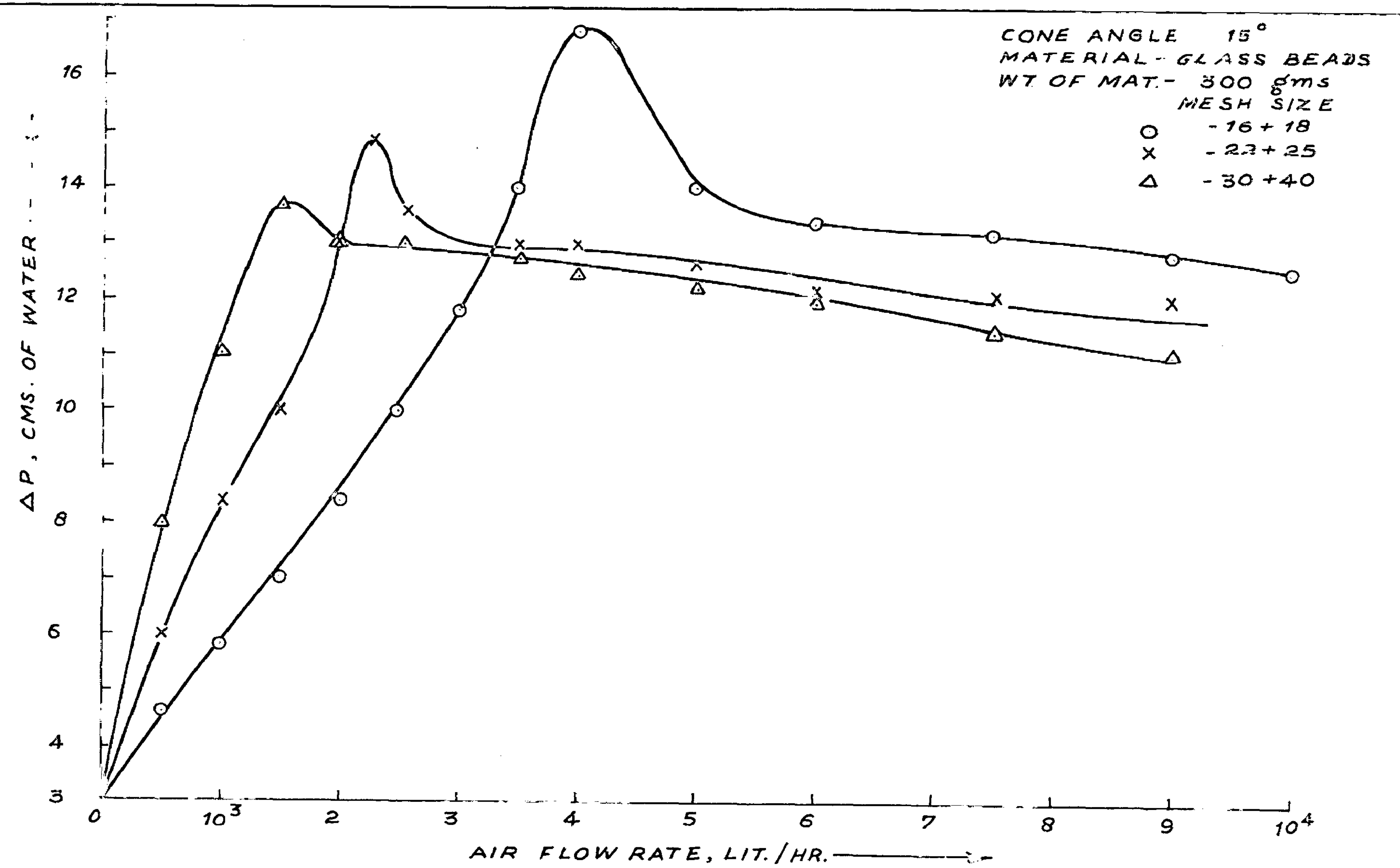


FIG. 4.8 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT SIZES OF SPHERICAL PARTICLES IN 15° CONE

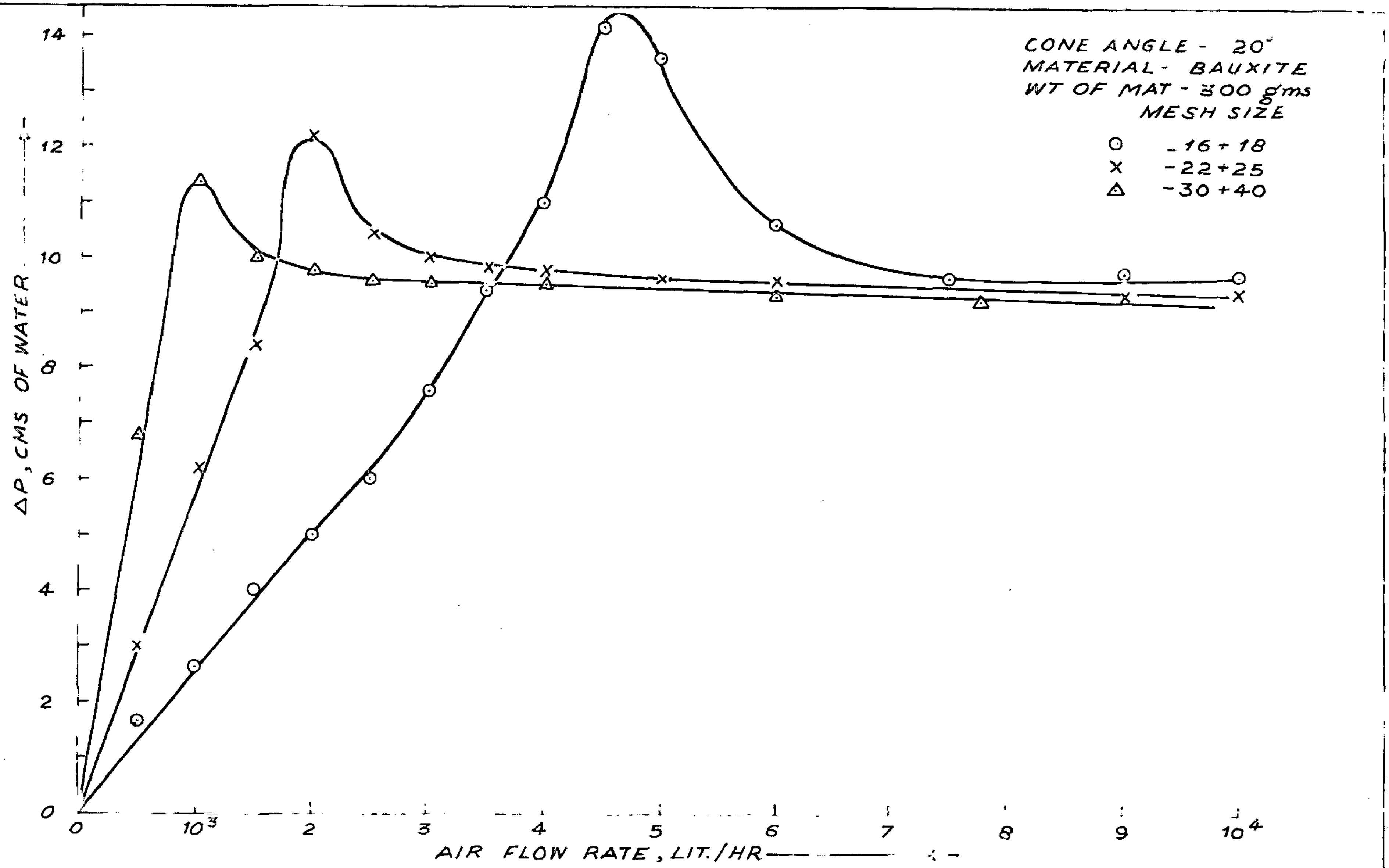


FIG. 4.9 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT PARTICLE SIZES IN 20° CONE

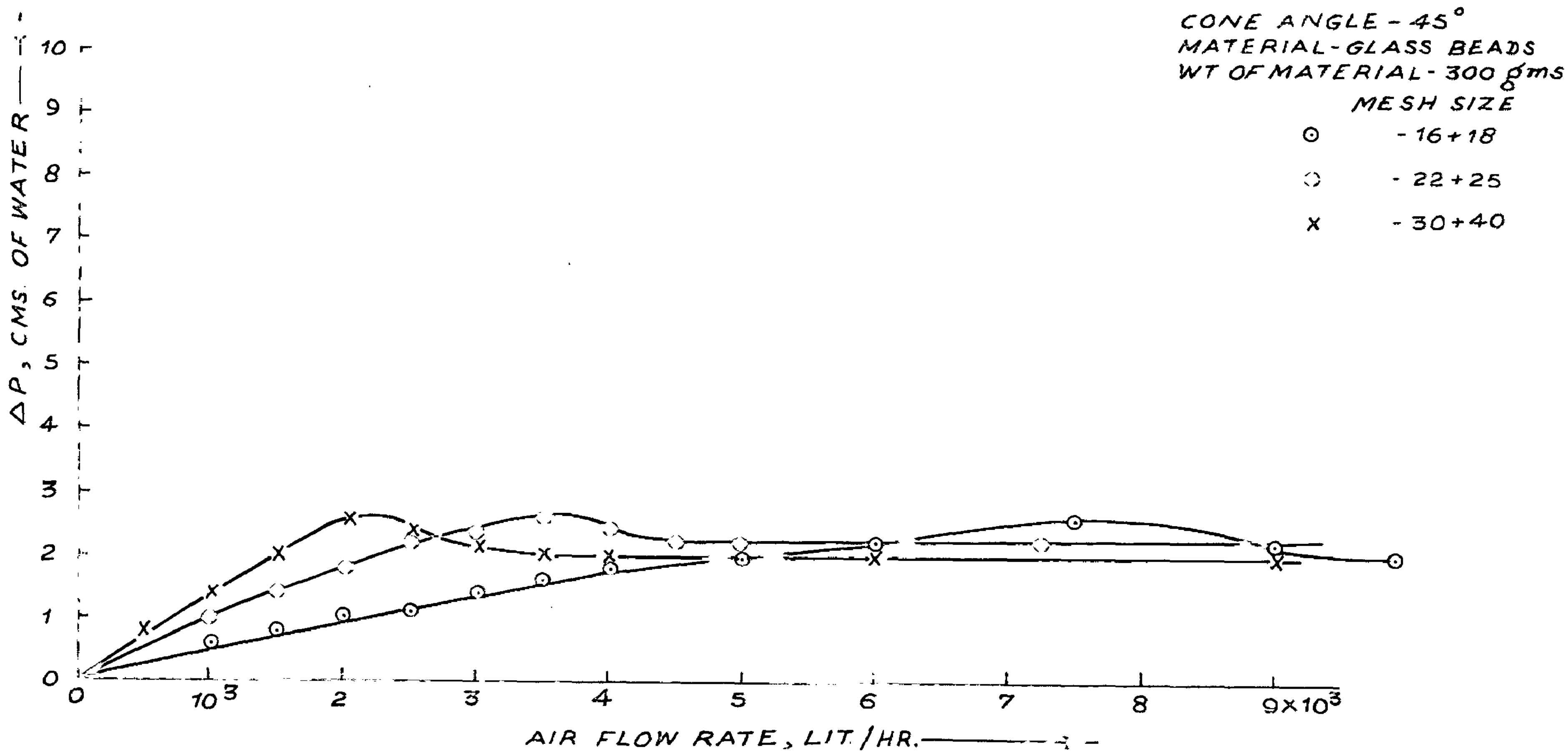


FIG. 4.10 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFEREN PARTICLE SIZES IN 45° CONE

These curves show that with increase in cone angle pressure drop goes an reducing, the reason being that bed height goes on reducing very rapidly with cone angle for the same bed weight.

Pressure peak values are noted to be much reduced for 45° and 90° cones. The reason for this is , reduced bed height and the fact that only a limited part of the bed, confined to the central portion is fluidized. This phenomenon is shown in Fig. 4.16 by photograph. The solids near the wall remain quiet even at high air flow rates.

4.5 QUALITY OF FLUIDIZATION IN DIFFERENT CONES

Quality of fluidization is food for smaller cone angles (10, 15, and 20°) As the cone angle increases quality decreases. In 30° and 45° cones the bed behaves like a spouted bed. Solids cone down along the wall and rise up in the central portion. Thus the bed shape is convex upwards In lower degree cones the particles near the walls have a tendency to slide down along it. But once the angle of cone ($\alpha/2$) crosses the value below the angle of repose. of the solid particles, they have little tendency to slide down.

In 90° cone the fluidization is limited only upto the central portion.

In lower cone angles slugging is more pronounced and it reduces with increase in cone angle.

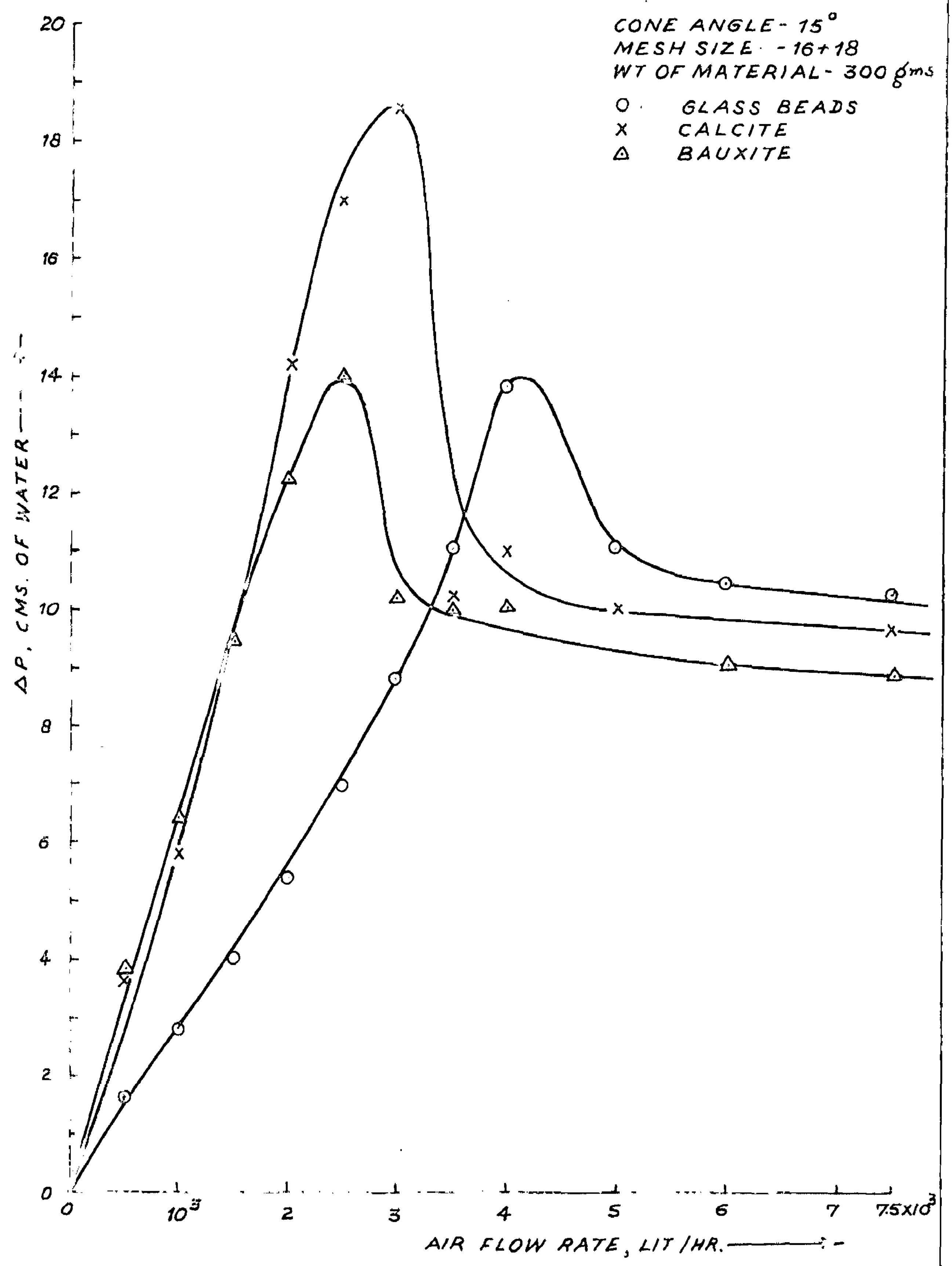


FIG. 4.11 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT MATERIALS OF SAME SIZE

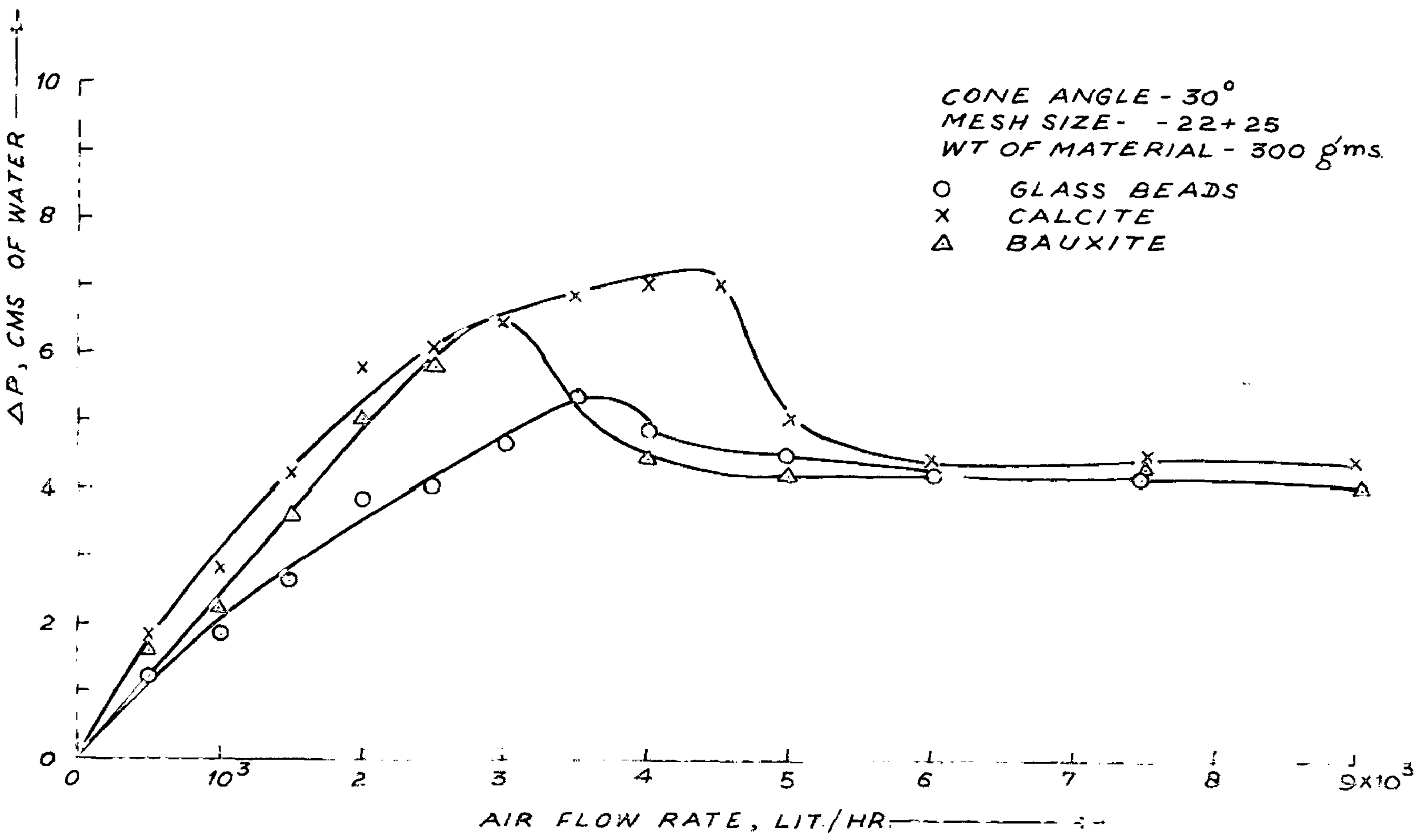


FIG. 4.12 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT MATERIALS OF SAME SIZE IN 30° CONE

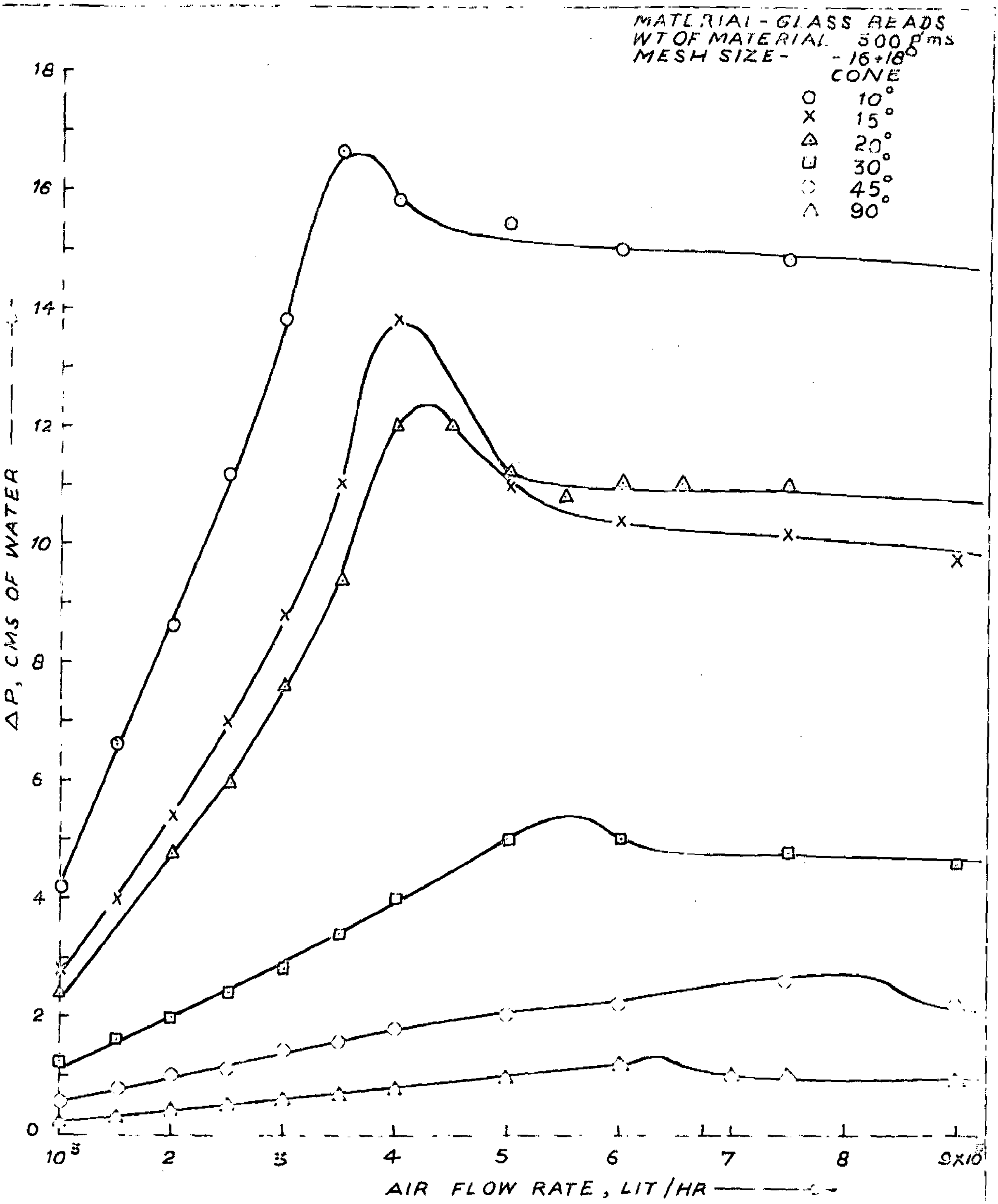


FIG. 4.13 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT CONE ANGLES USING GLASS BEADS

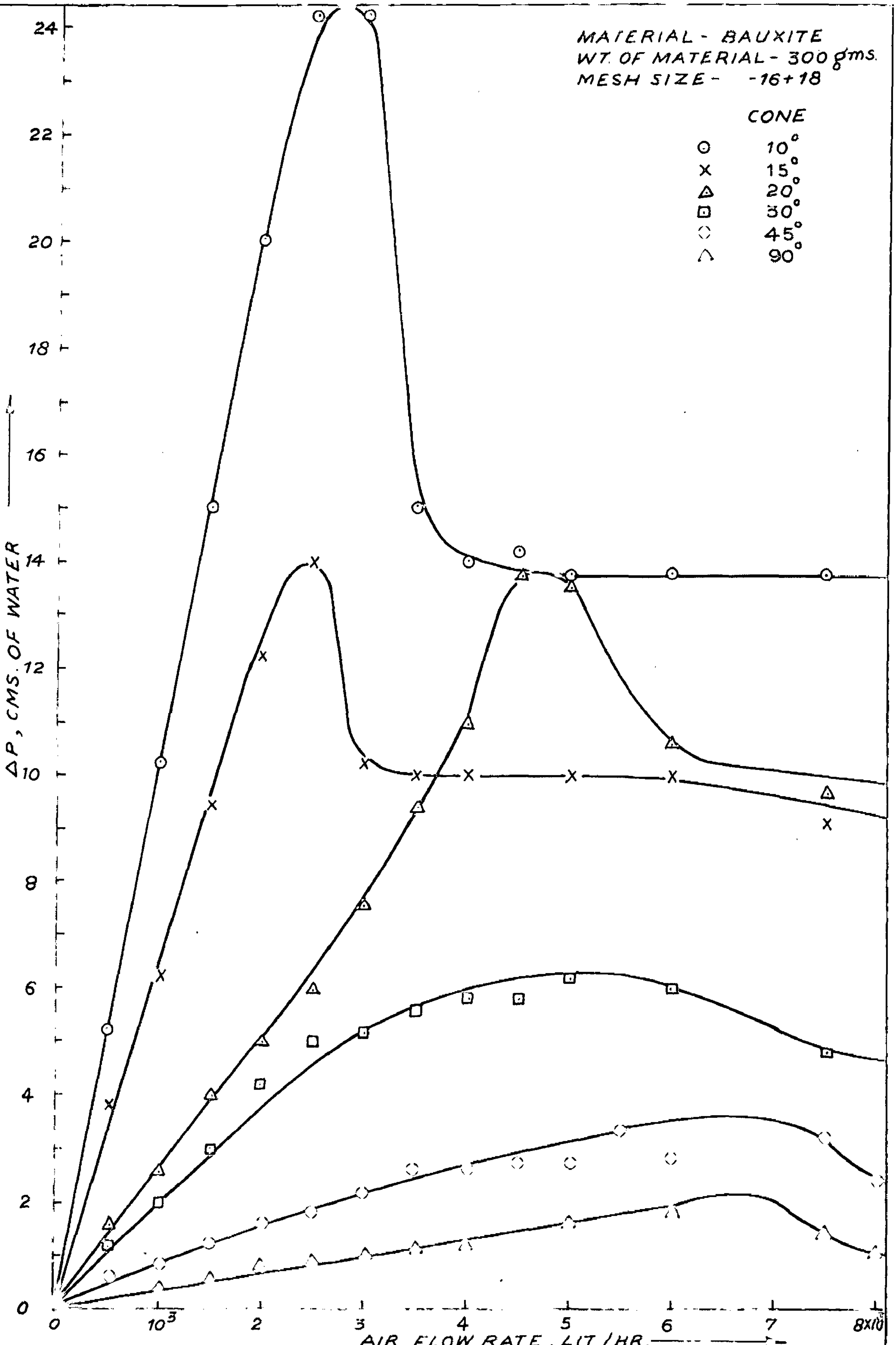


FIG. 4.14 VARIATION OF ΔP WITH AIR FLOW RATE FOR FOR DIFFERENT CONES USING BAUXITE

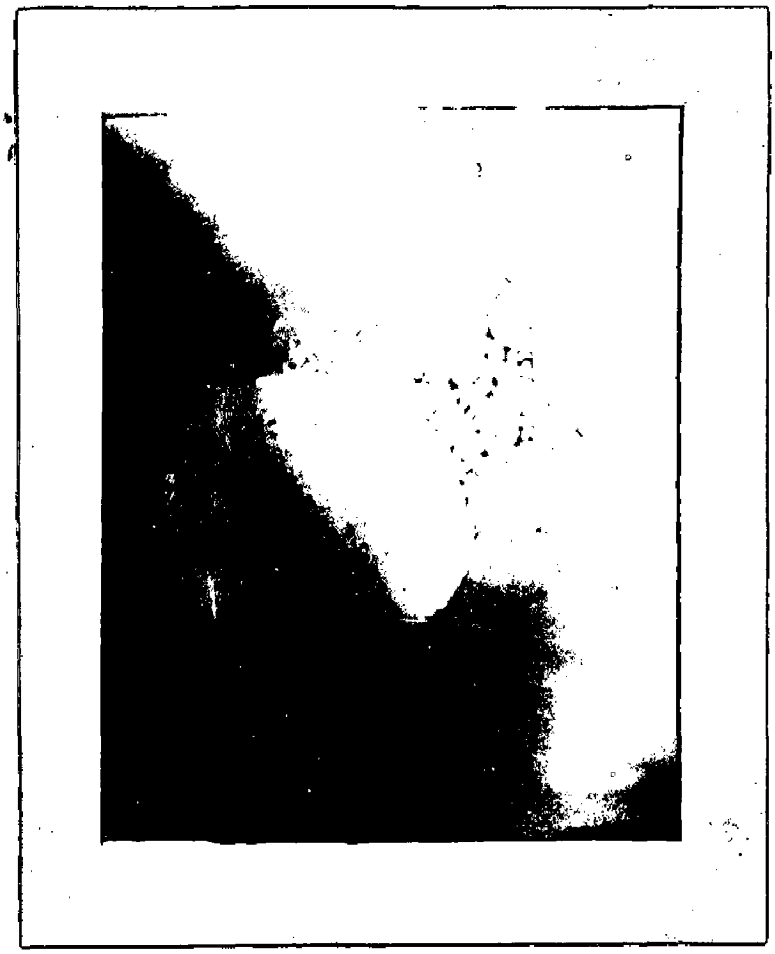


FIG. 4.16 FLUIDIZATION IN 90° CONE

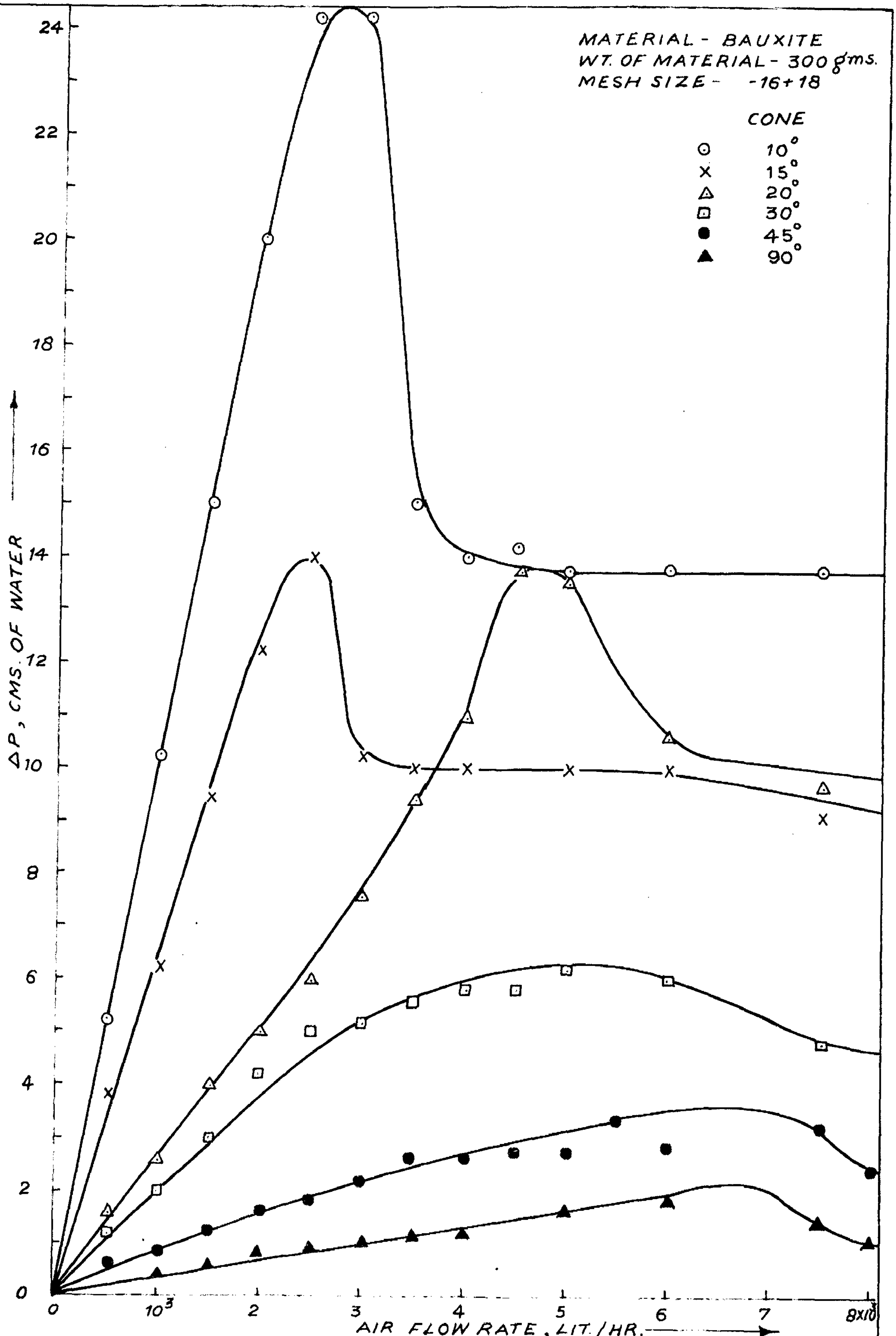


FIG. 4.14 VARIATION OF ΔP WITH AIR FLOW RATE FOR FOR DIFFERENT CONES USING BAUXITE

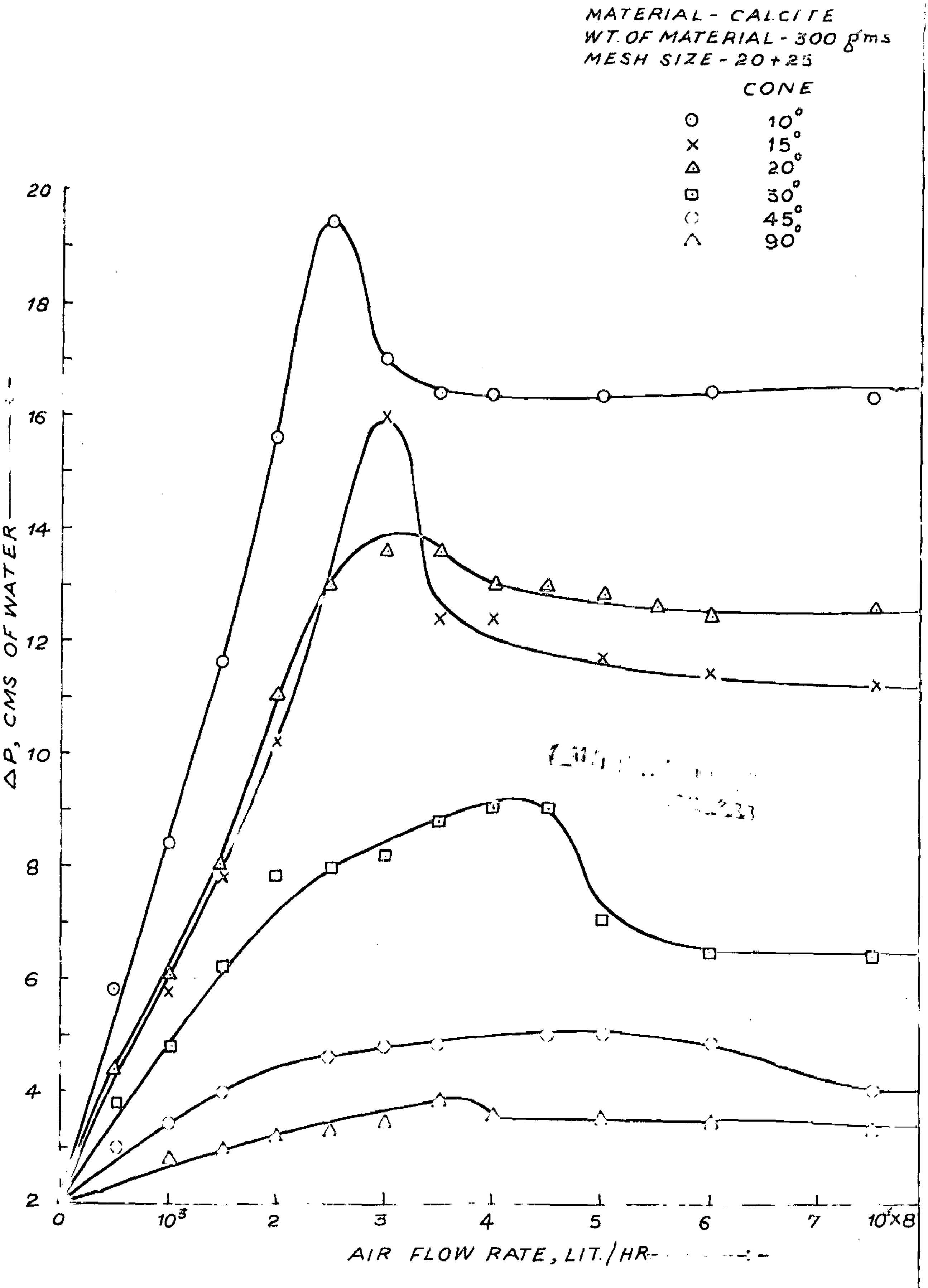


FIG. 4.15 VARIATION OF ΔP WITH AIR FLOW RATE FOR DIFFERENT CONE ANGLES USING CALCITE

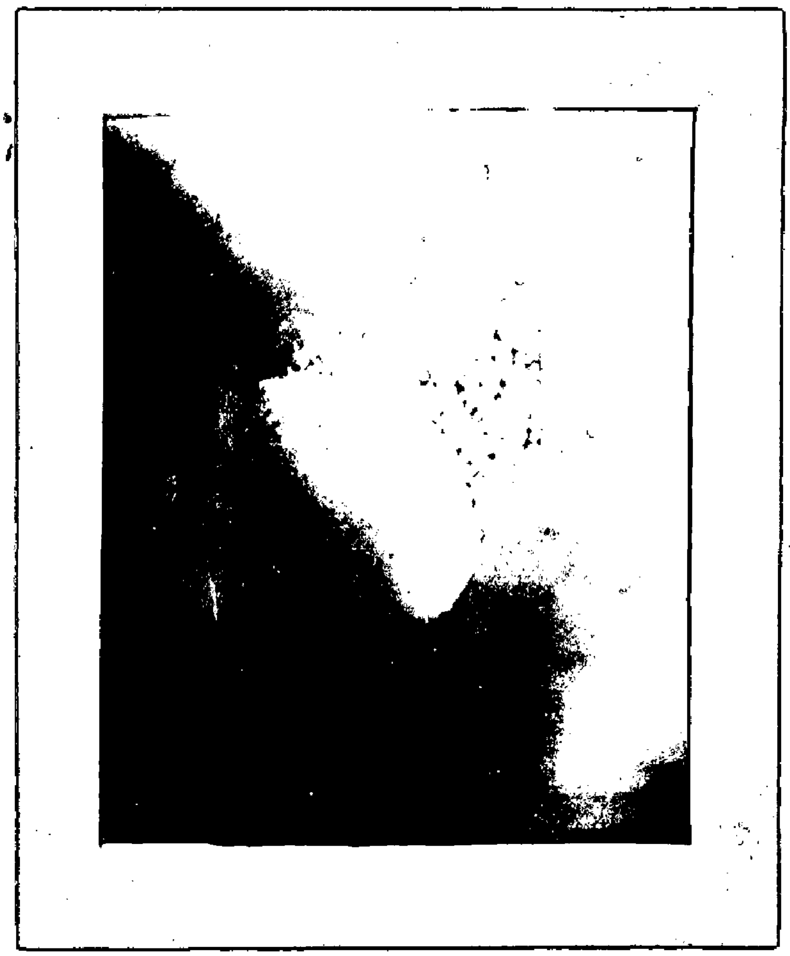


FIG. 4.16 FLUIDIZATION IN 90° CONE

CHAPTER - FIVE

CONCLUSIONS

Pressure drop data have been obtained in the fixed bed region, at the onset of fluidization and in the expanded bed zone. From the plots drawn between ΔP and air flow rate, it is observed that there is considerable pressure peak at the limit of stability. The peak is due to the conical form of the bed and is because of the fact that, the bed passes into the fluidized state only after fluidization of its upper portion.

For pressure peak a corelation in terms of dimensionless groups like ($R_{ep_{mf}}$, (D/D_o) and $(\tan \alpha/2)$ has been obtained and is given below-

$$\left[\frac{\Delta\pi}{\Delta P_{net}}\right] = 3.48 \times 10^{-2} \left(\frac{D}{D_o}\right)^{0.497} \left(\tan\frac{\alpha}{2}\right)^{-0.08} \left(R_{ep_{mf}}\right)^{.426}$$

The experimental and theoretical pressure drops were calculated and it was found that nearly 90% data vary between the range of ± 35% . The coefficient of variation for all the data on glass beads, bauxite and calcite comes out to be 43.49.

TABLE A - 1

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	:	1	Cone Angle	:	20°
Material	:	Glass beads	Wt. of material	:	100 gms.
Mesh size	:	-16 +18	d_p	=	1.205 mm.

Height of fixed bed = 4.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cm. of Water)	Bed Height (cm.)	Remarks
1.	1000	1.6	4.8	Fixed bed.
2.	2000	2.4	4.8	"
3.	2500	3.2	4.8	"
4.	3000	3.6	4.8	"
5.	3500	4.0	5.0	"
6.	4000	3.8	5.5	Incipient Fluidization
7.	4500	3.8	6.2	
8.	5000	3.8	6.6	
9.	5500	3.8	6.8	
10.	7500	3.9	7.5	
11.	10,000	4.0	Slugging	

The above correlation is valid only upto 45°Conc. In 90° cone the peak is not so pronounced.

It was observed that gas-solid contact is more efficient with larger particle sizes and smaller cone angles. For smaller size of particles and larger cone angles the fluidization is limited to a central core with large layers of particles remaining stationary near the walls.

Slugging is more predominant in smaller angle comes and for larger cone angles it is completely absent.

APPENDIX.

TABLE A - 1

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 1 Cone Angle : 20°

Material : Glass beads Wt. of material : 100 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 4.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cm. of Water)	Bed Height (cm.)	Remarks
1.	1000	1.6	4.8	Fixed bed.
2.	2000	2.4	4.8	"
3.	2500	3.2	4.8	"
4.	3000	3.6	4.8	"
5.	3500	4.0	5.0	"
6.	4000	3.8	5.5	Incipient Fluidization
7.	4500	3.8	6.2	
8.	5000	3.8	6.6	
9.	5500	3.8	6.8	
10.	7500	3.9	7.5	
11.	10,000	4.0	Slugging	

TABLE A - 3

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	:	3	Cone Angle	:	20°
Material	:	Glass beads.	Wt. of material	:	300 gms.
Mesh size	:	-16 +18	d_p	=	1.205 mm.

Height of fixed bed = 9.6 cms.

S.No.	Air Flow rate LPH	Δ P Across Bed (cm. of Water)	Bed Height (cms.)	Remarks
1.	1000	2.4	9.6	Fixed bed.
2.	2000	4.8	9.6	"
3.	2500	6.0	9.6	"
4.	3000	7.6	9.6	"
5.	3500	9.4	9.6	"
6.	4000	12	9.6	"
7.	4500	12	9.8	"
8.	5000	12	9.8	Incipient Fluidization
9.	5500	10.8	10.5	
10.	6000	11.1	10.8	
11.	6500	11.0	11.0	
12.	7500	11.0	11.5	
13.	8500	10.6	11.7	
14.	10,000	10.5	12.5	

TABLE A - 4

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 4 Cone Angle : 20°

Material : Glass beads. Wt. of material : 400 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 11.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cm. of Water)	Bed Height (cms)	Remarks
1.	1000	2.6	11.8	Fixed bed.
2.	2000	4.8	11.8	"
3.	2500	6.0	11.8	"
4.	3000	8.0	11.8	"
5.	3500	9.6	11.8	"
6.	4000	12.0	11.8	" "
7.	4500	14.0	11.8	"
8.	5000	17.0	11.8	"
9.	5500	19.4	11.8	"
10.	6000	13.6	12.5	Incipient Fluidiza-
11.	6500	1.4	12.7	tion.
12.	7500	13.2	13.0	
13.	8000	14	13.5	
14.	10,000	13.4	13.8	
15.	12,500	13.4	15.0	

TABLE A - 5

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	: 5	Cone Angle	: 20°
Material	: Glass beads	Wt. of material	: 300 gms.
Mesh size	: -22 +25	d_p = 0.787 mm.	

Height of fixed bed = 10.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms of water)	Bed Height (cms.)	Remarks
1.	500	2.8	10.0	Fixed bed.
2.	1000	5.0	10.0	"
3.	1500	7.6	10.0	"
4.	2000	10.8	10.1	"
5.	2500	11.4	10.2	"
6.	3000	11.0	10.3	Incipient Fluidiza-
7.	3500	11.0	10.6	tion.
8.	4000	11.0	11.2	
9.	4500	10.8	12.0	
10.	5000	10.6	12.2	Slugging
11.	6000	10.6	-	
12.	7500	10.6	-	
13.	9000	10.0	-	
14.	10,000	9.8	-	

TABLE A - 6

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 6 Cone Angle : 20°

Material : Glass beads. Wt. of material : 300 gms.

Mesh size : -30 +40 d_p = 0.5075 mm.

Height of fixed bed = 9.8 cms.

S.N.	Air Flow rate LPH	ΔP Across Bed (cms. of Water)	Bed Height (cms.)	Remarks
1.	1000	6.8	9.8	Fixed bed.
2.	1500	0.6	9.8	"
3.	2000	11.2	9.8	"
4.	2500	11.0	10.0	- Incipient Fluidization
5.	3000	10.8	10.5	- Fluidization
6.	3500	10.6	12.0	
7.	4000	10.4	12.5	
8.	5000	10.4	12.8	
9.	7500	10.4	-	Slugging
10.	10,000	10.2	-	

TABLE A - 7

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 7 Cone Angle : 20°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -16 +18 d_p = 1.205 mm

Height of fixed bed = 12.0 cms.

S.N.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.6	12	Fixed bed.
2.	1000	2.6	12	"
3.	1500	4.0	12	"
4.	2000	5.0	12	"
5.	2500	6.0	12	"
6.	3000	7.6	12	"
7.	3500	9.4	12	"
8.	4000	11.0	12	"
9.	4500	14.2	12.2	- Incipient Fluidization.
10.	5000	13.6	12.5	- Fluidization.
11.	6000	10.6	13	
12.	7500	9.6	14	
13.	9000	10.0	15	Slugging
14.	10,000	9.8	-	

TABLE A - 8

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 8 | Cone Angle : 20°

Material : Bauxite | Wt. of material : 300 gms.

Mesh size : -22 +25 | d_p = 0.787 mm.

Height of fixed bed = 11.7 cms.

S.No.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	3.0	11.7	Fixed bed
2.	1000	6.2	11.7	"
3.	1500	8.4	11.7	"
4.	2000	12.2	11.7	"
5.	2500	10.4	12	Incipient Fluidization.
6.	3000	10.0	12.3	
7.	3500	9.8	12.8	
8.	4000	9.8	13.3	
9.	5000	9.6	13.5	
10.	6000	9.6	-	Slugging
11.	7500	9.6	-	
12.	9000	9.4	-	
13.	10,000	9.4	-	

TABLE A - 9

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 9 Cone Angle : 20°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -30 +40 d_p = 0.5075 mm.

Height of fixed bed = 11.5 cms.

S.N.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	6.8	11.5	Fixed bed.
2.	1000	11.4	12.0	
3.	1500	10.0	12.5	Incipient Fluidization.
4.	2000	9.8	13.2	
5.	2500	9.6	14.0	
6.	3000	9.6	14.5	
7.	4000	9.6	15.0	Slugging.
8.	5000	9.6	-	
9.	6000	9.4	-	
10.	7500	9.4	-	
11.	9000	9.4	-	

TABLE A - 10

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 10 Cone Angle : 20°

Material : Calcite Wt. of material : 100 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 4.8 cms.

S.N.	Air Flow rate LPH	ΔP Across bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.8	4.8	Fixed bed.
2.	1000	1.4	4.8	"
3.	1500	2.2	4.8	"
4.	2000	2.6	4.8	"
5.	2500	3.8	4.8	"
6.	3000	4.0	5.5	Incipient Fluidization.
7.	3500	4.0	5.7	
8.	4000	4.0	5.8	
9.	4500	4.0	6.0	
10.	5000	3.8	6.3	Slugging.
11.	5500	3.8	-	
12.	6000	3.8	-	
13.	7500	4.0	-	
14.	9000	3.8	-	
15.	10,000	3.8	-	

TABLE A - 11

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 11 Cone Angle : 20°

Material : Calcite Wt. of material : 200 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 8.2 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.8	8.2	Fixed bed.
2.	1000	2.6	8.2	"
3.	1500	4.0	8.2	"
4.	2000	6.0	8.2	"
5.	2500	7.8	8.2	"
6.	3000	8.2	8.2	"
7.	3500	8.8	8.5	"
8.	4000	8.8	8.7	Incipient Fluidiza-
9.	4500	8.2	8.8	tion.
10.	5000	8.0	9.0	
11.	5500	8.0	9.5	
12.	6000	7.8	-	Slugging.
13.	7500	7.8	-	
14.	9000	7.7	-	
15.	10,000	7.8	-	

TABLE A - 12

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 12 Cone Angle : 20°

Material : Calcite Wt. of material : 300 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 10.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.4	10.8	Fixed bed.
2.	1000	2.6	10.8	"
3.	1500	4.8	10.8	"
4.	2000	5.6	10.8	"
5.	2500	7.0	10.8	"
6.	3000	8.8	10.8	"
7.	3500	10.6	10.8	"
8.	4000	12.0	10.8	"
9.	4500	13.0	10.8	"
10.	5000	14.0	11.0	Incipient Fluidiza-
11.	5500	11.8	11.3	tion.
12.	6000	11.4	12.0	
13.	7500	11.2	12.3	
14.	9000	11.2	-	Slugging.
15.	10,000	11.2	-	

TABLE A - 13

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 13 Cone Angle : 20°

Material : Calcite Wt. of material : 400 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 13.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.6	13.0	Fixed bed.
2.	1000	3.0	13.0	"
3.	1500	4.0	13.0	"
4.	2000	5.2	13.0	"
5.	2500	6.6	13.0	"
6.	3000	8.0	13.0	"
7.	3500	9.6	13.0	"
8.	4000	12.0	13.0	"
9.	4500	15.0	13.1	Bed expansion.
10.	5000	17.0	13.2	
11.	5500	19.4	13.3	
12.	6000	17.8	13.5	Incipient Fluidization.
13.	6500	18.6	13.8	
14.	7500	13	14.0	
15.	9000	12.8	14.5	
16.	10,000	12.8	-	Slugging.

TABLE A - 14

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 14   Cone Angle : 20°

Material : Calcite   Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 11.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	2.4	11.0	Fixed bed.
2.	1000	4.0	11.0	"
3.	1500	6.0	11.0	"
4.	2000	9.0	11.0	"
5.	2500	11.0	11.0	"
6.	3000	11.6	11.0	"
7.	3500	11.6	11.2	Incipient Fluidization.
8.	4000	11.0	11.5	
9.	4500	11.0	12.0	
10.	5000	10.8	12.5	
11.	5500	10.6	12.8	Slugging.
12.	6000	10.4	-	
13.	7500	10.6	-	
14.	9000	10.6	-	
15.	10,000	10.6	-	

TABLE A - 14

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 14   Cone Angle : 20°

Material : Calcite   Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 11.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks.
1.	500	2.4	11.0	Fixed bed.
2.	1000	4.0	11.0	"
3.	1500	6.0	11.0	"
4.	2000	9.0	11.0	"
5.	2500	11.0	11.0	"
6.	3000	11.6	11.0	"
7.	3500	11.6	11.2	Incipient Fluidization.
8.	4000	11.0	11.5	
9.	4500	11.0	12.0	
10.	5000	10.8	12.5	
11.	5500	10.6	12.8	Slugging.
12.	6000	10.4	-	
13.	7500	10.6	-	
14.	9000	10.6	-	
15.	10,000	10.6	-	

TABLE A - 15

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	: 15	Cone Angle	:	20°
Material	: Calcite	Wt. of material	:	300 gms.
Mesh size	: -30 +40	$d_p = 0.5075$		

Height of fixed bed = 10.0 cms.

S.N.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	5.6	10.0	Fixed bed.
2.	1000	10.4	10.2	
3.	1500	10.6	10.5	
4.	2000	10.6	11.0	Incipient Fluidization.
5.	2500	10.4	11.3	
6.	3000	10.4	11.6	
7.	3500	10.4	12.0	
8.	4000	10.4	12.3	Slugging.
9.	4500	10.2	-	
10.	5000	10.4	-	
11.	7500	10.4	-	
12.	9000	10.4	-	

TABLE A - 16

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 16 Cone angle : 10°

Material : Glass beads. Wt. of material : 100 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 5.3 cms.

S.N.	Air Flow rate LPH	Δ P Across bed (cms. of water)	Bed Height (cms.)		Remarks
1.	500	0.8	5.3		Fixed bed.
2.	1000	1.6	5.3		"
3.	1500	2.2	5.3		"
4.	2000	3.0	5.3		"
5.	2500	3.6	5.3		"
6.	3000	4.0	5.7	-	Incipient Fluidization.
7.	3500	4.0	6.2	-	Fluidization.
8.	4000	4.0	6.9		
9.	5000	4.0	8.5		
10.	6000	3.8	10.0		
11.	7500	4.0	-		Slugging.
12.	10,000	4.0	-		

TABLE A - 17

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 17 Cone Angle : 10°

Material : Glass beads. Wt. of material : 200 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 8.7 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms of water)	Bed Height (cms.)	Remarks
1.	500	2.4	8.7	Fixed bed.
2.	1000	4.4	8.7	"
3.	1500	5.8	8.7	"
4.	2000	8.6	8.7	"
5.	2500	10.2	8.7	"
6.	3000	10.0	9.0	Incipient Fluidization.
7.	3500	10.0	9.6	Fluidization.
8.	4000	10.0	10.5	
9.	5000	9.8	12.0	
10.	6000	9.4	-	Slugging.
11.	7500	9.0	-	
12.	10,000	8.8	-	

TABLE A - 18

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 18
Material : Glass beads.
Mesh size : -16 +18

Cone Angle : 10°
Wt. of material : 300 gms.
d_p = 1.205 mm.

Height of fixed bed = 11.8 cms.

S.N.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	2.6	11.8	Fixed bed.
2.	1000	4.2	11.8	"
3.	1500	6.6	11.8	"
4.	2000	8.6	11.8	"
5.	2500	11.2	11.8	"
6.	3000	13.8	11.8	"
7.	3500	16.6	12.0	"
8.	4000	15.8	12.9	Incipient Fluidization.
9.	5000	15.4	14.5	Fluidization.
10.	6000	15.0	15.0	Slugging.
11.	7500	14.8	-	
12.	10,000	14.2	-	

TABLE A- 19

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 19 Cone Angle : 10°

Material : Glass beads Wt. of material: 400 gms.

Mesh size : -16 +18 d_p = 1.205 mm

Height of fixed bed = 14.4 cms.

S.N.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms)	Remarks
1.	500	2.6	14.4	Fixed bed
2.	1000	5.6	14.4	"
3.	1500	7.0	14.4	"
4.	2000	9.6	14.4	"
5.	2500	12.0	14.4	"
6.	3000	14.2	14.4	"
7.	3500	17.4	14.4	"
8.	4000	21.6	14.4	"
9.	4500	18.4	15.5	Incipient Fluidization
10.	5000	17.8	16.0	
11.	6000	17.0	16.2	Slugging
12.	7500	18.0	-	
13.	10,000	18.0		

TABLE A - 20

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 20   Cone Angle : 10°

Material : Glass beads.   Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 11.7 cms.

S.N.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms)	Remarks
1.	500	4.8	11.7	Fixed bed.
2.	1000	8.0	11.7	"
3.	1500	12.8	11.7	"
4.	2000	13.8	12.2	Bed expansion.
5.	2500	14.4	12.5	"
6.	3000	14.0	13.0	Incipient Fluidization.
7.	3500	13.8	14.8	
8.	4000	13.4	15.1	Slugging.
9.	5000	12.4	-	
10.	6000	12.2	-	
11.	7500	11.8	-	
12.	10,000	11.8	-	

TABLE A - 21

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 21 | Cone Angle : 10°

Material : Glass beads. | Wt. of material : 300 gms.

Mesh size : -30 +40 | d_p = 0.5075 mm.

Height of **fixed** bed = 12.0 cms.

S. N.	Air Flow rate LPH	ΔP Across Bed (cms. of water)	Bed Height (cms)	Remarks.
1.	500	6.8	12.0	Fixed bed.
2.	1000	13.0	12.0	"
3.	1500	13.8	12.5	"
4.	2000	14.2	13.5	Incipient Fluidization.
5.	2500	13.6	15.0	
6.	3000	13.4	16.2	
7.	4000	13.0	-	
8.	5000	12.8	-	
9.	6000	13.6	-	
10.	7500	13.6	-	
11.	10,000	13.6	-	

TABLE A - 22

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 22 Cone Angle : 10°

Material : Bauxite Wt. of material : 300 gsm.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 13.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms)	Remarks
1.	500	5.2	13.8	Fixed bed.
2.	1000	10.2	13.8	"
3.	1500	15.0	13.8	"
4.	2000	20.0	13.8	"
5.	2500	24.4	13.8	"
6.	3000	24.4	14.0	Incipient Fluidization.
7.	3500	15	15.5	
8.	4000	14	16.0	
9.	5000	13.6	17.0	
10.	6000	13.8	18.0	Slugging.
11.	7500	13.8	-	
12.	9000	14	-	
13.	10,000	14	-	

TABLE A - 23

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 23 Cone Angle : 10°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 15.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	4.0	15.0	Fixed bed.
2.	1000	7.0	15.0	"
3.	1500	10.0	15.0	"
4.	2000	13.4	15.0	"
5.	2500	17.0	15.2	"
6.	3000	13.0	16.0	Incipient Fluidization
7.	3500	13.0	17.0	
8.	4000	12.4	17.5	
9.	5000	12.6	18.0	Slugging
10.	6000	12.6	-	
11.	7500	12.6	-	
12.	9000	12.4	-	
13.	10,000	12.4	-	

TABLE A - 24

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 24 Cone Angle : 10°

Material : Calcite Wt. of material : 300 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 12.0 cms.

S. N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	5.0	12.0	Fixed bed.
2.	1000	11.2	12.0	"
3.	1500	15.6	12.0	"
4.	2000	20.0	12.0	"
5.	2500	22.6	12.0	"
6.	3000	16.0	13.0	Incipient Fluidization.
7.	3500	16.0	13.5	
8.	4000	17.0	13.6	
9.	5000	14.0	15	
10.	6000	14.0	16	
11.	7500	13.8	-	
12.	9000	14.0	-	
13.	10,000	14.0	-	

TABLE A - 25

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 25 | Cone Angle : 10°

Material : Calcite | Wt. of material: 300 gms.

Mesh size : -22 +25 | d_p = 0.787

Height of fixed bed = 13.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	3.8	13.0	Fixed bed.
2.	1000	6.4	13.0	"
3.	1500	9.6	13.2	Bed expansion
4.	2000	13.6	13.5	"
5.	2500	17.4	13.5	"
6.	3000	15.0	14.2	Incipient Fluidization.
7.	3500	14.4	15.0	
8.	4000	14.4	15.5	
9.	5000	14.4	16.0	
10.	6000	14.6	16.3	Slugging.
11.	7500	14.4	-	
12.	9000	14.4	-	
13.	10,000	14.4	-	

TABLE A - 26

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 26 Cone Angle : 15°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 12.0 cms.

S.N.	Air Flow rate LPH	ΔP Across bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	3.8	12.0	Fixed bed.
2.	1000	6.4	12.0	"
3.	1500	9.4	12.0	"
4.	2000	12.2	12.0	"
5.	2500	14.0	12.2	"
6.	3000	10.2	12.8	Incipient Fluidization.
7.	3500	10.0	13.1	
8.	4000	10.0	13.2	
9.	5000	10.0	14	
10.	6000	9.0	14.3	Slugging.
11.	7500	8.8	-	
12.	9000	8.8	-	
13.	10,000	8.8	-	

TABLE A - 27

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 27 Cone Angle : 15°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 12.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	4.6	12	Fixed bed.
2.	1000	7.6	12.4	Bed expansion.
3.	1500	12	12.6	
4.	2000	11.2	13.0	
5.	2500	11.8	13.2	Incipient Fluidization
6.	3000	11.2	13.5	
7.	3500	11.0	14.2	
8.	4000	11.0	14.6	
9.	5000	10.8	15.2	
10.	6000	10.8	15.5	Slugging.
11.	7500	10.6	-	
12.	9000	10.4	-	
13.	10,000	10.4	-	

TABLE A - 28

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 28   Cone Angle : 15°

Material : Calcite   Wt. of material : 300 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 10.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks.
1.	500	3.6	10.8	Fixed bed.
2.	1000	5.8	10.8	"
3.	1500	9.4	10.8	"
4.	2000	14.2	10.8	"
5.	2500	17.0	10.8	"
6.	3000	18.6	11.0	Incipient Fluidization.
7.	3500	10.2	12.0	
8.	4000	11.0	12.2	Fluidization.
9.	5000	10.8	12.6	
10.	6000	10.6	13.3	
11.	7500	9.6	-	Slugging.
12.	9000	9.4	-	
13.	10,000	9.4	-	

TABLE A - 29

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 29

Material : Calcite

Mesh size : -22 +25

Cone Angle : 15°

Wt. of material : 300 gms.

d_p = 0.787 mm.

Height of fixed bed = 11.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	2.4	11.0	Fixed bed.
2.	1000	3.8	11.0	"
3.	1500	5.8	11.0	"
4.	2000	8.2	11.3	Bed expansion.
5.	2500	11.0	11.5	"
6.	3000	14.0	12.0	Incipient Fluidization.
7.	3500	10.4	12.5	Fluidization.
8.	4000	10.4	12.7	
9.	5000	9.6	13.0	
10.	6000	9.4	13.2	Slugging.
11.	7500	9.2	-	
12.	9000	9.2	-	
13.	10,000	9.2	-	

TABLE A - 30

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 20 | Cone Angle : 15°

Material : Glass beads. | Wt. of material : 300 gms.

Mesh size : -16 +18 | d_p = 1.205 mm.

Height of fixed bed = 10.6 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of Water)	Bed Height (cms.)	Remarks
1.	500	1.6	10.6	Fixed bed.
2.	1000	2.8	10.6	"
3.	1500	4.0	10.6	"
4.	2000	5.4	10.6	"
5.	2500	7.0	10.6	"
6.	3000	8.8	10.6	"
7.	3500	11.0	10.6	"
8.	4000	13.8	11.2	Incipient Fluidization.
9.	5000	11.0	11.7	Fluidization
10.	6000	10.4	12.2	
11.	7500	10.2	12.5	Slugging.
12.	• 9000	9.8	-	
13.	10,000	9.8	-	

TABLE A - 31

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 31 Cone Angle = 15°

Material : Glass beads. Wt. of material = 400 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 12.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms)	Remarks
1.	500	1.8	12.8	Fixed bed.
2.	1000	3.0	12.8	"
3.	1500	4.8	12.8	"
4.	2000	5.8	12.8	"
5.	2500	7.4	12.8	"
6.	3000	8.8	12.8	"
7.	3500	10.4	12.8	"
8.	4000	14.2	12.8	"
9.	5000	19.0	13.2	Incipient Fluidization.
10.	6000	12.4	13.8	
11.	7500	12.6	14.2	
12.	9000	12.2	-	Slugging.
13.	10,000	12.2	-	

TABLE A - 33

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 33 Cone Angle : 15°

Material : Glass beads Wt. of material : 400 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 12.6 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	3.6	12.6	Fixed bed.
2.	1000	5.8	12.6	"
3.	1500	8.8	12.6	"
4.	2000	12.8	12.6	"
5.	2500	14.6	12.6	"
6.	3000	13.0	13.1	Incipient Fluidization.
7.	3000	13.0	13.1	
8.	4000	12.0	13.8	
9.	5000	12.0	14.2	
10.	6000	12.0	-	Slugging.
11.	7500	11.6	-	
12.	9000	11.4	-	
13.	10,000	11.4	-	

TABLE A - 32

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 32 Cone Angle : 15°

Material : Glass beads. Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 10.6 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	3.0	10.6	Fixed bed.
2.	1000	5.4	10.6	"
3.	1500	7.0	10.6	"
4.	2000	10.0	10.6	"
5.	2500	10.4	10.6	" "
6.	3000	10.0	11.0	Incipient Fluidization.
7.	3500	10.0	11.4	
8.	4000	10.0	11.8	
9.	5000	9.6	12.4	
10.	6000	9.2	12.6	Slugging.
11.	7500	9.2	-	
12.	9000	9.2	-	
13.	10,000	9.2	-	

TABLE A - 34

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 34 Cone Angle : 15°

Material : Glass beads. Wt. of material : 300 gms.

Mesh size : -30 +40. d_p = 0.5075

Height of fixed bed = 10.6 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	5.0	10.6	Fixed bed.
2.	1000	8.0	10.6	"
3.	1500	10.8	10.8	
4.	2000	10.0	11.5	Incipient Fluidization.
5.	2500	10.0	12.0	
6.	3000	10.0	12.3	
7.	3500	9.8	13.5	
8.	4000	9.4	14.0	Slugging.
9.	5000	9.2	-	
10.	6000	9.0	-	
11.	7500	8.4	-	
12.	9000	8.0	-	
13.	10,000	7.8	-	

TABLE A - 35

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 35 Cone Angle : 15°

Material : Glass beads Wt. of material : 400 gms.

Mesh size : -30 +40 d_p = 0.5075 mm.

Height of fixed bed = 12.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	5.0	12.8	Fixed bed.
2.	1000	9.2	12.8	"
3.	1500	13.8	12.8	"
4.	2000	14.0	13.2	"
5.	2500	13.4	13.6	Incipient Fluidization.
6.	3000	12.8	14.0	
7.	3500	12.8	14.8	
8.	4000	12.2	15.5	Slugging.
9.	5000	12.0	15.8	
10.	6000	12.0	-	
11.	7500	11.8	-	
12.	9000	11.8	-	
13.	10,000	11.8	-	

TABLE A - 36

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 36

Material : Bauxite

Mesh size : -16 +18

Cone Angle : 30°

Wt. of material : 300 gms.

d_p = 1.205 mm.

Height of fixed bed = 8.3 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.2	8.3	Fixed bed.
2.	1000	2.0	8.3	"
3.	1500	3.0	8.3	"
4.	2000	4.2	8.3	"
5.	2500	5.0	8.3	"
6.	3000	5.2	8.4	Bed expansion.
7.	3500	5.6	8.4	"
8.	4000	5.8	8.5	"
9.	4500	5.8	8.7	"
10.	5000	6.2	8.8	"
11.	6000	6.0	8.9	Incipient Fluidization.
12.	7500	4.8	9.2	"
13.	9000	4.6	9.5	Fluidized bed.
14.	10,000	4.4	9.7	
15.	11,000	4.4	-	

TABLE A - 37

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 37 Cone Angle : 30°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787

Height of fixed bed = 8.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.6	8.0	Fixed bed.
2.	1000	2.2	8.0	"
3.	1500	3.6	8.0	"
4.	2000	5.0	8.0	"
5.	2500	5.8	8.2	Bed expansion.
6.	3000	6.4	8.3	"
7.	3500	5.2	8.7	Incipient Fluidization.
8.	4000	4.4	9.0	
9.	5000	4.2	9.2	
10.	6000	4.2	9.6	
11.	7500	4.2	10.0	Spouting starts.
12.	9000	4.0	-	
13.	10,000	4.2	-	

TABLE A - 38

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 38 Cone Angle : 30°

Material : Calcite Wt. of material : 300 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 7.5 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms)	Remarks
1.	500	1.2	7.4	Fixed bed.
2.	1000	2.0	7.4	"
3.	1500	3.2	7.4	"
4.	2000	4.4	7.4	"
5.	2500	5.2	7.4	Bed expansion.
6.	3000	5.8	7.5	"
7.	3500	5.4	7.7	"
8.	4000	6.2	7.8	"
9.	4500	6.2	8.0	"
10.	5000	6.4	8.1	"
11.	5500	6.4	8.2	"
12.	6000	6.4	8.4	- Incipient Fluidization.
13.	7000	5.0	8.5	- Fluidization.
14.	7500	4.8	8.8	
15.	9000	4.4	-	
16.	10,000	4.4	-	

TABLE A - 39

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 39 Cone Angle : 30°

Material : Calcite Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787

Height of fixed bed = 7.3 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.8	7.3	Fixed bed.
2.	1000	2.8	7.3	"
3.	1500	4.2	7.3	"
4.	2000	5.8	7.3	"
5.	2500	5.8	7.5	Bed expansion.
6.	3000	6.2	7.7	"
7.	4500	6.8	7.8	"
8.	4000	7.0	7.9	"
9.	4500	7.0	8.1	Incipient Fluidization.
10.	5000	5.0	8.5	
11.	6000	4.4	-	Fluidization.
12.	7500	4.4	-	
13.	9000	4.4	-	
14.	10,000	4.4	-	

TABLE A - 40

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 40 | Cone Angle : 30°

Material : Glass beads. | Wt. of material : 300 gms.

Mesh size : -16 +18 | d_p = 1.205 mm.

Height of fixed bed = 7.4 cms.

S.N.	Air Flow rate LPH	Δ P Across bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.8	7.4	Fixed bed.
2.	1000	1.2	7.4	"
3.	1500	1.6	7.4	"
4.	2000	2.0	7.4	"
5.	2500	2.4	7.4	"
6.	3000	2.8	7.4	"
7.	3500	3.4	7.4	"
8.	4000	4.0	7.4	"
9.	5000	5.0	7.5	"
10.	6000	5.0	7.7	Incipient Fluidization.
11.	7500	4.8	8.0	
12.	9000	4.6	8.1	Fluidization.
13.	10,000	4.4	8.2	

TABLE A - 42

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 42 Cone Angle : 30°

Material : Glass beads. Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 7.2 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.2	7.2	Fixed bed.
2.	1000	1.8	7.2	"
3.	1500	2.6	7.2	"
4.	2000	3.8	7.2	"
5.	2500	4.0	7.3	Bed expansion.
6.	3000	4.6	7.5	"
7.	3500	5.2	7.6	"
8.	4000	4.8	7.7	Incipient Fluidization.
9.	5000	4.4	7.8	Spouted bed.
10.	6000	4.2	7.9	
11.	7500	4.2	-	
12.	9000	4.2	-	
13.	10,000	4.2	-	

TABLE A - 43

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	: 43	Cone Angle	: 30°
Material	: Glass beads.	Wt. of material	: 400 gms.
Mesh size	: -22 +25	d_p = 0.787 mm.	

Height of fixed bed = 8.5 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.4	8.5	Fixed bed.
2.	1000	2.0	8.5	"
3.	1500	3.0	8.5	"
4.	2000	4.0	8.5	"
5.	2500	4.6	8.5	"
6.	3000	6.0	8.5	"
7.	3500	7.2	8.6	"
8.	4000	6.6	8.8	Incipient Fluidization.
9.	5000	6.4	9.0	
10.	6000	6.2	9.1	Spouted bed.
11.	7500	6.0	9.3	
12.	9000	5.8	-	Fluidization.
13.	10,000	5.8	-	

TABLE A - 44

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 44 — Cone Angle : 30°

Material : Glass beads. — Wt. of material : 300 gms.

Mesh size : -30 +40 — d_p = 0.5075 mm.

Height of fixed bed = 7.5 cms.

S.N.	Air Flow rate LPH	Δ P Across bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.8	7.5	Fixed bed.
2.	1000	2.6	7.5	"
3.	1500	3.6	7.5	"
4.	2000	3.2	7.6	"
5.	2500	3.2	7.7	Incipient Fluidization.
6.	3000	3.2	7.8	Spouted bed.
7.	3500	3.0	8.0	
8.	4000	2.8	8.1	
9.	5000	2.8	-	
10.	6000	2.8	-	Fluidization.
11.	7500	2.8	-	
12.	10,000	2.8	-	

TABLE A - 45

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 45 Cone Angle : 30°

Material : Glass beads. Wt. of material : 400 gms.

Mesh size : -30 +40 d_p = 0.5075 mm.

Height of fixed bed = 8.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.8	8.8	Fixed bed.
2.	1000	3.0	8.8	"
3.	1500	4.4	8.8	"
4.	2000	5.8	8.8	"
5.	2500	6.0	8.8	"
6.	3000	6.0	9.0	Incipient Fluidization.
7.	3500	5.8	9.2	Fluidization.
8.	4000	5.8	9.3	
9.	5000	5.4	9.5	
10.	6000	5.4	9.8	
11.	7500	5.4	-	
12.	10,000	5.2	-	

TABLE A - 46

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	: 46		Cone Angle	: 45°
Material	: Bauxite.		Wt. of material	: 300 gms.
Mesh size	: -16 +18		d_p = 1.205 mm.	

Height of fixed bed = 7.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.6	7.0	Fixed bed.
2.	1000	0.8	7.0	"
3.	1500	1.2	7.0	"
4.	2000	1.6	7.0	"
5.	2500	1.8	7.0	"
6.	3000	1.8	7.0	"
7.	3500	2.6	7.0	"
8.	4000	2.6	7.1	"
9.	4500	2.7	7.1	"
10.	5000	2.7	7.1	"
11.	6000	2.8	7.3	"
12.	7500	3.2	7.8	"
13.	8000	2.4	-	Incipient Fluidization.
14.	9000	2.2.	-	Spouted bed.
15.	10,000	2.2	-	

TABLE A - 47

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 47 Cone Angle : 45°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 6.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.0	6.8	Fixed bed.
2.	1000	1.8	6.8	"
3.	1500	2.2	6.8	"
4.	2000	2.6	6.8	"
5.	2500	3.0	7.0	"
6.	3000	3.2	7.2	"
7.	3500	3.4	7.3	"
8.	4000	3.4	7.5	Incipient Fluidization.
9.	4500	2.8	7.7	
10.	5000	2.0	7.9	Spouted bed.
11.	6000	2.0	8.0	"
12.	7500	2.0	-	"
13.	9000	2.0	-	"
14.	10,000	2.0	-	

TABLE A - 48

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 48 | Cone Angle : 45°

Material : Calcite | Wt. of material : 300 gms.

Mesh size : -16 +18 | d_p = 1.205 mm.

Height of fixed bed = 6.5 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.4	6.5	Fixed bed.
2.	1000	0.6	6.5	"
3.	1500	1.0	6.5	"
4.	2000	1.2	6.5	"
5.	2500	1.4	6.5	"
6.	3000	1.8	6.5	"
7.	3500	2.2	6.5	"
8.	4000	2.4	6.5	"
9.	5000	2.6	6.7	"
10.	6000	3.0	6.8	"
11.	7500	3.2	7.1	"
12.	8000	3.0	7.5	Incipient Fluidization.
13.	8500	2.6	7.6	Spouted bed.
14.	9000	2.0	7.6	
15.	10,000	2.0	-	

TABLE A - 49

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 49 Cone Angle : 45°

Material : Calcite Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 6.3 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.0	6.3	Fixed bed.
2.	1000	1.4	6.3	"
3.	1500	2.0	6.3	"
4.	2000	2.4	6.3	"
5.	2500	2.6	6.3	"
6.	3000	2.8	6.3	"
7.	3500	2.8	6.3	"
8.	4000	228	6.6	"
9.	4500	3.0	6.8	Incipient Fluidization.
10.	5000	3.0	7.0	
11.	6000	2.8	7.5	
12.	7500	2.0	-	Spouted bed.
13.	9000	2.0	-	
14.	10,000	2.0	-	

TABLE A - 50

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 50   Cone Angle : 45°

Material : Glass beads.   Wt. of material : 300 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 6.2 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.6	6.2	Fixed bed.
2.	1000	0.8	6.2	"
3.	2000	1.0	6.2	"
4.	2500	1.1	6.2	"
5.	3000	1.4	6.2	"
6.	3500	1.6	6.2	"
7.	4000	1.8	6.2	"
8.	5000	2.0	6.2	"
9.	6000	2.2	6.3	"
10.	7500	2.6	6.5	"
11.	9000	2.2	6.7	"
12.	10,000	2.0	-	Spouted bed.

TABLE A - 51

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 51 Cone Angle : 45°

Material : Glass beads. Wt. of material : 400 gms.

Mesh size : -16 +18 d_p = 1.205 mm.

Height of fixed bed = 7.0 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.6	7.0	Fixed bed.
2.	1000	0.8	7.0	"
3.	1500	1.2	7.0	"
4.	2000	1.4	7.0	"
5.	2500	1.6	7.0	"
6.	3000	1.8	7.0	"
7.	3500	2.0	7.0	"
8.	4000	2.4	7.0	"
9.	5000	3.2	7.2	"
10.	6000	3.4	7.3	"
11.	7500	4.0	7.4	"
12.	9000	4.0	7.6	Incipient Fluidization.
13.	10,000	3.4	7.7	
14.	11,000	3.2	-	Spouted bed.

TABLE A - 53

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 53

Material : Glass beads.

Mesh size : -22 +25

Cone Angle : 45°

Wt.of material : 400 gms.

d_p = 0.787 mm.

Height of fixed bed = 7.4 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.7	7.4	Fixed bed.
2.	1000	1.0	7.4	"
3.	1500	1.5	7.4	"
4.	2000	1.8	7.4	"
5.	2500	2.0	7.4	"
6.	3000	2.2	7.4	"
7.	3500	2.8	7.4	"
8.	4000	3.0	7.4	"
9.	5000	3.8	7.5	"
10.	6000	3.2	7.7	Incipient Fluidization.
11.	7500	3.0	7.8	Spouted bed.
12.	9000	3.0	-	
13.	10,000	3.0	-	

TABLE A - 55

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 55 Cone Angle : 45°

Material : Glass beads. Wt. of material : 400 gms.

Mesh size : -30 +40 d_p = 0.5075 mm.

Height of fixed bed = 7.3 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	1.0	7.3	Fixed bed.
2.	1000	1.6	7.3	"
3.	1500	2.2	7.3	"
4.	2000	2.6	7.3	"
5.	2500	2.8	7.5	"
6.	3000	3.6	7.6	Incipient Fluidization.
7.	3500	3.4	7.7	
8.	4000	3.2	7.8	Spouted bed.
9.	5000	3.2	-	
10.	6000	3.0	-	
11.	7500	3.0	-	Fluidization.
12.	9000	3.0	-	
13.	10,000	3.0	-	

TABLE A - 56

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	: 56	Cone Angle	: 90°
Material	: Bauxite	Wt. of material	: 300 gms.
Mesh size	: -16 +18	d_p = 1.205 mm.	

Height of fixed bed = 5.3 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	1000	0.4	5.3	Fixed bed.
2.	1500	0.6	5.3	"
3.	2000	0.8	5.3	"
4.	2500	0.9	5.3	"
5.	3000	1.0	5.3	"
6.	3500	1.1	5.3	"
7.	4000	1.2	5.3	"
8.	5000	1.6	5.3	"
9.	6000	1.8	5.3	"
10.	7500	1.4	5.4	Incipient Fluidization.
11.	8000	1.0	5.4	Fluidization in central portion only
12.	9000	1.0	-	
13.	10,000	1.0	-	

TABLE A - 57

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 57 Cone Angle : 90°

Material : Bauxite Wt. of material : 300 gms.

Mesh size : -22 +25 D_p = 0.787

Height of fixed bed = 5.2 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	1000	0.6	5.2	Fixed bed.
2.	1500	0.9	5.2	"
3.	2000	1.1	5.2	"
4.	2500	1.2	5.2	"
5.	3000	1.3	5.4	"
6.	3500	1.2	5.5	Incipient Fluidization.
7.	4000	1.2	5.6	Fluidization in central position only.
8.	5000	1.1	-	
9.	6000	1.0	-	
10.	7500	1.0	-	
11.	9000	0.8	-	
12.	10,000	0.8	-	

TABLE A - 58

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No.	: 58	Cone Angle	: 90°
Material	: Calcite	Wt. of material	: 300 gms.
Mesh size	: -16 +18	d_p = 1.205 mm.	

Height of fixed bed = 4.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	500	0.4	4.8	Fixed bed.
2.	1000	0.6	4.8	"
3.	1500	0.7	4.8	"
4.	2000	0.9	4.8	"
5.	2500	1.0	4.8	"
6.	3000	1.1	4.8	"
7.	3500	1.2	4.8	"
8.	4000	1.4	4.8	"
9.	5000	1.8	4.8	"
10.	6000	1.8	4.8	"
11.	6500	1.6	4.9	Incipient Fluidization.
12.	7500	1.2	5.0	Fluidization in central portion only.
13.	9000	1.0	-	
14.	10,000	1.0	-	

TABLE A - 59

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 59 Cone Angle : 90°

Material : Calcite Wt. of material : 300 gms.

Mesh size : -22 + 25. d_p = 0.787 mm.

Height of fixed bed = 4.9 cms.

S.N.	Air Flow rate LPH	Δ P Across bed (cms. of water)	Bed Height (cms.)	Remarks
1.	1000	0.8	4.9	Fixed bed.
2.	1500	1.0	4.9	"
3.	2000	1.2	4.9	"
4.	2500	1.3	4.9	"
5.	3000	1.4	5.0	"
6.	3500	1.8	5.0	"
7.	4000	1.6	5.1	Incipient Fluidization.
8.	5000	1.5	-	Fluidization in central portion only.
9.	6000	1.4	-	
10.	7500	1.2	-	
11.	10,000	0.9	-	

TABLE A - 60

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 60 | Cone Angle : 90°

Material : Glass beads. | Wt. of material : 300 gms.

Mesh size : -16 +18 | d_p = 1.205 mm.

Height of fixed bed = 4.7 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed height (cms.)	Remarks
1.	1000	0.2	4.7	Fixed bed.
2.	1500	0.3	4.7	"
3.	2000	0.4	4.7	"
4.	2500	0.5	4.7	"
5.	3000	0.6	4.7	"
6.	3500	0.7	4.7	"
7.	4000	0.8	4.7	"
8.	5000	1.0	4.7	"
9.	6000	1.2	4.8	"
10.	7000	1.0	4.9	Incipient Fluidization.
11.	7500	1.0	-	Fluidization in central portion only.
12.	9000	0.8	-	
13.	10,000	0.8	-	

TABLE A - 61

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 61 Cone Angle : 90°

Material : Glass beads. Wt. of material : 300 gms.

Mesh size : -22 +25 d_p = 0.787 mm.

Height of fixed bed = 4.8 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	1000	0.7	4.8	Fixed bed.
2.	1500	0.8	4.8	"
3.	2000	0.9	4.8	"
4.	2500	1.0	4.8	"
5.	3000	1.1	4.8	"
6.	3500	1.2	4.9	"
7.	4000	1.3	4.9	"
8.	5000	1.2	5.0	Incipient Fluidization.
9.	6000	1.1	-	Fluidization in Central portion only.
10.	7500	1.0	-	
11.	9000	0.9	-	
12.	10,000	0.9	-	

TABLE A - 62

FLUIDIZATION STUDIES IN TAPERED VESSELS

Run No. : 62 Code Angle : 90°

Material : Glass beads. Wt. of material : 300 gms.

Mesh size : -30 +40 d_p = 0.5075 mm.

Height of fixed bed = 4.7 cms.

S.N.	Air Flow rate LPH	Δ P Across Bed (cms. of water)	Bed Height (cms.)	Remarks
1.	1000	0.8	4.7	Fixed bed.
2.	1500	0.9	4.7	"
3.	2000	0.8	4.7	"
4.	2500	0.7	4.8	"
5.	3000	0.7	4.8	Incipient Fluidization.
6.	3500	0.7	4.9	Fluidization in central portion only.
7.	4000	0.7	-	
8.	5000	0.7	-	
9.	6000	0.7	-	
10.	7500	0.7	-	
11.	9000	0.7	-	
12.	10,000	0.7	-	

APPENDIX-COMPUTER PROGRAMMES

PROGRAMME -ONE CURVE FITTING

```
C  C  M.E. THESIS  BHUPAL SHARMA
      DIMENSION Y(70),X1(70),X2(70),X3(70)
      READ5,N
    5 FORMAT(I5)
      READ10,(Y(I),X1(I),X2(I),X3(I),I=1,N)
   10 FORMAT(4F15.5)
      DO15I=1,N
      Y(I)=LOGF(Y(I))
      X1(I)=LOGF(X1(I))
      X2(I)=LOGF(X2(I))
      X3(I)=LOGF(X3(I))
   15 CONTINUE
      SMY=0.0  $  SMX1=0.0  $  SMX2=0.0  $  SMX3=0.0
      DO20I=1,N
      SMY=SMY+Y(I)
      SMX1=SMX1+X1(I)
      SMX2=SMX2+X2(I)
      SMX3=SMX3+X3(I)
   20 CONTINUE
      AN=N
      YM=SMY/AN
      XM1=SMX1/AN
      XM2=SMX2/AN
      XM3=SMX3/AN
      PUNCH30,YM,XM1,XM2,XM3
   30 FORMAT(5X,3HYM=,F10.4,2X,4HXM1=,F10.4,2X,4HXM2=,F10.4,2X,4HXM3=,
     1F10.4)
      S1=0.0  $ S2=0.0  $  S3=0.0  $S4=0.0
      S6=0.0  $  S7=0.0  $  S8=0.0  $  S11=0.0  $  S12=0.0
      DO40I=1,N
      ZY=Y(I)-YM
      Z1=X1(I)-XM1
      Z2=X2(I)-XM2
      Z3=X3(I)-XM3
      S1=S1+Z1*Z1
      S2=S2+Z1*Z2
      S3=S3+Z1*Z3
      S4=S4+Z1*ZY
      S6=S6+Z2*Z2
      S7=S7+Z2*Z3
      S8=S8+Z2*ZY
      S11=S11+Z3*Z3
      S12=S12+Z3*ZY
   40 CONTINUE
      S5=S2
      S9=S3
      S10=S7
      PUNCH50,S1,S2,S3,S4
   50 FORMAT(/5X,3HS1=,F10.4,2X,3HS2=,F10.4,2X,3HS3=,F10.4,2X,
     13HS4=,F10.4//)
      PUNCH60,S5,S6,S7,S8
   60 FORMAT(/5X,3HS5=,F10.4,2X,3HS6=,F10.4,2X,3HS7=,F10.4,2X,
     13HS8=,F10.4//)
```

```
      PUNCH70,S9,S10,S11,S12
   70 FOPMAT(/5X,3HS9=,F10.4,2X,4HS10=,F10.4,2X,4HS11=,F10.4,2X,
     14HS12=,F10.4//)
      STOP
      END
52
```

0.10	1.52	0.0875	65.0
0.35	1.675	0.0875	72.3
0.167	1.545	0.0875	26.6
0.12	1.675	0.0875	29.5
0.1085	1.59	0.0875	14.1
0.0647	1.695	0.0875	11.4
0.372	1.73	0.1316	74.0
0.545	1.86	0.1316	75.0
0.2	1.745	0.1316	26.6
0.272	1.85	0.1316	30.7
0.17	1.755	0.1316	11.4
0.1832	1.89	0.1316	15.25
0.151	1.85	0.1763	77.5
0.437	2.095	0.1763	99.4
0.085	1.88	0.1763	26.6
0.203	2.042	0.1763	35.4
0.0768	1.915	0.1763	16.0
0.0714	2.11	0.1763	17.2
0.149	1.99	0.2679	101.2
0.233	2.16	0.2679	135.5
0.214	2.0	0.2679	43.6
0.197	2.14	0.2679	42.5
0.219	2.01	0.2679	12.92
0.185	2.16	0.2679	20.9
0.4	2.25	0.4142	146.2
0.40	2.46	0.4142	144.5
0.227	2.23	0.4142	43.2
0.266	2.475	0.4142	59.0
0.30	2.27	0.4142	17.2
0.161	2.46	0.4142	23.6
0.449	2.09	0.1763	81.4
0.284	2.042	0.1763	23.6
0.177	2.075	0.1763	7.62
0.785	1.61	0.0875	50.7
0.328	1.66	0.0875	30.65
0.40	1.80	0.1316	45.2
0.11	1.85	0.1316	18.9
0.408	2.13	0.2679	90.4
0.50	2.12	0.2679	35.4
0.273	2.49	0.4142	145.0
0.70	2.48	0.4142	46.2
0.25	1.965	0.1763	91.5
0.1575	1.975	0.1763	38.9
0.615	1.525	0.0875	45.2
0.208	1.59	0.0875	29.45
0.157	1.545	0.0875	7.6
0.772	1.72	0.1316	54.2
0.474	1.78	0.1316	35.4
0.50	2.06	0.2679	99.5
0.59	2.14	0.2679	51.0
0.60	2.44	0.4142	152.0
0.50	2.315	0.4142	55.5

```
C   C  M.E. THESIS  BHUPAL SHARMA
       YM=    -1.3783  XM1=      .6680  XM2=   -1.6953  XM3=     3.6857

       S1=     1.0302  S2=     3.7649  S3=     2.0005  S4=     1.0625

       S5=     3.7649  S6=    15.2158  S7=     8.3482  S8=     4.4363

       S9=     2.0005  S10=     8.3482  S11=   31.5936  S12=   13.9579

0      STOP END AT S. 0070 + 01 L.   Z
```

```
                    PROGRAMME-  TWO              DEVIATION
C   C   M.E.  THESIS  BHUPAL SHARMA
        DIMENSIONY(70),X1(70),X2(70),X3(70),CK(70)
        DIMENSIONYN(70),Z1(70),Z2(70),Z3(70)
        READ5,N
      5 FORMAT(I5)
        READ10,(Y(I),X1(I),X2(I),X3(I),I=1,N)
     10 FORMAT(4F15.5)
        DO20I=1,N
        Z1(I)=X1(I)**0.497
        Z2(I)=1.0/(X2(I)**0.08)
        Z3(I)=X3(I)**0.426
        CK(I)=Y(I)/(Z1(I)*Z2(I)*Z3(I))
     20 CONTINUE
        PUNCH10,(CK(I),I=1,N)
        SUM=0.0
        DO30I=1,N
     30 SUM=SUM+CK(I)
        AN=N
        CKAVG=SUM/AN
        PUNCH40,CKAVG
     40 FORMAT(5X,6HCKAVG=,F10.5)
        SUM1=0.0
        DO50I=1,N
        Z4=ABSF(CK(I)-CKAVG)
     50 SUM1=SUM1+Z4**2
        AN=N
        STD=SUM1/AN
        STD=SQRTF(STD)
        PUNCH60,STD
     60 FORMAT(5X,19HSTANDARD DEVIATION=,F10.5)
        COV=(STD/CKAVG)*100.0
        PUNCH70,COV
     70 FORMAT(5X,25HCOEFFICIENT OF VARIATION=,F10.5)
        DO80I=1,N
     80 YN(I)=CKAVG*Z1(I)*Z2(I)*Z3(I)
        PUNCH90,(Y(I),YN(I),I=1,N)
     90 FORMAT(2F15.5)
        S1=0.0
        S2=0.0
        DO100I=1,N
        S1=S1+Y(I)
        S2=S2+YN(I)
    100 CONTINUE
        AN=N
        YM=S1/AN
        YNM=S2/AN
        SY=0.0
        SYN=0.0
        DO110I=1,N
        VY=ABSF(Y(I)-YM)
        VYN=ABSF(YN(I)-YNM)
        SY=SY+VY**2
        SYN=SYN+VYN**2
    110 CONTINUE
        CAN=1.0-(SYN/SY)
        PUNCH10,CAN
        CAN1=SQRTF(CAN)
        PUNCH120,CAN1
```

```
120 FORMAT(//5X,34HMULTIPLE CORRELATION COEFFICIENT =,F15.5)
    STOP
    END
```

52

0.10	1.52	0.0875	65.0
0.35	1.675	0.0875	72.3
0.167	1.545	0.0875	26.6
0.12	1.675	0.0875	29.5
C.1085	1.59	0.0875	14.1
C.0647	1.695	0.0875	11.4
0.372	1.73	0.1316	74.0
0.545	1.86	0.1316	75.0
0.2	1.745	0.1316	26.6
0.272	1.85	0.1316	30.7
0.17	1.755	0.1316	11.4
0.1832	1.89	0.1316	15.25
C.151	1.85	0.1763	77.5
C.437	2.095	0.1763	99.4
C.085	1.88	0.1763	26.6
0.203	2.042	0.1763	35.4
C.0768	1.915	0.1763	16.0
0.0714	2.11	0.1763	17.2
0.149	1.99	0.2679	101.2
0.233	2.16	0.2679	135.5
0.214	2.0	0.2679	43.6
0.197	2.14	0.2679	42.5
C.219	2.01	0.2679	12.92
0.185	2.16	0.2679	20.9
0.4	2.25	0.4142	146.2
0.40	2.46	0.4142	144.5
0.227	2.23	0.4142	43.2
C.266	2.475	0.4142	59.0
0.30	2.27	0.4142	17.2
0.161	2.46	0.4142	23.6
0.449	2.09	0.1763	81.4
0.284	2.042	0.1763	23.6
C.177	2.075	0.1763	7.62
0.785	1.61	0.0875	50.7
0.328	1.66	0.0875	30.65
0.40	1.80	0.1316	45.2
C.11	1.85	0.1316	18.9
0.408	2.13	0.2679	90.4
C.50	2.12	0.2679	35.4
0.273	2.49	0.4142	145.0
0.70	2.48	0.4142	46.2
0.25	1.965	0.1763	91.5
0.1575	1.975	0.1763	38.9
C.615	1.525	0.0875	45.2
C.208	1.59	0.0875	29.45
0.157	1.545	0.0875	7.6
0.772	1.72	0.1316	54.2
0.474	1.78	0.1316	35.4
0.50	2.06	0.2679	99.5
0.59	2.14	0.2679	51.0
0.60	2.44	0.4142	152.0
C.50	2.315	0.4142	55.5

```
C  C  M.E.  THESIS  BHUPAL SHARMA
     .02136          .07211          .05228          .03622
     .04463          .02931          .07368          .10806
     .06130          .07887          .07480          .07171
     .02883          .07593          .02563          .05462
     .02881          .02621          .02472          .03441
     .05086          .04763          .08742          .06058
     .05545          .05620          .05285          .05477
     .10357          .04895          .08492          .09083
     .09176          .18742          .09732          .09810
     .03922          .07150          .13057          .03834
     .15998          .04472          .04058          .15340
     .06252          .08380          .17449          .12887
     .08384          .13200          .08243          .10499
  CKAVG=     .07353
  STANDARD DEVIATION=     .03933
  COEFFICIENT OF VARIATION=  43.48592
     .10000          .34422
     .35000          .35688
     .16700          .23489
     .12000          .24359
     .10850          .17875
     .06470          .16228
     .37200          .37125
     .54500          .37082
     .20000          .23989
     .27200          .25359
     .17000          .16712
     .18320          .18784
     .15100          .38513
     .43700          .42317
     .08500          .24384
     .20300          .27325
     .07680          .19602
     .07140          .20030
     .14900          .44310
     .23300          .49787
     .21400          .30939
     .19700          .30408
     .21900          .18419
     .18500          .22454
     .40000          .53043
     .40000          .52334
     .22700          .31583
     .26600          .35712
     .30000          .21298
     .16100          .24185
     .44900          .38874
     .28400          .22991
     .17700          .14182
     .78500          .30796
     .32800          .24781
     .40000          .29979
     .11000          .20624
     .40800          .41958
```

.50000	.28155
.27300	.52351
.70000	.32173
.25000	.41100
.15750	.28535
.61500	.29477
.20800	.24463
.15700	.13775
.77200	.32531
.47400	.27044
.50000	.43847
.59000	.32864
.60000	.53516
.50000	.35015
.68214	

MULTIPLE CORRELATION COEFFICIENT = .82592

0 STOP END AT S. 0120 + 01 L. Z

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