# LIQUID FLUIDIZATION IN TAPERED VESSELS

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## ABSTRACT

Present work involves the study of liquid fluidization in tapered vessels with tapering ranging from 10 to 120°. Coarse size solid particles (Glass beads, Quartz and Calcite) have been used for studying the effect of physical properties of the material, bed weight and cone angle on fluidization characteristics. Graphs plotted between pressure drop and liquid flow rate show the expected behaviour and trend. Following correlation has been proposed for the determination of pressure peak,

$$\left(\frac{\Delta P_m}{\Delta P}\right) = 1.02\times10^{-3}\left(\frac{D}{D_o}\right)^{1.63}\left(\tan\frac{\alpha}{2}\right)^{-1.25}\left(\frac{D_p G_{mf}}{\mu}\right)^{0.712}$$

It has been observed that smooth fluidization occurs only in lower cone angles i.e. 10, 15 and 20°, for the materials studied. In 30 and 45° cones particle movement is similar to the one observed in spouted beds. In overtapered vessels of cone angles greater than 45° and upto 120° mixing of solids is confined to the central part of the bed only with thick particle layer remaining stationary at the vessel wall.

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# CONTENTS

# CHAPTER I

# INTRODUCTION

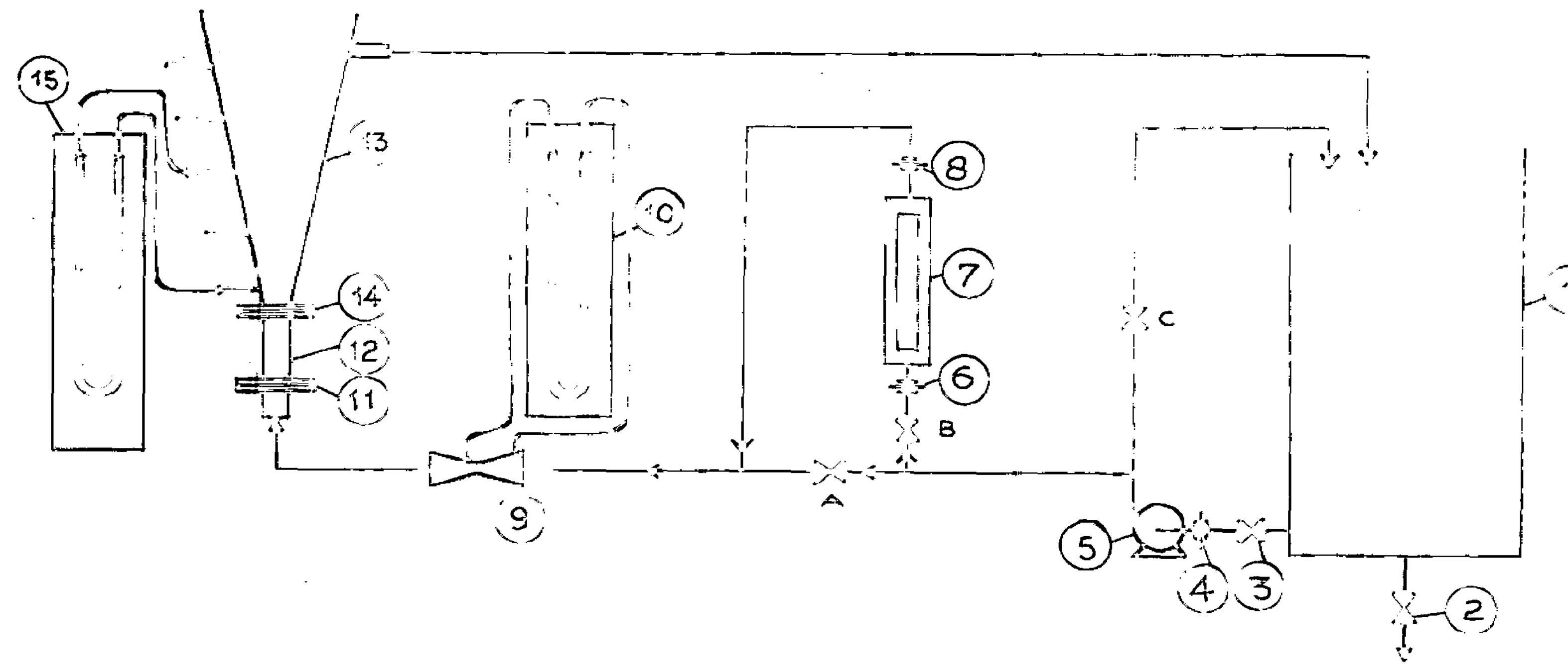
## 1.1 INTRODUCTION TO FLUIDIZATION PHENOMENON:

Fluidization is the operation by which fine solids are transformed into a fluid like state through contact with fluid stream.

When fluid is passed upward in a bed of closely sized granular solids, a pressure gradient is required to overcome friction. In order to increase the rate of flow, a greater pressure gradient is required. At low flow rates, fluid merely percolates through the void spaces between stationary particles. with increase in flow rate, particles move apart and a few are seen to vibrate and move about in restricted region. This is 'expanded bed'. At still higher velocities, a point is reached when the particles are all just suspended in the upward flowing stream. At this point the frictional force between a particle and fluid counter-balances 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 the bed in that section. The motion of the solids is created at superfecial velocities far below the terminal free settling velocities of the solid particles and constitutes the beginning of the fluidization. This is point of 'incipient or minimum fluidization'. The process is approximately equivalent to the inverse of hindered settling.

The precise behaviour of a mass of fluidized solids depends on the particle size and the nature of the fluid. When the fluid is liquid, fluidization begins as a gentle rocking or oscillation of the solid particles. In the fully fluidized bed, the particles move in random directions through all parts of the liquid. There are strong transient currents in the bed with many particles travelling temporarily in the same direction, but in general particles move as individuals. Gross flow instabilities are damped and remain small and large scale bubbling or heterogenity is not observed under normal working conditions. With further increase in the liquid rate a smooth progressive expansion of the bed results until each particle behaves as an individual and is unhindered as a freely settling body by the action of any other solid particle. This entire process is known as 'particulate fluidization'.

When the fluid is a gas, the action in the bed is somewhat different and is strongly influenced by the particle size. Under conditions for good fluidization ( with particles of the proper size and density ) some of the gas travels through the bed between individual particles, but much of it travels through in 'bubbles' or 'pockets' containing almost no solids. At the bed surface the bubbles break, 'splashing' individual particles or




A,B,C - CONTROL VALVE
1. STORAGE TANK
2,3. GLOBE VALVE
4,6,8. UNION
5. CENTRIFUGAL PUMP
7. ROTAMETER
9. VENTURIMETER
10. Hg- MANOMETER
11. SUPPORT PLATE
12. CALMING SECTION
13. TAPERED VESSEL
14. GRID PLATE
15. $CCl_4$- MANOM...

streamers into the space above. In the bed itself the particles move in distinct aggregates which are lifted by the bubbles or which move aside to let the bubbles past. A fluidizing action of this kind is known as 'aggregative fluidization'.

When particles are fluidized in a tall narrow vessel a phenomenon known as 'slugging' may occur. Bubbles of gas tend to coalesce and grow as they rise through the fluidized bed. The rate of growth depends on the size and density of the particles; it is rapid when the particles are large and heavy, slow when they are small and light. If a vessel that is small in diameter contains a deep bed of solids, the bubbles may grow until they fill the entire cross-section of the vessel. Successive bubbles then travel up the vessel, separated by the slugs of the solid particles. Operation is erratic and unstable.

A typical variation of pressure drop with superfecial velocity is shown in Fig. 1 where the logarithm of the pressure drop is plotted against the logarithm of fluid velocity. The straight line from A to B represents the variation of the pressure drop through the bed with fluid velocity during the period of fixed bed operation when no motion of the particles occurs. Fluid merely percolates through the void spaces between stationary particles and the pressure drop is given by Kozeny-carman equation. Eventually the pressure drop equals the force of gravity on the particles (Point B ). Bed has become unstable now and a minor movement and re-adjustment of the particles in the bed begin to take place to offer the maximum cross-sectional area for flow. Bed expands slightly with the grains still in contact. The change in the structure of the bed produces a deviation from the simple relationship between the pressure drop and the velocity shown in the section A to B. Instability of the bed continues as the velocity is increased, until at point C the loosest arrangement of particles in contact is established. With any further increase in the velocity of flow some of the particles in the bed are no longer in permanent contact with one another and becomes continuously agitated. This point 'C' is known as the point of incipient fluidization. At this point of fluidization the bed begins to expand with increasing fluid velocity thus more and more particles loosing contact with others. At point 'D' fluidization is complete and all the particles are in motion. From point 'C' to 'D' there is sudden though slight fall in the pressure drop due to unlocking of particles with each other. Further increase in fluid velocity beyond the point 'D' are attained by relatively slight increase in pressure drop merely that required to overcome the increase in frictional losses between fluid, suspended solids and walls of the container. Particles move more and more vigorously, swirling about and travelling in random directions. The contents of the tube strongly resemble a boiling liquid.

The linear velocity of the fluid between the particles is much higher than the velocity in the space above the bed. Consequently nearly all the particles drop out of the fluid above the bed. Even with vigorous fluidization only the smallest grains are entrained in the fluid and carried away. As fluid velocity is further increased the porosity of the bed rises, the bed of solids one expands, and its density falls. Entrainment becomes appreciable, then severe, then complete. At point 'E' all the particles have been entrained in the fluid, the porosity approaches unity, and the bed as such has ceased to exist. The phenomenon then becomes that of the simultaneous flow of two phases. From point 'D' to 'E' and beyond pressure drop rises with fluid velocity very slowly.

## 1.2 COMPARATIVE STUDY OF FLUIDIZATION IN CYLINDRICAL AND TAPERED VESSELS:

When fluidization is carried out in cylindrical vessels, a usual practice, solids mixing rate in longitudinal direction is quite severe when they are fluidized by gas stream. This severe solids mixing is responsible for increased heat and mass transfer rates between the two phases i.e. solids and the fluid stream due to increased bed turbulence but at the same time creats solids back - mixing in the same direction. Both increased bed turbulence and solids back mixing may not be desirable in some cases for example in case when solids are under use as catalyst, this extreme bed turbulence may result in a continuous attrition of solids and thus loss of catalyst as fines which will be carried out of the bed along with rising gas stream. In case of continuous processing of solids, where it is desirous that each solid particle should spend the same length of time in the bed as any other i.e. solids should move along with rising fluid stream in a piston like manner. Back mixing of solids in the bed will make that some solid particles will be grossly over-reacted whilest others may well pass through unreacted. In such cases it is advantageous to have reduced degree of mixing of solids in longitudinal direction but still retaining all the other desirable properties of the fluidization.

The back mixing of solids, as created by severe solids mixing rate is supposed to be reduced if fluidization is either carried out in long narrow tube with high L/D ratios or in 'multistages'. It has been observed that if fluidization is carried out in deep beds with high L/D ratios it is quite non-uniform. Since in such beds pressure drop is quite satisfactory and being a compressible fluid gas goes on expanding as it passes through the bed thus there is a consequent rise in its velocity. When the upper portion of the bed is made to fluidize satisfactorily it has been found that lower portion of the bed is not fluidized at all while when the gas velocity at the base or distributor corresponds to the Umf value i.e. bottom is made to fluidize satisfactorily the upper part of the bed is slugging badly. This is specially serious for uniformly sized large and dense solid particles where it is difficult to fludize the bed at all.

If fluidization is carried out in tapered/conical vessels with such a taper that superfecial gas velocity is more or less constant around Umf value as the gas rises up through the bed, the whole bed can be fluidized uniformly through out its height. This is only true for deep bed of dense material or with uniformly sized coarse/dense materials. solids mixing rate which was severe in cylindrical beds is reduced much in such vessels, still retaining other desirable important properties of the fluidized bed. This may also possible because of the major portion of the gas which flows through the bed as large practically solid free gas bubbles while the bed solids are suspended by a relatively slow moving gas.

In case of liquid fluidization it has been observed that when the bed is satisfactorily fluidised the bed expansion is not uniform. Porosity of the bed goes on increasing from bottom to the top. Further the interface at the top of the fluidized bed is not clear and distinct.

The another advantage of tapered vessel is that mixed sizes can be fluidized well, the fines or lighter being at the top while the coarser or dense at the bottom with intermediates in between. Thus ellutriation of solids as fines along with rising fluid stream is elliminated completely which is advantageous for catalytic reactions.

## 1.3 FLUIDIZATION IN TAPERED VESSELS:

When fluidization occurs in conical vessels tapering downward there is a considerable pressure peak at the limit of stability. This peak is much larger than at on set of fluidization in an apparatus with constant cross-section and is due to conical form of the bed. In some experiments of Golperin (1960)[8] the pressure drop before the on set of fluidization was two to three times greater than the value established after the limit of stability. In a conical apparatus the bed passes into the fluidized state only after fluidization of its upper portion. Since at this time the gas velocity in the lower and middle portions 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 its configuration in the same way that the hydraulic pressure on the bottom of a vessel does not depend on its shape.

$$\Delta P = (1-\epsilon)(\rho_s - \rho_f)\frac{g}{g_c}\cdot L = \frac{W_{act.}}{A_{avg.}} \qquad (1)$$

Here L is the bed height, W, the bed weight and $A_{avg}$, the average bed cross-sectional area.

As the fluid velocity is furthur increased the pressure drop does not remain constant but, in contrast to the cylindrical bed, begin to fall. The reason being that as the fractional voidage "$\epsilon$" increases, the bed height more or less do not increases with the same speed and thus the product $L(1-\epsilon)$ goes on decreasing.(Fig. 1.2)

Experiments have revealed that in conical vessels the point of incipient fluidization is not as clear cut as in cylindrical vessels. Further, as the upward flow of fluid through the fixed bed of particles in a conical vessel is increased from zero, a compacting effect is noted. This effect is seen well below the point of incipient fluidization. The explanation appears to be that the particles near the bottom of the bed can experience a substantial upward drag force, due to relatively large velocity of the fluid near the bottom of the bed. The 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 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 the particles near the bottom is upward and the resultant force on the particles near the top is downward. The bed height reaches a minimum value due to this compaction effect and a minimum observed porosity is thus realized.

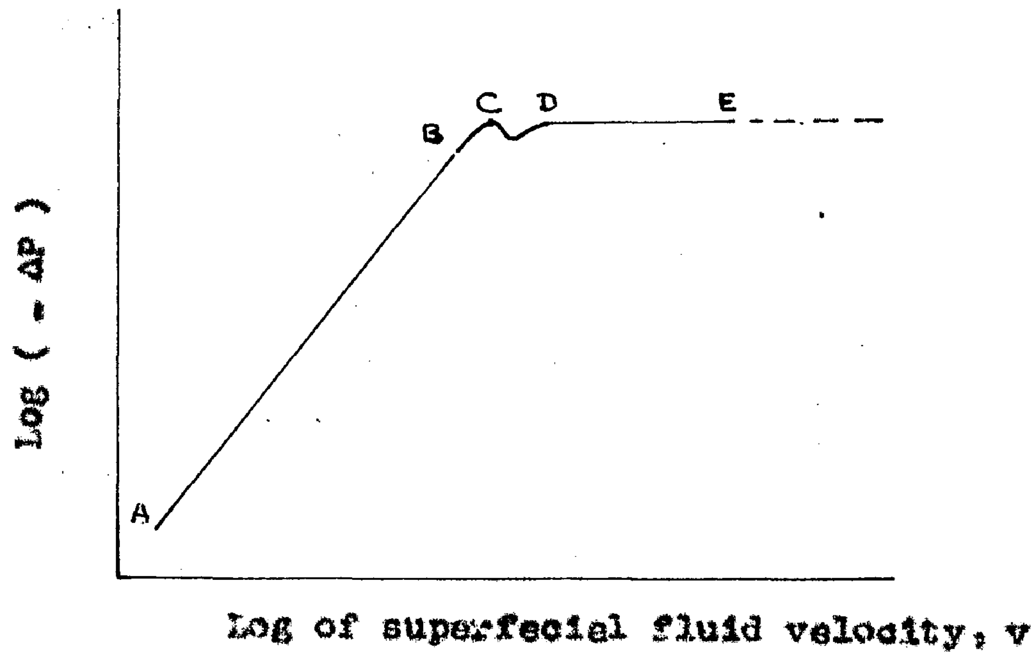



FIG.1.1 - PRESSURE DROP VS. FLOW RATE CURVE FOR A BED OF CLOSELY SIZED PARTICLES

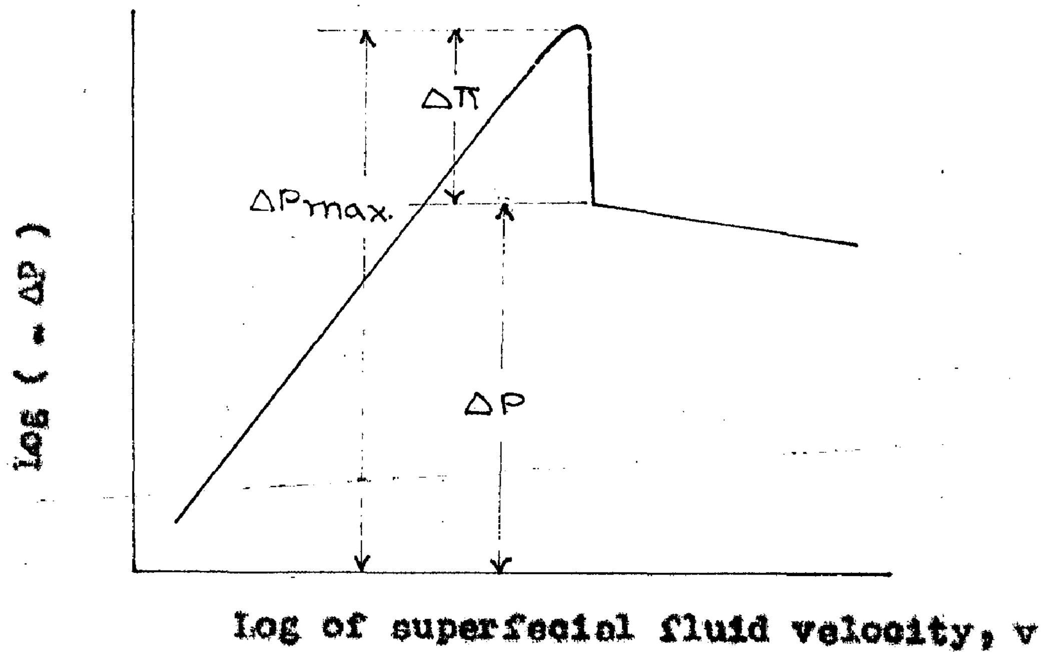
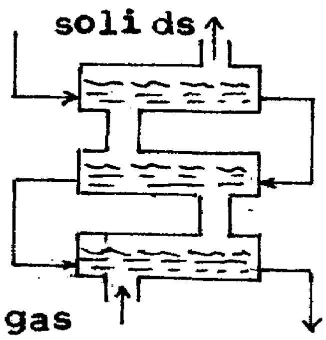



FIG. 1.2 - PRESSURE DROP VS. FLOW RATE CURVE FOR SOLID PARTICLES IN A TAPERED VESSEL

## 2. LITERATURE REVIEW

### 2.1 FLUIDIZATION OF SOLIDS BY GAS STREAM:

As already stated that in case of gas fluidization solids mixing rate in vertical direction is quite severe in cylindrical beds. Brotz (1952)[2] and Roman (1955)[3] stated that the mixing rate increases with increasing fluid velocity. Most of the mixing of solids in the fluidized bed occurs by the bulk movements of the solid material. Such bulk movements are generally associated with eddies in liquid fluidized beds and with bubbles in gas fluidized systems. This severe mixing in longitudinal direction causes back mixing of solids in the bed. Experimental[1, 9, 10] works to know the residence time distribution of solid particles in a continuously fed gas fluidized bed have shown that solids behave approximately as the contents of a continuously stirred tank or perfectly mixed vessel. Spread of residence time is very wide indeed. So that the wide range of residence time distribution in a continuous gas fluidization column may be reduced, either fluidization is to be carried out in multistages[11] with a narrow range of solids residence time in each with overall counter current flow of gas and solids (Fig. 2.1) or to make the bed very deep in relation to its diameter in order to make mixing of the upper and




( Fig. 2.1 )

lower regions of the bed more difficult. But this leads to the non-uniformity of fluidisation quality.

If deep beds are employed in cylindrical vessels the pressure drop between bottom and top of the bed, which is needed for the gas flow to occur through the packed bed and to over come the resistance offered by the solids in the passages and thus fluidise the bed, becomes satisfactory. The gas velocity increases considerably due to the gas expansion as gas passes through the bed from bottom to top. This means that if the gas velocity is only made sufficient to give normal fluidising conditions in the upper regions of the bed, the base of the bed will be completely static. If the gas velocity is increased until fluidisation occurs immediately above the support plate at the bottom of the bed, then the bed is violently agitated at the top, and transport of bed material may occur.

It was originally suggested by Omae and Furukawa (1953)[21], for liquid fluidsed beds, that a possible solution to the problem of smooth operation of deep beds would be to increase the bed cross - sectional area upwardly through the bed so that increase in gas volume could be accomodated i.e. to construct a bed tapering towards its base. Thus uniformly expanded bed, in case of liquid fluidization, can be achieved. The first such bed to be constructed and operated was that of Levey et. al (1960)[1] who were investigating the possibilities of a fluidized bed reactor for the conversion of Uranium Oxide to Uranium Flouride by fluidization with Hydrogen Flouride gas mixed with Nitrogen as a diluent to moderate the reaction and carry away the heat. Spheriodally shaped $UO_3$ particles in size range 20-40 mesh were fluidized in 4-5" cylindrical tubes and for bed heights above two feet fluidization was highly non-uniform with violent bed erruptions and inefficient contacting of the fluid. Fluidization was observed to begin at the upper surface of the bed and proceeded downward through the bed as the inlet gas velocity was raised and when the gas velocity was sufficient to fluidise the bed completely the upper portion of the bed was slugging. Since the super fecial gas velocity increases considerably along the bed owing to the expansion of the gas ( the pr. drop being approximately 1.75 psi/ft ) the bobble volume increases steadily along the bed, and thus deeper the bed and higher the particle density or size, the greater is the tendency of the bed to slug. Bed expansion was quite high and a much higher velocity is required to fluidize the whole bed, than for a shallow bed.

To compensate for the gas expansion thus to have constant superfecial gas velocity along the bed, they employed a suitably tapered tube. The angle of taper for the ideally fluidized bed was as calculated out, for conical vessels:

$$\alpha = \tan^{-1} (a_o \rho_B/2p_b) \qquad (2)$$

Here $a_o$ is the distance normal to the longitudinal axis of the column between tapered sides. $\rho_B$ is bulk density of the bed and $p_b$ is pressure at the inlet to the bed.

In such beds it was noted that pressure drop-flow rate curves are like those ordinarily encountered in fluidized beds, a linear portion before the bed is fluidized and thereafter a horizontal linear portion. Thus quite uniform fluidization was seen taking place. All the properties normally associated with the fluidized state, such as flow ability of the bed and good heat and mass transfer were retained and the bed expansion was reduced, gas bobble formation was largely supperessed and most important of all, the ammount of mixing between the upper and lower regions of the bed was reduced by atleast an orderof magnitude. It was noted that at velocities substantially above the minimum, bubbles do appear but they do not coalesce and in many cases disappear before reaching the upper surface.

According to Romero and Johanson (1962) the reduced rate of mixing of solids is caused by operating ~~rate of~~ close to the minumum fluidizing velocity.

Sutherland (1961)[4] carried out mixing rate experiments using a tapered bed of copper shot, sized between 30-52 Mesh. Nickel spheres of the same size and density acted as a tracer material which were added ( about 1% of the bed weight ) from the top while the bed was under just fluidization state and then increasing the gas velocity to the desired values. Qualitatively, the curves of Nickel concentration against time for various probe locations showed that vertical solid mixing rate was greatly reduced in the tapered beds. It was also shown that this effect is found only with deep beds of dense materials and only at flow rates less than 30% above the MFV and to bed heights greater than 2 feet. Sutherland also observed like levey et. al[1] that particle movements and bubbling in untapered beds began at the top of the bed as the air rate was increased and that by the time particle movements was observed at the base, the top was slugging violently. In tapered beds he observed that the fluidization at lower velocities was more even with bubbles appearing in the lower as well as in the upper part of the bed. Once the flow rate reached 1.2 - 1.3 times of Umf, however, the whole bed began to slug and to appear very similar to the corresponding non-tapered beds. In contrast to cylindrical beds, a more precise value of Umf was obtained for tapered beds. Thus main effect of tapering would appear to be the stabilizing of the just fluidized state through out the depth of the bed.

Later work of Sutherland and Howe (1964)[5] was directed at elucidating the mixing mechanism. A bed of copper shots was overlaid with a Nickel shot layer and fluidized for varying periods. It was concluded that with out bubbles in the bed there was no mixing and the range of flow rates in which the bed was fluidized but bubbles were absent was very narrow. Only in this range could the bed be operated as a continuous plug flow reactor.

Littman (1964) also compared the solids mixing rates for dense particles ( -140 +200 mesh copper ) in straight and tapered fluidized beds of rectangular cross-section. Gas velocities upto 110% above the MFV and bed height to diameter ratios of 8 and 16 to 1 were employed. Again it was noted that at gas velocities close to MFV axial solids mixing rates is quite slow.

## 2.2 LIQUID FLUIDIZATION OF SOLIDS:

Like gas-solid system, here also the point of incipient fluidization is not as clear cut as in cylindrical vessels, as noted by Farkas (1973)[14]. It is also noted the point at which pressure drop reaches to a maximum value, just before the sharp decrease is reproducible and so it is selected arbitrarily as the point of incipient fluidization.

Various correlations for the determination of the point of incipient fluidization in tapered vessels have been proposed. The first is due to Gel-perin et. al (1960)[8] with basic assumption that 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 incipient fluidization velocity characteristick of the particular particle fluid system in cylindrical vessels. The same assumption is quoted by Gorshtein and Mukhlonov (1964)[15]. Baskakov and Gal perin (1965)[16] assumed that the bed begins to expand at the moment when the resistance to the flow becomes equal to the net weight of the particles in the container which is

$$W_{nos} = M - \frac{M}{\rho_S} \qquad (3)$$

Here M being the particles weight, $\rho_S$ particle density in the bed, and they gave the correlation,

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

The values of $C_1$ and $C_2$ are again as given by Ergun (1952) i.e. $C_1$ = 150 and $C_2$ = 1.75 and A and B are as follows:

$$A = (\mu / g_c D_p^2)(1-\epsilon)^2/\epsilon^3$$

$$B = (\rho_f / g_c D_p)(1-\epsilon)/\epsilon^3$$

It should be noted that assumption of B-as-Kakov is quite different from that of Gol'perin et. al[8]. except in case of cylindrical vessels. Recent experimental study made by Farkas (1973)[14] has shown the later as correct. Equation of Baskakov already given can be used to get incipient fluidization velocity from maximum experimental pressure drop value if appropriate values of constants $C_1$, $C_2$ and $\epsilon$ are used.

The behaviour of beds composed of particles of mixed size has been investigated in cylindrical beds by McCune and Wilhelm (1949)[19]. They observed that the smaller which relates the resistance of the fixed bed and the fluid velocity;

$$\Delta P = K\, W_f\, H_{Sta} \qquad (6)$$

$H_{Sta}$ and $\rho_{Sta}$ are the height and bulk density of the stationary bed respectively and $W_f$ is superficial fluid velocity at the base.

An another theoretical equation as derived by Gol'perin et. al (1960)[8] again valid for laminar flow is, for fixed bed pressure drop,

$$\Delta P = K\, U D\,(\,D/D_o - 1\,)\; 2 \tan \alpha/2 \qquad (7)$$

The coefficient K is as given :

$$K = C\, \mu / 2\, D_p^{\,2} \qquad (8)$$

The value of constant C was not given by the authors. Baskakov and Gal'perin (1969)[16] presented the following equation:

$$\Delta P = C_1 A \frac{R_o}{R}(R-R_o)U_o + C_2 B \left(\frac{R_o}{3R^3}\right)(R^3-R_o^3)U_o^2$$

The Coefficient $C_1$ and $C_2$ are the proposed values of Ergun i.e. $C_1 = 150$ and $C_2 = 1.75$, constants A and B have already been described.

Actually the assumption for uniform distribution of gas is far from fulfilled in practice. For this purpose they proposed[8].

$$\Delta\pi = F\left( D/D_o, \tan \alpha/2 \right) \quad (10)$$

— true for a single gas solid system, for example for sand-air system the correlation is as given:

$$\Delta\pi_{Expt} = 2.53 \left( \frac{D}{D_o} \right)^{2.35} (\tan \alpha/2)^{-1.19} \quad (11)$$

Here, ranges of $\alpha$ and $D/D_o$ are 10-16$^o$ and (1 - 30) to 6.77 respectively.

In usual practice the ratio $(\Delta\pi/\Delta P)_{Expt}$ value is lower than theoretical one due to non-uniform distribution of gas which led to the fluidization of a more or less narrow column of material before the mean velocity at the exit cross-section reaches the critical value $W_{1-s}$ i.e. at smaller hydrodynamic resistances of the fluidized bed.

The recent experimental studies made by Farkas (1973)[14] has revealed that conical or tapered vessel data can be correlated by equation of Baskakov if new values of coefficients $C_1$ and $C_2$ were substituted for the cylindrical vessel coefficients, even where the apex angle is small. They substituted axial distance Z for radial distance R and $\Phi_S D_p$ for $D_p$, thus introducing a particle shape factor. Constant $C_1$ and $C_2$ are strongly dependent on the geometry of the bed (conical, half conical of two-dimentional), may be due to 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. As pointed out by Farkas the pr. drop as to be used above is $\Delta P_f$, frictional losses in the bed and is given by the relation,

$$\Delta P_f = \Delta P_{Gross} - \Delta P_{Static} \qquad (11)$$

i.e. substracting from the Gross value the 'static head value' for the bed. This fact can be verified from Bernoulli's equation.

2.4 BED EXPANSION IN TAPERED BEDS:

Kolar (1963)[17] studied expansion of solids particles fluidized with liquid in 10, 20 and 30° conical beds. He correlated average bed porosity with the expressions,

$$\epsilon = 1.037\ (U/U_t)^{0.234} \text{ for } 10^\circ \text{ cone and} \qquad (12)$$

$$\epsilon = 1.07\ (U/U_t)^{0.182} \text{ for } 20^\circ \text{ cone.} \qquad (13)$$

In these equations, properties of particles are accounted only through terminal velocity $U_t$.

Richardson and Zaki (1954)[18] has suggested that more general correlating equation for expansion of liquid fluidized beds in conical/tapered vessel would be:

$$\epsilon^x = U/U_t \qquad (14)$$

Here exponent x is expected to depend on particle properties.

Expansion studies by Farkas (1973)[14] have verified the above equation on log-log plot with $\bar{U}$ as ordinate and $\epsilon$ as absicca, the intercept as found is $\log_{10} V_t$ as predicted by this equation, except for 16-18 mesh particles in $5^0$ two-dimensional bed. Here wall effect is considerable and intercept is $\log_{10} V_t - D_p/1.25$ where 1.25 is the spacing between the walls in cm. It is concluded that exponent x depend both on the bed form and on the properties of particles. At larger apex angleparticles properties have a smaller influence.

2.5 DESIGN OF TAPERED BEDS:

Levey et. al (1960)[1] observed that in a deep non-tapered bed the upper part was fluidized violently while the lower part was hardly moving at all. By overtapering he was able to obtain a bed in which the lower part was well fluidized while the top of the bed was stationary. In both these cases, there is no true MFV for the bed as a whole.

As the aim is to produce uniform fluidization, the voidage and bed density can be taken uniform thus to keep the gas velocity ~~can be taken uniform thus to keep the gas velocity~~ constant, through out the bed, pressure will be linear function of the bed height above the base.

Thus based on the assumptions that (i) absolute gas pressure varies linearly with height in a tapered bed (ii) the bed particles are round, smooth and of uniform size (iii) the particles are uniformly packed through out the bed i.e. $\epsilon$ is constant, the maintenance of constant gas velocity through out the depth of the bed requires that the cross-sectional area at any point along the axis be inversely proportional to the gas pressure at this point. This led to the following relation,

$$r^2 = \frac{r_b^2}{1 - \frac{\Delta P}{p_b} \frac{\ell}{\ell_{mf}}} = \frac{r_t^2}{1 + \frac{\Delta P}{p_t} \frac{\ell_{mf} - \ell}{\ell_{mf}}} \qquad (15)$$

where $\Delta P$ is given by the relation,

$$\Delta P = \ell_{mf}\, \rho_s (1 - \epsilon_{mf}) = p_b - p_t \qquad (16)$$

If pressure drop across an incipiently fluidized bed is equal to the bed weight per unit cross-sectional area, or finally,

$$r^2 = \frac{r_b^2 \left[ p_t + \ell_{mf}\, \rho_s (1 - \epsilon_{mf}) \right]}{p_t + \rho_s (1 - \epsilon_{mf}) (\ell_{mf} - \ell)} \qquad (17)$$

$$= \frac{r_t^2\, p_t}{p_t + \rho_s (1 - \epsilon_{mf}) (\ell_{mf} - \ell)} \qquad (18)$$

Here r is the radius of tapered tube at a axial distance L from the base.

Thus the curvature of the profile being parabolic and this is true for dense materials like copper shot ( $\rho_s = 8.93$ ) but for light materials like sand or glass, the curvature of profile can be ignored and taper is given by the following simplified form:

$$r_t = r_b \sqrt{1 + \frac{L_{mf}\,\rho_s\,(1 - \epsilon_{mf})}{p_t}} \qquad (18)$$

Actually in cases where bed expansion increases regularly up the bed in proportional to the gas expansion, the tapering is not desirous. It is probable that all beds will exhibit some increased expansion, so that a bed tapered on the assumption of uniform expansion would then be slightly over-tapered. In fact the design formula as given by levey et. al (1960)[1]. (Eq. 2) give the angle of taper less than the theoretical.

Ridgway (1965)[6] has concluded that when the pressure drop across the bed is large in compared to absolute gas pressure, effect of gas density along with the velocity change is also to be accounted, because the drag force of the particles is as given by[22],

$$F = C_d \left( \frac{\pi D_p^2}{4} \right) \rho_f U^2 \quad \text{where } C_d \text{ is drag coeff.} \qquad (19)$$

Hence design of taper is tobe such that not $U^2$ but $\rho_f U^2$ should be constant so that the drag force is constant on the particles which gives the final relation,

$$r^4 = r_b^4 \Big/ 1 - \frac{\Delta P}{P_b} \frac{\ell}{\ell_{mf}} \quad \text{- - - - (20)}$$

Previous studies carried out by various research workers on fluidization in tapered vessels are confined upto 60° cone angles. Present work involves the study of liquid fluidization in tapered vessels with tapering ranging from 10° to 120°. Coarse size solid particles both spherical and crushed ( glass beads, quartz and calcite ) in different sizes are used to see the effect of particle size, shape factor, solid density and bed weight/height on pressure peak, pressure drop and liquid flow rate at onset of fluidization.

# 3. EXPERIMENTAL SETUP AND PROCEDURE :

## 3.1 EXPERIMENTAL SET UP:

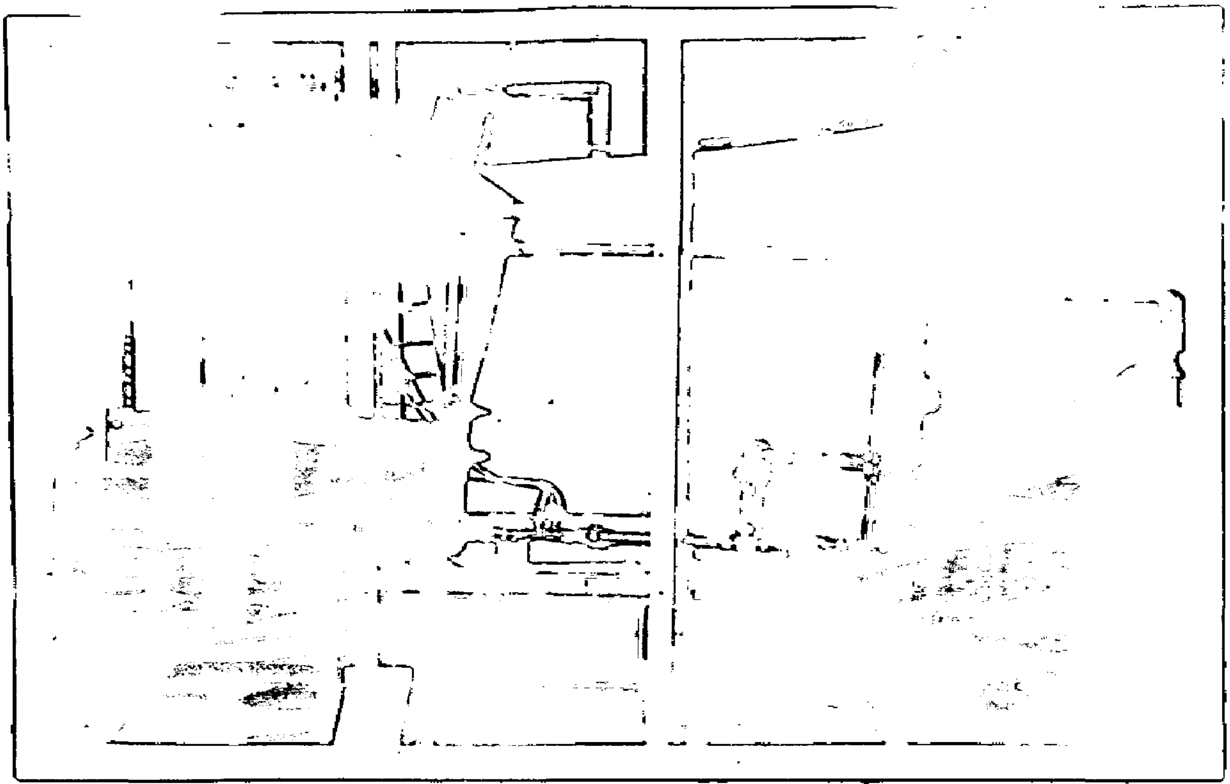
Schematic diagram of the experimental set up is shown in Fig. 3.1 and also in plate No. 1 (a, b ).

Set up consists of a tank (1) connected to the inlet of a centrifugal pump (6). Outlet of the pump is connected to the bottom of the fluidizing column (13) through rotameter (7) and venturimeter (9). Rotameter (7) is put in parallel to the main stream line from the pump. Globe values ( A, B and C ) are provided to control the liquid flow rates. Overflow from the fluidizing column is delivered back to the tank itself. A grid plate (14) is provided at the bottom of the fluidizing column (13) to support the solid particles. A calming section (12) is also provided below the grid plate packed with 0.5 cm dia. glass beads to smoothen the liquid stream entering to the fluidizing column.

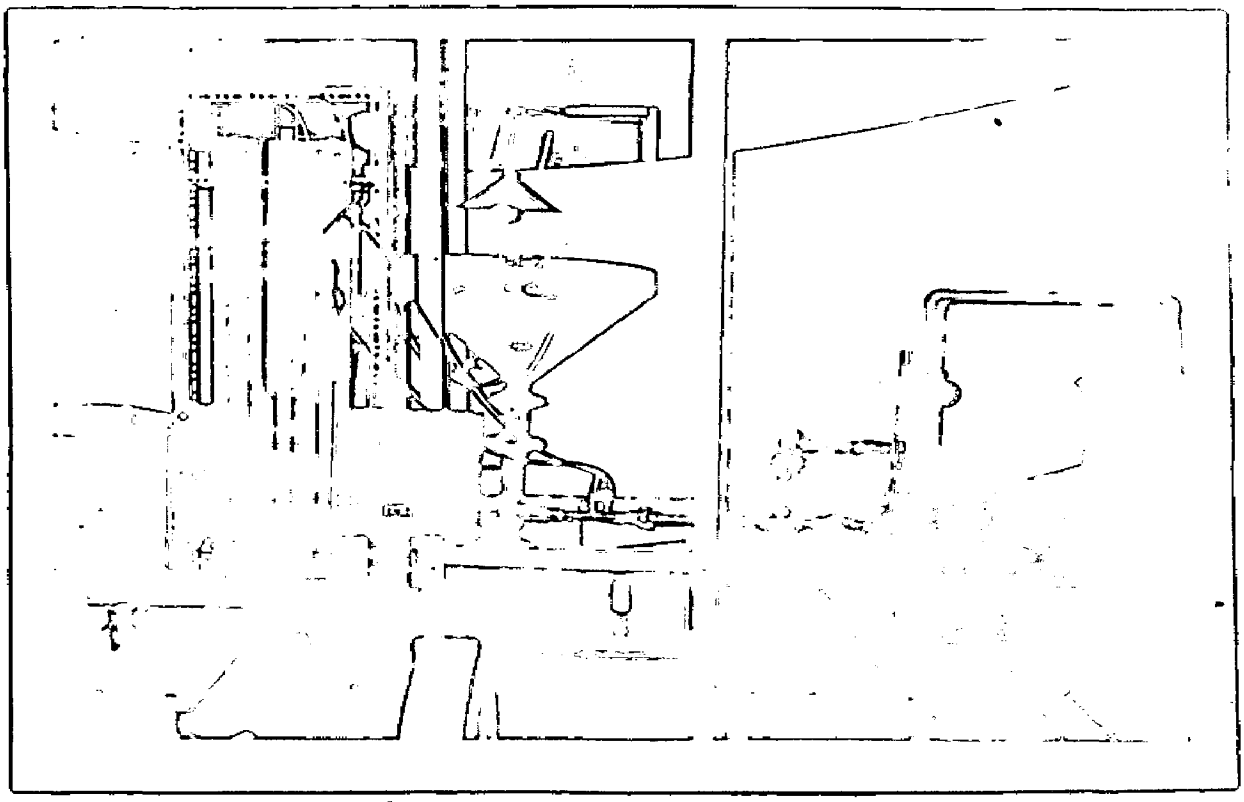
A one meter long carbon tetra chloride-manometer (15) is provided to measure pressure drop across the bed and a 1/2 meter long mercury-manometer (10) across the venturimeter. ~~3.1(a) fluidising columns (tapered vessels)~~

### 3.1(a) Fluidising columns (tapered vessels):

Seven different conical vessels with different cone angles i.e. 10°, 15°, 20°, 30°, 45°, 90° and 120°



(A) 20° CONE



(B) [illegible] CONE

PLATE I. EXPERIMENTAL SETUP

has been used. They are fabricated from 1/16 inch. thick mild steel sheet. Bottom diameter of each cone is kept 4 cm. About 12 cms below from the top 1 inch socket is welded for liquid outlet. A 10 cm flange is welded at the bottom of each cone. Through out the height of each cone along the wall, a perspex sheet, 1 inch in width and 1/10 inch thick is fixed by araldite. Pressure taps are provided at different but equal heights along the wall of each cone.

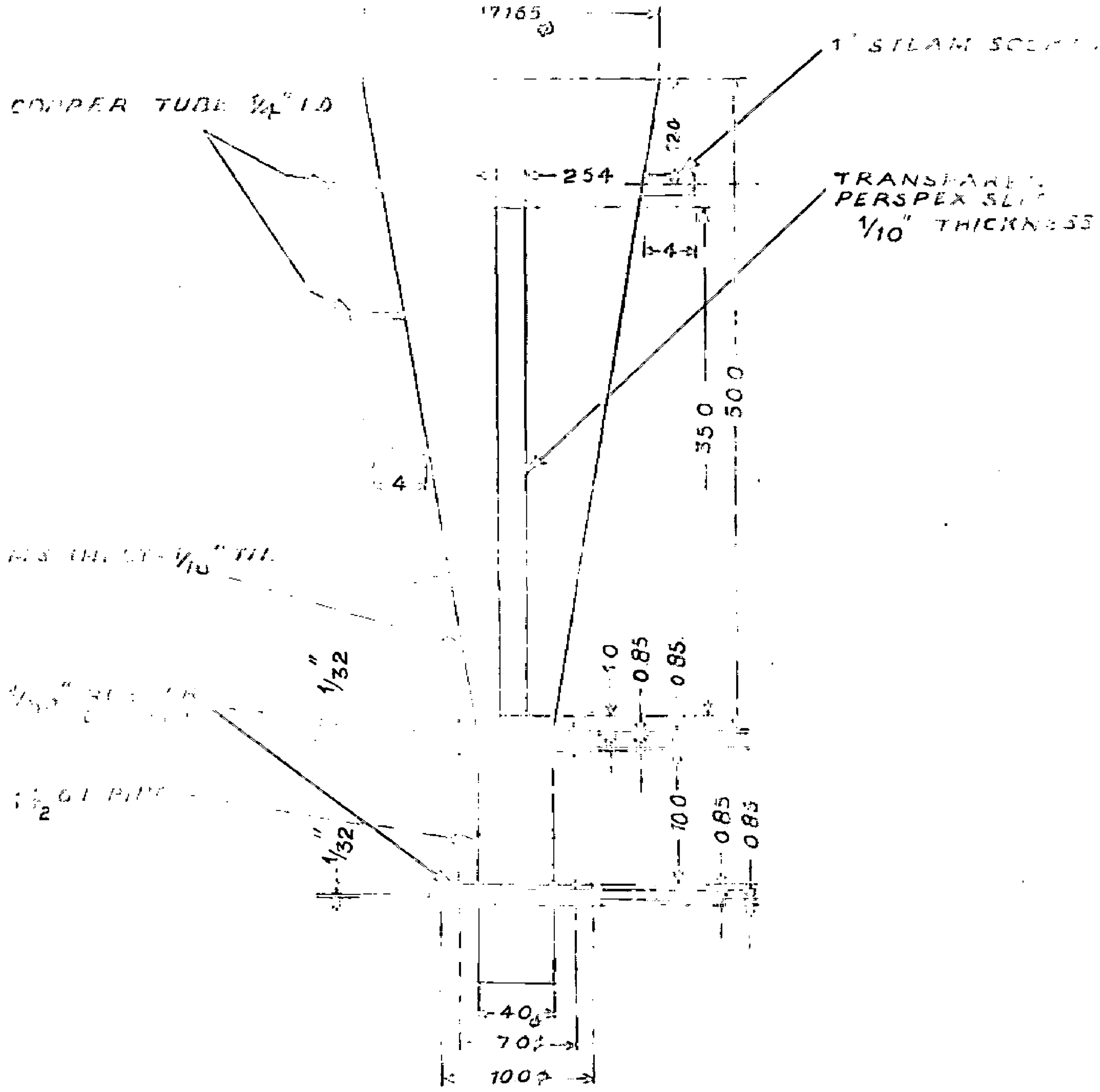
Detailed drawing of 15° tapered vessel is shown in Fig. 3.2 and for others plate no. 2(a, b) can be followed. Main dimensions of each cone are given in table 3.1.

Table 3.1

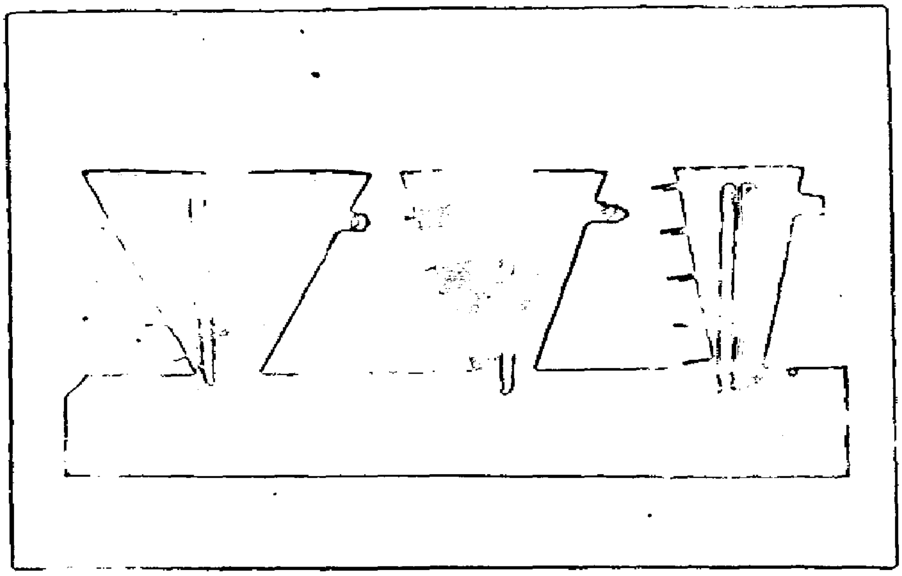
| Cone angle | Top diameter cm | Bottom diameter cm | Column height cm |
|---|---|---|---|
| 10° | 12.5 | 4 | 50 |
| 15° | 16.5 | 4 | 50 |
| 20° | 20.0 | 4 | 50 |
| 30° | 32.0 | 4 | 50 |
| 45° | 47.5 | 4 | 50 |
| 90° | 59.5 | 4 | 28 |
| 120° | 62.0 | 4 | 17 |

3.1(b) Grid plate :

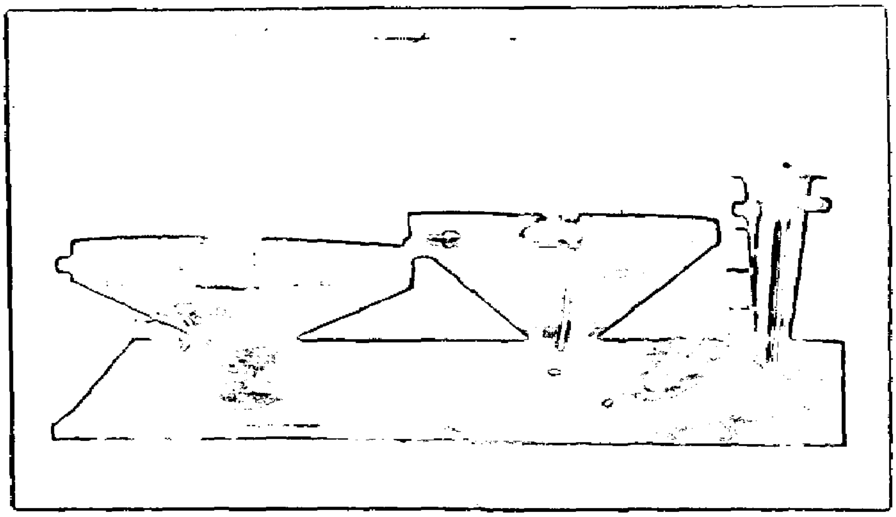
Grid plate is made from a 10 cm diameter, 1/32 inch thick aluminium plate. Holes of size 1/16 in. are




FLUIDIZING COLUMN
DIMENSIONS IN CM.



45° 30° 20°



120° 90° 10°

PLATE 2: TAPERED VESSELS

drilled in a square pitch of 0.25 cms through out the central portion of the plate in 4.5 cm dia. A fine mesh copper wire cloth piece in 5 cm dia is fixed at the above surface of the plate by araldite.

The same type of plate, except with copper wire mesh is used at the bottom of the calming section so as to support packing material.

3.1(c) Calming Section :

Calming section is made from a 1.5 inch nominal size G.I. pipe of 10 cm long threaded on both sides to have flanges. 0.5 cm dia glass beads are employed as packing materail.

3.2 EXPERIMENTAL PROCEDURE :

Data have been taken for three different materials ( Glass beads, Quartz and Calcite ) in the size range of -8+10, -10+12 and -16+18 mesh nos. (for glass beads instead of -8+10, Mesh size 5 is used ). Pressure drop variations and onset of fluidization studies are made for three different bed weights for each sample in steps.

At the start of a run, the weighted ammount of material is put in the fluidizing column and initial bed height is noted down. There after pump is started keeping values 'A' and 'B' closed except 'C' fully open. Now by gradual opening of valve 'B' flow rate is allowed to increase in gradual steps and corresponding pressure drop across the bed and bed height is noted down. In case when more liquid rate is required beyond the range of rotameter, valve 'A' is allowed to open gradually and pressure drop across venturimeter gives the corresponding liquid flow rate. Care was taken at the limit of stability when pressure drop reaches a maximum value and there after suddenly falls down to a constant value. Thus pressure peak and pressure drop at the onset of fluidisation across the bed is noted down. Flow rates are further increased till the whole bed is fully fluidised and particles are under vigorous stirring action.

The data in the same way are repeated for other bed heights and solid materials.

# C H A P T E R   IV

## 4. EXPERIMENTAL DATA, RESULT AND DISCUSSION :

The experimental data were obtained in different tapered vessels in fixed bed region and at onset of fluidization. The pressure drop - flow rate data are shown in tables 4.1, 2, 3, 9, 10, 11, 17, 18, 19, 25, 28, 31 and 34 and figures 4.1, 2, 3, 4, 9, 12, 14, 17, 19, 22, 25 and 26 for glass beads, tables 4.4, 5, 6, 12, 13, 14, 20, 21, 22, 26, 29, 32 and 35 and figures 4.5, 6, 7, 8, 10, 13, 15, 18, 20 and 23 for quartz and tables 4. 7, 8, 15, 16, 23, 24, 27, 30, 33, 36 and figure 4. 11, 16, 21, 24 for calcite.

Effect of bed height :

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

Higher value of pressure drop is due to more resistance offered by increased no. of particles to liquid flow through the void spaces. Higher value of pressure peak and liquid flow rate is due to increased degree of interlocking between the adjacent particles. So that particles may loose contact with each other and thus may fluidize, a greater liquid force is required. After attaining the pressure peak value, pressure drop suddenly falls down to a steady value corresponding to the net weight of the bed.

Effect of particle size :

For the same material and bed weight, pressure peak value seems to increase with particle size. In addition it is found that there is a intermediate range of particle size for which this value is maximum. Hence it can be concluded that upto particle size -10+12 mesh pressure peak value goes on increasing and when the particle size exceeds this value pressure peak starts falling.

Like pressure peak, liquid flow rate at onset of fluidization is also found to increase with particle size while the pressure drop value at onset of fluidization is almost constant.

Increased value of pressure peak and liquid flow rate is due to increased degree of interlocking between particles as particle size increases while the pressure drop value is almost constant equal to the net weight of the bed. Interlocking is supposed to be more perfect for particle size for which pressure peak is found maximum.

Effect of shape factor :

Pressure peak is found ~~more susceptive~~ to increase as particles are non-spherical in nature. For the same bed weight pressure peaks for quartz and calcite are quite high as compared to glass beads. Liquid flow rate at onset of fluidisation is a little higher for crushed materials while pressure drop value a little lower, as compared to spherical particles of the same size.

The lower value of pressure drop after the onset of fluidisation is due to particles, being completely loose with each other at onset of fluidisation, have oriented themselves so as to provide maximum permissible area for flow which is even greater than for spherical particles of the same size.

The higher value of pressure peak and flow rate required at onset of fluidisation is due to the non - spherical nature of the particles which have the better interlocking characteristics with each other.

EFFECT OF CONE ANGLE:

For the same material, particle size and bed weight, the values of pressure peak, pressure drop and liquid flow rate at onset of the fluidisation decrease as cone angle increases. The reason being that bed height goes on reducing very rapidly with cone angle for the same weight of the bed.

Pressure peak values are noted to be much reduced for 90° cone and even further for 120°. The reason being that (a) the bed heights are quite small in these vessels for the same weight of the bed as in the others (b) only a limited part of the bed, confined to the central region only is fluidized (see plate no. 3(a,b). The solids in between the wall and outside this central region, which consist a major part of the bed, are quite stationary just like as in fixed bed.

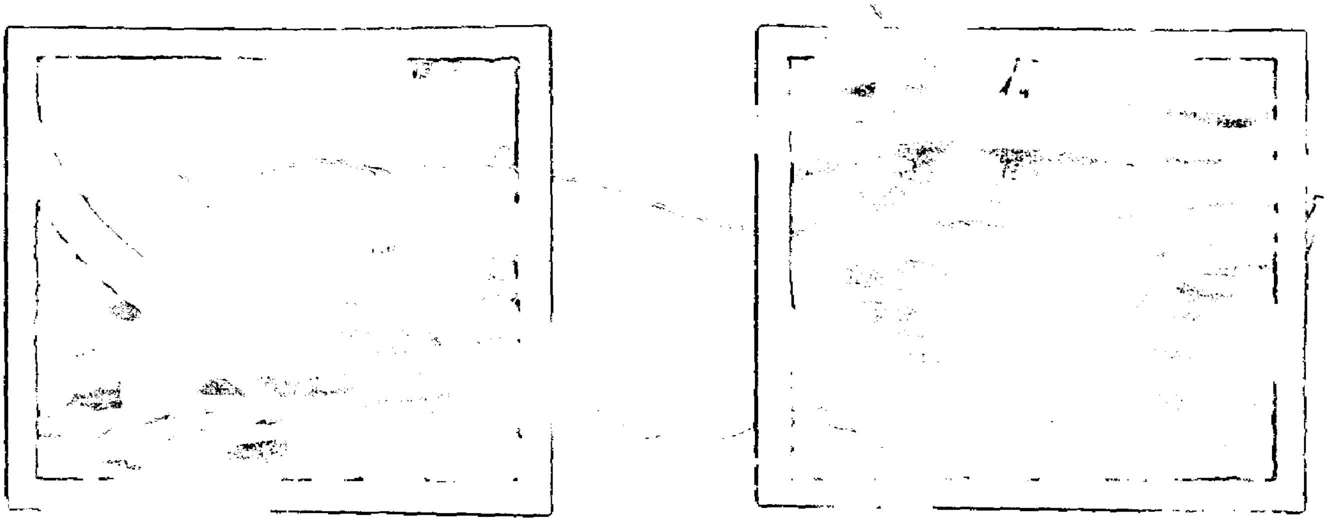
Quality of fluidization in different vessels :

True fluidization is seen to occur in lower cone angles i.e. 10, 15°, and 20°. In 30° and 45° cones fluidization is just like as in spouted beds, solids may be seen coming down by the side of the wall of vessels and rising up in the central part of the bed upto some height thus having interface at the top of the bed convex instead of being flat as in lower angles. In over tapered beds like 90° and 120° fluidization of solids is only confined to the central region of the bed, leaving the sorroundings quite stationary. Even at much higher velocities the same is seen to happen except solids in the central zone go upto much higher distance. It is concluded that all the liquid seems to pass through this central region of the bed.

Actually when angle is less solids have tendency to slide down along the wall so mixing of solids is confined to the whole bed (see Fig. 4.27). The counter-current motion of solids is more pronounced in 30° and 45° cones. In case of over tapered beds since the angle of cone has increased to such a value, below angle of repose of solid particles that solids have lost the tendency to slide down along the wall hence mixing of solid does not extend to the whole bed ( see Fig. 4.28 ).

As far as fluidization in 10°, 15° and 20° cone angles is concerned it is seen that in 10° cone, glass beads are fluidised in a quite smooth way having clear interface at the top. No slugging inside the bed is seen at all. For both calcite and quartz in this cone, it is seen that whole bed is lifted up upto some distance, compacted, till this starts disintegrating to individual particles and finally to re-formation of the compacted bed which is again lifted up.

As cone angle increases from 10 to 15° slugging goes on reducing for both calcite and quartz. Now whole bed has stopped to be compacted and horizontal water ripples are seen within the bed rising upto some heights and then disappearing themselves. In 20° cone, fluidization for these materials is quite smooth and uniform with clear interface at the top and no slugging inside the bed. For glass beads in these vessels fluidization has worsened. Thus it is concluded that as particles are non-spherical in nature the cone angle required to fluidize them, in a uniform and smooth way is as larger.



(A) [illegible] (B) [illegible]

PLATE 3. MIXING OF SOLIDS IN CENTRAL REGION

BED POROSITY AND PRESSURE DROP AT ONSET OF FLUIDIZATION

It has been observed that for ir-regular particles i.e. Quartz and Calcite bed height goes on reducing with increase in liquid flow rate, till the minimum value is reached at the limit of stability. This is due to reorientation of particles and due to bed compaction effect. Any how the reduction in bed height is very small and almost absent for spherical ones. At onset of fluidization suddenly bed expands a little and goes on expanding as liquid flow rate increases.

Equation 1 has been checked sith experimental data and it has been confirmed that it is $a_o$ not $a_{avg}$ in the equation. In table 4.37, $\Delta P_{Theo}$ value has been compared with $\Delta P_{obs}$ values for each cone. Mesh size, as selected, is -10+12 and bed weight 1 kg. $\Delta P_{obs}$ is the observed value

Table No. 4.37

| Material | $\Delta P_{Theo} = W_{not}/a_o$ | $\Delta P_{obs}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 10° | 15° | 20° | 30° | 45° | 90° | 120° |
| Glass beads | 47.6 | 49.7 | 43.8 | 37.7 | 24.1 | 14.7 | 7.2 | 3.3 |
| Quartz | 50.0 | 46.0 | 37.6 | 35.6 | 30.0 | 11.8 | 5.1 | 3.0 |
| Calcite | 50.0 | 49.5 | 40.3 | 33.0 | 22.2 | 12.3 | 6.8 | 3.3 |

of pressure drop in gm/cm² (pressure drop, as obtained, is multiplied by 1.595, the sp. gr of $CCl_4$) $\Delta P_{Theo}$ is calculated by dividing $W_{net}$ value (eq. 3) with $a_o$, area of the cone at the base. Data show that whole bed is suspended in the rising fluid stream at MFV provided the cone angle is low

Table No. 4.1

Cone angle, 10°  $D_p$ = 0.335 cm

Material, Glass beads  $\rho_s$ = 2.5 gm/cc

Mesh No., 6  $\phi_s$ = 1

| Sl. No. | Bed wt. kg | Liq. flow rate, lit/min. | Manometer legs readings cms | | ΔP, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.8 | 52.1 | 2.9 | 2.9 | 14.1 |
| 2 | | 4.0 | 55.7 | 10.2 | 10.2 | 14.1 |
| 3 | | 6.8 | 61.7 | 22.2 | 22.2 + | 14.1 |
| 4 | 0.4 | 8.0 | 65.2 | 29.2 | 29.2 x | 14.1 |
| 5 | | 8.0 | 59.7 | 18.2 | 18.2 | 15.0 |
| 6 | | 12.0 | 59.5 | 17.9 | 17.9 | 16.0 |
| 7 | | 16.0 | 59.5 | 17.8 | 17.8 | 17.0 |
| 1 | | 1.4 | 51.9 | 49.2 | 2.7 | 19.8 |
| 2 | | 4.8 | 59.0 | 42.2 | 16.8 | 19.8 |
| 3 | | 7.6 | 68.8 | 32.3 | 36.5 | 19.8 |
| 4 | 0.7 | 10.0 | 74.1 | 27.0 | 47.1 + | 19.8 |
| 5 | | 10.0 | 63.3 | 37.8 | 25.5 x | 22.0 |
| 6 | | 14.3 | 63.0 | 38.0 | 25.0 | 22.3 |
| 7 | | 18.0 | 62.8 | 38.2 | 24.6 | 22.8 |
| 1 | | 1.4 | 52.0 | 49.2 | 2.8 | 24.4 |
| 2 | | 3.9 | 57.2 | 43.9 | 13.3 | 24.4 |
| 3 | | 7.0 | 68.1 | 33.0 | 35.1 | 24.4 |
| 4 | 1.0 | 11.6 | 84.1 | 17.0 | 67.1 + | 24.4 |
| 5 | | 11.6 | 66.0 | 35.1 | 30.9 x | 26.7 |
| 6 | | 17.6 | 65.5 | 35.5 | 30.0 | 27.3 |

\+ Pressure peak value ( at limit of stability ) for fixed bed.

x Pressure drop value at onset of fluidization.

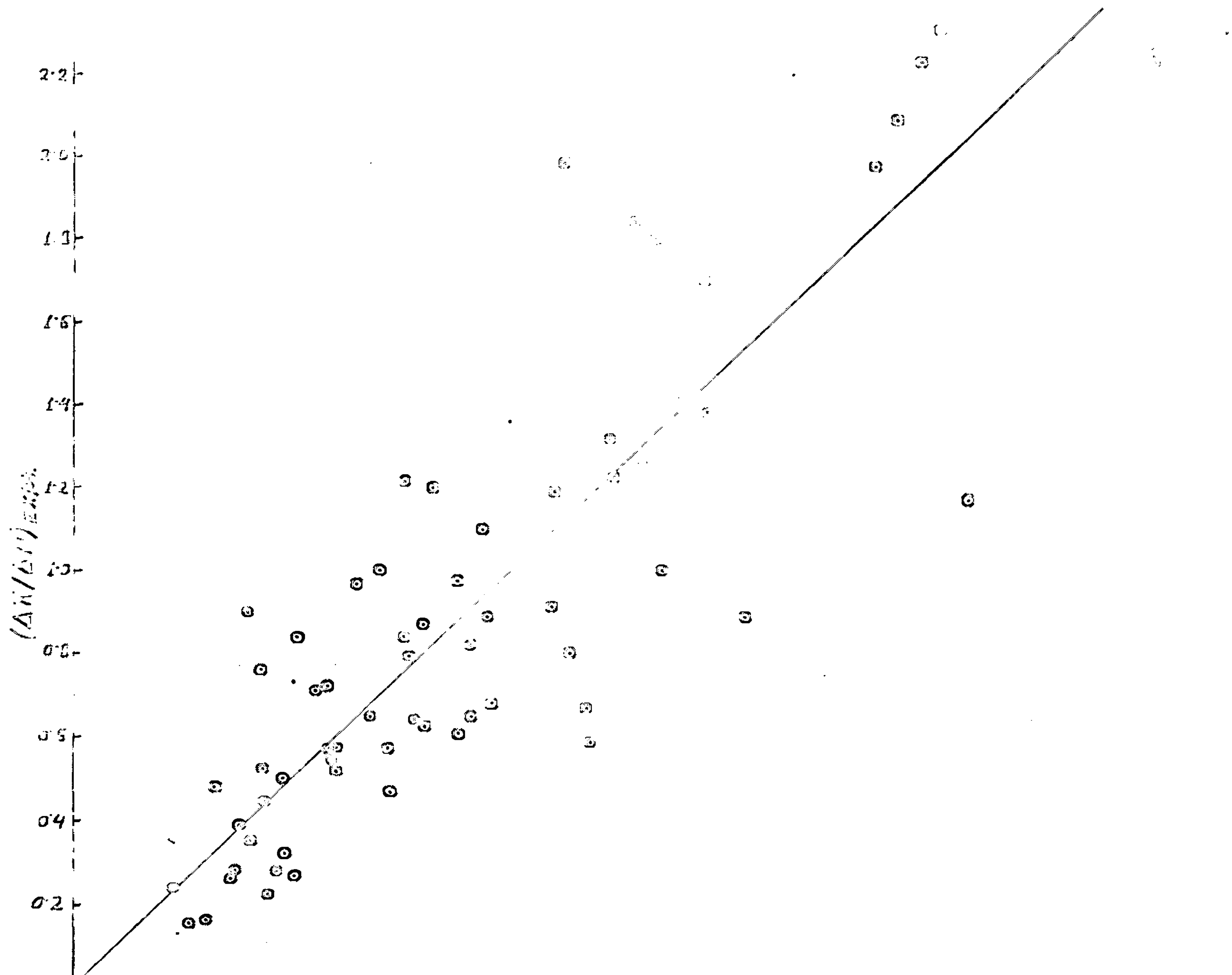

(ΔH/ΔT) expt.
2·2
2·0
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2

Table No. 4.2

Cone angle, 10° — $D_p$ = 0.1517 cm

Material, Glass beads — $\rho_s$ = 2.5 gm/cc

Mesh No., -10+12 — $\phi_s$ = 1

| Sl. No. | Bed wt. kg | Liq. flow rate, lit/min. | Manometer legs readings, cms | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm |
|---|---|---|---|---|---|---|
| 1 | | 0.7 | 51.2 | 47.4 | 3.8 | 13.3 |
| 2 | | 1.2 | 52.6 | 45.9 | 6.7 | 13.3 |
| 3 | | 2.0 | 55.8 | 42.7 | 13.1 | 13.3 |
| 4 | | 2.7 | 60.8 | 37.8 | 23.0 | 13.3 |
| 5 | 0.4 | 4.5 | 65.6 | 33.0 | 32.6 ✧ | 13.3 |
| 6 | | 4.5 | 58.3 | 40.2 | 18.1 x | 14.7 |
| 7 | | 6.1 | 58.1 | 40.4 | 17.7 | 15.0 |
| 8 | | 9.0 | 58.2 | 40.5 | 17.5 | 16.0 |
| 1 | | 0.8 | 51.8 | 46.6 | 5.2 | 18.7 |
| 2 | | 1.6 | 55.0 | 43.4 | 11.6 | 18.7 |
| 3 | | 2.6 | 61.0 | 37.4 | 23.6 | 18.7 |
| 4 | | 3.5 | 68.0 | 30.3 | 37.7 | 18.7 |
| 5 | 0.7 | 5.0 | 72.8 | 25.5 | 47.3 ✧ | 18.7 |
| 6 | | 5.0 | 61.8 | 36.7 | 25.1 x | 19.3 |
| 7 | | 7.4 | 61.5 | 36.9 | 24.6 | 20.5 |
| 8 | | 12.0 | 61.4 | 37.0 | 24.4 | 22.0 |
| 1 | | 1.1 | 54.1 | 46.9 | 7.2 | 23.1 |
| 2 | | 2.8 | 64.3 | 36.6 | 27.7 | 23.1 |
| 3 | | 3.7 | 71.8 | 28.9 | 42.9 | 23.1 |
| 4 | | 6.0 | 84.2 | 16.5 | 67.7 ✧ | 23.1 |
| 5 | | 6.0 | 66.0 | 34.8 | 31.2 x | 24.4 |
| 6 | | 11.0 | 65.4 | 35.4 | 30.0 | 25.5 |

✧ Pressure peak value ( at limit of stability ) for fixed bed.

x Pressure drop value at onset of fluidization.

Table No. 4.3

Cone angle, 10° $D_p$ = 0.0927 cm

Material, Glass beads $\rho_s$ = 2.5 gm/cc

Mesh No., -16+18 $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings, cms. | | loss ΔP, cm-$CCl_4$ | Bed ht. cm |
|---|---|---|---|---|---|---|
| 1 | | 0.7 | 53.7 | 46.6 | 7.1 | 13.2 |
| 2 | | 1.1 | 56.9 | 43.4 | 13.5 | 13.2 |
| 3 | | 1.2 | 60.5 | 39.8 | 20.7 | 13.2 |
| 4 | 0.4 | 2.7 | 66.3 | 36.0 | 30.3 ✦ | 13.2 |
| 5 | | 2.7 | 59.0 | 41.4 | 17.6 x | 14.1 |
| 6 | | 3.9 | 58.7 | 41.7 | 17.0 | 14.7 |
| 7 | | 6.0 | 58.6 | 41.9 | 16.7 | 15.6 |
| 1 | | 0.7 | 54.5 | 46.1 | 8.4 | 13.7 |
| 2 | | 1.1 | 58.5 | 42.1 | 16.4 | 13.7 |
| 3 | | 1.7 | 63.5 | 37.1 | 26.4 | 13.7 |
| 4 | 0.7 | 3.1 | 72.9 | 27.7 | 45.2 ✦ | 13.7 |
| 5 | | 3.1 | 63.0 | 37.5 | 25.5 x | 20.2 |
| 6 | | 6.2 | 62.6 | 37.8 | 24.8 | 21.0 |
| 7 | | 9.0 | 62.4 | 38.0 | 24.4 | 22.6 |
| 1 | | 0.6 | 55.4 | 45.1 | 10.3 | 22.9 |
| 2 | | 1.2 | 61.8 | 38.8 | 23.0 | 22.9 |
| 3 | 1.0 | 3.8 | 84.4 | 16.0 | 68.4 ✦ | 22.9 |
| 4 | | 3.8 | 65.8 | 34.7 | 31.1 x | 24.8 |
| 5 | | 5.5 | 65.9 | 35.4 | 30.5 | 26.0 |

✦ Pressure peak value ( at limit of stability ) for fixed bed.

x Pressure drop value at onset of fluidization.

Table No. 4.4

Cone angle, 10° — $D_p$ = 0.1865 cm

Material, Quartz — $\rho_s$ = 2.7 gm/cc

Mesh No., -8+10 — $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer legs readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.8 | 51.3 | 49.3 | 2.0 | 14.7 |
| 2 | | 2.07 | 53.5 | 46.9 | 6.6 | 14.6 |
| 3 | | 3.2 | 57.8 | 42.8 | 15.0 | 14.5 |
| 4 | | 4.0 | 62.8 | 37.8 | 25.0 | 14.5 |
| 5 | 0.4 | 4.4 | 67.1 | 33.5 | 33.5+ | 14.5 |
| 6 | | 6.7 | 80.3 | 20.3 | 60.0 | 15.1 |
| 7 | | 6.7 | 58.8 | 41.7 | 17.1x | 16.0 |
| 8 | | 11.6 | 58.5 | 42.0 | 16.5 | 17.5 |
| 9 | | 15.5 | 58.2 | 42.2 | 16.0 | 18.0 |
| 1 | | 0.8 | 51.5 | 49.0 | 2.5 | 20.6 |
| 2 | | 2.1 | 54.4 | 46.1 | 8.3 | 20.6 |
| 3 | | 3.0 | 59.6 | 41.0 | 18.6 | 20.6 |
| 4 | 0.7 | 4.9 | 66.7 | 34.0 | 32.7+ | 20.5 |
| 5 | | 9.2 | 85.6 | 15.0 | 70.6 | 20.5 |
| 6 | | 9.2 | 62.0 | 38.5 | 23.5x | 22.4 |
| 7 | | 12.4 | 61.5 | 39.0 | 22.5 | 23.5 |
| 8 | | 18.5 | 61.2 | 39.2 | 22.0 | 24.5 |
| 1 | | 0.6 | 51.4 | 49.2 | 2.2 | 25.4 |
| 2 | | 2.9 | 57.2 | 43.4 | 13.8 | 25.4 |
| 3 | | 4.5 | 65.8 | 34.9 | 30.9 | 25.3 |
| 4 | 1.0 | 6.0 | 75.3 | 25.3 | 50.0+ | 25.2 |
| 5 | | 10.4 | 99.1 | 1.5 | 97.6 | 25.2 |
| 6 | | 10.4 | 65.0 | 36.0 | 29.0x | 27.0 |
| 7 | | 14.0 | 63.8 | 36.8 | 27.0 | 27.5 |

\+ Pressure peak value ( at limit of stability ) for fixed bed.

x Pressure drop value at onset of fluidization.

Table No. 4.6

Cone angle, 10° | $D_p$ = 0.1517 cm
Material, Quartz | $\rho_s$ = 2.7 gm/cc
Mesh No., -10+12 | $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer legs readings, cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.2 | 55.0 | 45.9 | 9.1 | 13.7 |
| 2 | | 2.2 | 60.6 | 40.2 | 20.4 | 13.6 |
| 3 | 0.4 | 5.2 | 74.5 | 26.5 | 48.0✧ | 13.5 |
| 4 | | 5.2 | 58.7 | 42.0 | 16.7π | 16.2 |
| 5 | | 7.7 | 58.5 | 42.2 | 16.3 | 17.0 |
| 6 | | 10.4 | 58.4 | 42.3 | 16.1 | 18.5 |
| 1 | | 0.7 | 52.7 | 48.2 | 4.5 | 20.3 |
| 2 | | 2.4 | 62.1 | 39.0 | 23.1 | 20.0 |
| 3 | 0.7 | 3.6 | 71.0 | 30.0 | 41.0 | 20.0 |
| 4 | | 6.6 | 90.0 | 11.0 | 79.0✧ | 19.7 |
| 5 | | 6.6 | 62.4 | 38.8 | 23.6π | 22.5 |
| 6 | | 9.6 | 61.8 | 39.5 | 22.3 | 23.2 |
| 1 | | 0.7 | 52.5 | 48.7 | 3.8 | 25.4 |
| 2 | | 1.7 | 57.2 | 44.1 | 13.1 | 25.2 |
| 3 | | 2.9 | 65.7 | 35.7 | 30.0 | 24.9 |
| 4 | 1.0 | 4.4 | 81.2 | 19.5 | 61.7 | 24.7 |
| 5 | | 7.3 | 90.0 | 20.0 | 96.0✧ | 24.7 |
| 6 | | 7.8 | 64.8 | 36.0 | 28.8π | 26.7 |
| 7 | | 9.2 | 64.6 | 36.3 | 28.3 | 27.6 |
| 8 | | 11.2 | 63.7 | 37.0 | 26.7 | 28.5 |

✧ Pressure peak value ( at limit of stability ) for fixed bed.

π Pressure drop value at onset of fluidization.

Table No. 4.6

Cone angle, 10°  $D_p$ = 0.0927 cm

Material, Quartz  $\rho_s$ = 2.7 gm/cc

Mesh No., -16+18  $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer legs readings, cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.0 | 54.6 | 46.3 | 8.3 | 15.3 |
| 2 | | 1.7 | 59.5 | 41.5 | 18.0 | 15.3 |
| 3 | 0.4 | 4.0 | 68.8 | 32.2 | 36.6 * | 15.2 |
| 4 | | 4.0 | 58.9 | 42.2 | 16.7 x | 17.4 |
| 5 | | 4.9 | 58.7 | 42.3 | 16.4 | 18.0 |
| 6 | | 7.2 | 58.6 | 42.4 | 16.2 | 19.5 |
| 1 | | 0.8 | 65.0 | 46.0 | 0.0 | 21.4 |
| 2 | | 1.7 | 62.7 | 38.5 | 24.2 | 21.8 |
| 3 | | 2.4 | 69.5 | 31.8 | 37.7 | 21.1 |
| 4 | 0.7 | 4.6 | 85.2 | 15.8 | 69.4 * | 21.1 |
| 5 | | 4.6 | 62.2 | 38.9 | 23.3 x | 23.7 |
| 6 | | 6.5 | 62.8 | 39.6 | 23.2 | 24.0 |
| 7 | | 9.0 | 61.7 | 39.4 | 22.3 | 25.0 |
| 1 | | 0.8 | 55.4 | 45.7 | 9.7 | 26.3 |
| 2 | | 2.1 | 66.4 | 34.9 | 31.5 | 26.2 |
| 3 | | 2.8 | 74.0 | 27.3 | 46.7 | 26.1 |
| 4 | 1.0 | 3.4 | 81.5 | 19.5 | 62.0 | 26.1 |
| 5 | | 4.9 | 80.0 | 11.0 | 70.0 * | 26.1 |
| 6 | | 4.9 | 65.2 | 35.8 | 29.4 x | 28.7 |
| 7 | | 6.4 | 64.4 | 36.7 | 27.7 | 29.0 |
| 8 | | 10.0 | 64.0 | 37.2 | 26.8 | 30.0 |

* Pressure peak value ( at limit of stability ) for fixed bed.

x Pressure drop value at onset of fluidization.

Table No. 4.7

Cone angle, 10° $D_p$ = 0.1865 cm

Material, Calcite $\rho_s$ = 2.7 gm/cc

Mesh No., -8+10 $\phi_s$ =

| Sl. no. | Bed wt. kg | Liq. flow rate, lit/min. | Manometer readings cms | legs | $\Delta P$, cm-$CCl_4$ | Bed ht. cm |
|---|---|---|---|---|---|---|
| 1 | | 1.1 | 52.0 | 48.8 | 3.2 | 14.0 |
| 2 | | 1.8 | 53.9 | 47.1 | 6.8 | 13.8 |
| 3 | | 3.0 | 59.0 | 42.1 | 16.9 | 13.6 |
| 4 | | 4.5 | 67.5 | 33.5 | 34.0 | 13.5 |
| 5 | 0.4 | 6.6 | 71.5 | 29.5 | 42.0 ✦ | 13.5 |
| 6 | | 6.6 | 59.9 | 40.9 | 19.0 x | 15.7 |
| 7 | | 8.0 | 59.5 | 41.3 | 18.2 | 16.5 |
| 8 | | 11.4 | 59.3 | 41.6 | 17.7 | 17.3 |
| 1 | | 1.1 | 52.2 | 48.5 | 3.7 | 20.0 |
| 2 | | 2.6 | 56.8 | 44.1 | 12.7 | 19.3 |
| 3 | | [illegible].8 | 63.4 | 37.5 | 25.9 | 19.7 |
| 4 | 0.7 | 8.0 | 74.5 | 26.5 | 48.0 | 1[illegible].7 |
| 5 | | 10.0 | 84.3 | 16.3 | 68.0 ✦ | 1[illegible].7 |
| 6 | | 10.0 | 63.2 | 37.7 | 25.5 x | 22.3 |
| 7 | | 14.0 | 62.7 | 38.0 | 24.7 | 22.8 |
| 1 | | 0.9 | 52.5 | 48.8 | 3.7 | 24.3 |
| 2 | | 2.7 | 59.4 | 42.1 | 17.3 | 24.1 |
| 3 | | 3.9 | 67.9 | 33.6 | 34.3 | 23.9 |
| 4 | | 5.2 | 78.9 | 22.3 | 56.6 | 24.0 |
| 5 | | 9.6 | 96.5 | 3.5 | 93.0 ✦ | 24.0 |
| 6 | | 9.6 | 66.1 | 34.7 | 31.4 x | 26.4 |
| 7 | | 12.0 | 65.5 | 35.5 | 30.0 | 27.2 |
| 8 | | 15.0 | 65.0 | 36.0 | 29.0 | 28.0 |

✦ Pressure peak value ( at limit of stability ) for fixed bed.

x Pressure drop value at onset of fluidization.

Table No. 4.8

Cone angle, 10°  $D_p$ = 0.1517 cm

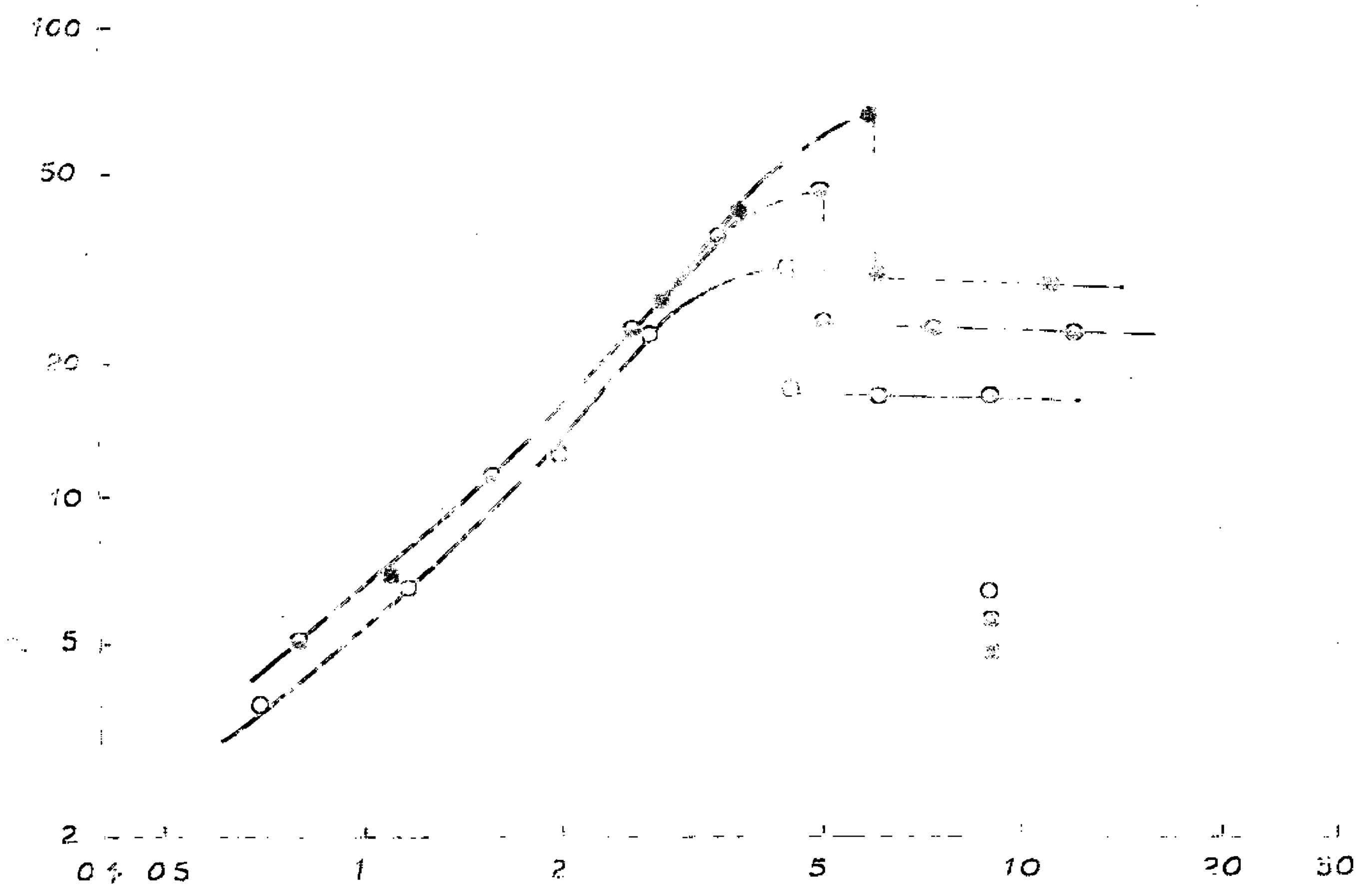
Material, Calcite  $\rho_s$ = 2.7 gm/cc

Mesh No., -10+12  $\phi_s$ =

| Sl. No. | Bed wt. kg | Liq. flow rate, lit/min. | Manometer legs readings, cms | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm |
|---|---|---|---|---|---|---|
| 1 | | 1.0 | 52.8 | 47.3 | 5.0 | 14.0 |
| 2 | | 1.7 | 56.2 | 44.5 | 11.7 | 13.3 |
| 3 | | 2.3 | 61.0 | 39.7 | 21.3 | 13.5 |
| 4 | 0.4 | 3.1 | 66.0 | 34.5 | 31.5$^{+}$ | 13.5 |
| 5 | | 5.0 | 71.6 | 29.0 | 42.0 | 13.5 |
| 6 | | 5.3 | 59.2 | 41.5 | 17.7$^{x}$ | 16.0 |
| 7 | | 7.2 | 58.9 | 41.7 | 17.2 | 16.8 |
| 8 | | 10.0 | 58.3 | 41.9 | 16.9 | 17.5 |
| 1. | | 0.7 | 52.7 | 48.1 | 4.6 | 19.0 |
| 2 | | 1.7 | 57.8 | 43.0 | 14.8 | 19.7 |
| 3 | | 3.0 | 68.5 | 32.5 | 36.0 | 19.5 |
| 4 | 0.7 | 3.5 | 72.5 | 28.4 | 44.1$^{+}$ | 19.5 |
| 5 | | 7.4 | 89.8 | | 70.8 | 19.5 |
| 6 | | 7.4 | 62.7 | 38.3 | 24.4$^{x}$ | 22.3 |
| 7 | | 10.0 | 62.4 | 38.6 | 23.8 | 22.0 |
| 8 | | 12.0 | 62.0 | 39.0 | 23.0 | 23.7 |
| 1. | | 0.9 | 53.3 | 47.7 | 5.6 | 24.0 |
| 2 | | 1.7 | 58.2 | 42.9 | 15.3 | 24.5 |
| 3 | | 3.2 | 70.3 | 30.9 | 39.4 | 24.4 |
| 4 | 1.0 | 3.9 | 78.8 | 22.2 | 56.6$^{+}$ | 24.3 |
| 5 | | 6.4 | 100.5 | −0.5 | 100.0 | 24.3 |
| 6 | | 6.4 | 65.9 | 34.9 | 31.0$^{x}$ | 26.6 |
| 7 | | 9.0 | 65.2 | 35.5 | 29.7 | 27.2 |
| 8 | | 12.0 | 64.4 | 36.3 | 28.1 | 2[illegible].0 |

$+$  Pressure peak value ( at limit of stability ) for fixed bed.

x  Pressure drop value at onset of fluidisation.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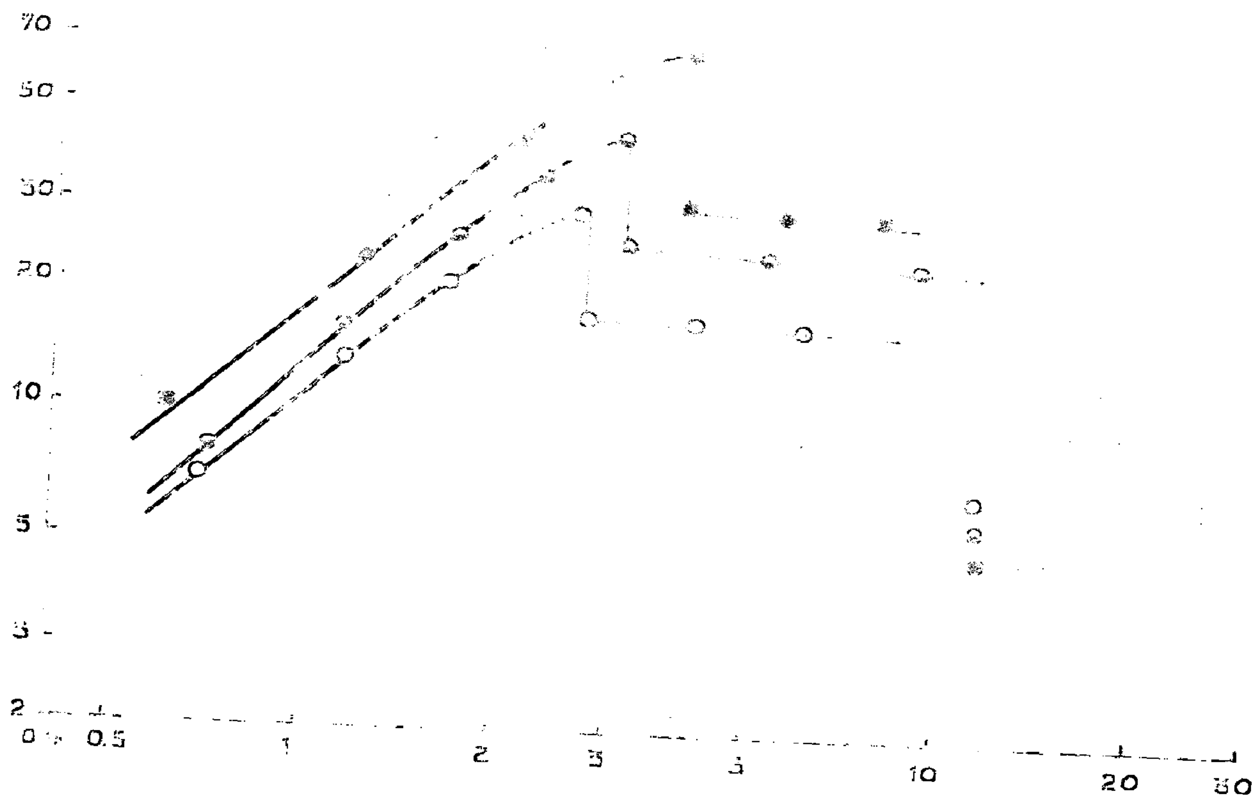
30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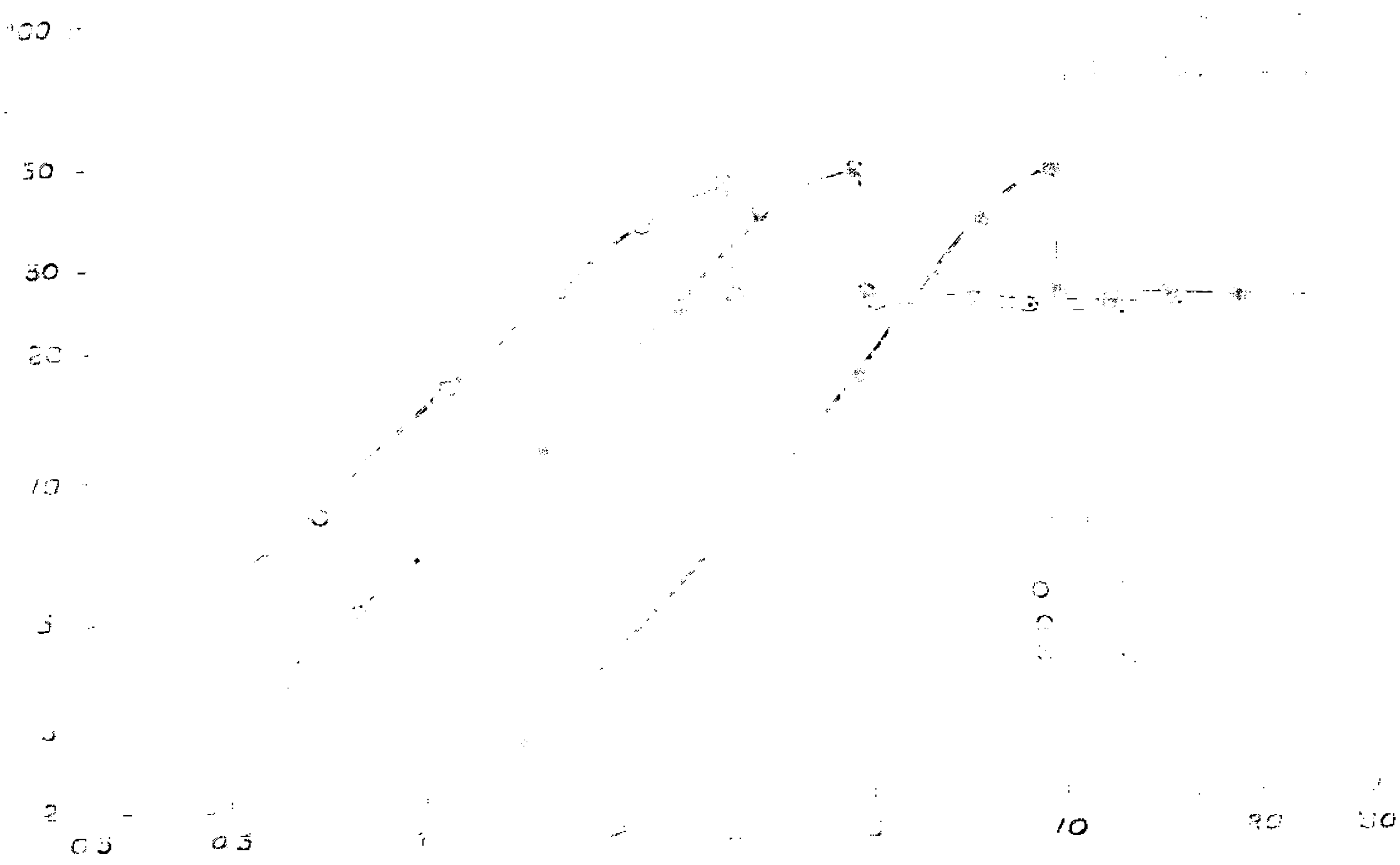
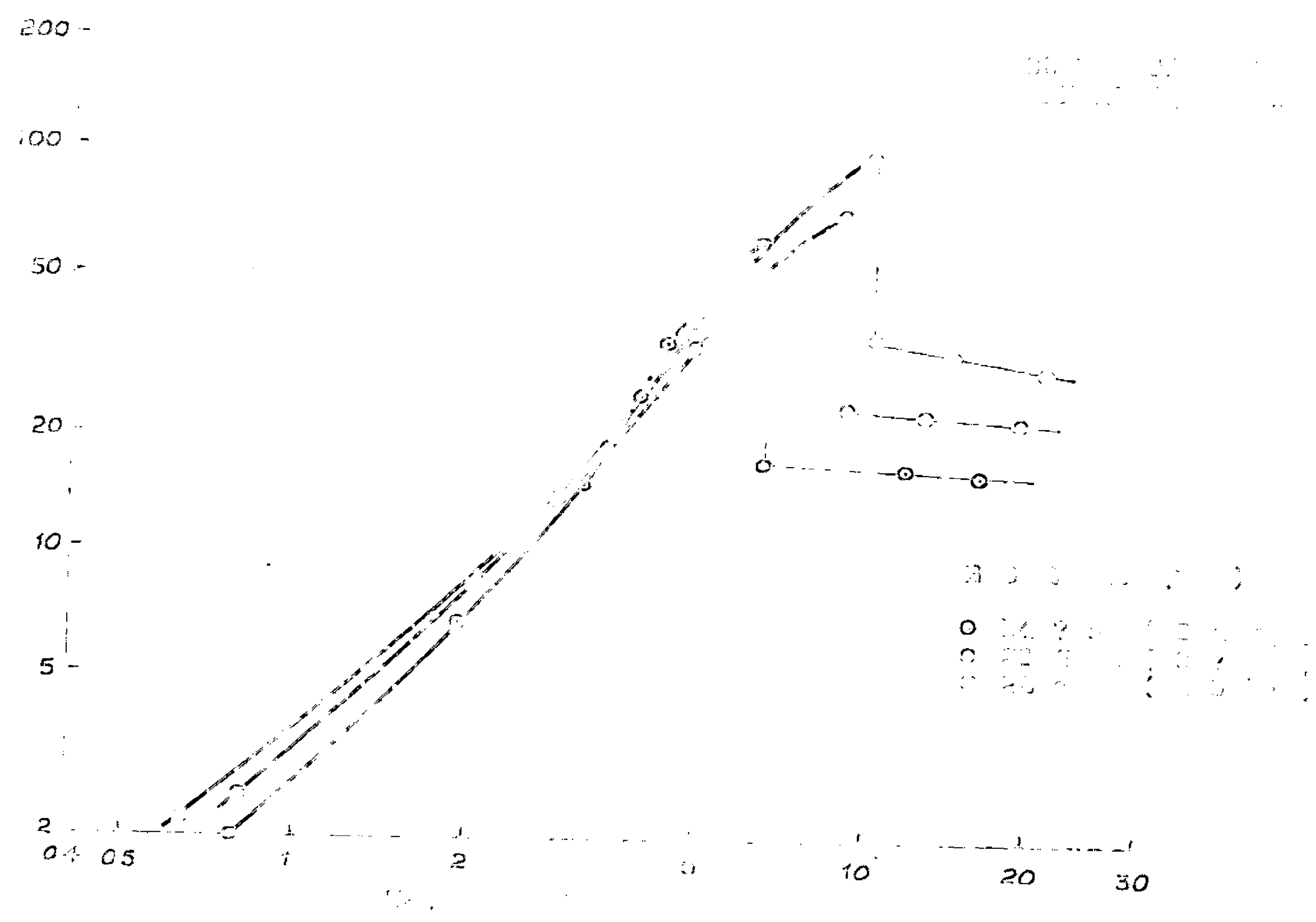
3
5
10
20
30





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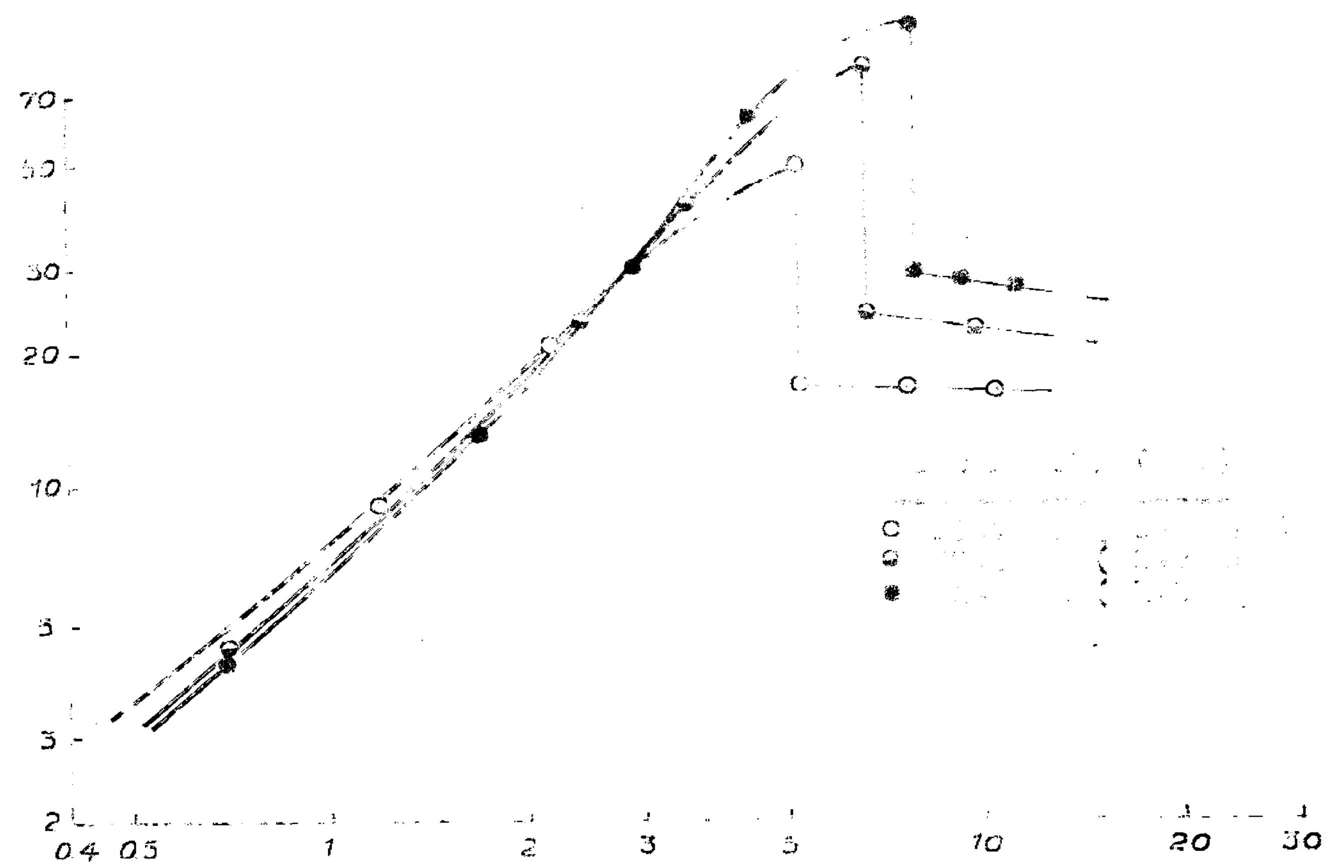
1
2
10
20
30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30
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20
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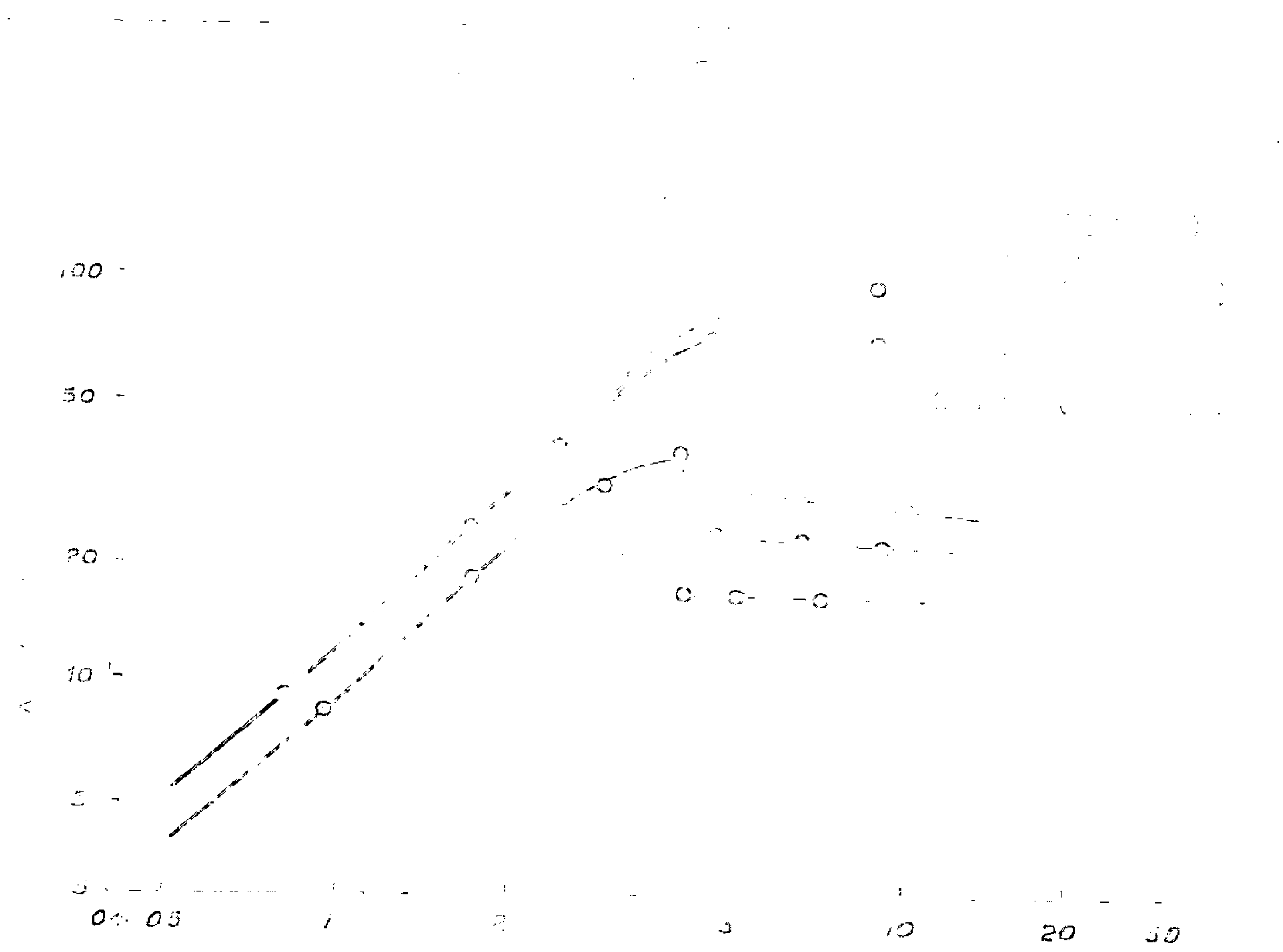

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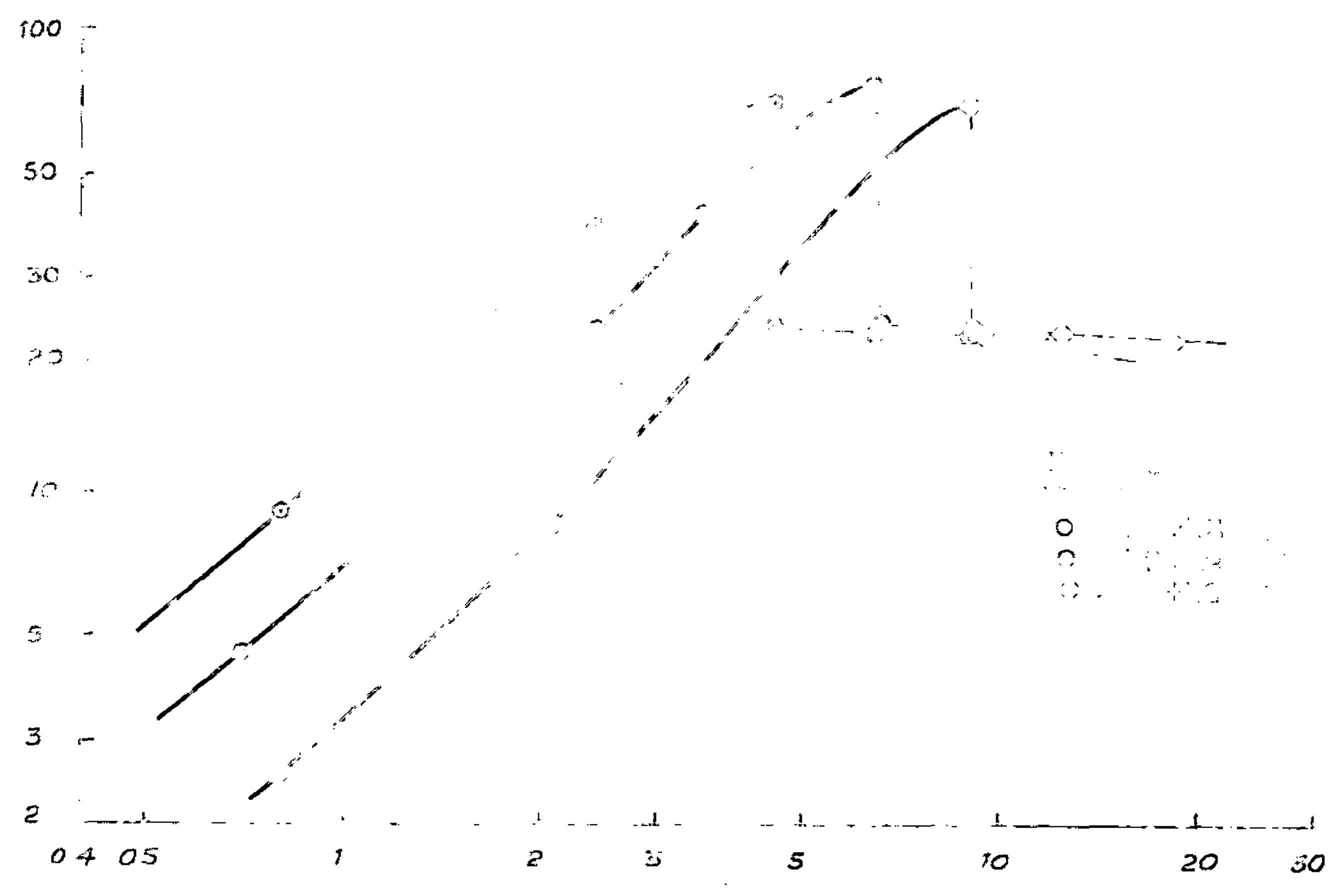
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0 5
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30

Table No. 4.9

Cone angle, 15°  $D_p$ = 0.335 cm

Material, Glass beads  $\rho_s$ = 2.5 gm/cc

Mesh No., 6  $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.3 | 50.3 | 48.1 | 2.2 | 11.1 |
| 2 | | 2.4 | 51.1 | 47.2 | 3.9 | 11.1 |
| 3 | | 3.9 | 53.7 | 44.7 | 9.0 | 11.1 |
| 4 | 0.4 | 4.4 | 55.7 | 42.7 | 13.0 | 11.0 |
| 5 | | 6.9 | 59.1 | 39.3 | 19.8 ⌖ | 11.0 |
| 6 | | 6.9 | 56.7 | 41.6 | 15.1 x | 11.6 |
| 7 | | 9.6 | 56.5 | 41.9 | 14.6 | 12.6 |
| 1 | | 1.1 | 50.2 | 48.0 | 2.2 | 16.1 |
| 2 | | 2.7 | 52.1 | 46.2 | 5.9 | 16.1 |
| 3 | | 3.8 | 54.8 | 43.5 | 11.3 | 16.1 |
| 4 | | 5.4 | 59.9 | 38.5 | 21.4 | 16.1 |
| 5 | 0.7 | 7.6 | 65.0 | 33.4 | 31.6 ⌖ | 16.0 |
| 6 | | 7.6 | 59.9 | 38.5 | 21.4 x | 16.6 |
| 7 | | 11.6 | 59.4 | 39.0 | 20.4 | 17.3 |
| 8 | | 13.5 | 59.1 | 39.2 | 19.9 | 18.3 |
| 1 | | 1.2 | 50.4 | 47.9 | 2.5 | 19.3 |
| 2 | | 2.7 | 52.3 | 45.9 | 6.4 | 19.0 |
| 3 | | 4.0 | 55.4 | 42.8 | 12.6 | 19.3 |
| 4 | | 6.1 | 62.0 | 36.3 | 25.7 | 19.0 |
| 5 | 1.0 | 10.1 | 71.6 | 26.7 | 44.9 ⌖ | 19.3 |
| 6 | | 10.0 | 62.0 | 36.2 | 25.8 x | 20.7 |
| 7 | | 14.0 | 61.5 | 36.7 | 24.8 | 21.5 |
| 8 | | 17.5 | 61.3 | 36.8 | 24.5 | 22.4 |

⌖ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.10

Cone angle, 16° $D_p$ = 0.1517 cm

Material, Glass Beads $\rho_s$ = 2.5 gm/cc

Mesh No., -10+12 $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq flow rate lit/min. | Manometer readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.7 | 51.3 | 47.3 | 4.0 | 10.9 |
| 2 | | 0.9 | 52.0 | 46.6 | 5.4 | 10.9 |
| 3 | | 1.3 | 53.5 | 45.1 | 8.4 | 10.9 |
| 4 | | 1.9 | 56.5 | 42.0 | 14.5 | 10.9 |
| 5 | 0.4 | 2.0 | 59.5 | 39.0 | 20.5 ✧ | 10.9 |
| 6 | | 2.8 | 57.4 | 41.1 | 16.3 x | 11.4 |
| 7 | | 3.6 | 57.2 | 41.3 | 15.9 | 11.6 |
| 8 | | 5.8 | 57.0 | 41.5 | 15.5 | 12.1 |
| 9 | | 7.6 | 56.9 | 41.6 | 15.3 | 12.6 |
| 1 | | 0.6 | 51.5 | 46.8 | 4.7 | 16.0 |
| 2 | | 0.9 | 52.6 | 45.8 | 6.8 | 15.0 |
| 3 | | 1.7 | 56.8 | 41.6 | 15.2 | 15.7 |
| 4 | | 2.2 | 60.8 | 37.8 | 23.0 | 15.6 |
| 5 | 0.7 | 3.5 | 67.4 | 33.5 | 36.2 ✧ | 15.6 |
| 6 | | 3.5 | 60.5 | 38.0 | 22.5 x | 16.1 |
| 7 | | 4.4 | 60.3 | 38.1 | 22.2 | 16.5 |
| 8 | | 6.8 | 59.8 | 38.6 | 21.2 | 17.0 |
| 9 | | 10.0 | 59.8 | 38.6 | 21.2 | 18.0 |
| 1 | | 0.5 | 51.4 | 47.1 | 4.3 | 19.4 |
| 2 | | 1.0 | 53.7 | 44.7 | 9.0 | 19.3 |
| 3 | | 2.0 | 60.0 | 38.5 | 21.5 | 19.1 |
| 4 | 1.0 | 4.2 | 72.0 | 26.5 | 45.5 ✧ | 19.0 |
| 5 | | 4.2 | 63.0 | 35.5 | 27.5 x | 19.8 |
| 6 | | 5.8 | 62.5 | 36.0 | 26.5 | 20.3 |
| 7 | | 11.4 | 62.1 | 36.3 | 25.8 | 21.0 |

✧ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidisation.

Table No. 4.11

Cone angle, 15° $D_p$ = 0.0927 cm

Material, Glass beads $\rho_s$ = 2.5 gm/cc

Mesh No., -16+18 $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.5 | 52.7 | 45.8 | 6.9 | 10.9 |
| 2 | | 0.7 | 53.9 | 44.6 | 9.3 | 10.9 |
| 3 | | 0.8 | 54.7 | 43.9 | 10.8 | 10.9 |
| 4 | | 0.9 | 55.2 | 43.4 | 11.8 | 10.9 |
| 5 | | 1.6 | 58.6 | 40.0 | 18.6 + | 10.9 |
| 6 | 0.4 | 1.6 | 57.4 | 41.2 | 16.2 x | 11.3 |
| 7 | | 1.9 | 57.3 | 41.2 | 16.1 | 11.5 |
| 8 | | 2.4 | 57.1 | 41.5 | 15.6 | 11.8 |
| 9 | | 3.2 | 57.0 | 41.7 | 15.3 | 12.0 |
| 10 | | 5.0 | 56.8 | 41.8 | 15.0 | 13.0 |
| 1 | | 0.5 | 52.2 | 46.2 | 6.0 | 15.9 |
| 2 | | 0.7 | 55.1 | 43.5 | 11.6 | 15.6 |
| 3 | | 1.2 | 60.1 | 38.5 | 21.6 | 15.5 |
| 4 | | 2.1 | [illegible] | [illegible] | 39.2 + | 15.4 |
| 5 | 0.7 | 2.1 | 60.2 | 38.4 | 21.8 x | 15.9 |
| 6 | | 2.5 | 60.1 | 38.4 | 21.7 | 16.2 |
| 7 | | 3.5 | 59.7 | 38.6 | 21.1 | 16.6 |
| 8 | | 6.2 | 59.7 | 38.8 | 20.9 | 18.6 |
| 1 | | 0.4 | 52.2 | 46.1 | 6.1 | 19.4 |
| 2 | | 0.6 | 54.7 | 43.7 | 11.0 | 18.9 |
| 3 | | 1.2 | 61.3 | 37.2 | 24.1 | 18.7 |
| 4 | | 1.4 | 63.2 | 35.4 | 27.8 | 18.6 |
| 5 | 1.0 | 2.6 | 69.8 | 28.5 | 41.3 + | 18.6 |
| 6 | | 2.6 | 62.7 | 35.8 | 26.9 x | 19.8 |
| 7 | | 4.5 | 62.2 | 36.4 | 25.8 | 20.1 |
| 8 | | 7.0 | 62.1 | 36.5 | 25.6 | 20.6 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.12

Cone angle, 15°  $D_p$ = 0.1865 cm

Material, Quartz  $\rho_s$ = 2.7 gm/cc

Mesh No., -8+10  $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.0 | 50.6 | 48.0 | 2.6 | 12.1 |
| 2 | | 2.5 | 54.1 | 44.5 | 9.6 | 11.9 |
| 3 | | 4.0 | 59.0 | 39.7 | 19.3+ | 11.8 |
| 4 | 0.4 | 6.8 | 64.2 | 34.5 | 29.7x | 11.8 |
| 5 | | 6.8 | 56.7 | 41.9 | 14.8 | 12.6 |
| 6 | | 9.6 | 56.3 | 42.3 | 14.0 | 13.6 |
| 7 | | 14.0 | 56.2 | 42.4 | 13.8 | 14.6 |
| 1 | | 0.8 | 50.3 | 48.3 | 2.0 | 17.2 |
| 2 | | 3.0 | 56.0 | 42.6 | 13.4 | 16.3 |
| 3 | | 4.5 | 62.1 | 36.5 | 25.6+ | 16.7 |
| 4 | 0.7 | 8.0 | 72.6 | 26.0 | 46.6x | 16.6 |
| 5 | | 8.0 | 59.3 | 39.1 | 20.2 | 18.5 |
| 6 | | 12.0 | 58.8 | 39.8 | 19.0 | 19.0 |
| 7 | | 22.0 | 58.6 | 39.9 | 18.7 | 20.0 |
| 1 | | 0.8 | 50.2 | 48.3 | 1.9 | 20.6 |
| 2 | | 1.5 | 51.4 | 47.2 | 4.2 | 20.4 |
| 3 | | 3.0 | 56.0 | 42.9 | 13.1 | 20.3 |
| 4 | | 4.0 | 61.8 | 37.0 | 24.8 | 20.2 |
| 5 | 1.0 | 5.6 | 70.5 | 28.4 | 42.1+ | 20.1 |
| 6 | | 9.0 | 81.2 | 17.7 | 63.5x | 20.0 |
| 7 | | 9.0 | 62.0 | 36.6 | 25.4 | 21.2 |
| 8 | | 11.0 | 61.0 | 37.5 | 23.6 | 22.0 |
| 9 | | 22.0 | 59.9 | 38.6 | 21.3 | 24.5 |

\+ Pressure at peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.13

Cone angle, 15°  $D_p$ = 0.1517 cm

Material, Quartz  $\rho_s$ = 2.7 gm/cc

Mesh No. -10+12  $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$.cm.$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.6 | 51.7 | 48.4 | 3.3 | 12.1 |
| 2 | | 1.1 | 53.9 | 46.3 | 7.6 | 11.9 |
| 3 | | 1.6 | 56.7 | 43.4 | 13.3+ | 11.8 |
| 4 | 0.4 | 3.5 | 65.6 | 34.5 | 31.1 | 11.8 |
| 5 | | 3.5 | 57.9 | 42.3 | 15.7x | 12.7 |
| 6 | | 7.0 | 57.3 | 42.8 | 14.5 | 13.6 |
| 7 | | 14.0 | 56.9 | 43.2 | 13.7 | 14.6 |
| 1 | | 0.5 | 51.2 | 49.0 | 2.2 | 17.3 |
| 2 | | 1.5 | 55.2 | 44.9 | 10.3 | 17.0 |
| 3 | | 2.6 | 61.8 | 38.2 | 23.6 | 16.9 |
| 4 | | 6.0 | 78.0 | 22.0 | 56.0+ | 16.8 |
| 5 | 0.7 | 5.6 | 60.0 | 40.0 | 20.0x | 17.9 |
| 6 | | 6.8 | 59.8 | 40.3 | 19.5 | 18.5 |
| 7 | | 9.6 | 59.2 | 40.8 | 18.4 | 19.3 |
| 8 | | 14.0 | 59.1 | 40.9 | 18.2 | 20.0 |
| 1 | | 0.5 | 51.1 | 48.8 | 2.3 | 21.0 |
| 2 | | 2.1 | 57.5 | 42.5 | 15.0 | 20.8 |
| 3 | | 3.5 | 66.2 | 33.8 | 32.4 | 20.7 |
| 4 | 1.0 | 7.4 | 86.3 | 13.7 | 72.6+ | 20.6 |
| 5 | | 7.4 | 61.7 | 38.1 | 23.6x | 21.5 |
| 6 | | 10.6 | 61.2 | 38.7 | 22.5 | 22.0 |
| 7 | | 19.0 | 60.8 | 39.2 | 21.6 | 23.5 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.14

Cone angle, 15° $D_p$ = 0.0927 cm

Material, Quartz $\rho_s$ = 2.7 gm/cc

Mesh No. -16+18 $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.7 | 53.2 | 46.6 | 6.6 | 12.9 |
| 2 | | 1.2 | 56.7 | 43.3 | 13.4 | 12.6 |
| 3 | | 2.4 | 64.0 | 36.0 | 28.0 $^{+}$ | 12.5 |
| 4 | 0.4 | 2.4 | 57.2 | 42.6 | 14.6 $^{x}$ | 13.3 |
| 5 | | 3.6 | 57.0 | 42.8 | 14.2 | 14.4 |
| 6 | | 10.0 | 56.4 | 43.3 | 13.1 | 15.1 |
| 1 | | 0.5 | 52.6 | 47.5 | 5.1 | 17.5 |
| 2 | | 1.5 | 59.6 | 40.5 | 19.1 | 17.3 |
| 3 | | 3.5 | 69.4 | 30.7 | 38.7 $^{+}$ | 17.2 |
| 4 | 0.7 | 3.5 | 59.9 | 40.1 | 19.8 $^{x}$ | 19.0 |
| 5 | | 5.2 | 59.8 | 40.3 | 19.5 | 19.5 |
| 6 | | 6.6 | 59.3 | 40.7 | 18.6 | 19.9 |
| 7 | | 9.2 | 59.3 | 40.8 | 18.5 | 20.3 |
| 1 | | 0.6 | 52.9 | 47.6 | 5.3 | 21.5 |
| 2 | | 1.5 | 58.4 | 42.0 | 16.4 | 21.3 |
| 3 | | 3.0 | 62.4 | 38.0 | 24.4 | 21.3 |
| 4 | 1.0 | 4.6 | 74.9 | 25.5 | 49.4 $^{+}$ | 21.2 |
| 5 | | 4.6 | 61.7 | 38.3 | 23.4 $^{x}$ | 22.7 |
| 6 | | 6.3 | 61.3 | 38.6 | 22.7 | 23.5 |
| 7 | | 8.5 | 60.8 | 39.3 | 21.6 | 24.3 |

+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.15

Cone angle, 15°      $D_p$ = 0.1865 cm

Material, Calcite      $\rho_s$ = 2.7 gm/cc

Mesh No. -8+10      $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings, cms. | | ΔP, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.8 | 50.0 | 48.2 | 1.8 | 12.1 |
| 2 | | 2.1 | 62.3 | 45.9 | 16.4 | 12.1 |
| 3 | | 3.4 | 57.0 | 41.5 | 15.5 | 12.0 |
| 4 | | 6.5 | 63.6 | 34.6 | 29.0 * | 11.9 |
| 5 | 0.4 | 6.5 | 56.8 | 41.6 | 15.2 x | 12.8 |
| 6 | | 8.0 | 56.6 | 41.7 | 14.9 | 13.5 |
| 7 | | 10.0 | 56.1 | 42.2 | 13.9 | 13.9 |
| 8 | | 16.0 | 56.0 | 42.3 | 13.7 | 14.4 |
| 1 | | 0.8 | 50.4 | 48.2 | 2.2 | 16.4 |
| 2 | | 1.9 | 52.8 | 46.0 | 6.8 | 16.3 |
| 3 | | 3.4 | 58.6 | 40.1 | 18.5 | 16.1 |
| 4 | | 4.7 | 64.8 | 33.8 | 31.0 | 16.1 |
| 5 | 0.7 | 7.0 | 73.6 | 25.0 | 48.6 * | 16.0 |
| 6 | | 7.0 | 60.2 | 38.3 | 21.9 x | 17.1 |
| 7 | | 9.0 | 59.7 | 38.8 | 20.9 | 17.0 |
| 8 | | 12.4 | 59.2 | 39.2 | 20.0 | 18.0 |
| 9 | | 16.5 | 58.6 | 40.0 | 18.6 | 18.1 |
| 1 | | 0.5 | 50.0 | 48.5 | 1.5 | 20.3 |
| 2 | | 2.5 | 55.7 | 42.7 | 13.0 | 20.0 |
| 3 | | 3.9 | 62.5 | 36.0 | 26.5 | 20.0 |
| 4 | | 5.1 | 69.4 | 29.2 | 40.2 | 19.9 |
| 5 | 1.0 | 10.0 | 87.6 | 11.0 | 76.6 * | 19.9 |
| 6 | | 10.0 | 61.9 | 36.5 | 25.4 x | 21.8 |
| 7 | | 12.0 | 61.4 | 37.0 | 24.4 | 22.0 |
| 8 | | 17.6 | 60.3 | 38.1 | 22.2 | 22.6 |
| 1 | | 1.3 | 52.1 | 48.0 | 4.1 | 25.1 |
| 2 | | 2.0 | 56.6 | 43.5 | 13.0 | 25.1 |
| 3 | | 5.0 | 66.4 | 33.7 | 32.6 | 25.1 |
| 4 | | 7.4 | 80.5 | 19.4 | 61.1 | 25.0 |
| 5 | 1.5 | 9.0 | 92.7 | 7.2 | 85.5 | 24.9 |
| 6 | | 13.6 | 105.0 | - 5.0 | 110.0 * | 24.9 |
| 7 | | 13.6 | 65.8 | 34.2 | 31.6 x | 27.1 |
| 8 | | 21.0 | 64.7 | 35.2 | 29.5 | 28.1 |
| 9 | | 30.0 | 64.0 | 36.0 | 28.0 | 30.1 |

* Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

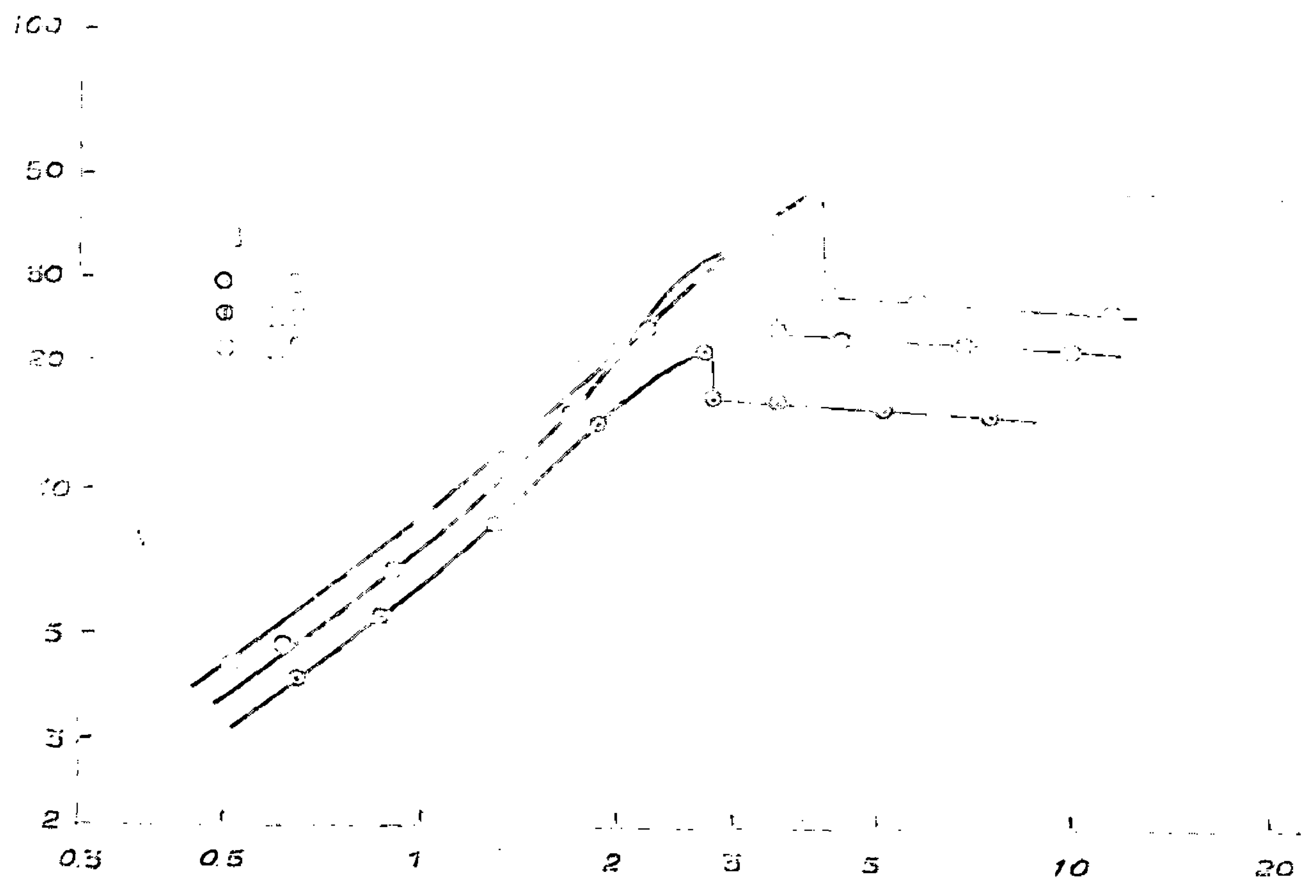
Table No. 4.16

Cone angle, 16° | $D_p$ = 0.1617 cm
Material, Calcite | $\rho_s$ = 2.7 gm/cc
Mesh No. -10+12 | $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | ΔP, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.7 | 50.7 | 48.0 | 2.7 | 11.6 |
| 2 | | 2.2 | 56.2 | 42.6 | 3.6 | 11.5 |
| 3 | | 2.8 | 59.8 | 39.0 | 20.8 | 11.5 |
| 4 | 0.4 | 4.4 | 63.8 | 34.8 | 29.0 + | 11.4 |
| 5 | | 4.4 | 57.2 | 41.5 | 15.7 x | 12.3 |
| 6 | | 6.4 | 5[illegible].7 | 41.9 | 14.0 | 12.5 |
| 7 | | 10.3 | 53.3 | 42.4 | 13.9 | 14.6 |
| 1 | | 0.7 | 50.9 | 47.8 | 3.1 | 10.8 |
| 2 | | 2.3 | 57.2 | 41.5 | 15.7 | 16.0 |
| 3 | | 3.8 | 63.6 | 35.1 | 28.5 | 16.4 |
| 4 | 0.7 | 6.6 | 74.3 | 24.6 | 49.6 + | 16.4 |
| 5 | | 6.6 | 59.8 | 38.8 | 21.0 x | 17.7 |
| 6 | | 9.0 | 59.5 | 39.2 | 20.3 | 18.5 |
| 7 | | 13.0 | 58.7 | 40.0 | 18.7 | 19.0 |
| 1 | | 0.6 | 58.0 | 55.1 | 2.9 | 20.1 |
| 2 | | 2.[illegible] | 64.8 | 48.2 | 16.6 | 20.0 |
| 3 | | 3.5 | 73.7 | 39.2 | 34.5 | 19.9 |
| 4 | | 7.5 | 83.9 | 10.1 | 74.8 + | 19.3 |
| 5 | 1.0 | 7.5 | 69.1 | 43.8 | 25.3 x | 21.7 |
| 6 | | 9.0 | 68.8 | 44.3 | 24.5 | 22.0 |
| 7 | | 12.4 | 68.3 | 44.8 | 23.5 | 22.5 |
| 8 | | 16.4 | 67.7 | 45.3 | 22.4 | 23.0 |
| 9 | | 20.0 | 67.0 | 46.0 | 21.0 | 23.5 |
| 1 | | 0.7 | 52.3 | 48.8 | 4.0 | 21.5 |
| 2 | | 1.1 | 54.0 | 46.5 | 7.5 | 21.5 |
| 3 | | 1.6 | 56.0 | 44.5 | 11.5 | 21.4 |
| 4 | | 2.4 | 60.5 | 39.8 | 20.7 | 21.3 |
| 5 | 1.5 | 3.5 | 68.3 | 31.9 | 36.4 | 21.3 |
| 6 | | 9.0 | 100.0 | 0.0 | 100.0 + | 21.3 |
| 7 | | 9.0 | 65.5 | 34.8 | 30.7 x | 27.0 |
| 8 | | 11.2 | 64.7 | 35.7 | 29.0 | 27.5 |
| 9 | | 20.0 | 63.7 | 36.5 | 27.2 | 28.0 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.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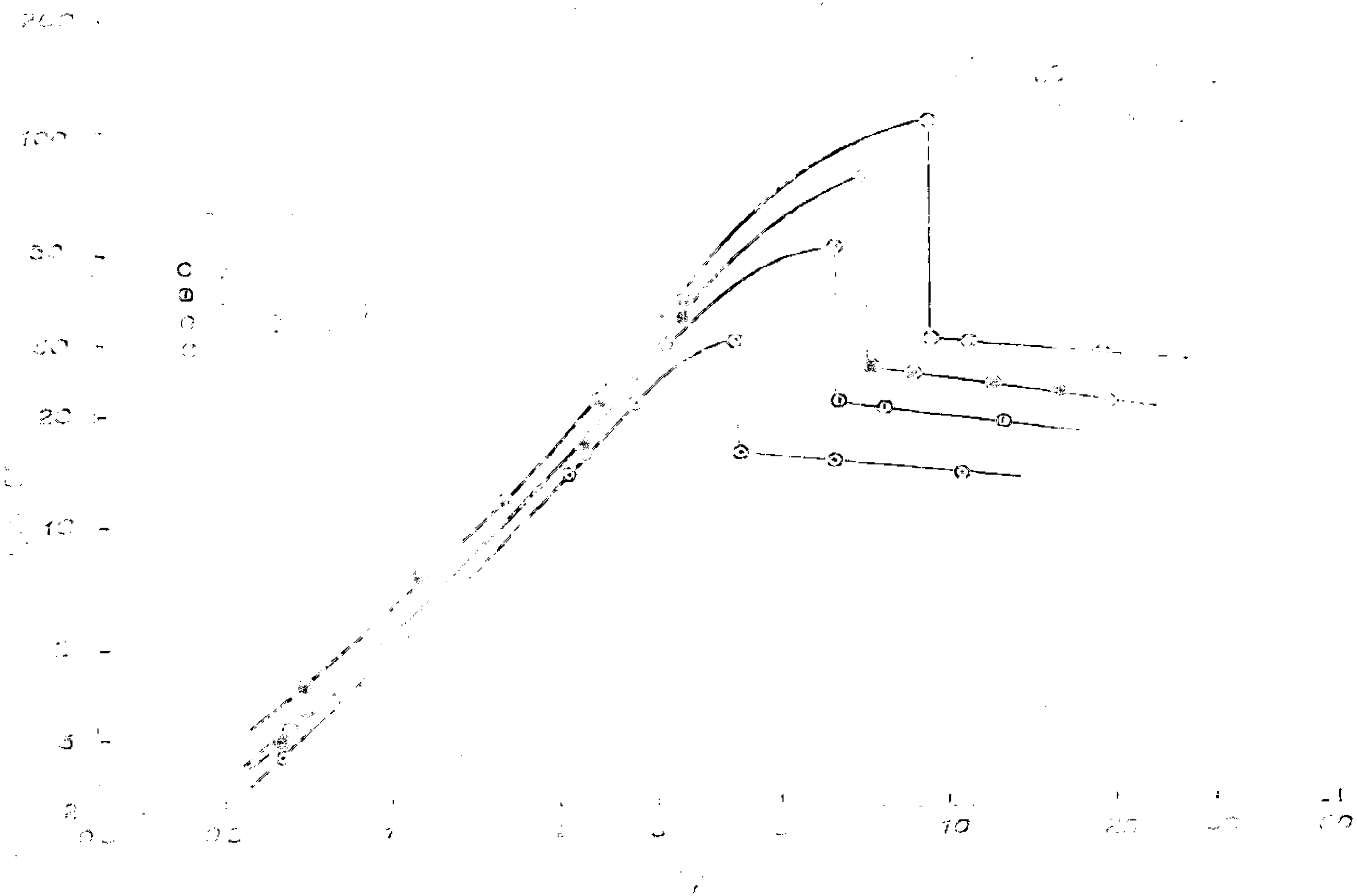
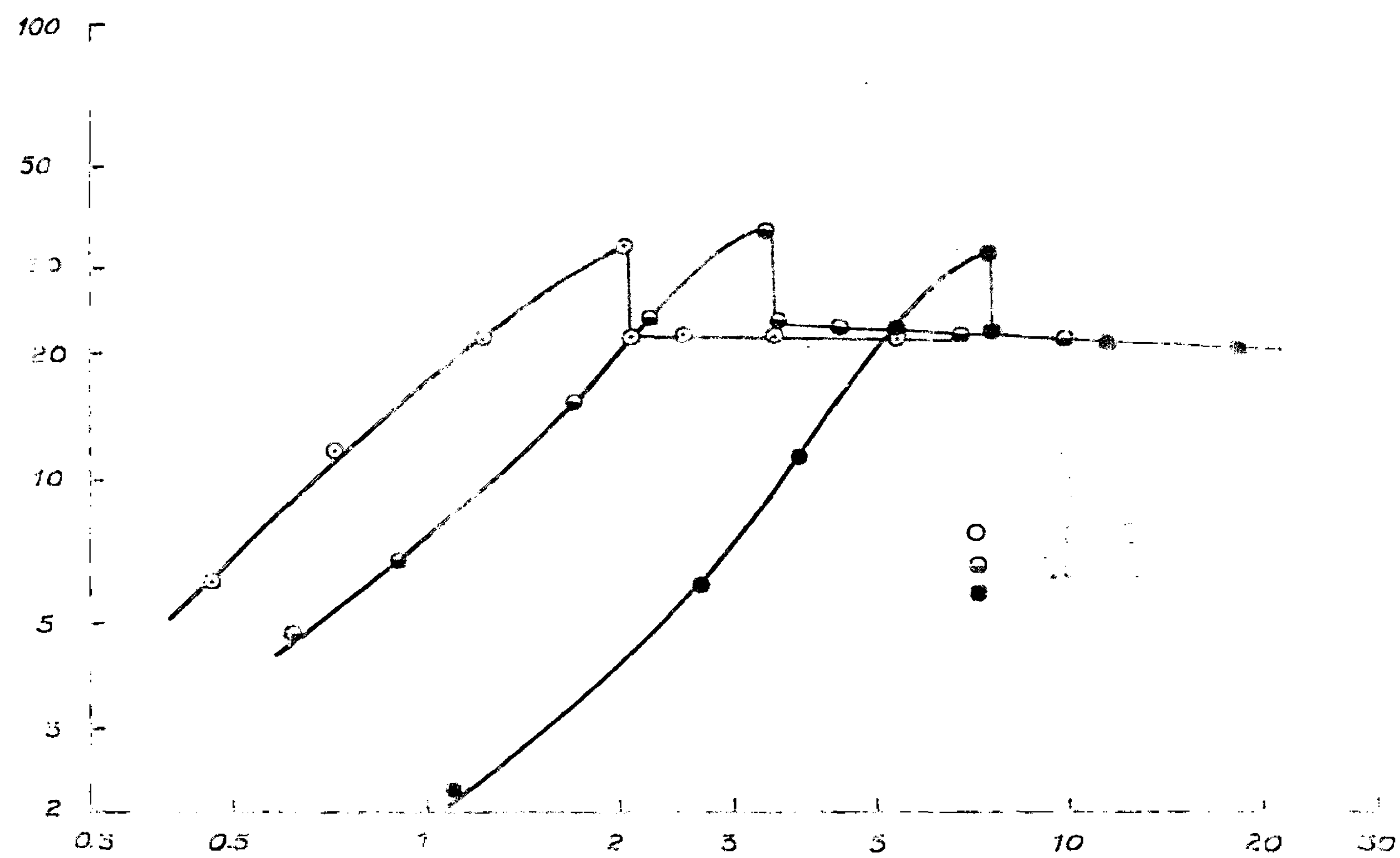
20



20
10
5
10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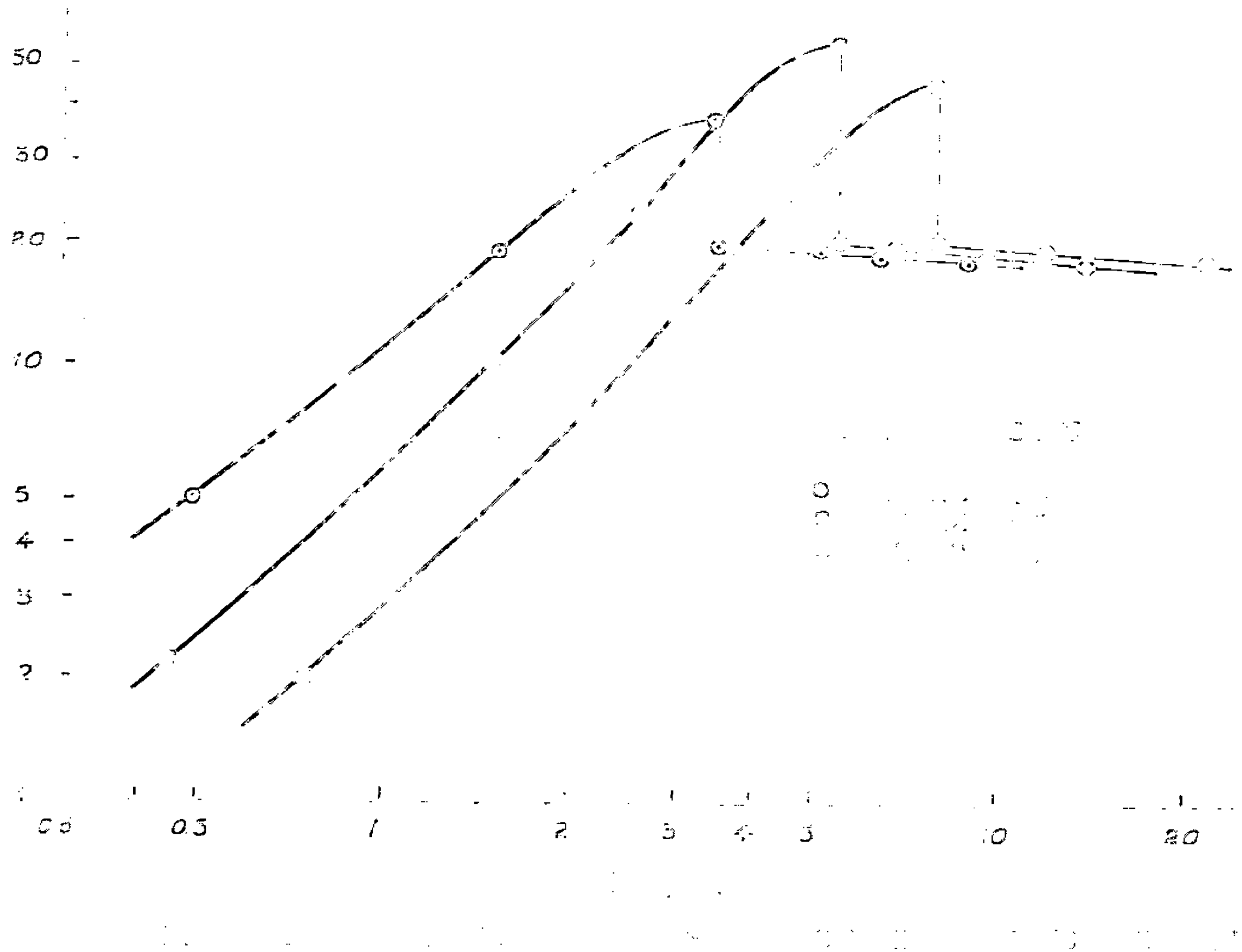


50
30
20
10
5
4
3
2
0.5
1
2
3
4
5
10
20

Table No. 4.17

Cone angle, 20°  $D_p$ = 0.336 cm

Material, Glass beads  $\rho_s$ = 2.5 gm/cc

Mesh No., 6  $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | ΔP, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.3 | 46.0 | 44.1 | 1.9 | 10.0 |
| 2 | | 2.2 | 47.1 | 43.0 | 4.1 | 10.0 |
| 3 | | 3.5 | 49.7 | 40.4 | 9.3 | 10.0 |
| 4 | 0.4 | 6.0 | 56.9 | 33.2 | 23.7* | 10.0 |
| 5 | | 6.0 | 52.0 | 38.1 | 13.9x | 10.5 |
| 6 | | 11.6 | 51.7 | 38.4 | 13.3 | 11.7 |
| 7 | | 19.2 | 51.0 | 39.0 | 12.0 | 13.3 |
| 1 | | 1.4 | 46.0 | 44.1 | 1.9 | 14.6 |
| 2 | | 3.0 | 47.9 | 42.3 | 5.6 | 14.6 |
| 3 | | 4.2 | 50.1 | 40.0 | 10.1 | 14.6 |
| 4 | 0.7 | 7.2 | 58.0 | 32.0 | 26.0* | 14.6 |
| 5 | | 7.2 | 54.7 | 35.5 | 19.2x | 14.8 |
| 6 | | 11.2 | 54.4 | 35.7 | 18.7 | 15.6 |
| 7 | | 19.0 | 53.6 | 36.5 | 17.1 | 16.3 |
| ~~1~~ | | ~~2.0~~ | ~~47.8~~ | ~~40.6~~ | ~~13.8~~ | |
| 1 | | 1.6 | 46.6 | 43.6 | 3.0 | 17.4 |
| 2 | | 3.0 | 48.5 | 41.7 | 6.8 | 17.4 |
| 3 | | 4.8 | 52.9 | 37.3 | 15.6 | 17.4 |
| 4 | 1.0 | 5.6 | 56.2 | 36.0 | 20.2 | 17.4 |
| 5 | | 8.0 | 60.7 | 29.5 | 31.2* | 17.4 |
| 6 | | 8.0 | 56.4 | 33.8 | 22.6x | 17.8 |
| 7 | | 14.8 | 56.0 | 34.2 | 21.8 | 18.7 |
| 8 | | 22.4 | 56.1 | 36.1 | 20.0 | 19.7 |

* Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.18

Cone angle, 20° $\quad D_p$ = 0.1517 cm

Material, Glass beads $\quad \rho_s$ = 2.5 gm/cc

Mesh No., -10+12 $\quad \phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.5 | 45.8 | 44.1 | 1.7 | 10.3 |
| 2 | | 1.0 | 47.4 | 42.3 | 5.1 | 10.3 |
| 3 | | 1.7 | 50.9 | 38.0 | 12.9 | 10.3 |
| 4 | 0.4 | 2.3 | 53.9 | 35.0 | 18.9✧ | 10.3 |
| 5 | | 2.8 | 52.3 | 37.5 | 14.8x | 10.5 |
| 6 | | 4.2 | 52.0 | 37.7 | 14.3 | 10.9 |
| 7 | | 6.0 | 51.8 | 38.0 | 13.8 | 11.3 |
| 8 | | 10.0 | 51.7 | 38.1 | 13.6 | 12.8 |
| 1 | | 0.5 | 45.8 | 43.8 | 2.0 | 14.5 |
| 2 | | 0.9 | 47.4 | 42.3 | 5.1 | 14.5 |
| 3 | | 1.4 | 50.8 | 38.9 | 11.9 | 14.5 |
| 4 | 0.7 | 1.9 | 54.1 | 35.6 | 18.5 | 14.5 |
| 5 | | 3.4 | 59.7 | 30.0 | 29.7✧ | 14.5 |
| 6 | | 3.4 | 55.0 | 34.8 | 20.2x | 14.8 |
| 7 | | 4.0 | 54.6 | 35.1 | 19.5 | 16.0 |
| 8 | | 6.4 | 54.5 | 35.3 | 19.2 | 16.3 |
| 9 | | 11.2 | 54.3 | 35.5 | 18.8 | 16.3 |
| 1 | | 0.7 | 47.0 | 42.8 | 4.2 | 17.5 |
| 2 | | 1.3 | 50.2 | 39.5 | 10.7 | 17.5 |
| 3 | | 1.7 | 53.0 | 36.7 | 16.3 | 17.5 |
| 4 | 1.0 | 2.0 | 55.5 | 34.2 | 21.3 | 17.5 |
| 5 | | 4.0 | 64.7 | 25.0 | 39.7✧ | 17.5 |
| 6 | | 4.0 | 56.7 | 33.1 | 23.6x | 17.7 |
| 7 | | 8.0 | 56.3 | 33.4 | 22.9 | 18.2 |
| 8 | | 12.0 | 56.0 | 33.7 | 22.3 | 18.7 |

✧ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.19

Cone angle, 20°  $D_p$ = 0.0827 cm

Material, Glass beads  $\rho_s$ = 2.5 gm/cc

Mesh No., -16+18  $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm.$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.3 | 46.5 | 43.5 | 3.0 | 10.0 |
| 2 | | 0.5 | 47.6 | 42.3 | 5.3 | 10.0 |
| 3 | | 0.9 | 50.5 | 39.4 | 11.1 | 10.0 |
| 4 | 0.4 | 1.2 | 52.4 | 37.5 | 14.9 ✧ | 10.0 |
| 5 | | 1.6 | 54.4 | 35.5 | 18.9 | 10.0 |
| 6 | | 1.8 | 52.6 | 37.3 | 15.3 x | 10.2 |
| 7 | | 2.4 | 52.4 | 37.5 | 14.9 | 10.3 |
| 8 | | 4.0 | 51.9 | 37.9 | 14.0 | 11.1 |
| 1 | | 0.3 | 46.9 | 42.9 | 4.0 | 14.0 |
| 2 | | 0.6 | 49.0 | 40.7 | 8.3 | 14.0 |
| 3 | | 0.8 | 51.8 | 38.0 | 13.8 | 14.0 |
| 4 | 0.7 | 1.3 | 54.6 | 35.3 | 19.3 ✧ | 14.0 |
| 5 | | 2.2 | 57.4 | 32.5 | 24.9 | 14.0 |
| 6 | | 2.2 | 55.3 | 34.6 | 20.7 x | 14.3 |
| 7 | | 3.4 | 55.0 | 34.9 | 20.1 | 14.9 |
| 8 | | 6.4 | 54.5 | 35.5 | 19.0 | 16.8 |
| 1 | | 0.3 | 47.4 | 42.4 | 5.0 | 16.9 |
| 2 | | 0.6 | 50.2 | 39.6 | 10.6 | 16.9 |
| 3 | | 1.0 | 53.8 | 36.1 | 17.7 | 16.9 |
| 4 | 1.0 | 1.6 | 57.4 | 32.4 | 25.0 ✧ | 16.9 |
| 5 | | 2.7 | 61.4 | 28.5 | 32.9 | 16.9 |
| 6 | | 2.7 | 57.4 | 32.5 | 24.9 x | 17.2 |
| 7 | | 4.4 | 56.9 | 33.0 | 23.9 | 17.7 |
| 8 | | 7.6 | 56.2 | 33.6 | 22.6 | 18.2 |

✧ Pressure peak ( at limit stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.20

Cone angle, 20° $\qquad D_p$ = 0.1865 cm

Material, Quartz $\qquad \rho_s$ = 2.7 gm/cc

Mesh No., -8+10 $\qquad \phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | ΔP, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.8 | 46.5 | 44.2 | 2.1 | 10.6 |
| 2 | | 2.0 | 49.5 | 41.1 | 8.5 | 10.6 |
| 3 | | 2.4 | 51.0 | 39.5 | 11.5◊ | 10.4 |
| 4 | 0.4 | 4.0 | 55.0 | 35.5 | 19.5x | 10.4 |
| 5 | | 4.0 | 52.5 | 38.0 | 14.5 | 10.7 |
| 6 | | 6.4 | 51.9 | 38.6 | 13.3 | 11.0 |
| 7 | | 9.6 | 51.0 | 39.5 | 11.5 | 11.8 |
| 1 | | 1.0 | 47.3 | 44.0 | 3.3 | 14.5 |
| 2 | | 1.7 | 49.2 | 41.7 | 7.5 | 14.4 |
| 3 | | 2.4 | 52.3 | 38.5 | 13.8 | 14.3 |
| 4 | 0.7 | 2.7 | 54.0 | 37.0 | 17.0◊ | 14.3 |
| 5 | | 5.0 | 60.5 | 30.5 | 30.0x | 14.2 |
| 6 | | 5.0 | 55.7 | 36.2 | 19.5 | 14.8 |
| 7 | | 6.5 | 54.8 | 36.0 | 18.8 | 15.3 |
| 8 | | 10.0 | 54.0 | 37.0 | 17.0 | 15.8 |
| 1 | | 1.0 | 46.8 | 43.6 | 3.2 | 18.7 |
| 2 | | 1.9 | 50.0 | 40.5 | 9.5 | 18.6 |
| 3 | | 3.0 | 56.0 | 34.5 | 21.5◊ | 18.5 |
| 4 | 1.0 | 6.0 | 65.5 | 25.0 | 40.5x | 18.2 |
| 5 | | 6.0 | 55.7 | 34.7 | 21.0 | 18.7 |
| 6 | | 10.0 | 55.0 | 35.3 | 19.7 | 19.7 |

◊ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.21

Cone angle, 20°  $D_p$ = 0.1517 cm

Material, Quartz  $\rho_s$ = 2.7 gm/cc

Mesh No. -10+12  $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm.-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.8 | 47.1 | 43.3 | 3.8 | 10.8 |
| 2 | | 1.7 | 49.5 | 41.0 | 8.5 | 10.8 |
| 3 | | 2.4 | 52.5 | 38.0 | 14.5 | 10.7 |
| 4 | 0.4 | 3.8 | 55.5 | 35.0 | 20.5 + | 10.6 |
| 5 | | 3.8 | 52.0 | 38.5 | 13.5 x | 11.3 |
| 6 | | 5.0 | 51.7 | 39.0 | 12.7 | 11.8 |
| 7 | | 7.2 | 50.7 | 40.0 | 10.7 | 12.3 |
| 1 | | 0.8 | 47.4 | 42.9 | 4.5 | 15.7 |
| 2 | | 1.4 | 49.5 | 40.8 | 8.7 | 15.6 |
| 3 | | 2.0 | 52.5 | 37.7 | 14.8 | 15.5 |
| 4 | 0.7 | 2.3 | 54.5 | 35.8 | 18.7 | 15.5 |
| 5 | | 4.4 | 60.3 | 30.0 | 30.3 + | 15.4 |
| 6 | | 4.4 | 54.5 | 36.0 | 18.5 x | 16.2 |
| 7 | | 6.6 | 53.5 | 36.8 | 16.7 | 16.7 |
| 8 | | 7.6 | 53.3 | 37.0 | 16.3 | 17.2 |
| 1 | | 0.5 | 46.5 | 44.0 | 2.5 | 18.7 |
| 2 | | 1.6 | 50.0 | 40.0 | 10.0 | 18.6 |
| 3 | | 2.6 | 55.2 | 35.0 | 20.2 | 18.6 |
| 4 | 1.0 | 5.0 | 62.7 | 27.5 | 35.2 + | 18.4 |
| 5 | | 5.0 | 56.3 | 34.0 | 22.3 x | 19.2 |
| 6 | | 6.0 | 56.0 | 34.3 | 21.7 | 19.7 |
| 7 | | 8.0 | 55.0 | 35.5 | 19.5 | 20.7 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.22

Cone angle, 29° $D_p$ = 0.0927 cm

Material, Quartz $\rho_s$ = 2.7 gm/cc

Mesh No., -16+18 $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.6 | 47.2 | 43.1 | 4.1 | 11.6 |
| 2 | | 1.2 | 50.0 | 40.5 | 9.5 | 11.5 |
| 3 | | 1.6 | 52.0 | 38.5 | 13.5+ | 11.5 |
| 4 | 0.4 | 2.4 | 55.3 | 35.2 | 20.1x | 11.4 |
| 5 | | 2.4 | 52.0 | 38.5 | 13.5 | 11.8 |
| 6 | | 3.2 | 51.5 | 39.0 | 12.5 | 12.3 |
| 7 | | 5.2 | 51.2 | 39.2 | 12.0 | 13.3 |
| 1 | | 0.4 | 46.6 | 43.8 | 2.8 | 16.1 |
| 2 | | 1.1 | 51.0 | 39.5 | 11.5 | 16.0 |
| 3 | | 1.6 | 54.5 | 36.0 | 18.5+ | 15.9 |
| 4 | 0.7 | 2.8 | 59.0 | 31.5 | 27.5x | 15.7 |
| 5 | | 2.8 | 54.5 | 36.0 | 18.5 | 16.2 |
| 6 | | 3.6 | 54.0 | 36.5 | 17.5 | 16.7 |
| 7 | | 5.2 | 53.7 | 37.0 | 16.7 | 17.3 |
| 8 | | 8.0 | 53.0 | 37.5 | 15.5 | 18.2 |
| 1 | | 0.6 | 48.0 | 42.4 | 5.6 | 19.4 |
| 2 | | 1.1 | 50.8 | 39.7 | 11.1 | 19.3 |
| 3 | | 1.7 | 55.0 | 35.5 | 19.5 | 19.2 |
| 4 | | 2.2 | 58.0 | 32.5 | 25.5+ | 19.2 |
| 5 | 1.0 | 3.8 | 62.5 | 28.0 | 34.5x | 19.1 |
| 6 | | 3.8 | 56.1 | 34.2 | 21.9 | 19.5 |
| 7 | | 5.0 | 55.5 | 35.0 | 20.5 | 20.1 |
| 8 | | 7.2 | 54.9 | 35.6 | 19.3 | 21.0 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.23

Cone angle, 20°   $D_p$ = 0.1865 cm

Material, Calcite   $\rho_s$ = 2.7 gm/cc

Mesh No., -8+10   $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.8 | 45.9 | 44.5 | 1.4 | 10.6 |
| 2 | | 1.3 | 46.6 | 43.9 | 2.7 | 10.5 |
| 3 | | 2.7 | 49.1 | 41.4 | 7.7 | 10.5 |
| 4 | | 6.0 | 58.0 | 32.5 | 25.5✧ | 10.4 |
| 5 | 0.4 | 6.0 | 52.4 | 38.0 | 14.4x | 11.0 |
| 6 | | 7.2 | 52.2 | 38.1 | 14.1 | 11.6 |
| 6 | | 11.2 | 51.5 | 38.8 | 12.7 | 12.6 |
| 8 | | 16.0 | 50.8 | 39.5 | 11.3 | 13.3 |
| 1 | | 1.1 | 46.2 | 44.2 | 2.0 | 15.1 |
| 2 | | 2.3 | 48.2 | 42.2 | 6.0 | 15.1 |
| 3 | | 3.4 | 51.4 | 39.0 | 11.4 | 15.0 |
| 4 | | 5.0 | 56.8 | 33.5 | 23.3 | 14.9 |
| 5 | 0.7 | 7.6 | 64.8 | 25.5 | 30.3✧ | 14.9 |
| 6 | | 7.6 | 54.0 | 36.3 | 17.7x | 15.6 |
| 7 | | 9.6 | 53.9 | 36.3 | 17.6 | 15.8 |
| 8 | | 13.6 | 53.2 | 37.2 | 16.0 | 16.8 |
| 9 | | 16.0 | 52.5 | 37.7 | 14.8 | 17.3 |
| 1 | | 1.5 | 46.9 | 43.5 | 3.4 | 18.4 |
| 2 | | 3.0 | 50.4 | 40.0 | 10.4 | 18.3 |
| 3 | | 3.8 | 53.7 | 36.5 | 17.2 | 18.3 |
| 4 | | 4.9 | 59.0 | 31.5 | 27.5 | 18.2 |
| 5 | 1.0 | 6.0 | 63.5 | 26.5 | 37.0 | 18.1 |
| 6 | | 8.6 | 74.0 | 16.0 | 58.0✧ | 18.0 |
| 7 | | 8.6 | 55.6 | 34.9 | 20.7x | 18.4 |
| 8 | | 15.2 | 54.8 | 35.6 | 19.2 | 20.2 |

✧ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.24

Cone angle, 20°  $D_p$ = 0.1517 cm

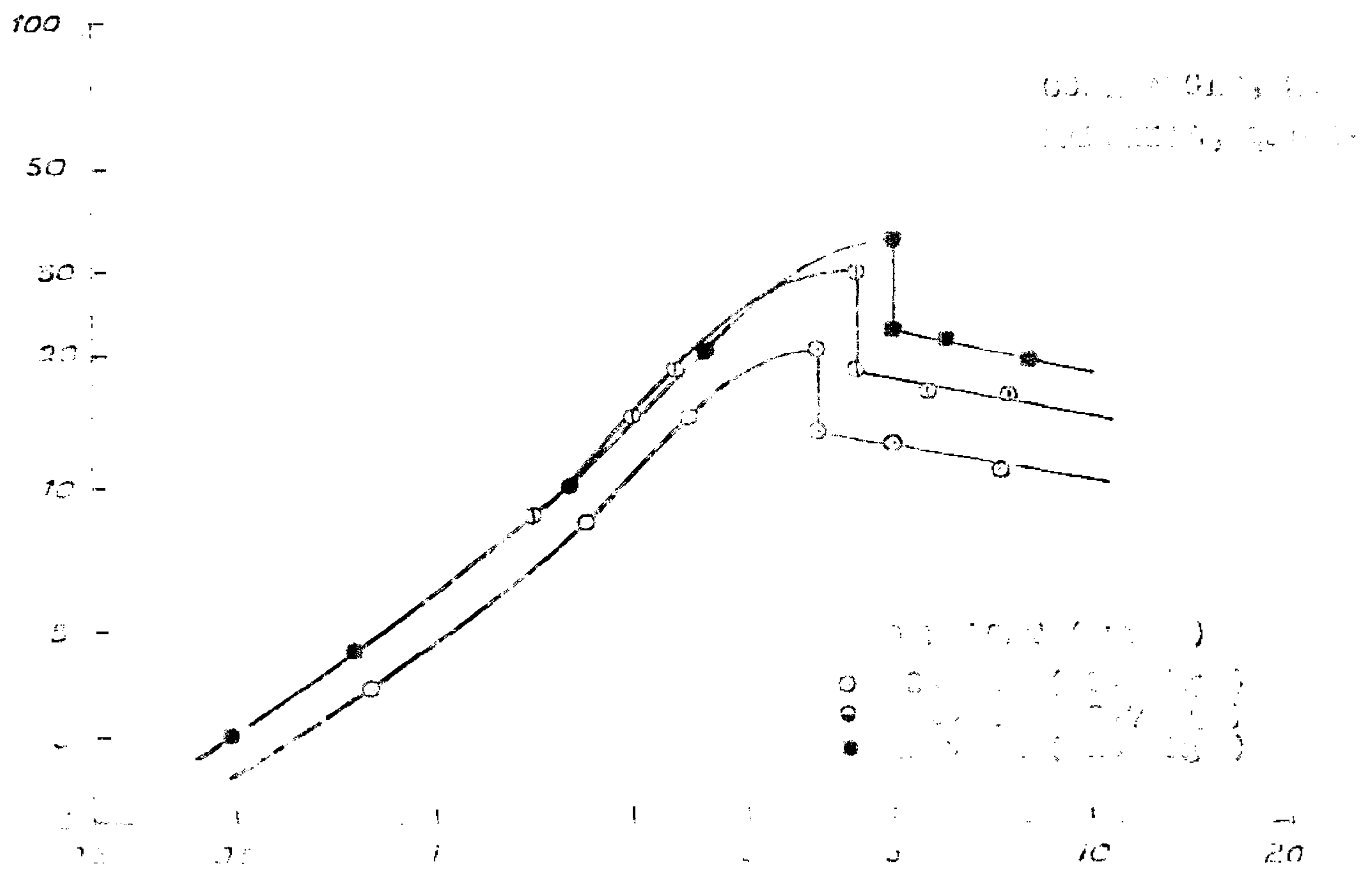
Material, Calcite  $\rho_s$ = 2.7 gm/cc

Mesh No., -10+12  $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.6 | 46.2 | 44.0 | 2.2 | 10.6 |
| 2 | | 1.5 | 47.9 | 42.2 | 5.7 | 10.5 |
| 3 | | 2.0 | 49.6 | 40.5 | 9.1 | 10.5 |
| 4 | | 2.6 | 51.9 | 38.1 | 13.8+ | 10.4 |
| 5 | 0.4 | 3.6 | 56.0 | 34.0 | 22.0x | 10.3 |
| 6 | | 3.6 | 52.0 | 38.0 | 14.0 | 11.0 |
| 7 | | 4.0 | 51.7 | 38.3 | 13.4 | 11.5 |
| 8 | | 5.8 | 51.0 | 39.0 | 12.0 | 11.0 |
| 1 | | 0.6 | 46.3 | 43.8 | 2.5 | 15.1 |
| 2 | | 1.1 | 47.5 | 42.5 | 5.0 | 15.0 |
| 3 | | 1.9 | 49.7 | 40.2 | 9.5 | 15.0 |
| 4 | 0.7 | 2.3 | 51.7 | 38.2 | 13.5+ | 15.0 |
| 5 | | 4.0 | 60.0 | 30.0 | 30.0x | 15.0 |
| 6 | | 4.8 | 53.0 | 37.0 | 16.0 | 15.5 |
| 7 | | 10.0 | 52.0 | 38.0 | 14.0 | 16.3 |
| 8 | | | | | | |
| 1 | | 0.6 | 46.3 | 43.7 | 2.6 | 18.5 |
| 2 | | 1.1 | 47.8 | 42.2 | 5.6 | 18.4 |
| 3 | | 1.4 | 48.7 | 41.4 | 7.3 | 18.3 |
| 4 | | 1.7 | 50.0 | 40.0 | 10.0 | 18.3 |
| 5 | 1.0 | 2.7 | 55.0 | 35.0 | 20.0+ | 18.2 |
| 6 | | 6.0 | 63.0 | 27.0 | 36.0x | 18.2 |
| 7 | | 6.0 | 51.2 | 39.0 | 18.0 | 18.7 |
| 8 | | 12.0 | 50.7 | 39.5 | 15.5 | 20.7 |

+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.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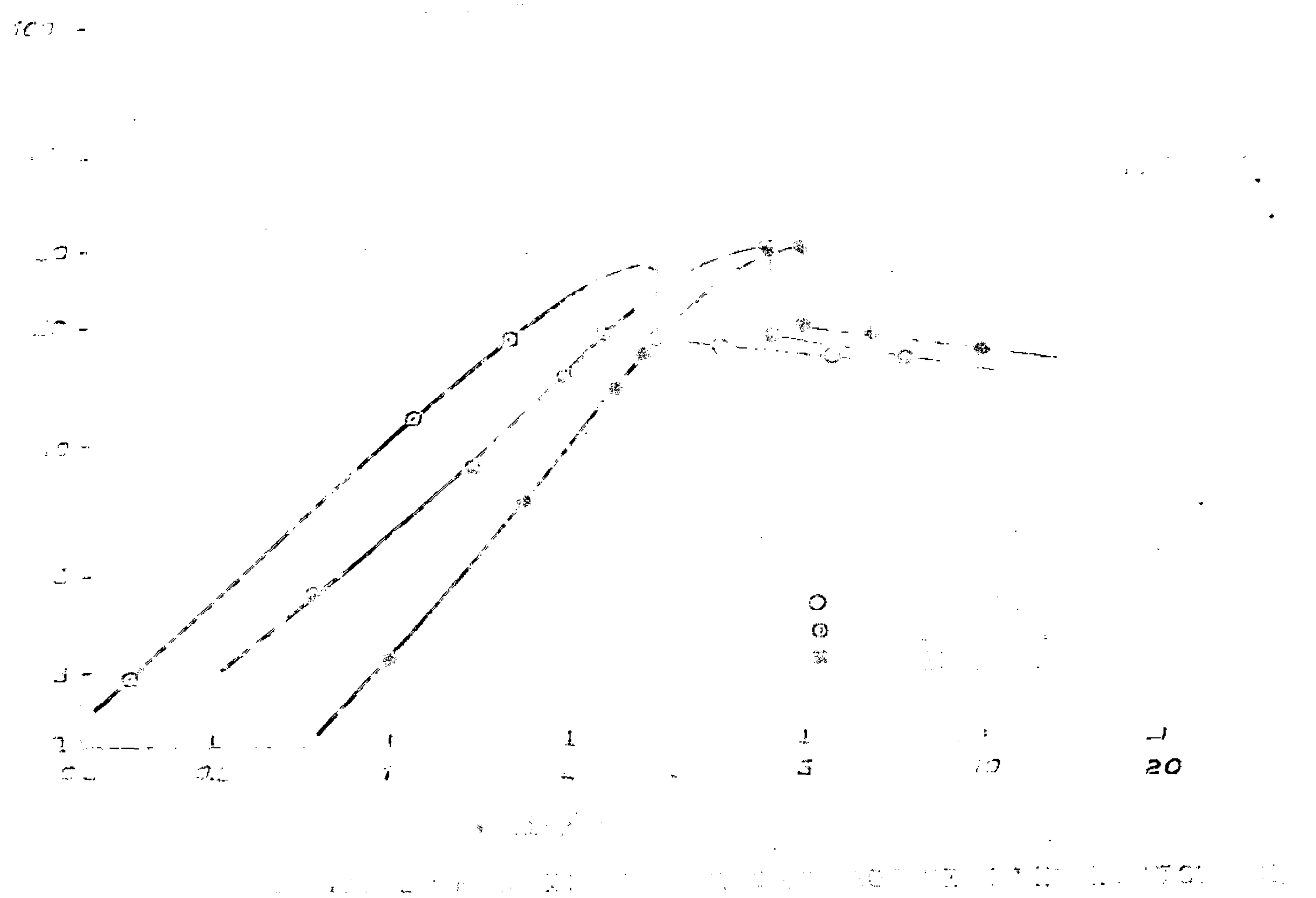
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Table No. 4.25

Cone angle, 30° — $D_p$ = 0.1517 cm

Material, Glass beads — $\rho_s$ = 2.5 gm/cc

Mesh No. -10+12 — $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate lit/min. | Manometer readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.7 | 48.3 | 46.8 | 1.5 | 6.4 |
| 2 | | 1.6 | 49.7 | 46.3 | 4.4 | 6.4 |
| 3 | | 2.3 | 51.1 | 43.9 | 7.2 | 6.4 |
| 4 | | 3.7 | 52.2 | 42.8 | 9.4 ◆ | 6.4 |
| 5 | 0.4 | 3.7 | 51.6 | 43.5 | 8.1 x | 6.6 |
| 6 | | 4.8 | 51.4 | 43.6 | 7.8 | 6.8 |
| 7 | | 5.6 | 51.2 | 43.8 | 7.4 | 6.9 |
| 8 | | 9.6 | 51.2 | 43.9 | 7.3 | 7.5 |
| 1 | | 0.6 | 48.2 | 46.8 | 1.4 | 9.0 |
| 2 | | 1.2 | 49.3 | 45.7 | 3.6 | 9.1 |
| 3 | | 2.4 | 52.4 | 42.7 | 9.7 | 9.2 |
| 4 | | 4.3 | 54.8 | 40.3 | 14.5 ◆ | 9.3 |
| 5 | 0.7 | 4.3 | 53.5 | 41.6 | 11.0 x | 9.3 |
| 6 | | 6.0 | 53.1 | 41.8 | 11.3 | 9.4 |
| 7 | | 8.0 | 52.8 | 42.2 | 10.6 | 9.8 |
| 8 | | 12.0 | 52.7 | 42.3 | 10.4 | 10.5 |
| 1 | | 0.8 | 48.8 | 46.2 | 2.0 | 9.5 |
| 2 | | 1.5 | 50.9 | 44.2 | 6.7 | 10.5 |
| 3 | | 2.5 | 53.9 | 41.1 | 12.8 | 10.5 |
| 4 | | 4.5 | 57.0 | 38.0 | 19.0 ◆ | 10.5 |
| 5 | 1.0 | 4.5 | 56.1 | 40.0 | 16.1 x | 11.0 |
| 6 | | 6.1 | 54.6 | 40.5 | 14.1 | 11.3 |
| 7 | | 8.6 | 54.2 | 40.9 | 13.3 | 11.5 |
| 8 | | 12.4 | 54.0 | 41.1 | 12.9 | 13.0 |
| 1 | | 0.7 | 48.6 | 46.5 | 2.1 | 13.0 |
| 2 | | 1.6 | 51.5 | 43.6 | 7.9 | 13.0 |
| 3 | | 2.2 | 53.7 | 41.4 | 12.3 | 13.0 |
| 4 | | 3.1 | 56.5 | 38.5 | 18.0 | 13.0 |
| 5 | 1.5 | 5.6 | 60.8 | 34.2 | 26.6 ◆ | 13.0 |
| 6 | | 5.6 | 56.9 | 38.2 | 18.7 x | 13.0 |
| 7 | | 7.6 | 56.5 | 38.7 | 17.8 | 13.9 |
| 8 | | 11.2 | 55.8 | 39.3 | 16.5 | 14.4 |
| 9 | | 13.0 | 55.5 | 39.6 | 15.9 | 16.0 |

◆ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidisation.

ΔTable No. 4.26

Cone angle, 30° $D_p$ = 0.1617 cm

Material, Quartz $\rho_s$ = 2.7 gm/cc

Mesh No. -10+12 $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.7 | 48.1 | 47.4 | 0.7 | 7.2 |
| 2 | | 2.0 | 49.3 | 46.1 | 3.2 | 7.0 |
| 3 | | 2.8 | 50.3 | 45.2 | 5.1 | 7.0 |
| 4 | | 3.2 | 50.8 | 44.7 | 6.1 | 7.0 |
| 5 | 0.4 | 5.4 | 53.1 | 42.4 | 10.7 + | 7.0 |
| 6 | | 5.4 | 51.4 | 44.0 | 7.4 x | 7.2 |
| 7 | | 6.0 | 51.3 | 44.1 | 7.2 | 7.2 |
| 8 | | 9.8 | 50.8 | 44.6 | 6.2 | 8.0 |
| 1 | | 0.5 | 48.0 | 47.5 | 0.5 | 9.8 |
| 2 | | 1.4 | 49.1 | 46.4 | 2.7 | 9.7 |
| 3 | | 2.7 | 51.1 | 44.5 | 6.6 | 9.7 |
| 4 | | 3.9 | 53.1 | 42.4 | 10.7 | 9.7 |
| 5 | 0.7 | 6.8 | 56.5 | 39.0 | 17.5 + | 9.7 |
| 6 | | 6.8 | 53.1 | 42.5 | 10.6 x | 10.1 |
| 7 | | 8.5 | 52.8 | 42.8 | 10.0 | 10.2 |
| 8 | | 13.0 | 52.0 | 43.6 | 8.4 | 11.1 |
| 1 | | 0.5 | 48.1 | 47.4 | 0.7 | 11.9 |
| 2 | | 1.6 | 49.4 | 46.1 | 3.3 | 11.9 |
| 3 | | 3.2 | 51.6 | 44.0 | 7.6 | 11.8 |
| 4 | | 4.3 | 54.3 | 41.3 | 13.0 | 11.8 |
| 5 | 1.0 | 8.0 | 60.1 | 35.5 | 24.6 + | 11.8 |
| 6 | | 8.0 | 54.1 | 41.6 | 12.5 x | 12.3 |
| 7 | | 11.2 | 53.4 | 42.1 | 11.3 | 12.7 |
| 8 | | 15.2 | 52.8 | 42.7 | 10.1 | 13.5 |
| 1. | | 0.4 | 48.1 | 47.3 | 0.8 | 14.9 |
| 2 | | 1.9 | 49.9 | 45.7 | 4.2 | 14.8 |
| 3 | | 4.2 | 54.2 | 41.4 | 12.8 | 14.6 |
| 4 | | 4.4 | 56.2 | 39.4 | 16.8 | 14.5 |
| 5 | 1.5 | 9.2 | 65.6 | 30.0 | 35.6 + | 14.5 |
| 6 | | 9.2 | 55.6 | 39.8 | 15.8 x | 15.0 |
| 7 | | 13.2 | 54.7 | 40.8 | 13.9 | 15.3 |
| 8 | | 18.8 | 54.5 | 41.0 | 13.5 | 15.5 |

+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.27

Cone angle, 30° — $D_p$ = 0.1517 cm

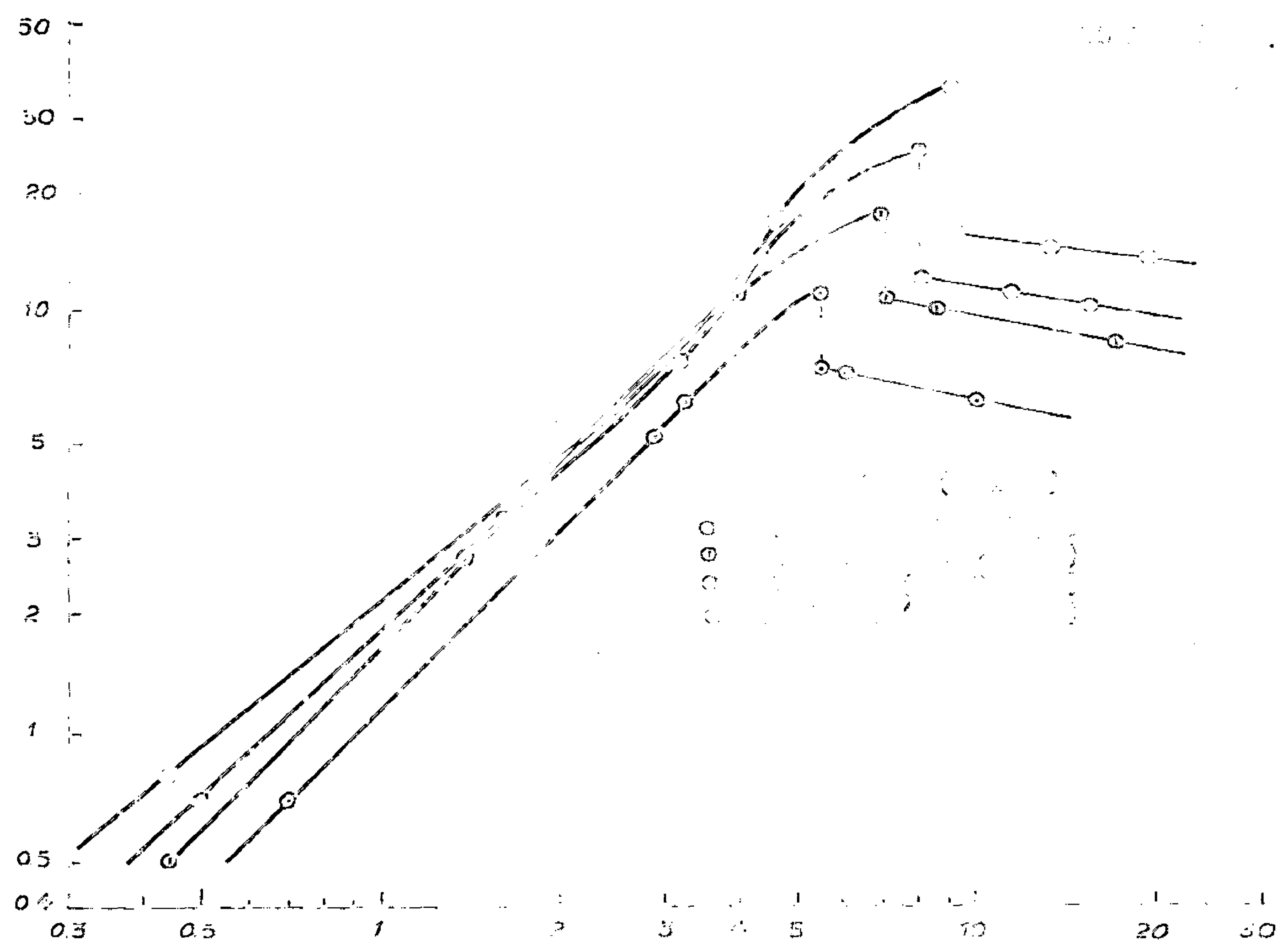
Material, Calcite — $\rho_s$ = 2.7 gm/cc

Mesh No., -10+12 — $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq flow rate lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 0.6 | 48.2 | 47.4 | 0.8 | 7.0 |
| 2 | | 1.4 | 48.9 | 46.7 | 2.2 | 7.0 |
| 3 | | 3.3 | 51.2 | 44.4 | 6.8 | 6.9 |
| 4 | | 3.6 | 51.8 | 43.8 | 8.0✦ | 6.9 |
| 4 | | 5.0 | 52.9 | 42.7 | 10.2x | 6.8 |
| 5 | 0.4 | 5.0 | 51.6 | 44.0 | 7.6 | 7.0 |
| 6 | | 7.2 | 51.3 | 44.2 | 7.1 | 7.2 |
| 7 | | 15.0 | 51.0 | 44.7 | 6.3 | 7.8 |
| 8 | | | | | | |
| 1 | | 0.6 | 48.3 | 47.3 | 1.0 | 9.5 |
| 2 | | 1.9 | 49.7 | 46.0 | 3.7 | 9.5 |
| 3 | | 3.4 | 51.6 | 44.0 | 7.6 | 9.5 |
| 4 | | 4.4 | 54.1 | 41.6 | 12.5✦ | 9.4 |
| 5 | 0.7 | 6.0 | 56.7 | 39.0 | 17.7x | 9.4 |
| 6 | | 6.0 | 53.4 | 42.2 | 11.2 | 9.7 |
| 7 | | 8.4 | 53.0 | 42.6 | 10.4 | 9.0 |
| 8 | | 15.0 | 52.6 | 43.1 | 9.5 | 11.2 |
| 1 | | 0.9 | 48.5 | 47.1 | 1.4 | 11.6 |
| 2 | | 2.2 | 4[illegible].8 | 45.8 | 4.0 | 11.4 |
| 3 | | 3.6 | 51.8 | 43.9 | 7.9 | 11.4 |
| 4 | | 4.0 | 53.4 | 42.3 | 11.1 | 11.3 |
| 5 | 1.0 | 5.1 | 56.4 | 39.2 | 17.2✦ | 11.2 |
| 6 | | 7.6 | 59.1 | 36.5 | 22.6x | 11.1 |
| 7 | | 7.6 | 54.8 | 40.9 | 13.9 | 11.7 |
| 8 | | 8.6 | 54.3 | 41.3 | 13.0 | 11.8 |
| 9 | | 12.8 | 53.7 | 41.9 | 11.8 | 12.4 |
| 1 | | 0.7 | 48.3 | 47.4 | 0.9 | 14.5 |
| 2 | | 2.0 | 49.5 | 46.2 | 3.3 | 14.4 |
| 3 | | 3.4 | 51.7 | 43.9 | 7.8 | 14.3 |
| 4 | | 4.7 | 46.0 | 41.6 | 12.4 | 14.2 |
| 5 | 1.5 | 6.1 | 57.9 | 37.7 | 20.2 | 14.2 |
| 6 | | 7.1 | 61.2 | 34.4 | 26.3✦ | 14.1 |
| 7 | | 9.4 | 64.6 | 31.0 | 33.6x | 14.1 |
| 8 | | 9.4 | 56.5 | 39.0 | 17.5 | 14.6 |
| 9 | | 14.0 | 55.2 | 40.3 | 14.9 | 14.9 |
| 10 | | 22.8 | 54.4 | 41.2 | 13.2 | 1[illegible].0 |

✦ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.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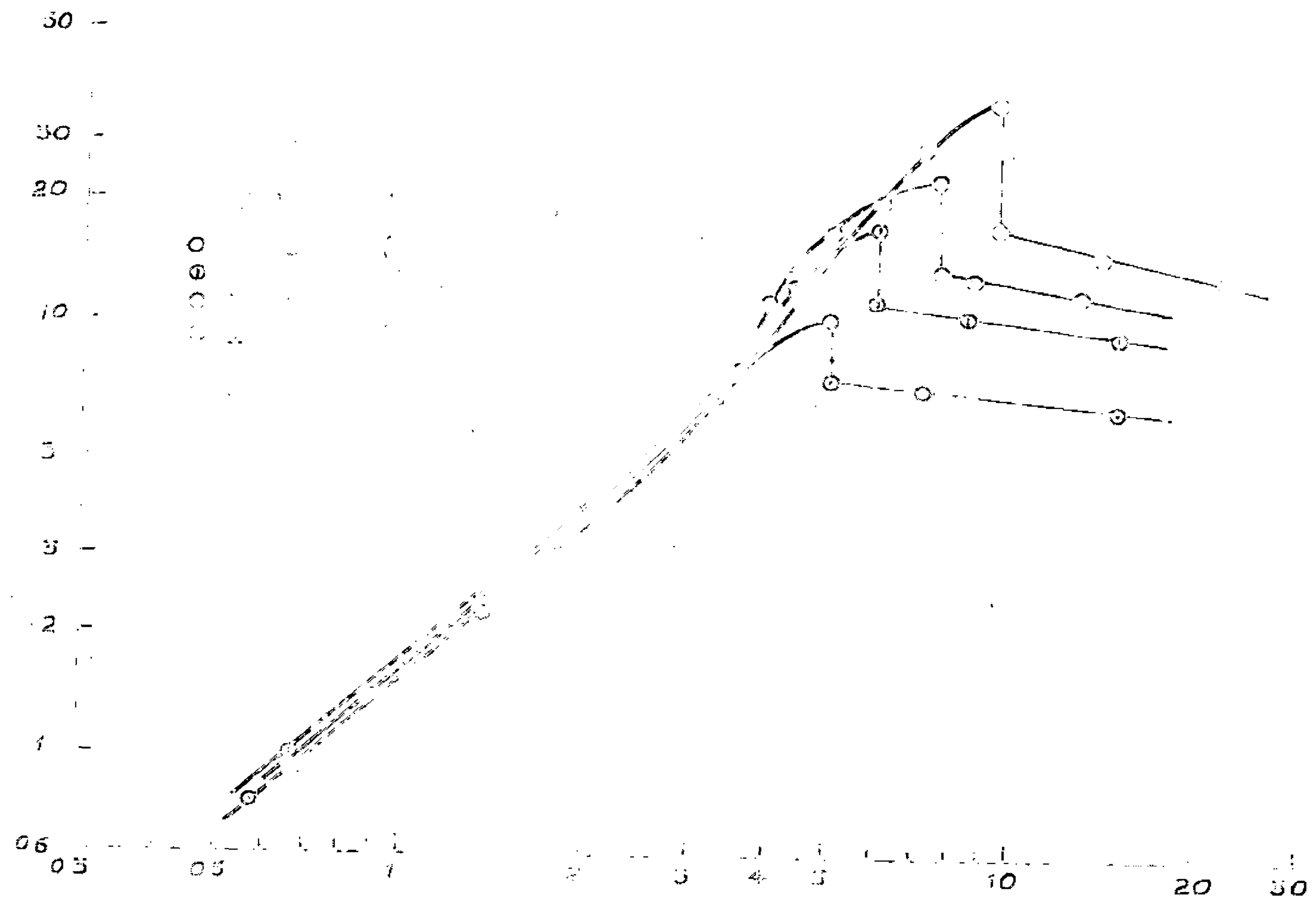


Table No. 4.23

Cone angle, 45° $D_p$ = 0.1517 cm

Material, Glass beads $\rho_s$ = 2.5 gm/cc

Mesh No., -10+12 $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.1 | 48.5 | 47.2 | 1.3 | 8.1 |
| 2 | | 1.4 | 48.8 | 47.1 | 1.7 | 8.1 |
| 3 | | 2.4 | 49.8 | 46.1 | 3.7 | 8.1 |
| 4 | | 3.9 | 51.1 | 44.8 | 6.3 | 8.1 |
| 5 | 0.5 | 4.7 | 51.9 | 44.0 | 7.9✧ | 8.1 |
| 6 | | 4.7 | 51.1 | 44.8 | 5.7x | 8.1 |
| 7 | | 6.9 | 50.7 | 45.2 | 5.5 | 8.1 |
| 8 | | 11.2 | 50.6 | 45.3 | 5.3 | 8.1 |
| 1 | | 0.7 | 48.3 | 47.5 | 0.8 | 9.7 |
| 2 | | 1.8 | 49.1 | 46.7 | 2.4 | 9.7 |
| 3 | | 3.4 | 50.5 | 45.4 | 5.1 | 9.7 |
| 4 | | 4.0 | 51.6 | 44.2 | 7.4 | 9.7 |
| 5 | 1.0 | 6.5 | 55.8 | 40.0 | 15.8✧ | 9.7 |
| 6 | | 6.5 | 52.3 | 43.1 | 9.2x | 9.7 |
| 7 | | 8.4 | 52.3 | 43.5 | 8.8 | 9.7 |
| 8 | | 11.4 | 52.1 | 43.7 | 8.4 | 9.7 |
| 1 | | 0.9 | 48.6 | 47.5 | 1.1 | 10.6 |
| 2 | | 1.8 | 49.4 | 46.7 | 2.7 | 10.6 |
| 3 | | 3.5 | 51.2 | 44.8 | 6.4 | 10.6 |
| 4 | | 4.6 | 53.5 | 42.6 | 10.9 | 10.6 |
| 5 | 1.5 | 5.6 | 55.5 | 40.6 | 14.9 | 10.6 |
| 6 | | 8.0 | 56.6 | 39.5 | 22.0✧ | 10.6 |
| 7 | | 8.0 | 54.1 | 41.9 | 12.0x | 10.6 |
| 8 | | 10.3 | 53.4 | 42.6 | 10.8 | 10.6 |
| 9 | | 20.8 | 53.1 | 42.9 | 10.2 | 10.6 |

✧ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.29

Cone angle, 45°   $D_p$ = 0.1517 cm

Material, Quartz   $\rho_s$ = 2.7 gm/cc

Mesh No., -10+12   $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.4 | 48.4 | 47.7 | 0.7 | 6.9 |
| 2 | | 3.0 | 49.0 | 47.2 | 1.8 | 6.9 |
| 3 | | 4.4 | 50.0 | 46.2 | 3.8+ | 6.9 |
| 4 | 0.5 | 6.5 | 52.2 | 43.8 | 8.4x | 6.9 |
| 5 | | 6.5 | 50.5 | 45.7 | 4.8 | 6.9 |
| 6 | | 9.0 | 50.3 | 45.8 | 4.5 | 6.9 |
| 7 | | 14.8 | 50.0 | 46.0 | 4.0 | 6.9 |
| 1 | | 1.0 | 48.4 | 47.7 | 0.7 | 9.7 |
| 2 | | 3.1 | 49.6 | 46.4 | 3.2 | 9.7 |
| 3 | | 5.9 | 52.5 | 43.5 | 9.0+ | 9.7 |
| 4 | 1.0 | 9.0 | 56.2 | 39.8 | 16.4x | 9.7 |
| 5 | | 9.0 | 51.7 | 44.3 | 7.4 | 9.7 |
| 6 | | 15.0 | 51.3 | 44.7 | 6.6 | 9.7 |
| 7 | | 26.0 | 51.0 | 44.9 | 6.1 | 9.7 |
| 1 | | 0.9 | 48.2 | 47.7 | 0.5 | 12.9 |
| 2 | | 4.0 | 49.8 | 46.0 | 3.8 | 12.9 |
| 3 | | 7.6 | 53.4 | 42.5 | 10.9+ | 12.9 |
| 4 | 1.5 | 12.4 | 59.1 | 36.8 | 22.3x | 12.9 |
| 5 | | 12.4 | 52.9 | 42.9 | 10.0 | 12.9 |
| 6 | | 14.4 | 52.3 | 43.5 | 8.8 | 12.9 |
| 7 | | 24.0 | 51.9 | 43.9 | 8.0 | 12.9 |

+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.30

Cone angle, 45°  $D_p$ = 0.1517 cm

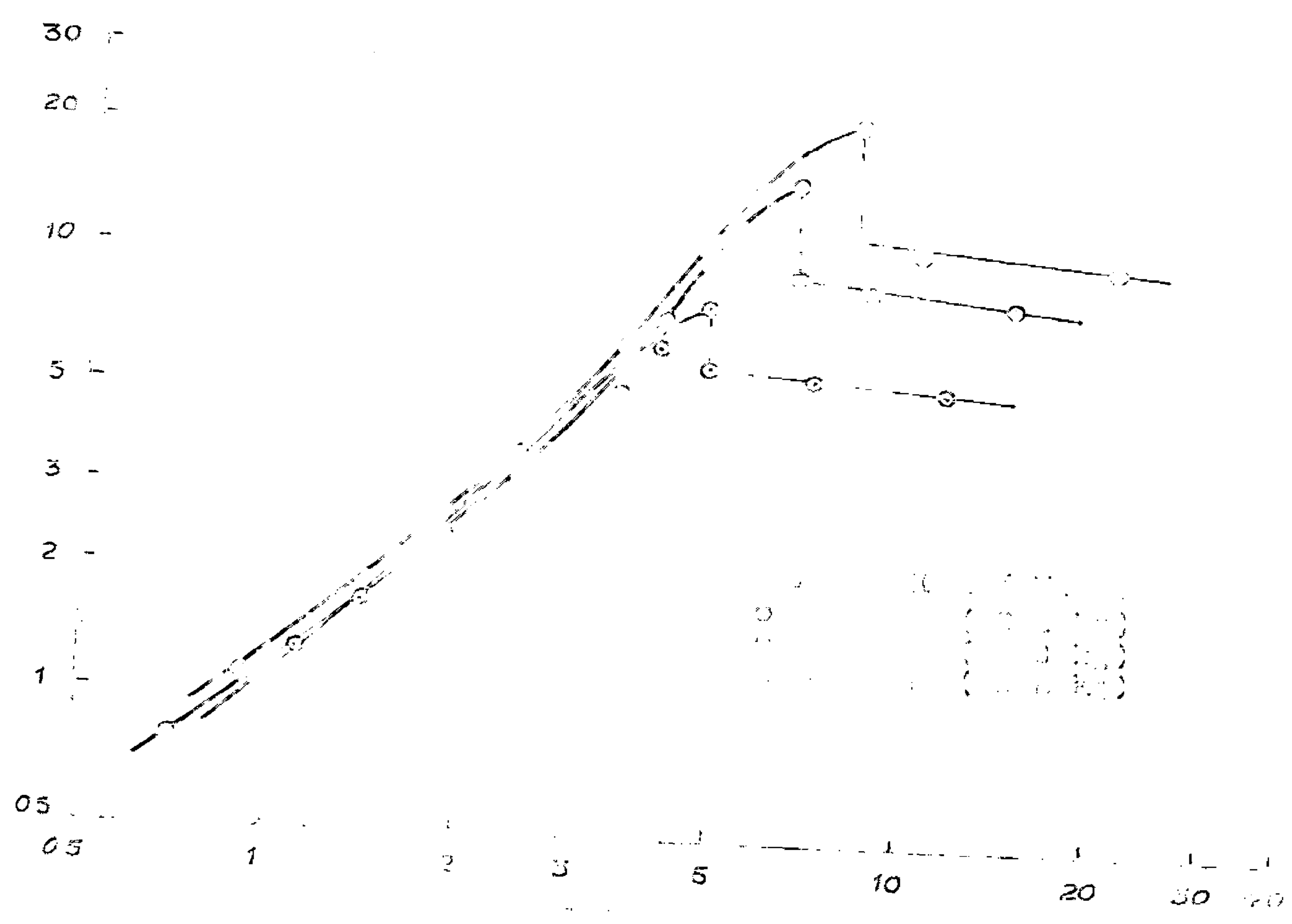
Material, Calcite  $\rho_s$ = 2.7 gm/cc

Mesh No., -10+12  $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.8 | 48.1 | 47.3 | 0.8 | 6.5 |
| 2 | | 3.5 | 48.7 | 46.7 | 2.0 | 6.5 |
| 3 | | 5.3 | 49.8 | 45.6 | 4.2 | 6.5 |
| 4 | | 6.5 | 51.1 | 44.3 | 6.8 | 6.5 |
| 5 | 0.5 | 9.6 | 52.4 | 43.0 | 9.4 ◇ | 6.5 |
| 6 | | 9.6 | 50.3 | 45.2 | 5.1 x | 6.5 |
| 7 | | 16.0 | 49.9 | 45.6 | 4.3 | 6.5 |
| 8 | | 20.0 | 49.6 | 45.9 | 3.7 | 6.5 |
| 1 | | 2.0 | 48.3 | 47.2 | 1.1 | 9.8 |
| 2 | | 4.0 | 49.2 | 46.2 | 3.0 | 9.8 |
| 3 | 1.0 | 7.8 | 52.0 | 43.5 | 8.5 ◇ | 9.8 |
| 4 | | 12.0 | 55.8 | 41.7 | 14.1 | 9.8 |
| 5 | | 12.0 | 51.5 | 43.8 | 7.7 x | 9.8 |
| 6 | | 16.8 | 50.9 | 44.4 | 6.5 | 9.8 |
| 7 | | 23.0 | 50.5 | 44.9 | 5.6 | 9.8 |
| 1 | | 1.6 | 47.9 | 46.9 | 1.0 | 11.8 |
| 2 | | 3.8 | 49.2 | 45.6 | 3.6 | 11.8 |
| 3 | | 6.6 | 51.7 | 43.1 | 8.6 | 11.8 |
| 4 | | 8.4 | 53.5 | 41.2 | 12.3 | 11.8 |
| 5 | 1.5 | 14.0 | 58.4 | 36.3 | 22.1 ◇ | 11.8 |
| 6 | | 14.0 | 52.1 | 42.6 | 9.5 x | 11.8 |
| 7 | | 19.2 | 51.7 | 43.1 | 8.6 | 11.8 |
| 8 | | 26.0 | 51.4 | 43.4 | 8.0 | 11.8 |

◇ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.



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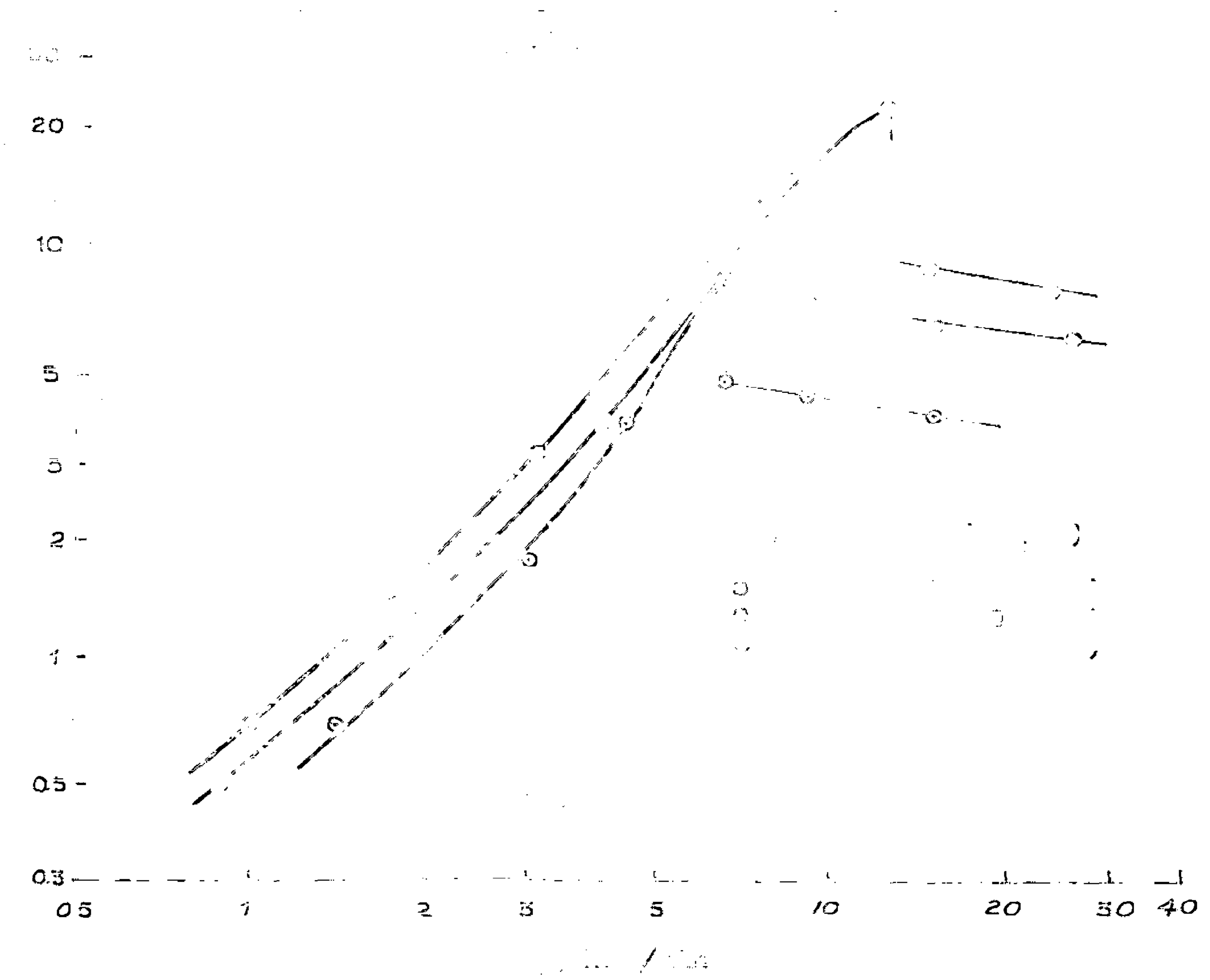

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40

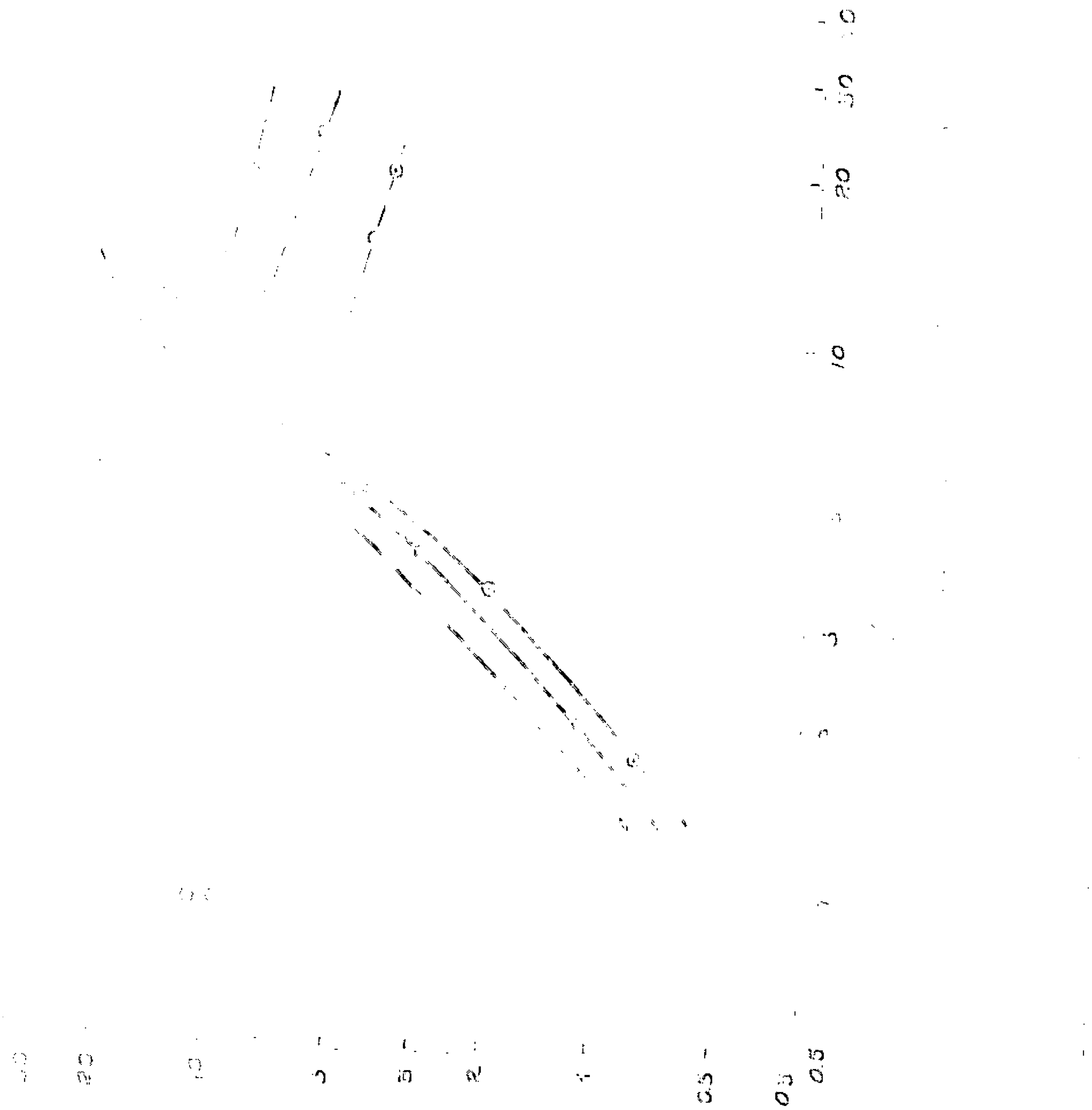


Table No. 4.II

Cone angle, 20°

Material, Glass beads

Mesh No., -10+12

$D_p$ = 0.1517 cm

$\rho_s$ = 2.5 gm/cc

$\phi_s$ = 1

| Sl. No. | Bed wt. gk. | Liq. flow rate, lit/min. | Manometer readings cms. | | ΔP, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.2 | 48.2 | 47.4 | 0.8 | 5.0 |
| 2 | | 2.0 | 48.9 | 46.7 | 2.2 ♦ | 5.0 |
| 3 | | 3.4 | 50.2 | 46.4 | 4.1 π | 5.0 |
| 4 | 0.5 | 3.4 | 49.2 | 46.4 | 2.8 | 5.0 |
| 5 | | 4.8 | 49.2 | 46.5 | 2.7 | 5.0 |
| 6 | | 10.0 | 49.2 | 46.5 | 2.7 | 5.0 |
| 1 | | 1.2 | 48.3 | 47.4 | 0.9 | 5.9 |
| 2 | | 3.8 | 49.5 | 46.3 | 3.2 ♦ | 5.9 |
| 3 | | 6.0 | 51.5 | 44.3 | 7.2 π | 5.9 |
| 4 | 1.0 | 6.0 | 50.1 | 45.6 | 4.5 | 5.9 |
| 5 | | 9.6 | 50.0 | 45.7 | 4.3 | 5.9 |
| 6 | | 16.0 | 49.9 | 45.7 | 4.2 | 5.9 |
| 7 | | 20.0 | 49.9 | 45.8 | 4.1 | 5.9 |
| 1 | | 1.6 | 48.5 | 47.2 | 1.3 | 6.7 |
| 2 | | 3.4 | 49.6 | 46.1 | 3.5 | 6.7 |
| 3 | | 4.6 | 50.4 | 45.3 | 5.1 ♦ | 6.7 |
| 4 | 1.5 | 8.0 | 52.2 | 43.5 | 8.7 π | 6.7 |
| 5 | | 8.0 | 50.5 | 45.2 | 5.3 | 6.7 |
| 6 | | 12.8 | 50.3 | 45.4 | 4.9 | 6.7 |
| 7 | | 12.0 | 50.3 | 45.4 | 4.9 | 6.7 |

♦ Pressure peak ( at limit of stability ) for fixed bed.

π Pressure drop at onset of fluidization.

Table No. 4.32

Cone angle, 20° $D_p$ = 0.1517 cm

Material, Quartz $\rho_s$ = 2.7 gm/cc

Mesh No., -10+12 $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.4 | 47.6 | 47.2 | 0.4 | 5.5 |
| 2 | | 2.3 | 47.9 | 46.8 | 1.1 | 5.5 |
| 3 | | 4.0 | 48.9 | 46.0 | 2.9 + | 5.5 |
| 4 | 0.5 | 6.6 | 50.0 | 44.7 | 5.3 x | 5.5 |
| 5 | | 6.6 | 48.5 | 46.3 | 2.2 | 5.5 |
| 6 | | 10.0 | 48.3 | 46.5 | 1.8 | 5.5 |
| 7 | | 17.0 | 48.2 | 46.6 | 1.6 | 5.5 |
| 1 | | 1.6 | 47.8 | 47.1 | 0.7 | 6.6 |
| 2 | | 2.8 | 48.4 | 46.4 | 2.0 | 6.6 |
| 3 | | 6.8 | 50.5 | 45.4 | 5.1 + | 6.6 |
| 4 | 1.0 | 10.0 | 51.0 | 45.0 | 6.0 x | 6.6 |
| 5 | | 10.0 | 49.0 | 45.8 | 3.2 | 6.6 |
| 6 | | 14.0 | 48.8 | 46.0 | 2.8 | 6.6 |
| 7 | | 24.0 | 48.7 | 46.1 | 2.6 | 6.6 |
| 1 | | 1.4 | 47.7 | 47.1 | 0.6 | 7.4 |
| 2 | | 2.3 | 48.2 | 46.6 | 1.6 | 7.4 |
| 3 | | 5.8 | 50.0 | 44.8 | 5.2 + | 7.4 |
| 4 | 1.5 | 13.6 | 51.8 | 43.0 | 8.8 x | 7.4 |
| 5 | | 13.6 | 49.4 | 45.5 | 3.9 | 7.4 |
| 6 | | 18.4 | 49.1 | 45.8 | 3.3 | 7.4 |
| 7 | | 28.0 | 49.0 | 45.9 | 3.1 | 7.4 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.33

Cone angle, 20°  $D_p$ = 0.1517 cm

Material, Calcite  $\rho_s$ = 2.7 gm/cc

Mesh No., -10+12  $\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 2.2 | 48.3 | 47.3 | 1.0 | 5.5 |
| 2 | | 3.1 | 48.8 | 46.9 | 1.9 | 5.5 |
| 3 | | 6.4 | 49.9 | 45.8 | 4.1 + | 5.5 |
| 4 | 0.5 | 6.4 | 49.0 | 46.5 | 2.5 x | 5.5 |
| 5 | | 11.8 | 48.9 | 46.7 | 2.2 | 5.5 |
| 6 | | 24.0 | 48.8 | 46.8 | 2.0 | 5.5 |
| 1 | | 1.6 | 48.2 | 47.4 | 0.8 | 6.9 |
| 2 | | 2.5 | 48.8 | 46.8 | 2.0 | 6.9 |
| 3 | | 5.2 | 50.5 | 45.0 | 5.5 + | 6.9 |
| 4 | 1.0 | 10.4 | 51.5 | 44.0 | 7.5 | 6.9 |
| 5 | | 10.4 | 50.0 | 45.7 | 4.3 x | 6.9 |
| 6 | | 14.8 | 49.5 | 46.1 | 3.4 | 6.9 |
| 7 | | 26.0 | 49.2 | 46.4 | 2.8 | 6.9 |
| 1 | | 2.0 | 48.3 | 47.3 | 1.0 | 7.8 |
| 2 | | 4.6 | 49.8 | 45.7 | 4.1 | 7.8 |
| 3 | | 7.7 | 51.4 | 44.3 | 7.1 + | 7.8 |
| 4 | 1.5 | 16.0 | 52.7 | 43.0 | 9.7 | 7.8 |
| 5 | | 16.0 | 50.0 | 45.6 | 4.4 x | 7.8 |
| 6 | | 20.0 | 49.8 | 45.8 | 4.0 | 7.8 |
| 7 | | 30.0 | 49.6 | 46.0 | 3.6 | 7.8 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

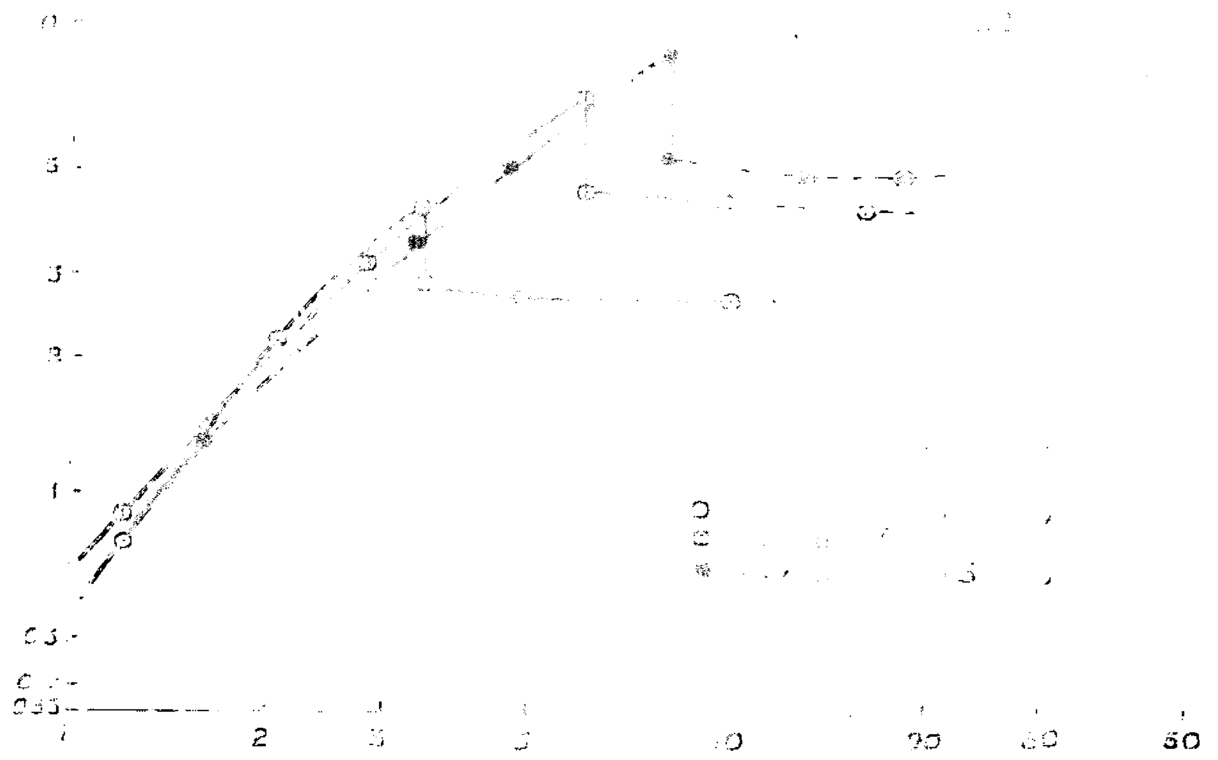


Table No. 4.34

Cone angle, 120°  $D_p$ = 0.1617 cm

Material, Glass beads  $\rho_s$ = 2.5 gm/cc

Mesh No. 10÷12  $\phi_s$ = 1

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.0 | 30.3 | 29.9 | 0.4 | 3.2 |
| 2 | | 2.0 | 30.5 | 29.8 | 0.7 | 3.2 |
| 3 | | 3.4 | 31.0 | 29.3 | 1.7✧ | 3.2 |
| 4 | 0.5 | 3.4 | 30.9 | 29.5 | 1.4x | 3.2 |
| 5 | | 6.0 | 30.8 | 29.6 | 1.2 | 3.2 |
| 6 | | 16.0 | 30.7 | 29.7 | 1.0 | 3.2 |
| 1 | | 1.3 | 30.5 | 29.8 | 0.7 | 4.0 |
| 2 | | 2.4 | 31.2 | 29.3 | 1.9 | 4.0 |
| 3 | | 3.0 | 31.6 | 28.9 | 2.7✧ | 4.0 |
| 4 | 1.0 | 3.8 | 31.3 | 29.2 | 2.1x | 4.0 |
| 5 | | 6.0 | 31.2 | 29.2 | 2.0 | 4.0 |
| 6 | | 10.8 | 31.2 | 29.3 | 1.9 | 4.0 |
| 1 | | 1.6 | 30.7 | 29.9 | 0.8 | 4.7 |
| 2 | | 2.7 | 31.6 | 28.9 | 2.7 | 4.7 |
| 3 | | 4.2 | 32.7 | 27.8 | 4.9✧ | 4.7 |
| 4 | 1.5 | 6.2 | 31.8 | 28.8 | 3.0x | 4.7 |
| 5 | | 7.0 | 31.6 | 28.9 | 2.7 | 4.7 |
| 6 | | 24.0 | 31.4 | 29.1 | 2.3 | 4.7 |

✧ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.36

Cone angle, 120°

Material, Quartz

Mesh No. -10+12

$D_p$ = 0.1517 cm

$\rho_s$ = 2.7 gm/cc

$\phi_s$ =

| Sl. No. | Bed wt. gk. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm. $CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.7 | 30.5 | 29.9 | 0.6 | 3.2 |
| 2 | | 2.5 | 30.8 | 29.6 | 1.2✧ | 3.2 |
| 3 | | 3.9 | 31.3 | 29.1 | 2.2x | 3.2 |
| 4 | 0.5 | 3.9 | 30.9 | 29.7 | 1.2 | 3.2 |
| 5 | | 7.0 | 30.8 | 29.8 | 1.0 | 3.2 |
| 6 | | 16.8 | 30.7 | 29.8 | 0.9 | 3.2 |
| 1 | | 1.9 | 30.6 | 29.9 | 0.7 | 4.3 |
| 2 | | 3.9 | 31.7 | 28.9 | 2.8✧ | 4.3 |
| 3 | 1.0 | 5.8 | 32.2 | 28.4 | 3.8x | 4.3 |
| 4 | | 5.8 | 31.2 | 29.3 | 1.9 | 4.3 |
| 5 | | 17.6 | 31.1 | 29.5 | 1.6 | 4.3 |
| 1 | | 2.0 | 30.7 | 29.9 | 0.8 | 5.0 |
| 2 | | 3.0 | 31.3 | 29.3 | 2.0 | 5.0 |
| 3 | | 4.4 | 31.9 | 28.7 | 3.2✧ | 5.0 |
| 4 | 1.5 | 6.3 | 32.6 | 28.0 | 4.6x | 5.0 |
| 5 | | 6.3 | 31.3 | 29.3 | 2.0 | 5.0 |
| 6 | | 10.0 | 31.2 | 29.3 | 1.9 | 5.0 |

✧ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.

Table No. 4.36

Cone angle, 120°　　　　$D_p$ = 0.1517 cm

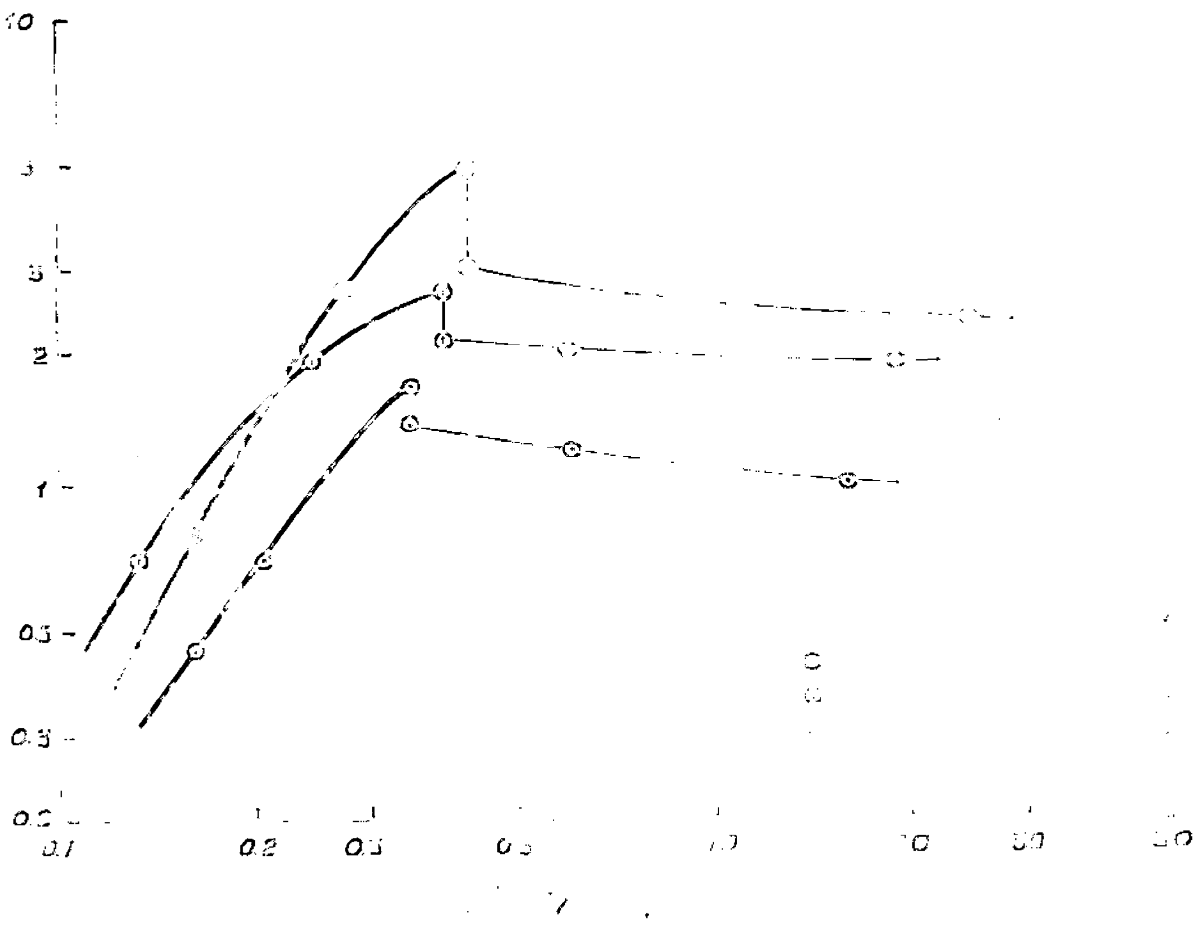
Material, Calcite　　　　$\rho_s$ = 2.7 gm/cc

Mesh No., -10+12　　　　$\phi_s$ =

| Sl. No. | Bed wt. kg. | Liq. flow rate, lit/min. | Manometer readings cms. | | $\Delta P$, cm-$CCl_4$ | Bed ht. cm. |
|---|---|---|---|---|---|---|
| 1 | | 1.4 | 30.5 | 30.0 | 0.5 | 3.4 |
| 2 | | 2.0 | 30.7 | 29.7 | 1.0 | 3.4 |
| 3 | | 4.0 | 31.5 | 29.0 | 2.5 + | 3.4 |
| 4 | 0.5 | 4.0 | 31.0 | 29.6 | 1.4 x | 3.4 |
| 5 | | 7.0 | 30.95 | 29.6 | 1.35 | 3.4 |
| 6 | | 16.0 | 30.9 | 29.6 | 1.3 | 3.4 |
| 1 | | 1.6 | 30.5 | 29.9 | 0.6 | 4.2 |
| 2 | | 3.6 | 31.4 | 29.1 | 2.3 | 4.2 |
| 3 | 1.0 | 6.8 | 32.6 | 27.9 | 4.7 + | 4.2 |
| 4 | | 6.2 | 31.3 | 29.1 | 2.2 x | 4.2 |
| 5 | | 16.0 | 31.1 | 29.3 | 1.8 | 4.2 |
| 1 | | 1.8 | 30.5 | 29.8 | 0.7 | 5.0 |
| 2 | | 4.0 | 31.6 | 28.8 | 2.8 | 5.0 |
| 3 | 1.5 | 7.2 | 33.0 | 27.4 | 5.6 + | 5.0 |
| 4 | | 7.2 | 31.3 | 28.7 | 3.1 x | 5.0 |
| 5 | | 18.0 | 31.4 | 29.0 | 2.4 | 5.0 |

\+ Pressure peak ( at limit of stability ) for fixed bed.

x Pressure drop at onset of fluidization.


10
2
1
0.1
0.2

# CHAPTER 5

CONCLUSIONS

Experimental studies were carried out in tapered vessels with apex angle ranging from 10° to 120°, to investigate the optimum cone angle for solid-liquid contact. Based on experimental studies using glass beads, calcite and Quartz of different particle sizes it has been observed that a cone angle greater than 45° adversely affects the solid-liquid contact. In vessels having a cone angle more than 45° the particle movement is limited to a central core with particles remaining stationary in a thick layer adjacent to the vessel wall.

It has been observed that increase in bed height increases the pressure peak value. For the same particle size pressure peak is more for crushed materials than for spherical particles. Pressure peak is more in case of material having size distribution than for a material of uniform size.

Pressure peak is a characteristic of solid-fluid contact in tapered vessels, which is not so prominent in case of cylindrical vessels. The pressure peak in conical vessels is comparable in value to the net bed weight pressure drop. Pressure peak has been correlated in terms of $\tan \alpha/2$, $D/D_o$ and $Re_{p_{mf}}$ based on the entrance. The correlation given below is valid for conical vessels ranging from 10° to 45° for spherical as well as crushed materials in size range -10+12 to -16+18 mesh nos.

$$(\Delta\Pi/\Delta P) = 1.02 \times 10^{-3} (D/D_o)^{1.63} (\tan \alpha/2)^{-1.25} (D_p G_{mf}/\mu)^{0.712}$$

The percentage deviation has been found to be ± 35%.

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## NOMENCLATURE

$A$ = $(\mu / g_c D_p^2)(1-\epsilon)^2/\epsilon^3$

$A_{avg}$ = Average cross-sectional area of the bed.

$a_\delta$ = distance normal to the longitudinal axes of the column between tapered sides.

$B$ = $(\rho_f / g_c D_p)(1-\epsilon)/\epsilon^3$

$C$ = constant in equation (8).

$C_1, C_2$ = coefficients in Ergun type equation ( 4 and 9 ).

$C_D$ = Drag coefficient in equation (19).

$D, D_o$ = Bed diameters at the top and bottom of the bed respectively.

$D_p$ = Particle diameter.

$F$ = Drag force on the particles in equation ( 19 ).

$g$ = Acceleration due to gravity.

$g_c$ = Gravitational constant.

$k$ = coefficient in equation (7).

$L, l$ = Bed heights from bottom of the bed to the top and upto some intermediate point respectively.

$L_{mf}$ = Bed height at the minimum fluidization.

$M$ = Mass of the solid particles charged to the bed.

$\Delta P$ = Pressure drop across the bed, frictional.

$P_b, P_t$ = Pressures at the base and top of the bed respectively.

$R, R_o$ = Radial distance from the apex of the cone to the top of the bed and upto the distributor respectively.

$r_b, r_t, r$ = Bed radious at the base, top and at an intermediate point of the bed respectively.

$U_o$ = Superfecial fluid velocity at the distributor.

$U_t$ = Terminal velocity of the particles.

$W_{net}$ = Net weight or buoyant weight of material in the bed.

x = Exponent in equation (14).

$\epsilon$ = Bed porosity.

$\rho_s, \rho_f, \rho_b$ = Densities of the solid particles, fluid and of the bed (bulk) respectively.

$\alpha$ = apex angle of the cone.

$\mu$ = fluid viscosity.

$\Delta w$ = Pressure peak in the tapered vessels.

$\phi_s$ = particle shape factor.

# APPENDIX

## PROGRAMMES FOR LEAST SQUARE CURVE FITTING.

```
C   C  PROGRAMME NO. 1
C   C  ME THESIS ISHWAR CHANDRA CHEMICAL UOR
       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 FORMAT(/5X,3HS9=,F10.4,2X,4HS10=,F10.4,2X,4HS11=,F10.4,2X,
     14HS12=,F10.4//)
      STOP
      END
67
       0.26          1.68          .125        56.0
       1.17          1.98          .085       120.0
       0.88          1.9           .085       100.0
       0.8           1.56          .085        90.0
       0.61          2.0           .125        70.0
       0.66          2.21          .125        85.0
       0.28          1.32          .16         56.0
       0.47          2.16          .16         68.0
       0.68          2.4           .16         80.0
       0.71          1.96          .085        33.0
       0.79          1.8           .085        38.0
       1.19          1.98          .085        47.0
       0.15          1.58          .125        20.0
       0.52          2.0           .125        26.0
       0.54          2.21          .125        32.0
       0.24          1.8           .16         22.0
       0.28          2.12          .16         27.0
       0.32          2.35          .16         33.0
       0.16          1.9           .28         74.0
       0.22          2.26          .28         86.0
       0.27          2.37          .28         91.0
       0.64          2.82          .28        113.0
       0.84          3.3           .435       160.0
       0.72          3.11          .435       130.0
       0.39          2.76          .435        95.0
        .57          1.84          .16         72.0
        .88          2.2           .16         96.0
       1.0           2.48          .16        120.0
        .35          1.98          .28        101.0
        .58          2.72          .28        121.0
        .63          2.5           .28        153.0
        .92          3.9           .28        189.0
        .84          2.4           .435       193.0
        .82          3.11          .435       240.0
       1.32          3.5           .435       280.0
       1.41          1.38          .085       117.0
       2.23          1.83          .085       133.0
       2.23          2.03          .085       149.0
        .86          1.72          .125        88.0
       1.38          2.06          .125       133.0
       1.96          2.25          .125       151.0
       2.25          2.3           .125       181.0
        .45          2.0           .28        109.0
        .65          2.37          .28        137.0
        .96          2.6           .28        161.0
       1.25          3.1           .28        185.0
        .75          2.55          .435       131.0
       1.22          3.11          .435       181.0
       1.23          3.7           .435       250.0
```

```
 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
 67
      0.26            1.68            .125        56.0
      1.17            1.98            .085       120.0

      -------ALL THE SIXTY SEVEN DATA CARDS HERE AS PLACED IN
                                   PROGRAMME NO. 1 --------- -

      0.96            2.1             .125        42.0
      1.11            2.33            .125        55.0

C  C  ME THESIS ISHWAR CHANDRA  CHEMICAL UOR
        .00047       .00058        .00058        .00072
        .00071       .00057        .00061        .00067
        .00073       .00131        .00104        .00116
        .00057       .00123        .00093        .00103
        .00080       .00067        .00053        .00050
        .00054       .00083        .00114        .00125
        .00103       .00102        .00096        .00076
        .00088       .00090        .00080        .00075
        .00168       .00092        .00110        .00103
        .00118       .00092        .00109        .00097
        .00109       .00093        .00105        .00098
        .00111       .00098        .00179        .00167
        .00101       .00088        .00073        .00050
```

| | | | |
|---|---|---|---|
| .00151 | .00105 | .00081 | .00147 |
| .00121 | .00089 | .00151 | .00182 |
| .00126 | .00145 | .00138 | .00113 |
| .00233 | .00149 | .00120 | |

CKAVG= .00102
STANDARD DEVIATION= .00036
COEFFICIENT OF VARIATION= 35.31694

| | |
|---|---|
| .26000 | .56253 |
| 1.17000 | 2.04875 |
| .88000 | 1.54043 |
| .80000 | 1.13178 |
| .61000 | .87614 |
| .66000 | 1.18383 |
| .28000 | .47076 |
| .47000 | .71462 |
| .68000 | .95261 |
| .71000 | .55402 |
| .79000 | .77348 |
| 1.19000 | 1.05110 |
| .15000 | .27025 |
| .52000 | .43284 |
| .54000 | .59049 |
| .24000 | .23772 |
| .28000 | .35911 |
| .32000 | .49000 |
| .16000 | .30594 |
| .22000 | .45179 |
| .27000 | .50822 |
| .64000 | .78717 |
| .84000 | .75114 |
| .72000 | .58822 |
| .39000 | .38728 |
| .57000 | .57312 |
| .88000 | .94123 |
| 1.00000 | 1.34123 |
| .35000 | .40833 |
| .58000 | .60126 |
| .63000 | .80263 |
| .92000 | 1.25580 |
| .84000 | .51082 |
| .82000 | .91016 |
| 1.32000 | 1.23145 |
| 1.41000 | 1.39286 |
| 2.23000 | 1.93876 |
| 2.23000 | 2.48928 |
| .86000 | .80643 |
| 1.38000 | 1.45201 |
| 1.96000 | 1.83515 |
| 2.25000 | 2.47909 |
| .45000 | .43823 |
| .65000 | .68008 |
| .96000 | .88724 |
| 1.25000 | 1.30473 |
| .75000 | .42792 |
| 1.22000 | .74452 |
| 1.23000 | 1.24369 |
| .52000 | .60090 |
| .65000 | .91106 |

| | |
|---|---|
| .[illegible]8000 | 1.19347 |
| .48000 | .32378 |
| .50000 | .48639 |
| .57000 | .72005 |
| 1.85000 | 1.2895[illegible] |
| 2.33000 | 1.97342 |
| 2.33000 | 2.66722 |
| 1.20000 | .81235 |
| 1.98000 | 1.11333 |
| 1.70000 | 1.37660 |
| 1.00000 | .70477 |
| 1.80000 | 1.33411 |
| 2.08000 | 1.88412 |
| .90000 | .39401 |
| .96000 | .65947 |
| 1.11000 | .94646 |
| .09373 | |

MULTIPLE CORRELATION COEFFICIENT = .30616

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