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STUDIES OF PARTICLE SIZE DISTRIBUTION
IN FLUIDIZED BEDS

by

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STUDIES OF PARTICLE SIZE DISTRIBUTION IN FLUIDIZED BEDS

by

H. M. Katz*

ABSTRACT

A technique for the study of distribution of particle sizes in fluidized beds consisting of two particle sizes has been devised, and data have been obtained for a number of such systems. It has been shown that both static electricity in the bed and surface adsorption of moisture affect the particle size distribution. Experimental data indicate that the effects of these variables can be eliminated by use of a conducting column of conducting particles and the use of dry air for fluidization. In addition, a qualitative relationship between minimum fluidizing velocity for mixed particle sizes and pressure drop across the bed has been demonstrated.

I. INTRODUCTION

A. Purpose of Study

Although a great deal of data have appeared in the literature on the dynamics of gas fluidized solids,(3,4,7,9) almost all of the work has been concerned with solids of a single particle size, or with very narrow ranges of particle sizes. In many applications of the fluidization technique, it is necessary to use solids containing a wide range of particle sizes. For such applications, two important questions, which have not heretofore been investigated, arise.

The first of these questions is a knowledge of the minimum fluidizing velocity of any given mixture. Although the minimum fluidizing velocity of a bed consisting of a single particle size can be predicted from well-established relationships,(3) it is not known whether these same relationships can be applied to mixtures of sizes. It is not even known whether a mixture will fluidize in steps, each particle size beginning to fluidize at its own minimum fluidizing velocity, or whether the entire bed will fluidize at some intermediate velocity.

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The second question is whether a fluidized bed containing a mixture of particle sizes is uniformly mixed, or whether the particles segregate according to size. In continuous operation of a fluidized bed, it becomes very important to know if segregation occurs and to what extent. If there were segregation, and product was removed from the bottom of the bed, the initial product would contain a higher percentage of coarse particles than the feed, and a long period of unsteady-state operation would result. This might be particularly objectionable in the case of a multi-stage fluidized bed. Even after steady state was reached, the residence time for different particle sizes might be unequal and result in varying degrees of chemical reaction.

The purpose of this study was to attempt to provide answers to these two important questions.

B. Previous Work

The only previous study of particle size distribution in fluidized beds has been by Omae and Furukawa.⁽⁶⁾ This work was concerned with liquid fluidized beds, and because of the fundamental differences between liquid, or particulate, and gas, or aggregative, fluidization, the results are probably not applicable to gas fluidized beds. However, a brief description is included here for purposes of comparison.

Their work was conducted in a glass column provided with seven equally spaced side arms through which samples were drawn after the bed had reached steady state. Experiments were done on pairs of particle sizes, both of the same solids, and of solids of different densities. The ratio of diameters ranged from 1.39 to 4.72. They found that the beds consisted of two distinct sections, the lower section containing a higher percentage of coarse particles, with each section of essentially uniform composition. Complete mixing of the bed was not attained even at extremely high flow rates. A correlation was developed through analogy with partially miscible liquid systems. The ratio of concentrations of coarse particles in the upper phase to that in the lower phase was treated as a distribution coefficient, with liquid velocity analogous to temperature. Their final correlation was

$$\ln \frac{C_{\alpha}}{C_{\beta}} = \left(1.1 \frac{D_1}{D_2} - 1.66 \right) - \frac{5.13 D_1^3 + 0.53}{U},$$

where C_{α} and C_{β} are the concentrations of coarse particles in the upper and lower phases, respectively, D_1 and D_2 are the diameters of the coarse and fine particles, respectively, and U is the liquid velocity.

II. EXPERIMENTAL WORK

A. Glass Beads with Maximum Static

1. Apparatus

A schematic diagram of the apparatus used is shown in Figure 1. The first set of experimental runs was made using low-pressure air at room temperature and about ten per cent relative humidity for the fluidization of Scotchlite glass beads. These runs were performed in a Lucite column, two inches in diameter, mounted vertically over a sintered stainless steel disc, which served as bed support and gas distributor. Low-pressure air was passed through a reducing valve and metered through a calibrated rotameter or orifice, depending on the range of flow rates being used. A needle valve was used for regulation. In addition, there was another valve just below the column for by-passing the air and a tap just below the disc for measuring the pressure drop across disc and bed.

FIGURE 1
SCHEMATIC DIAGRAM OF APPARATUS

2. Procedure

The experimental procedure used was as follows: the column was loaded with 400 grams of the desired mixture of glass beads. When other materials were being fluidized, the total bed weight was varied with the density of the material so as to keep the static bed height fixed at about six inches. The air flow then was brought up to a rate sufficiently high to achieve complete mixing in the bed. The needle valve was then shut rapidly

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and the by-pass below the column opened simultaneously. With the by-pass valve still open, the flow rate was adjusted to the desired value, and then the by-pass valve was rapidly shut, admitting the air to the bed. An alternate procedure was to mix the bed completely at a high flow rate, and then rapidly to decrease the flowrate to the desired value without using the by-pass. Either procedure gave the same result. The bed was then allowed to fluidize for ten minutes. Preliminary experiments showed that in most cases steady state was actually reached in less than five minutes. At the end of the ten-minute period the air was shut off rapidly, using both the needle valve and the by-pass valve. By shutting off the air flow very rapidly, no significant particle size segregation occurred during this period, and the resulting fixed bed had the same relative particle size distribution as the fluidized bed. Evidence of this was the fact that, at very high flow rates, the resulting fixed bed showed essentially uniform particle size distribution.

Two different procedures were used to sample the various sections of the bed. In earlier runs, after the air was shut off, a hot gelatine solution was poured into the bed, carefully, so as to disturb the position of the particles as little as possible. When the gelatine had penetrated the entire bed, the column was jacketed with dry ice and frozen. The column was then removed and sliced into sections by use of a hot-wire glass cutter. Each section was then washed with hot water to remove the gelatine, filtered, dried, and screened and weighed to determine the particle size distribution.

A second sampling technique, much quicker and simpler, was used during most of the experimental work. It was found that sections of the bed could be drawn off through a long tube into a sample bottle, employing suction provided by an air ejector. This eliminated most of the steps of the previous technique and yielded the same results. Although the former method is much more tedious, it possesses the advantage over the latter that the sections may be cut radially as well as axially.

In addition to the actual size-distribution measurements, a series of pressure drop measurements as a function of flow rate were made for each mixture studied.

The procedures of operation and sampling just described were used to obtain all the experimental data described in subsequent sections of this report.

3. Experimental Results

The results of this series of experiments can best be described by referring to Figure 2, which is a typical schematic plot of pressure drop across the bed as a function of air flow rate. For the narrow cuts (20-40 mesh and 140-200 mesh) the curves have the usual characteristic shape. In the case of the mixtures, however, a different type of behavior

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FIGURE 2
RELATIONSHIP BETWEEN PRESSURE DROP AND GAS FLOW RATE
FOR VARIOUS MIXTURES OF GLASS BEADS

can be observed. Referring to Figure 2, at flow rates below point A there is no particle movement and the usual fixed bed relationships apply. Between A and B there is a slight expansion and rearrangement, with some particle size segregation. This is an unstable region, showing poor reproducibility. In the linear region from B to C, the bed consists of two distinct sections. The bottom section, consisting mainly of large particles, is fixed. The upper section, mostly fine particles, is completely fluidized. The interface between the two sections is well defined, and the reproducibility of data in this region is good. As the flow is increased from B to C, the length of the fixed bed section decreases and that of the fluidized section increases. Finally, at point C the fixed section disappears and the bed is completely fluidized.

The variation of composition with vertical distance in the bed, and with air flow rate, is illustrated in Figure 3. In these runs, the beds were sampled in six sections of equal height. The two distinct sections of the bed are clearly indicated, with a sharp change in composition at the interface. It can also be seen that the composition of the upper phase approaches the overall bed composition and that the lower phase disappears with increasing flow rate. At flow rates above point C on Figure 2, the bed is uniformly mixed, except for a very short section at the bottom of the bed, containing a high percentage of coarse particles. It is important to note that the fluidized section was always homogeneous. On the basis of these observations, all subsequent beds were divided into just three sections, one to a point just above the interface, another to a point just below the interface and finally, the bottom portion of the bed.

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FIGURE 3
DISTRIBUTION OF PARTICLES IN A FLUIDIZED BED
CONSISTING OF A MIXTURE OF GLASS BEADS
(STARTING MIXTURE - 20% 20-40 MESH, 80% 140-200 MESH)

Typical results of a series of such runs are illustrated in Figure 4, in which the composition of the top and bottom phases is shown as a function of air flow rate. Similar results were obtained for three other sets of particle sizes, all using 20-40 mesh particles as the larger size.

Several sections of these beds were also sectioned radially to determine if there were any radial particle size distribution. The results of these experiments, shown in Table I, indicate that there is a higher concentration of coarse particles near the walls of the column. This may be explained as follows:

When the air is turned on, the entire bed fluidizes momentarily, and then the fixed bed section slowly builds up. Since the normal pattern of particle movement is up the center of the bed and down along the walls, and since the larger particles fall more rapidly, they reach the bottom of the bed first and remain there along the walls, while the finer particles reach the bottom of the bed later, and are forced to accumulate in the center of the bed. It should be noted that the data in Table I are for sections taken from the fixed portion of the bed. Similar experiments done on sections from the fluidized portion of the bed showed no radial distribution.

All the results of this series of runs seemed to indicate that the compositions of the top and bottom phases were independent of the overall bed composition for any given set of particle sizes. It is also interesting to note that, for any given composition, the flow rate read from the

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FIGURE 4

"PHASE DIAGRAM" RELATING BED COMPOSITION TO AIR FLOW RATE FOR MIXTURES OF 20-40 AND 140-200 MESH GLASS BEADS

POINT A REPRESENTS A BED OF OVERALL COMPOSITION 40% COARSE, WITH AIR FLOW OF 100 lb/(hr)(sq ft). B REPRESENTS THE COMPOSITION OF LOWER PHASE, AND C IS THE COMPOSITION OF THE UPPER PHASE. RELATIVE AMOUNT OF TWO PHASES IS REPRESENTED BY RATIO OF AD TO AE, THE BED WOULD BE COMPLETELY FLUIDIZED AT VELOCITY F.

Table I

RADIAL DISTRIBUTION OF PARTICLES IN A PARTIALLY FLUIDIZED BED

Concentration of 20-40 mesh particles, %		Air flow rate, pounds/hr-sq ft	Distance above bed entrance, inches
Inner section	Outer section		
38.3	62.6	22.9	1
29.4	60.9	22.9	2
42.5	92.0	40.9	1 $\frac{1}{4}$
35.4	95.0	40.9	2 $\frac{3}{4}$

lower curve of Figure 4 is the same as that represented by point B on Figure 2, and the flow rate read from the upper curve of Figure 4 is the same as that represented by point C on Figure 2. Thus Figure 4 may be regarded as a phase diagram, analogous to a temperature-composition diagram for vapor-liquid equilibrium. The lower curve represents the flow rate at which fluidization begins, and the upper curve the flow rate at which fluidization is complete. It can further be shown

by single particle size and overall material balances that the relative weights of the fixed and fluidized sections in equilibrium may be obtained from this diagram by use of the familiar lever rule.

It thus appeared that correlation of these data would be possible by development of a phase equilibrium analogy. However, when investigation of other systems, using a 40-60 mesh cut as the larger size, was attempted, results shown in Figure 5 were obtained. The differences in the shapes of the curves shown in Figure 4 and 5 could be attributed to two possible causes.

FIGURE 5
"PHASE DIAGRAM" RELATING BED COMPOSITION TO AIR FLOW RATE
FOR MIXTURES OF 40-60 AND 140-200 MESH GLASS BEADS

One is the fact that a 20-40 mesh cut represents a considerably wider range of sizes than a 40-60 mesh cut. Later qualitative observations seemed to indicate that the type of curve illustrated in Figure 4 is approached as a wider range of particle sizes is used. For this reason, narrower particle size cuts were used in all subsequent runs.

The second possible cause for the difference in the shape of the curve is the existence of variable electrostatic effects in the bed. There was definite evidence of such effects in the sticking of fine particles to the walls of the column. Lewis, et al.,⁽⁴⁾ have shown in their work with glass beads that static has a very significant effect on the excess pressure drop in fluidized beds. On the basis of the relationship between Figures 2 and 4, it is reasonable to assume that any variable which affects pressure drop would also affect the particle size distribution. Therefore, a program was undertaken to determine if static could be eliminated or controlled, and what effect this would have on the data.

B. Glass Beads with Humidified Air

The first attempt at elimination of electrostatic effects was by use of humidified air. For this purpose, the fluidizing air was passed through a water bubbler before entering the column. A very large number of runs was made with several different sets of particle sizes under these conditions, and the reproducibility of the data was very poor. Results appeared to vary from day to day without any apparent changes being made in operating conditions. In general, these curves were similar, at low flow rates, to the data shown in Figure 5. At higher flow rates, however, there was a sharp break in the curve, characterized by a sudden decrease in the percentage of coarse particles in the upper phase. On further increasing the flow rate, the composition of coarse particles in the upper phase again increased, but complete mixing occurred at much higher flow rates than before. The scatter in the data was worse at flow rates above the break point. Observation showed that, at flow rates below the break point, the bed consisted of a fixed and a fluidized section, as before. At flow rates above the break point, the entire bed was fluidized, but still exhibited a fairly sharp interface, with the bottom section consisting entirely of coarse particles. This is in contrast to previously observed behavior, where complete fluidization and complete mixing occurred at the same flow rate.

One of the reasons for the poor reproducibility of these data may have been variation in humidity due to changing air flow rates and temperatures in the water bubbler. This might have resulted in variable electrostatic effects. Therefore, the humidifier was placed in a constant temperature bath, and modifications were made to keep the air flow rate through the bubbler constant by bleeding the excess air off before metering. This resulted in fairly effective humidity control, and data taken under these conditions appeared for a while to be quite consistent. However, it later developed that even very slight variations in the humidity of the fluidizing air caused significant variations in the particle size distribution. This is illustrated in Figure 6, which shows two sets of data taken under conditions which were identical except for a variation of 0.5 F in the dry bulb temperature of the fluidizing air. Undoubtedly the humidity control during the course of previous runs was even poorer than this, thus accounting for the wide scatter. It is unfortunate that humidity measurements were not made during all those runs, since this variable proved to be of such significance.

An attempt was made to achieve better humidity control by bubbling the fluidizing air through various saturated salt solutions maintained at constant temperature, but this did not result in any appreciable improvement in control. In an effort to increase the conductivity of the air further, a small amount of ammonia was added to the water in the bubbler, but this did not help either.

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FIGURE 6
EFFECT OF HUMIDITY OF FLUIDIZING AIR ON PARTICLE SIZE DISTRIBUTION
FOR MIXTURES OF 30-40 AND 80-100 MESH GLASS BEADS

One further disadvantage of the use of humidified air for control of static is the possibility of surface adsorption of moisture by the particles, causing them to stick together. Experiments showed that at a relative humidity of 50 per cent, glass beads adsorb only 0.05 per cent by weight of water. However, when fluidization was attempted with air of 80 per cent relative humidity, the entire bed stuck together as one lump and could not be fluidized. It therefore seems possible that even at lower humidities sufficient moisture could be picked up by the beads to cause some sticking and give results which vary with humidity. Further evidence of this was obtained later during the course of runs made in a copper column. When the beads were left in an open container for several days during which the ambient humidity was very high, there was noticeable clumping of the beads and sticking to the walls of the column. This was almost certainly not due to static, since the column was grounded and such behavior was not normally observed under these conditions.

Because of the extreme sensitivity of the data to variations in humidity, due either to variable electrostatic effects or moisture adsorption, it was concluded that the use of humidified air was an unsatisfactory method of static control.

C. Other Attempts to Control Static with Glass Beads

Many other attempts were made to control or eliminate static electricity. A commercial destaticizer was applied to the beads, but, when used in high enough concentration to cause any visible reduction in static, the beads become sticky and did not fluidize well. Various grounding schemes to conduct static away from the column as rapidly as it was formed were unsuccessful, probably due to the low conductivity of Lucite. In an

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effort to increase the conductivity of the bed, these experiments were repeated using a glass column immersed in an oil bath at 130-150 C. In addition, copper coils were immersed in the bath to preheat the fluidizing air. This did not improve the reproducibility of the data significantly.

Several attempts were made to ionize the air in order to discharge the static electricity as it was formed. For this purpose the use of a polonium strip on the walls of the column and the use of ultra-violet radiation were tried, but the intensity of radiation was not sufficient to cause any appreciable ionization.

In order to increase the conductivity of the column, the inside wall was platinized and grounded to conduct static away as it was formed. A small vertical window was left uncoated for observation. Although the platinum surface showed little evidence of particle sticking due to static, the window became so heavily coated that observation was impossible. Since this method of attack showed some promise, a two-inch copper column was obtained, and a small vertical section cut out of it, which was replaced by a Lucite window for observation; the column was grounded to a laboratory water line. In all of these runs the fluidizing air was dry.

Some typical results are shown in Figure 7. These curves are somewhat similar in appearance to those shown in Figure 5, except that there is some dependence on overall bed composition as the beds approach a completely fluidized state. It may be that insufficient data were obtained at these flow rates during the runs shown in Figure 5 to observe this behavior. The unusual shape of the upper part of these curves is probably not due to random scatter of the data, for it was obtained consistently. These curves may be interpreted as follows. Consider, for example, the 80 per cent mixture in Figure 7. Below a flow rate of about 75 pounds per hour per square foot, the bed consisted of a fixed section at the bottom and a fluidized section on top. At a flow rate of about 75 pounds per hour per square foot, the bed was completely fluidized and almost completely mixed. On increasing the flow rate to 90 pounds per hour per square foot, the bed was still completely fluidized, but there was a larger bottom section, consisting entirely of coarse particles. Further increases in flow rate resulted in smaller bottom sections, until at flow rates of 130 pounds per hour per square foot and higher, the bed was completely mixed. A few later experiments with 35-40 mesh and 140-200 mesh particles showed that this behavior was even more pronounced in the Lucite column, indicating that static might again be causing difficulty. The effect of static charge on the walls of the column is illustrated in Figure 8, which shows the results of two sets of runs, occurring under identical conditions, one set in the Lucite column and the other in the copper column. Although building of static charge on the walls of the copper column seemed almost impossible, it is possible that a charge may have been built up within the bed since the glass beads are nonconducting.

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FIGURE 7

"PHASE DIAGRAM" RELATING BED COMPOSITION TO AIR FLOW RATE FOR MIXTURES OF 35-40 AND 80-100 MESH GLASS BEADS

FIGURE 8

EFFECT OF STATIC ON COLUMN WALLS ON PARTICLE SIZE DISTRIBUTION IN MIXTURES OF 35-40 AND 140-200 MESH GLASS BEADS

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Although these attempts to eliminate or control static electricity did not produce a final solution to the experimental difficulties, several conclusions may be drawn from them. First, the data indicate that static electricity is a critical variable in the study of particle size distribution. Secondly, control of static by humidifying the air or by increasing its conductivity through other means is not feasible. Finally, the observations made using a copper column indicated that it might be possible to conduct static out of the system as rapidly as it is formed if conducting materials were used.

D. Magnesium Particles in Copper Column

Based on these conclusions, a series of experiments was planned in which both the bed container and the bed material had a high electrical conductivity. To accomplish this, magnesium beads, obtained from the Dow Chemical Company, were fluidized in the two-inch copper column, again using dry air. This run was made prior to those described in the preceding section, that is, before the window had been cut out of the copper column. Because of the lack of visibility, the sampling procedure had to be modified slightly during these runs. It was assumed that the bed reached steady state within ten minutes, as in previous runs, and the constancy of the pressure drop readings seemed to validate this assumption. After the ten-minute period, sampling was accomplished, with the fluidizing air still on, by slowly sucking material off the top of the bed until observation from the top of the column indicated that the interface was being approached. This could be judged by observing the quality of fluidization. Another sample was then drawn to a point where no fluidization was visible; for the fixed section, sampling was very difficult, and the data showed a large amount of scatter. For this reason the curves are not shown here. However, at higher flow rates, the sampling method appeared to be satisfactory and curves very similar to the glass bead data shown in Figure 7 were obtained. A number of runs were also made using magnesium beads in the Lucite Column, but there was definite evidence of static in these runs. Subsequent investigation showed that the conductivity of the magnesium beads was not appreciably higher than that of the glass beads, probably due to the formation of an oxide coating. Thus, these runs provided no information on the effect of static charge within the bed; an attempt was made to find some other bed material of high conductivity.

E. Graphite Particles

The only material which was readily available in the desired range of particle sizes and which possessed high electrical conductivity was graphite. A series of runs were made with this material in both the copper and Lucite columns. A total of seven different sets of particle sizes were run and some typical results obtained in the copper column are shown in Figure 9. It is interesting to note that these curves are generally similar in shape to those obtained with glass beads in the copper column, except that in the case of the

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FIGURE 9
 "PHASE DIAGRAM" RELATING BED COMPOSITION TO AIR FLOW RATE
 FOR MIXTURES OF 40-60 AND 140-200 MESH GRAPHITE PARTICLES

graphite the dependence on overall bed composition appears at lower flow rates and is much more marked. Numerous attempts to correlate these data proved unsuccessful, primarily due to the unusual behavior of the systems in which 35-40 mesh particles were used. Subsequent checks of these systems showed that different data were obtained using the same particle sizes screened from different batches of graphite. Some rough measurements indicated that there may be significant variations in particle density of the graphite used, among different particle sizes in the same batch of material as well as from batch to batch. Microscopic examination definitely showed that these particles were highly irregular in shape, and that the shape factor varied with particle size, the smaller particles being more nearly spherical. In addition, there was a serious attrition problem with graphite particles. Because of this, it is felt that these data are inconclusive, even though they probably are not subject to electrostatic effects.

Although these runs could not be used as a basis for correlation of particle size distribution data, they did yield one very important piece of information. A number of runs were made first with dry air and were then repeated using humidified air. The fact that there was no significant difference between these two sets of runs indicates that when static is removed by use of conducting particles and conducting column, the data are not affected by changes in the conductivity of the fluidizing gas.

III. CONCLUSIONS

The following conclusions concerning minimum fluidizing velocity and particle size distribution in beds of mixed particle sizes have resulted from the experiments described in this report.

1. In a packed bed consisting of two particle sizes, the transition from a fixed bed to a fluidized bed occurs over a range of flow rates, in contrast to the behavior of single particle sizes where this transition takes place completely at a well-defined flow rate.

As the difference between the particle sizes becomes bigger, this transition range becomes wider, but it is always less than the range between the minimum fluidizing velocities of the two particle sizes which are present. In the range of flow rates in this transition region, the bed consists of two sections, with a well-defined interface. The lower portion of the bed is fixed and contains a higher percentage of coarse particles than the overall bed composition, while the upper portion of the bed is fluidized and contains a lower percentage of coarse particles than the overall bed composition.

2. In this transition region, as the flow rate is increased, the amount of material in the fluidized section of the bed increases while that in the fixed section decreases, and the percentage of coarse material in the fluidized section increases. The relative weights of the two sections may be calculated from their composition and the overall bed composition, applying the lever rule used in similar calculations with phase equilibrium diagrams. The compositions of the two phases in this range of flow rates appear to be independent of the overall bed composition for bed compositions between 20% and 80%.

3. The composition of the fluidized portion of the bed in this transition region is uniform, while the fixed bed section shows a radial particle size gradient, with the coarse particles segregating near the walls of the bed.

4. The flow rates at which fluidization begins, and is complete, may be determined from measurements of total pressure drop across the bed as a function of flow rate.

5. Both static electricity and adsorbed surface moisture are important variables affecting particle size distribution. The presence of either of these effects results in segregation of coarse particles at the bottom of a completely fluidized bed. Increase of flow rate under these conditions decreases the amount of segregation, and at sufficiently high flow rates complete mixing is attained. It has not been established whether this segregation occurs in the absence of electrostatic effects.

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6. Electrostatic effects may be eliminated by the use of conducting particles and a conducting column, properly grounded. The control of static by use of humidified air or other means of increasing the conductivity of the fluidizing gas does not appear to be feasible. Operation at temperatures up to 150 C is not effective in controlling static when non-conducting materials are used.

IV. RECOMMENDATIONS FOR FURTHER STUDY

Based on the results of the experiments described in this report, it is felt that further studies in this field are definitely justified, and the following recommendations can be offered:

1. The use of a conducting column and conducting particles of uniform physical properties is recommended for initial studies, in order to eliminate electrostatic effects. Such particles might be manufactured by directing a fine spray of molten copper or other metal into a vessel filled with water. Another possibility is to remove the oxide coating from magnesium or aluminum particles, and fluidize them with nitrogen to prevent re-oxidation. The narrowest possible particle size cuts should be used, and particles of irregular shape rejected. Particles should be stored in a closed dessicated container to prevent surface adsorption of moisture from air of varying humidity.
2. Data should be taken using several different solids and several fluidizing gases, or air at different temperatures, in order to evaluate the effect of solid density and physical properties of the gas.
3. Further studies should be made of radial particle size distribution in the bottom section of these beds. Such information might serve as a basis for a correlation between particle size distribution and pressure drop measurements. For this purpose, some knowledge of void fraction would be necessary. This may be estimated from measurement of the height and weight of both sections. Because of the oscillation of the interface, especially at higher flow rates, such measurements might not be very accurate. If it appears to be necessary, more exact measurement of void fractions might be made using X-ray absorption. Grohse⁽²⁾ has demonstrated this technique.
4. Some means should be found for measurement of static charge in fluidized beds. One of the techniques described by Dallavalle⁽¹⁾ might be adapted for this purpose. He has described measurements of static charge on dust clouds of various finely divided materials. With such a technique, the effect of static electricity could be evaluated by running a series of experiments on non-conducting materials. Note that it would be necessary to measure the charge both on the wall of the column and within the bed.

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5. It would also be of considerable interest to determine the effects of static charge on the fluidization characteristics of single particle sizes. It seems possible that some of the anomalous fluidization data which have appeared in the literature might be explained on the basis of variable electrostatic effects.

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