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The Use of a Helium Bubble Generator to Evaluate the
Role of Entrained Airflow in Dust Generation

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Introduction

Falling solids induce air motion. When a slug of powder falls, a velocity gradient exists between the falling solid and the air through which the powder is falling. As a result, part of the kinetic energy of the falling solid will be converted into air motion. This air motion has been termed an induced or entrained airflow. Dennis and Bubenick¹ developed equations to predict the amount of induced airflow for a continuous stream of free falling powders. These equations were developed to estimate local exhaust ventilation requirements during powder handling operations. Unfortunately, these equations do not provide insight into the role of the induced airflow in aerosol generation by free falling powders.

A study of dust generation by free falling powders in a test chamber prompted an interest in the role of induced airflow in dust generation. When small quantities of powder were dropped in this test chamber, particles with an aerodynamic diameter of 20 micrometers were arriving at a height of 150 cm about 100 seconds after the powder was dropped. In the absence of air motion, gravitational settling would have eliminated particles larger than 20 micrometers from the top half of the test chamber. The presence of particles larger than 20 micrometers in the top half of the test chamber indicates that the air in the test chamber is being mixed. This mixing could be due to either random air motion or to the airflow induced by the free fall of the powder.

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In order to resolve this issue, a helium bubble generator (SAI Bubble Generator, Model 33, Sage Action, Ithaca, NY) was purchased. The helium bubble generator produces neutrally buoyant bubbles which have diameters between 2 and 5 mm. Because these bubbles are neutrally buoyant, they should have an aerodynamic diameter of nearly zero and closely follow the airflow in the test chamber. The air motion in the test chamber can be studied by illuminating the bubbles and video taping their motion. In order to determine whether random air motion or induced airflow is responsible for the transport of particles larger than 20 micrometers, the motion of the bubbles was videotaped while a mass of material was dropped in the test chamber. The air motion before the BB's (4.5 mm diameter steel shot used in air guns) were dropped is caused by random air movement in the test chamber. The change in air motion in the test chamber is caused by the free fall of the material.

Experimental Evaluation of an Induced Airflow.

The helium bubbles were used to study the airflow patterns caused by dropping "powders" in the large test chamber shown in Figure 1. The helium bubbles were released into the top of the test chamber and allowed to settle through the "egg-crate" flow straightener. In order to allow the material to pass through the flow straightener, a square hole was cut in the center of the flow straightener. The bubbles are illuminated by a light source (SAI Portable Light System) which is under the test chamber. The floor of the test chamber

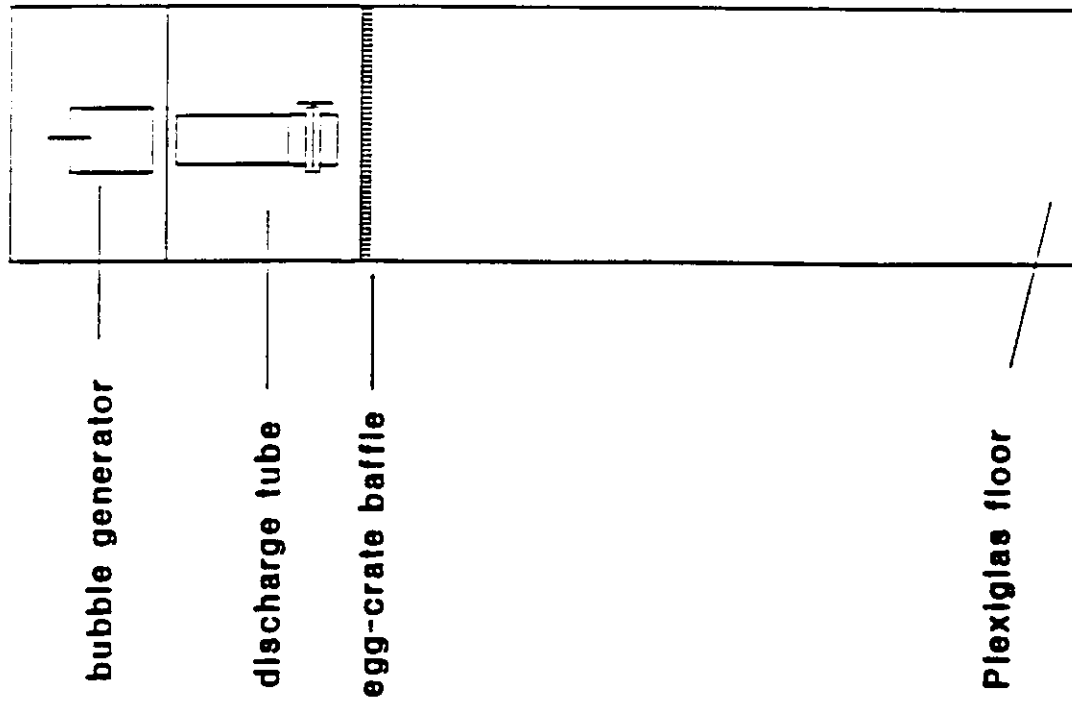
is transparent Plexiglas. When powder is dropped in this test chamber, the motion of the bubbles is obscured by light scattered by the aerosol. In order to overcome this problem, BBs were discharged through a trap door mounted at a height of 150 cm above the floor of the test chamber. The diameter of the slug of BB's was 12.5 cm and the thickness was 2 cm. The volume of the slug was estimated to be 250 mL. The helium bubbles were continuously released into the test chamber during the experiment.

The displacement of the helium bubbles was used to measure the air velocity before and after the drop into the test chamber. The test was performed twice under different lighting conditions. In the first test, the light beam illuminated the center of the chamber. In a second test, the light beam illuminated the far wall of the chamber. The bubbles produced by the generator were not neutrally buoyant, but were observed to settle at a rate of 4.7 cm/sec. The measure displacement divided by the exposure duration was corrected by 4.7 cm/sec to estimate the actual velocity. The following table summarizes the results:

Table 1
Velocity Measurements Based Upon Displacement of the Helium Bubbles

	average velocity	direction	coefficient of variation
before drop	4.7 cm/sec	down	20%
center, 0-2 seconds after drop ^a	5.8 cm/sec	down	40%
back wall, 0-2 seconds after drop ^a	11.2 cm/sec	up	40%

a. These measurements were adjusted for the average settling velocity of the helium bubbles which was 4.7 cm/sec.



NOTES

- The test chamber is 200 x 66 X 66 cm.
- Directly under the discharge tube, a 20 X 20 cm square hole was cut in the egg crate.
- The Plexiglas floor had 20 equally spaced spaced, 1 cm diameter holes to allow air to flow out of the test chamber.
- The air flow out of the bubble generator was 50 lpm.

[] -----light source

mirror

Figure 1. Test Chamber for Bubble Generation

Dropping the material in the test chamber caused a circular airflow pattern. The air flows down the center of the chamber and up the wall of the chamber. After the drop, the average velocity measured near the back wall of the test chamber was 11.2 cm/sec. This would convey particles with an aerodynamic diameter of up to 60 micrometers. Because the quantity of entrained airflow is known to increase with decreasing particle size¹, dropping a powder with a smaller particle size than the BB's will result in higher air velocities. When a similar volume of powder is dropped into a box in the test chamber, the videotape revealed that plume of dust moves upward at a rate of about 30 cm/sec, which would be able to convey particles in excess of 100 micrometers.

Figure 2 contains a series of one-second time exposures. Before the slug of steel shot is dropped, the bubbles fall vertically towards the bottom of the test chamber. In pictures taken 2-4 seconds after the steel shot was dropped, the bubbles appear to be flowing in a random motion. This motion disappears after several minutes.

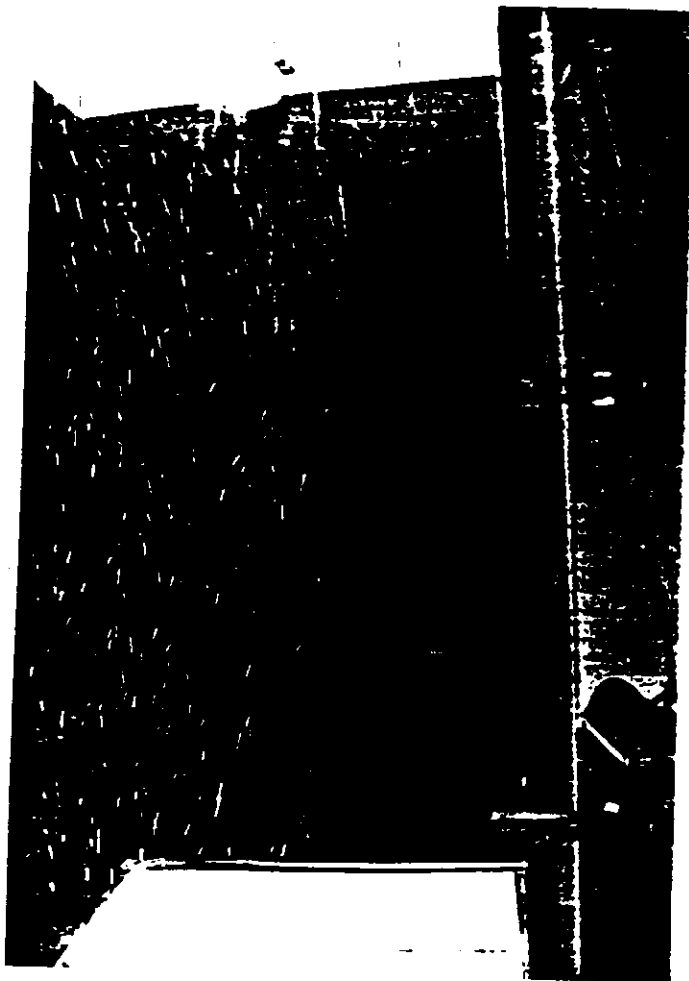


Figure 2a.



Figure 2b.

Figure 2. One second time exposures of helium filled bubbles before and after the BB's are dropped. a) before the BB's are dropped. b) while the BB's are dropped, c) one second after the BB's are dropped, and d) about 4 seconds after the BB's are dropped.

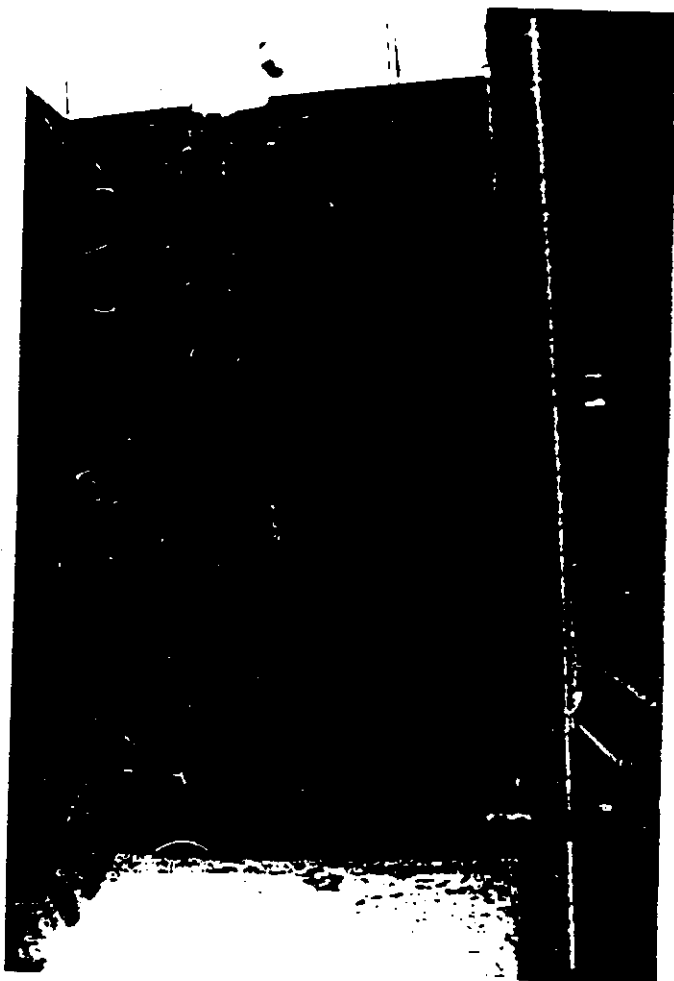


Figure 2c.

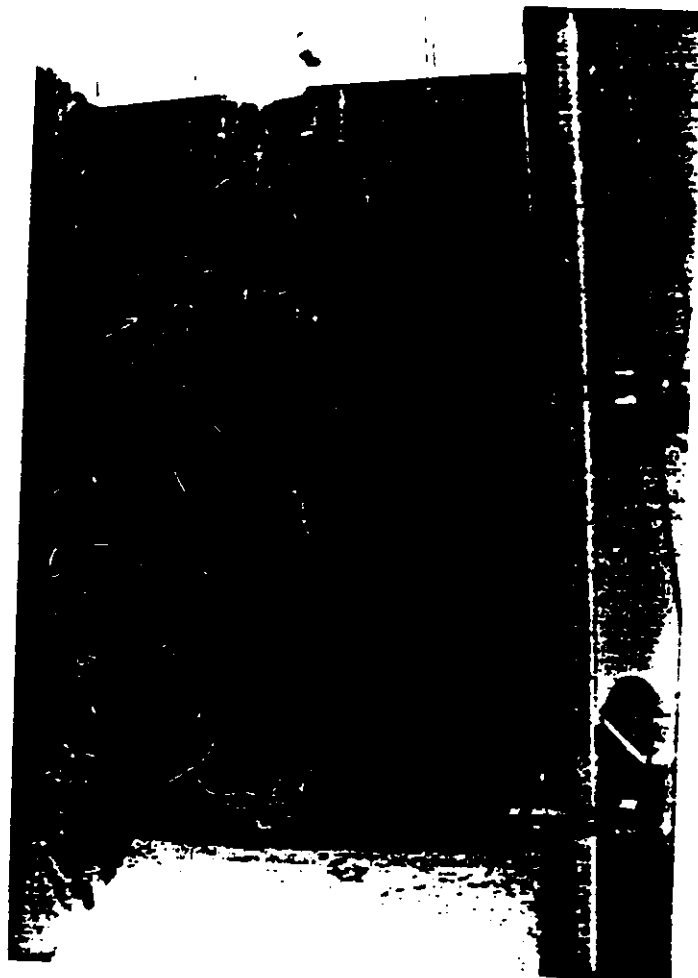


Figure 2d.

Figure 2. One second time exposures of helium filled bubbles before and after the BB's are dropped. a) before the BB's are dropped. b) while the BB's are dropped, c) one second after the BB's are dropped, and d) about 4 seconds after the BBs are dropped.

Theoretical Estimate of Induced Airflow

The amount of theoretically expected air motion can be estimated by assuming that the falling solid does work on the air in the test chamber, and all of this work is converted into kinetic energy. This is the same assumption that Dennis and Bubenick¹ used to theoretically estimate the quantity of entrained airflow for a falling stream of powders. The amount of energy transferred from the BBs to the air is computed by assuming that the BB's fall as a mass resembling a flat disk. The drag force F_D is computed:

$$F_D = f \rho v_s^2 A;$$

Where:

A - frontal area of the powder.

v_s - velocity of falling solid.

f - fanning friction factor (0.44 for Reynolds numbers larger than 1000), and

ρ - density of air.

Because the drag force is much smaller than the object's weight, it can be neglected and the the value of v_s was estimated as:

$$v_s = (2gh)^{0.5};$$

Where:

g - gravitational acceleration (980 cm/ sec²), and

h - distance through which the powder has fallen.

The work (W) done by the drag force on the fluid can be estimated from:

$$W = \int_0^H F_D dh$$

$$W = Af\rho 2g \int_0^H h dh = Af\rho gH^2.$$

Where:

H = total distance that the powder falls

Assuming that all the work done by the drag force on the fluid is converted into kinetic energy, the following equation can be used to estimate the average fluid velocity in the test chamber:

$$W = 0.5\rho v_f^2 V ;$$

Where:

v_f = average fluid velocity in the test chamber.

V = the volume of the test chamber.

Solving for v_f :

$$v_f = (2AfgH^2/V)^{0.5}$$

For the experiment described in the previous pages, the estimated value of v_f is 75 cm/sec. This is much higher than the values listed in Table 1.

Dennis and Bubenick observed that theoretically predicted induced airflows overestimate the observed induced airflows by a factor of 3. The disagreement here is greater. Because the air is circulating close to the chamber walls, the air's kinetic energy is probably being dissipated at the test chamber's wall at a larger than anticipated rate. Furthermore, the total work which the falling solid did on the air was estimated to be a mere 0.03 calories. This is a very small quantity. When this fluid kinetic energy is converted to heat, it would cause a the air temperature in the test chamber to increase by 0.0001 °C.

Discussion and Conclusions

The average settling velocity of the Helium bubbles was 4.7 cm/sec with a standard deviation of 1 cm/sec. Because the air velocity is estimated from the difference between the bubbles' velocity measured before and after the solid is dropped, an air velocity of 2 cm/sec would barely exceed the statistical errors associated with this difference in air velocities. As a result, further data was not taken with the bubble generator under conditions which would result in lower air velocities. These conditions included lower drop heights and a smaller number of EB's dropped.

Based upon the data collected with the helium bubble generator, two conclusions can be stated:

1. There are no extraneous airflow patterns in the test chamber. The transport of aerosol in the test chamber is due to the air motion caused by the fall of the solids in the test chamber.
2. The bubbles followed the fall of the solid. This motion appeared to persist for only a few seconds after the fall of the solid. The air motion would transport any dust generated during and at the end of the fall. This motion initially appears to be direct convection rather than a random air motion. However, the variability of the air motion was increased by the falling solids, which indicates some turbulence.

These results show that a small quantity of solid can entrain enough air flow to transport particles with an aerodynamic diameters greater than 40 micrometers. In the industrial environment, there is probably far more random air motion than is present in a test chamber. This suggests that dustiness testers should be designed to collect whatever particles are generated in the dustiness test up to a size of at least 40 micrometers.

References

1. Dennis, R. and D. Bubenick: Fugitive Emissions Control for Solid Materials Handling Operations, Journal of the Air Pollution Control Association 33:1156-1161. (1983).
2. Franke, J.E., F. A. Wadden and P. A. Scheff: Some Observations of Eddy Diffusivities in Industrial Settings. Presented at: 1989 American Industrial Hygiene Conference, May 16-21, 1989, St. Louis Mo. (1989).