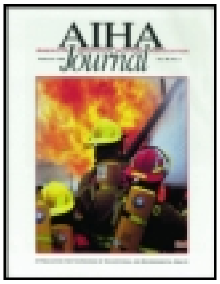

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Factors Affecting the Heubach and MRI Dustiness Tests

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Factors Affecting the Heubach and MRI Dustiness Tests*

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The effect of test parameters upon material dustiness measured by the Heubach dust measurement appliance and the MRI dustiness tester was studied. The users of these tests can alter test parameters such as flow rate, sampling time, mass of material tested, bulk density, and vibrator setting. The effect of these parameters upon the aerosol produced in the dustiness tester was experimentally studied. All of the parameters affected in a complicated manner, the amount of dust and the size distribution of the dust generated during these tests. Therefore, dustiness test results should not be adjusted for variations in test parameters. The users of dustiness tests need to carefully control dustiness test parameters in order to have reproducible dustiness tests.

Dustiness tests are laboratory bench procedures which are used to compare the propensity of different materials to release dust into the air. These tests involve a method of generating airborne dust coupled to a method of quantifying the amount of airborne dust which is generated during the test. Potentially, these tests are of interest to both industrial hygienists and powder producers. Powder manufacturers develop and use these tests to evaluate their products. Although the extent to which dustiness tests are used by manufacturers is unclear, there is enough interest for the British Occupational Hygiene Society to have formed a working group on dustiness estimation and to have published a report on dustiness tests.[1] At least one powder manufacturer uses dustiness test results to market a low-dust form of a product.

Because dustiness tests are potentially very useful, National Institute for Occupational Safety and Health (NIOSH) researchers, with support from the Office of Toxic Substances of the U.S. Environmental Protection Agency (EPA), are studying two dustiness tests in the field and in the laboratory. These tests are the Midwest Research Institute (MRI) dustiness test (MRI, Kansas City, Mo.) and the Heubach Dust Measurement Appliance (Heubach, Langelsheim, West Germany). Field trials show that in some cases there is a correlation between worker dust exposure and dustiness test results.[2] The present study was done to evaluate the effect of operational parameters upon dustiness test results. In the Heubach test, the flow rate, sampling time, and mass tested can be varied by the user. In the MRI dustiness test, the bulk density, sampling rate, sampling time, and vibrator intensity can be varied. In order to have reproducible dustiness tests, these test parameters may need to be controlled. The objective of this study is to evaluate whether these parameters do.

In order to understand the procedures used to evaluate the dustiness tests, one needs to understand how these two dustiness tests are normally conducted. Both tests are relatively straightforward. In the Heubach test (Figure 1), a known mass of powder is placed in the dust generator which rotates at 30 rpm. This dust generator has three baffles which repeatedly lift the powder to the top, and the powder free-falls through about 14 cm to the bottom of the generator. Air flows through the shaft between the dust generator and the motor and into the dust generator. This air transports the dust through the settling chamber and onto the filter which collects the airborne dust. The weight gain of the filter after blank correction is the mass of dust generated. The Heubach dustiness index is 100 times the mass of dust generated, divided by the mass of powder tested. There are no standard operating conditions for this dustiness test. The user selects the mass of material to be tested, the test time, and the flow rate through the tester so that a measurable quantity is collected on the filter.

In the MRI test (Figure 2), powder is poured out of a metal beaker, and the resulting airborne dust is collected on a 47-mm glass fiber filter at the top of the test chamber. The beaker is filled level with powder and the weight of the powder is recorded. The beaker is placed in a shaft which rotates at 5.5 rpm. When the test is started, the beaker rotates until it is completely inverted and the powder has emptied from the beaker. The resulting airborne dust is collected by drawing air through a preweighed filter at a flow rate of 10 L/min. After 10 min, the vacuum pump is turned off and the filter is weighed. The weight gain of the filter, after blank correction, is the mass of dust generated during the test. Dustiness can be computed as the milligrams of dust

*Disclaimer: Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health. This work was supported in part by the U.S. Environmental Protection Agency through interagency agreement DW75931706-01-0.

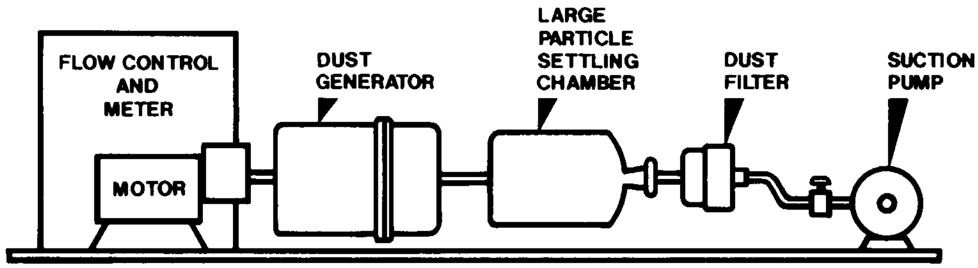

Figure 1—Heubach Dust Measurement Appliance.

generated per kilograms of powder tested. The user of this test can easily vary the flow rate, the vibrator setting, and the bulk density of material being tested. In the field study mentioned, a sampling rate of 10 L/min and a sampling time of 10 min were used.

PROCEDURES

The operational characteristics of the dustiness tests were studied by varying the parameter of interest and measuring the change in the mass and size distribution of the test material which would be collected on a filter. The test material was a powdered limestone (T11 from Franklin Limestone, Nashville, Tenn.), which has a mass median diameter of 5 μm as measured by a SediGraph (Micromeritics, Norcross, Ga.). This instrument sizes particles based upon settling velocity. According to the SediGraph, 95% of the mass of this material is made up of particles having diameters less than 17 μm.

In order to obtain size-dependent results, the filter and filter holder on the dustiness tester were replaced with a TSI Diluter (model 3302) and an APS model 3310 Aerodynamic Particle Sizer (TSI Incorporated, St. Paul, Minn.).[3,4] This necessitated special arrangements for introducing the sample into the APS diluter. For both the Heubach and the MRI dustiness tests, the aerosol flows through the TSI Diluter (model 3302) and model 3310 Aerodynamic Particle Sizer. The diluter was used to reduce the aerosol concentration into the APS so that coincidence effects in the APS are minimized.

The APS consists of a sensor, which measures the aerodynamic diameter of individual particles, and a host personal computer which is used to control and operate the sensor. The sensor was calibrated against polystyrene latex spheres at the factory. At the command of the personal computer, the APS determines the aerodynamic size of individual particles by measuring their transit time as the particles exit from an accelerating orifice. Shortly after the particles exit from this orifice, they pass through two parallel beams of light from a laser. A photomultiplier tube is used to detect the light scattered by the particles as they cross the two beams. The transit time between the two beams is measured by two timers. One has a resolution of 2 nsec and the other has a resolution of 66 nsec. The latter timer did not respond to the limestone aerosol, limiting the size analysis to diameters between 0.5 and 17 μm.

The data obtained from the APS did not need to be corrected for the concentration of background aerosol in the test room. The background concentration of less than 0.5 particles/cm^3 is small in relationship to the concentrations produced during the tests which exceeded 1000 particles/cm^3.

Heubach Tester

The connection between the Heubach dustiness tester and the APS is shown in Figure 3. Instead of placing the filter holder into the outlet of the settling chamber, a 2-cm diameter pipe was placed into the outlet of the settling chamber. An airflow of 5 L/min is drawn through the APS. Additional airflow is obtained by using calibrated critical flow orifices to draw air through the bottom of the connector assembly.

In the test stand for the Heubach dustiness tester, elbow losses can occur because of the inertial impaction of particles on the elbow walls. The penetration of particles with an aerodynamic

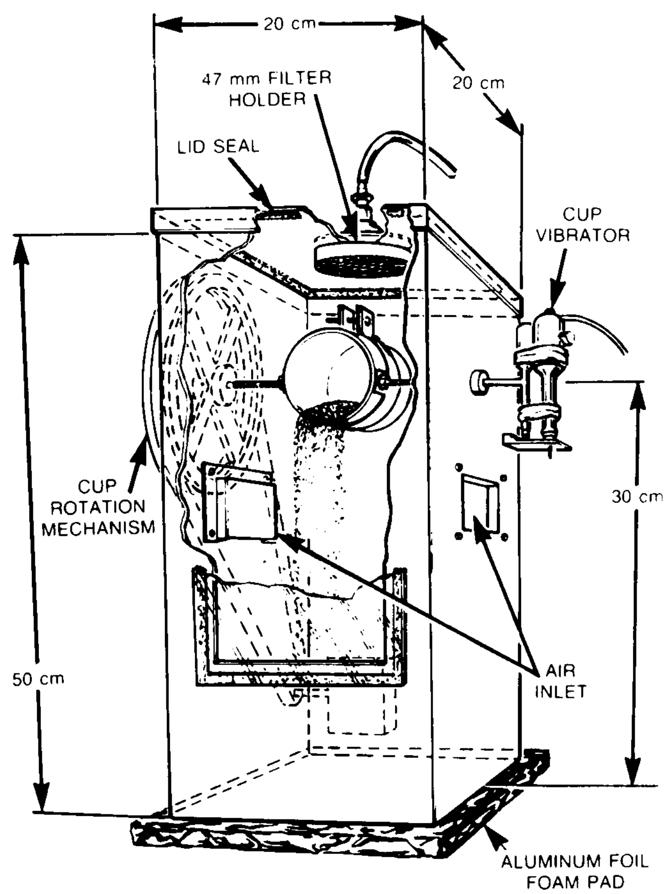

Figure 2—MRI dustiness tester.

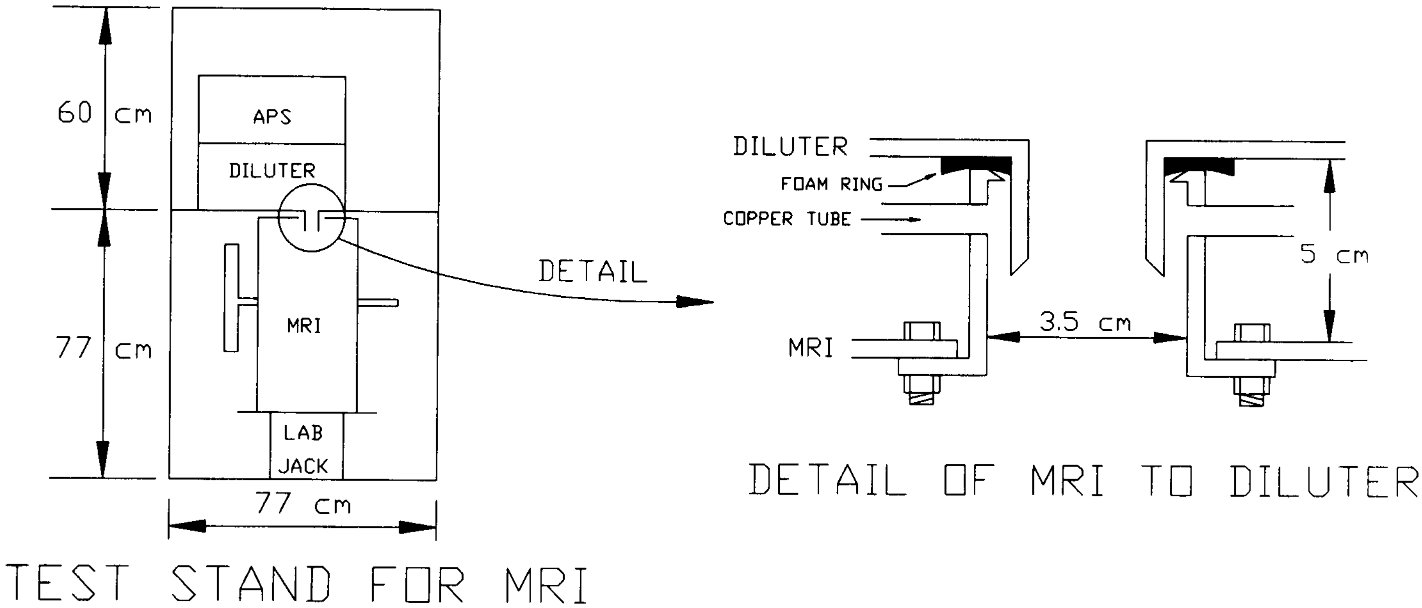

Figure 3—Schematic of connection between Heubach tester and APS diluter.

diameter of less than 25 μm was calculated to be better than 95% at the maximum flow rate of 20 L/min.[5]

In order to evaluate the effect of flow rate upon dustiness tester performance, 20 g of limestone was placed in the dust generator, and the Heubach dustiness test was conducted at total flow rates of 5, 10, 15, and 20 L/min. The sampling time was 5 min. The total airflow through the sampling train, the APS airflow through the sampling train, and the dilution airflow were checked for each run with a digital flow meter (Kurz, Model 1040, Carmel Valley, Calif.). Flow rates were maintained within 2% of the nominal flow rates.

In order to evaluate the effect of sampling time upon the cumulative mass of dust which would be collected on a filter, the APS was used to collect a series of sequential 15-sec samples at flow rates of 5, 10, 15, and 20 L/min. The computer required 5 sec between samples to process the data and store the data on the computer's fixed disk.

To evaluate the effect of mass upon Heubach dustiness test results, the tests were conducted with different masses of powdered limestone. These tests were conducted for a period of 5 min at a flow rate of 5 L/min. Because this would result in concentrations which were too high for the APS to measure without coincidence effects, the amount of mass collected on the filters was determined gravimetrically. The filter weighings and all the dustiness tests were conducted in a room where the temperature and humidity were controlled to within ±1°C and ±2% relative humidity. The test conditions for the Heubach dustiness test are summarized in Table I.

TABLE I
Parameters for Heubach Dustiness Test

Parameter Studied	Levels in Experiment
Flow rate	5, 10, 15, 20 L/min
Sampling time	15-sec intervals
Mass	10, 20, 40, 80, and 160 g

MRI Test

Figure 4 illustrates the arrangement for using the APS to quantify the aerosol produced in the MRI dustiness test. The TSI Diluter and APS were set inverted on the test stand. The filter holder on the MRI tester was replaced with a special coupler. This coupler has an inside diameter of 3.5 cm. The inlet to the APS diluter sets in the middle of the coupler. The airflow into the diluter is 5 L/min. Additional flow is obtained by drawing air through the tubes which are set in the side of the coupler. For a total airflow of 27 L/min into the coupler, the maximum error caused by anisokinetic sampling was estimated to be less than 2% for particles with an aerodynamic diameter of 17 μm.[6] This error decreases with particle size.

MRI dustiness tests were conducted using the limestone. Separate experiments were conducted to evaluate the effect of flow rate, bulk density, and vibrator setting upon the mass and size distributions of aerosol generated during the dustiness test procedures. These experiments were conducted to measure the

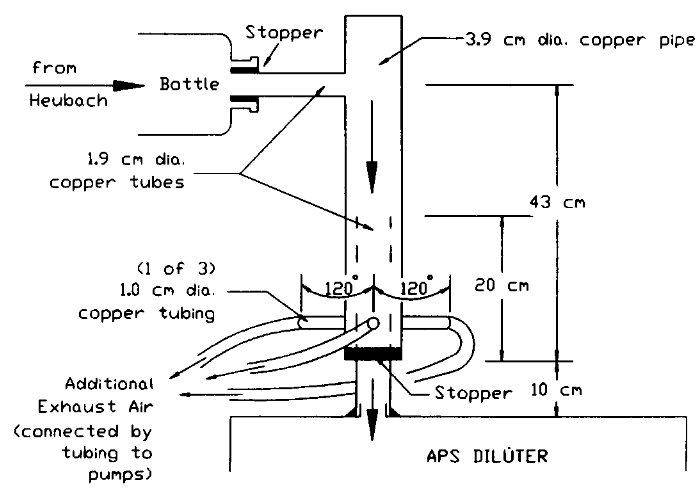

Figure 4—Schematic of test stand for MRI dustiness tester.

TABLE II
Parameters for MRI Dustiness Test

Parameter Studied	Levels in Experiment
Flow rate	5, 10, 20, 27 L/min
Sampling time	20-sec intervals
Bulk density	0.73, 0.875, 0.99, and 1.07 g/cc
Vibrator setting	Off, 1, 3, 5

effect of deviations from normal test conditions on the size distribution and mass of airborne dust produced in these experiments. The normal flow rate, sampling time, and vibrator setting for the MRI tester are, respectively, 10 L/min, 10 min, and a vibrator setting of 3. The "normal" bulk density of 0.73 g/cc was simply the mean bulk density obtained by pouring the powder into the beaker. This process was remarkably consistent; the standard deviation of this process was 0.02 g/cc based on 14 replications. The test conditions are summarized in Table II. The flow rates were varied by changing the amount of air drawn through the side coupling collar. During the flow rate tests, a vibrator setting of 3 was used, and the material's bulk density was not altered from its typical value of 0.73 g/cc. During the tests involving the vibrator, the vibrator setting was varied by changing the setting, and the bulk density and flow rate were held constant at 0.73 g/cc and 10 L/min.

In order to test the effect of bulk density upon the MRI dustiness test results, the limestone's bulk density was increased. After placing 500 g of limestone in a 1.5-L metal beaker, the beaker was repeatedly dropped from a height of 2 cm. This caused the limestone to be compressed. The metal beaker containing the compressed limestone was transferred to the dustiness tester. The MRI dustiness test was conducted on the limestone which had bulk densities of 0.875, 0.99, and 1.07 g/cc. The bulk density was the mass of material in the beaker divided by the volume of the beaker. In addition, an MRI dustiness test was conducted on the limestone, which was placed in the 250-mL metal beaker without any effort to increase the bulk density of the material beyond 0.73 g/cc.

The effect of sampling time upon the amount of material which would be collected on a filter was evaluated at flow rates

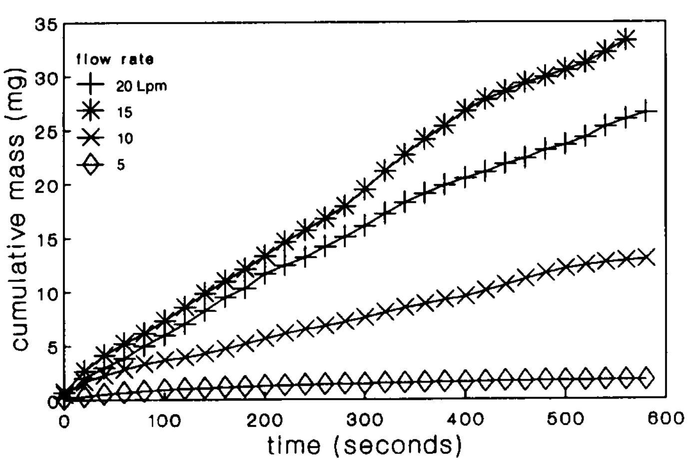

Figure 5—Cumulative mass collected (milligrams) for different flow rates (L/min) through the Heubach dustiness tester.

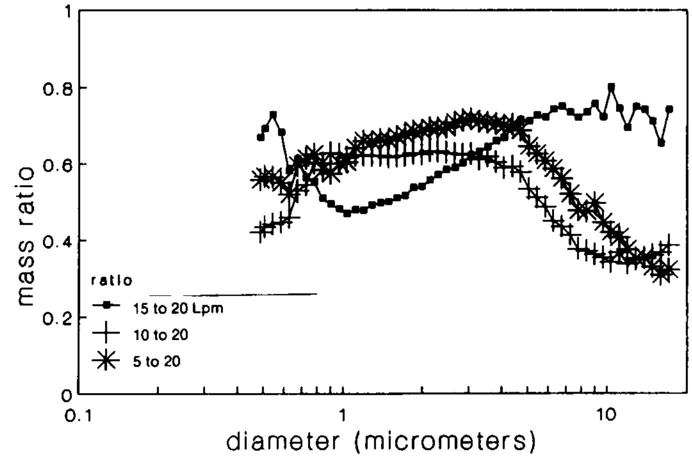

Figure 6—As a function of aerodynamic diameter, the effect of flow rate upon relative amounts of dust size collected in Heubach dustiness tester.

of 5, 10, and 18 L/min. Instead of using the APS to collect a single 10-min sample, it was used to collect a series of sequential 20-sec samples. Between each sample, the computer used 6 sec to process the data and store the data on a floppy disk.

RESULTS

Heubach Test

The effect of flow rate and sampling time upon the Heubach dustiness tester was evaluated by varying the flow rate and conducting Heubach dustiness tests on 20 g of limestone. The Heubach dustiness test was operated at flow rates of 5, 10, 15, and 20 L/min. The results of this experiment are shown in Figures 5 and 6. Figure 5 shows cumulative mass of aerosol that would be collected on a filter as a function of time. Apparently, the amount of mass which would be collected on a filter varies with the flow rate and the sampling time. At flow rates of 5 and 10 L/min, the mass collected on a filter does not appear to be increasing in direct proportion to the length of sample. Figure 6 compares the size distribution produced at 20 L/min to the size distributions produced at 5, 10, and 15 L/min for a 300-sec sample. The dependent variable in Figure 6 is the ratio of particles collected on a filter at the specified flow rate to particles collected at 20 L/min. Because at least 200 particles were counted in each channel of APS size distribution data, the two standard deviation limits for the ratios presented in Figure 6 are smaller than ±20%. Clearly, the size distributions obtained at 15 and 20 L/min are different from the size distributions produced at 5 and 10 L/min.

Figure 7 shows that the mass of material tested affects the Heubach dustiness index. The relationship between the amount of mass collected and the dustiness index is not a simple linear relationship. The amount of dust collected on a filter increases with tester loading until a plateau is reached. This results in a maximum in the dustiness index which is presented in Figure 7. A pooled coefficient of variation based upon replicate tests was computed to be 8.5%. The Tukey-Kramer multiple comparison test was used to evaluate the significance of the difference between dustiness tests conducted at different loadings at an overall level of confidence of 95%.[7] The differences between dustiness test

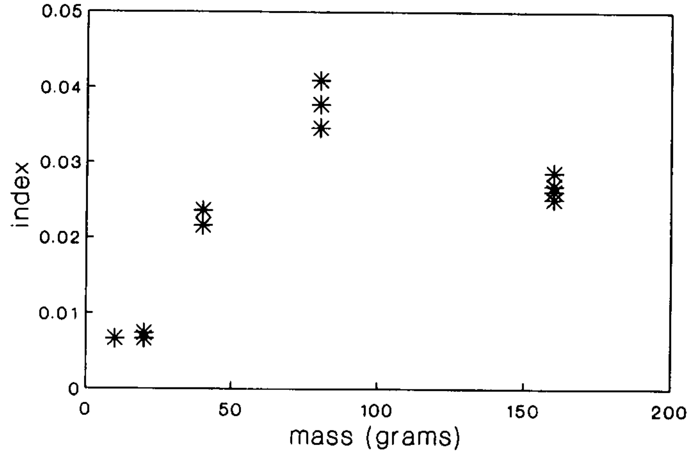

Figure 7—Heubach dustiness index as a function of mass.

results at 10 and 20 g, and at 40 and 160 g, were not significantly different from each other. All other differences between loadings were significantly different.

MRI Dustiness Test

To evaluate the effect of flow rate and sampling time upon the MRI dustiness tester results, limestone was used to conduct MRI dustiness tests at flow rates of 5, 10, 19.6, and 27 L/min. Figures 8 and 9 show the effect of flow rate upon the mass collected on a filter and upon the relative size distribution of the aerosol produced by the dustiness tester. In Figure 8, the amount of material which would be collected on a filter levels off after 5 to 6 min. Clearly, a 10-min sampling time is sufficient to allow the airborne dust produced in the test to be collected on the filter. The flow rate also affects the mass of material collected. It does not appear to change the size distribution when the flow rate is 5, 10, or 27 L/min. At a flow rate of 19.6 L/min, there is some increase in the number of particles which would be collected on a filter for particles between 10 and 17 μm in size. For particles between 1 and 10 μm, more than 100 particles per channel were counted by the APS. Between 20 and 40 particles were counted, however, by the APS in channels corresponding to sizes larger than 12 μm. As a result, the 95% confidence interval for the ratios was approximately ±40%. At a flow rate of 27 L/min, the APS counted only 20 particles in the channel for 17.3 μm. The 95% confidence interval for the ratio for 19.6 to 27 L/min would be ±54%. Because of the small number of counts, this difference in the distribution is not significant.

Figures 10 and 11 illustrate the effect of bulk density on the mass of material collected on a filter during the MRI test. In Figure 10, increasing the bulk density from 0.73 to 1.07 g/cc significantly decreases the number of particles between 5 and 17 μm which will be collected on a filter. This causes the MRI index to decrease with increasing bulk density (Figure 11). Increasing the bulk density appears, however, to increase the number of particles in the 1 to 5 μm range. The time required to empty the beaker also increased with increasing bulk density. At a bulk density of 0.73 g/cc, the beaker empties in 20 to 30 sec. At bulk densities of 0.875 and 0.99 g/cc, 32 and 34 sec, respectively, were required to empty the beaker. At a bulk density of 1.07 g/cc, however, 60 sec was required to empty the beaker. Altering a material's bulk density can affect the cohesion of a powder and the amount and size distribution of the dust which is generated during the MRI dustiness test.[8]

The vibrator setting on the MRI dustiness test can be varied. In order to determine whether this setting can affect dustiness test results, dustiness test were conducted on the T11 limestone with various vibrator settings. The settings were: Off, 1, 3, and 5. Figure 12 shows that the vibrator setting does not affect the relative size of the dust generated. When the vibrator is not used, the amount of airborne dust collected on the filter increases for the entire size range in Figure 12. Based upon a minimum number of counts per channel of 30 for a vibrator setting of 3 and a minimum number of counts per channel of 100 when the vibrator was not used, the 95% confidence interval for the ratio is ±40% and the difference is concluded to be significant over the entire size range. The mass of generated dust increased from 1.0 to 2.0 milligrams when the vibrator was turned off.

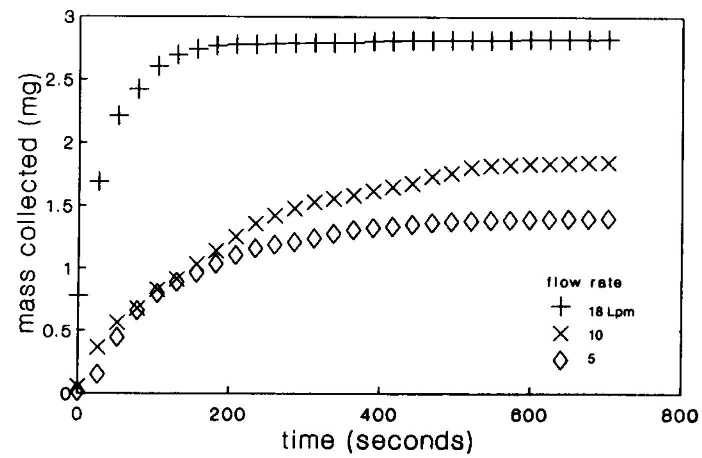

Figure 8—Cumulative mass collected (milligrams) for different flow rates through the MRI dustiness tester.

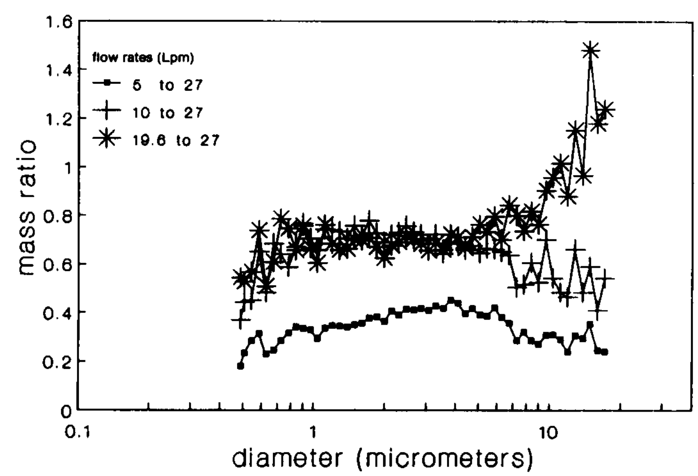

Figure 9—As a function of aerodynamic diameter, the effect of flow rate upon the relative amounts of dust collected during MRI dustiness test.

DISCUSSION

Heubach Dustiness Test

For the Heubach dustiness tester, airflow rate affects the size distribution and mass of material generated. As the airflow rate increases, larger particles are transported through the tester, which increases the mass of material which would be collected. A light beam was used to visualize the airflow patterns in the large particle settling chamber. The airflow appeared to expand as it entered the settling chamber, and this flow appeared to degenerate into turbulence. This suggests that the settling chamber is back mixed and some particles larger than the upper cutoff of the APS may be collected.

MRI Test

For the MRI tester, particles as large as 17 μm are transported to the top of the dustiness test chamber, even at airflows as low as 5 L/min. At such a low flow rate, the nominal velocity toward the top of the test chamber is 0.2 cm/sec (the terminal settling velocity for a particle of 8.0-μm aerodynamic diameter). This situation suggests that the airflow generated by the falling powder or wakes caused by the sample airflow in the MRI dustiness tester affect the manner in which dust is transported to the filter in the top of the test chamber.

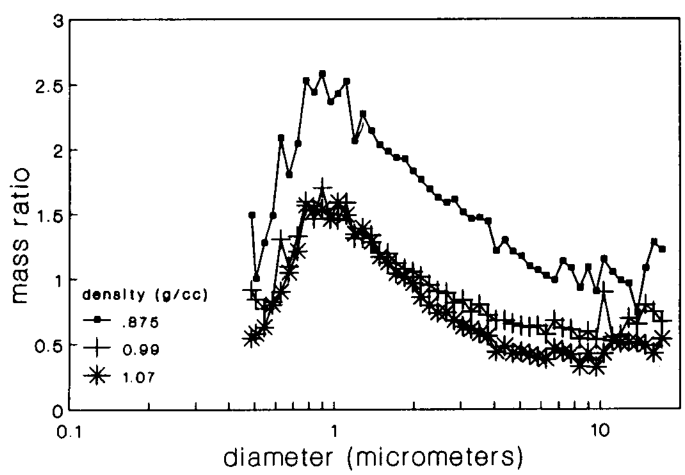

Figure 10—As a function of aerodynamic diameter, the effect of bulk density upon the relative amount of dust collected during MRI dustiness test.

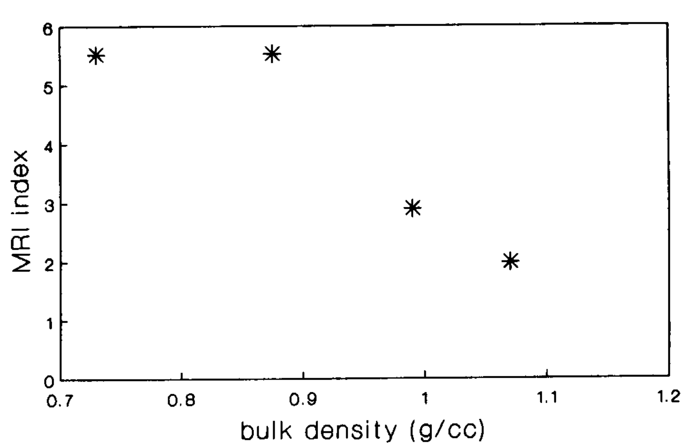

Figure 11—MRI index as a function of bulk density.

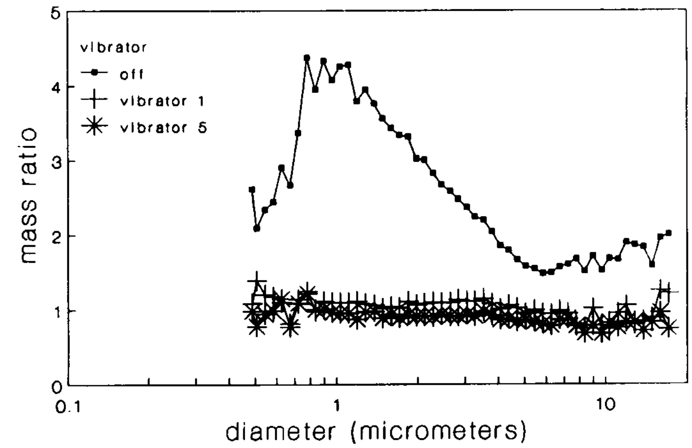

Figure 12—As a function of aerodynamic diameter, the effect of vibrator setting upon the relative amount of dust collected during the MRI dustiness test.

For the MRI dustiness tester, the use of the vibrator appeared to alter the manner in which the material came out of the cup. When the vibrator was not used, the powder appeared to flow out of the tester in lumps. Essentially, the mass flux of the powder was reduced and the amount of dust generated increased. This is consistent with the observations of Cheng.[9] He observed that on a mass basis, dust generation increased with decreasing mass flux. When the bulk density of the limestone was increased, however, the time to empty the beaker increased and the amount of dust generation decreased. As bulk density increases, the magnitude of the interparticle forces of adhesion are known to increase.[8] As a result, less dust is generated. This situation illustrates that dust generation is a complicated phenomenon.

The data presented in this paper show that the dustiness test parameters affect the amount and size distribution of the dust produced during this test. The manner in which these changes occur is complicated, and variables such as the mass of material tested and the flow rate should not be used to normalize test results. For example, changing the mass of solid tested in the MRI test changes the size distribution and mass of dust produced during this test. These changes will be different for every material because the interparticle forces of adhesion between particles change. For both tests, changing the flow rate changes the size distribution of the dust measured on this test. The magnitude of this effect will also vary from material to material. Changing the flow rate of both the Heubach and MRI dustiness tester affects the size distribution of the dust produced in the test. Because a change in the operational parameter of a test has a complicated effect upon the test results, dustiness test results should not be normalized to adjust for differences in variables such as mass tested and flow rate. Perhaps, these results should simply be reported as the mass of dust produced at the reported test conditions.

RECOMMENDATIONS

For the Heubach dustiness test, airflow rate, sampling time, and mass of material tested all need to be controlled. The airflow rate changes the size distributions and amounts of the airborne dust which are produced during the test. The airflow rate changes the transport of airborne dust through the Heubach dustiness tester. Doubling the sampling time does not always result in a doubling of the mass collected at flow rates of 5 and 10 L/min. The Heubach dustiness index varies with the mass charged into the tester. Therefore, these variables need to be controlled to within about 5%.

For the MRI dustiness tester, the user must strictly adhere to the test procedures. Because the mass of material collected reaches a plateau before 10 min, a 10-min sampling time is concluded to be adequate. The airflow rate affects the mass and size distributions of the dust which will be collected on the filter. Therefore, this parameter should be controlled to at least 5%. The bulk density of the powder can affect the mass and size distributions of the dust measured during the test. Furthermore, bulk density is known to affect the force of adhesion between particles. Therefore, care should be taken to avoid compressing the powders while handling the bulk samples. The vibrator setting on the MRI dustiness tester should be set to the same value for each dustiness test. Because the actual vibrator setting did not appear to greatly affect the amount of dust generated, the control of this setting is less important than the other variables, although it is important to use the vibrator to promote the flow of the material out of the metal beaker.

ACKNOWLEDGMENT

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