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Correlation of Tests for Material Dustiness with Worker Exposure from the Bagging of Powders

William A. Heitbrink, William F. Todd and Thomas J. Fischbach

National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering, Engineering Control Technology Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226

A significant correlation was found between worker dust exposure from a bag packing operation and the results of two dustiness testers. The dustiness testers were the Heubach Dust Measurement Appliance and the Midwest Research Institute (MRI) Dustiness Tester. Both the Heubach and MRI dustiness tester predicted dust exposures to within an order of magnitude for the operation studied. The width of the prediction interval reflects typical variability in worker dust exposure measurements. Although the correlation between dustiness test results and dust exposures may be different for other operations, these results suggest that dustiness tests can be used to compare the relative potential of different materials to cause dust exposures. Heitbrink, W.A.; Todd, W.F.; Fischbach, T.J.: Correlation of Tests for Material Dustiness with Worker Exposure from the Bagging of Powders. *Appl. Ind. Hyg.* 4:12-16; 1989.

Introduction

Laboratory dustiness tests have been devised to provide a relatively quick and convenient means of estimating a material's relative dustiness.⁽¹⁾ In using these dustiness tests, one assumes that the dust generation in the test simulates the dust generation in an actual powder handling operation. These tests are empirical in that they do not measure a fundamental property or response of the material being tested. In order to be useful, the results of these tests must be correlated with personal dust exposures. It is axiomatic that the more dusty the material, the more potential there is for dust exposure. The purpose of this article is to report on the correlation between worker dust exposure and dustiness test results at a bag filling operation.

The British Occupational Hygiene Society (BOHS) has published an extensive review of dustiness test procedures. Dustiness tests consist of a means of generating dust and a means of quantifying the airborne dust. This review illustrates 18 different dustiness testers. For a known amount of material, these tests generate dust by one of three techniques: 1) repeatedly dropping powder in a rotating drum (Figure 1), 2) dropping powder in a closed space (Figure 2), or 3) fluidizing the powder in a small fluidized bed. The amount of airborne dust generated is quantified by either gravimetric methods (filter or impactor) or by instrumental

methods (aerosol photometer). In reviewing the available data, the BOHS report noted that there needs to be a practical relationship between dustiness test results and dust exposures. Unfortunately, there have been no published evaluations of this relationship between dustiness test results and worker dust exposure.

Most of the dustiness tests reviewed by the BOHS were developed by powder producers. They devised these dustiness tests to evaluate the efficacy of various dust suppression methods. One producer uses dustiness test results to promote the purchase of a dust suppressed form of a pigment. Potentially, industrial hygienists and purchasers of powders could also use these tests. Industrial hygienists could use dustiness test results to evaluate the dust exposure potential of various products before they are used in actual plants. Such test results could be used to specify the level of control needed in order to handle the product safely. Purchasers of powders could incorporate dustiness test results into their procurement specifications in order to use powders which minimize dust exposures.

All of these uses for dustiness tests presume that there is a relationship between dustiness test results and dust exposure. Because this relationship has not been evaluated, National Institute for Occupational Safety and Health (NIOSH) researchers conducted a study to evaluate the correlation between worker dust exposure and the results of two dustiness tests. The two dustiness test devices are the Heubach Dust Measurement Appliance and the Midwest Research Institute (MRI) tester.^(2,3) The Heubach test was originally developed to aid in process control work for the production of pigments. The MRI test was developed by MRI in response to a research project sponsored by the U.S. Environmental Protection Agency (EPA) to develop an inexpensive and quick test for dustiness.

This study was conducted in the packaging room for a powdered acrylic resin production line. The plant produced a variety of resins which differ in bulk density, particle size, moisture content, and observed dustiness. The resin powders were auger fed into tuck-in valve bags. After the bags were filled with 50

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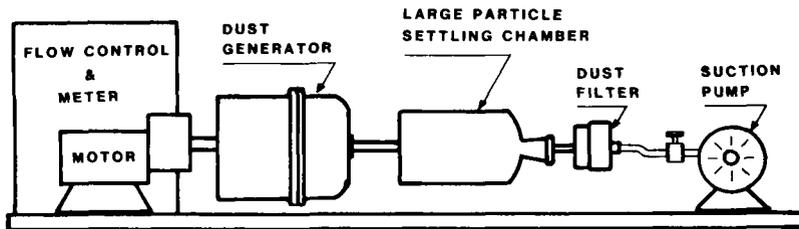


FIGURE 1. Heubach dustiness tester.

pounds of powder, they were sealed and dropped onto a conveyor belt which transported the bags to a palletizing operation elsewhere in the plant. The operator controlled a number of bag packing machines simultaneously. Several workers rotated between the bagging equipment and the palletizing equipment in an adjacent storage area. Local exhaust ventilation was applied to control the dust generated when the powder was fed into bags and when the bags were sealed. The dust generated during the bag filling process was exhausted by a hood placed around the feeding spout. In addition, workers routinely wore disposable respirators; for particularly dusty products, powered air-purifying respirators were utilized.

Experimental Procedures

The workers' dust exposures were measured and dustiness tests were conducted on bulk samples of the material to determine if the dust exposures and the dustiness test results were correlated. Next, the correlation between dustiness and bulk powder properties and between the workers' dust exposures and bulk powder properties were examined.

For each material packaged, exposures to total dust were measured using NIOSH Method 0500.⁽⁴⁾ Air samples were collected using personal pumps operated at 3.7 L/min. Separate sets of measurements were taken for different workers or pairs of workers who rotated through the bagging machine operations. Usually, four to six measurements were taken for each powder. In order to obtain sample volumes of 200–300 L, the filters were reconnected to the sampling pump and restarted each time an operator returned to the bagging machine.

The Heubach unit, depicted in Figure 1, consists of a horizontal rotating drum with internal baffles that produces a repeated dust fall through a regulated airstream. Air containing airborne dust from the drum enters a settling chamber and is then filtered. The test parameters (mass of material, air flow rate, and total flow) for the Heubach dustiness tester are not unique; they are set for each type of powder tested so that a measurable quantity of dust is collected on the filter. High dust loadings on the filter, near 200 mg, can cause losses during handling and weighing. The approach suggested by Heubach is to select the dustiest material for setup, then set the air flow rate and the test time so as to collect the desired amount of dust.⁽³⁾ A sample of about 20 g and a flow rate of 4 L/min was selected as appropriate for an organic material typically encountered in a transfer operation. These settings were used for the resins tested in this study.

For this study, a weighed dust sample (20 g) was placed in the rotor or dust generator, which is mounted on the shaft of a constant speed motor. This shaft rotates at 30 revolutions per minute. A glass fiber filter (50 mm, Schleicher and Schull GmbH) was weighed and placed in the filter holder. The apparatus was then assembled for the test. The test was run until a preset air volume (20 L in our study) had been metered. When the test was completed, the filter was removed from the sample train and

weighed. The results are reported as the percent of the original sample placed into the particle generator that was collected on the filter.

The MRI tester, shown in Figure 2, simulates the pouring and dumping of fine solids under specified conditions within an enclosed chamber fitted with a sampling filter (47-mm glass fiber Gelman type AE) and constant flow exhaust pump system. The cup was rotated at a constant speed to dump the powder. A vibrator mounted to the cup shaft helps to dislodge the dust. The sample pump, operated at 10.8 L/min, was run for 10 minutes, starting when the rotation of the cup was initiated. The sample cup was filled by gently pouring the material into the stainless steel cup. It was slightly overfilled and scraped level with the top of the cup with a metal straight edge; then the cup and material were weighed. The bulk density of the powder in the cup by the cup's volume. A preweighed filter was placed in the filter holder. The apparatus was then assembled for the test. During the test, the time that the powder begins to pour and the time the pouring is complete were recorded. When the test was completed, the

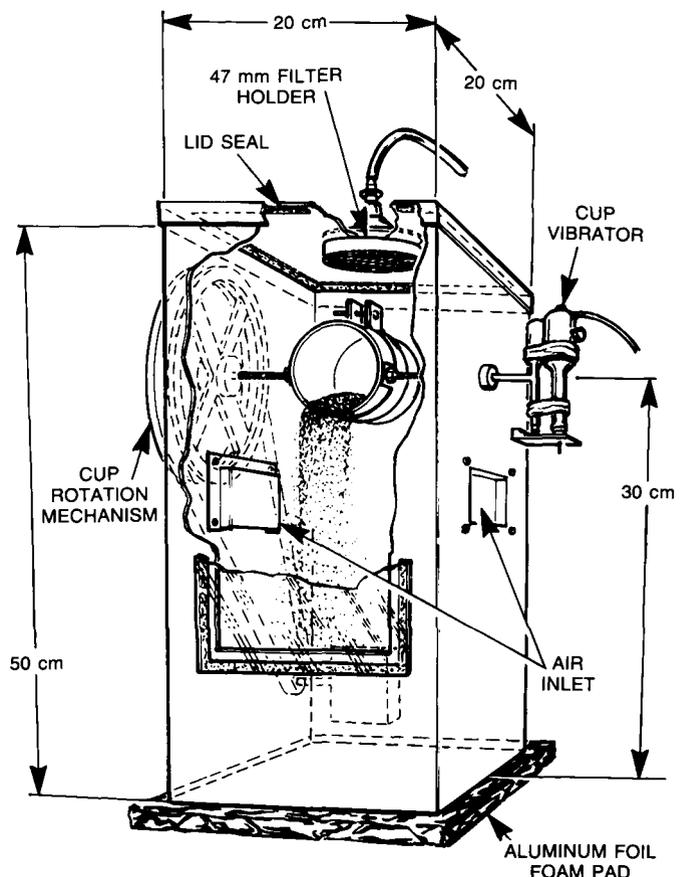


FIGURE 2. MRI dustiness tester.

filter was removed from the apparatus and weighed. The Dustiness Index is the ratio of the dust collected on the filter to the total sample, and divided by the air flow rate:

$$\text{Dustiness Index} = \frac{\text{Dust collected on filter (mg)}}{(\text{Weight of sample [Kg]})(\text{Flow rate [L/min]})}$$

Results and Statistical Analysis

The air sampling data and dustiness test data are summarized in Tables I, II, and III. Because the worker dust exposure data were found to be lognormally distributed, data analysis was performed on the logarithms of the data, and the worker dust exposure is reported in terms of geometric means and geometric standard deviations. After taking the natural logarithms of the data, an analysis of variance (ANOVA) was performed and a multiple comparison test, the Tukey's Studentized Range test, was used to examine the significance of differences between individual means. This test was conducted at an overall level of confidence of 95 percent. The SAS General Linear Models and Regression Procedures were used to examine whether there are significant differences in worker dust exposure between the different materials.⁽⁵⁾ The grouping column in Table I, which summarizes the results of the Tukey Test, shows that the material labeled P1 created a significantly higher dust exposure than the other materials which were studied. The differences between the other materials were not significant. A geometric standard deviation of 2.1 was computed from the root mean square error of the analysis of variance. This variability is so large that two geometric means in Table I must be different by a factor of about four in order for the difference to be considered significant in the multiple comparison test.

The dustiness tester results are summarized in Tables II and III. This data exhibits much less variability than the personal exposure data. As a result, the dustiness tests provide more discrimination between different materials as to their potential for dust generation than personal dust exposures did. In contrast to the personal exposures, the dustiness test data is relatively precise. A pooled coefficient of variation, based upon replicate tests of bulk samples, was computed to be 11 percent for the Heubach dustiness test and 14 percent for the MRI dustiness test.

Process variability is a potential confounding factor in this study and may be responsible for the variability observed in worker dust exposure measurements. The number of packing machines

TABLE I. Summary of Worker Dust Exposures

Material ^A	GM ^B (mg/m ³)	GSD ^C	N ^D	Grouping ^E
P1	16	1.5	6	A
P2	3.7	1.9	5	B
P3	2.8	3.1	6	B
P4	2.4	1.7	3	B
P5	1.5	2.1	5	B
P6	1.1	1.5	6	B

^ACode for the material.

^BGM = geometric mean.

^CGSD = geometric standard deviation.

^DN = number of samples.

^EGeometric Means with different letters under the grouping column differ significantly. For example, powders P2-P6 all belong to grouping B and there is no significant difference in dust exposures between these materials. However, the exposure for powder P1 is significantly different than the other dust exposures reported here. This multiple comparison test is conducted at an overall level of confidence of 95%.

TABLE II. Summary of Heubach Results

Material	Weight Fraction Lost		N	Grouping
	Average (%)	s ^A (%)		
P1	0.28	0.04	6	A
P2	0.18	0.008	2 ^B	B
P3	0.16	0.034	6	B
P4	0.19	0.017	6	B
P5	0.10	0.026	8	C
P6	0.019	0.007	4	D

^As = standard deviation.

^BTwo samples were deleted due to process upset.

TABLE III. Summary of MRI Results

Material	MRI Dustiness Index		N	Grouping
	Average	s		
P1	23	3.7	6	A
P2	10	5.2	5	C
P3	20	2.5	6	A,B
P4	15	3.8	6	B,C
P5	4.5	1.2	8	D
P6	2.7	0.7	4	D

in use and material flow rate varied by about 20 percent. The air flow patterns in this room were not constant due to changes in ambient air velocity and the use of a pedestal fan for cooling during the packaging of some materials. An adjacent bag opening station for underfilled/overfilled bags was intermittently operated; this operation may have inflated the dust exposures for materials "P4" and "P5." Because production schedules are based upon customer needs, it was not possible to use randomization to prevent potential confounding factors from biasing the study.

The personal dust exposure data (Table I) and the dustiness test indices (Tables II and III) were fit to a regression model of the following form:

$$\ln(X) = a + b(Y)$$

where:

a,b = regression coefficients

X = individual dust exposures or geometric mean dust exposures

Y = average dustiness test index for a material

For both the MRI and Heubach dustiness test indices, the regres-

TABLE IV. Evaluation of Exposure Models

Statistical Terms	Heubach	MRI
Intercept (a)	-0.5	-0.1
Slope (b)	10	0.09
<i>Dependent variable: geometric mean dust exposure</i>		
Probability of a larger F	0.0083	0.0502
R ²	0.85	0.65
Standard error of estimate (s _e)	0.32	0.407
<i>Dependent variable: individual worker dust exposures</i>		
Probability of a larger F	<0.0001	<0.0001
R ²	0.59	0.45
s _e	0.75	0.85
Significance level for lack of fit test (Probability of a larger F)	0.28	0.013

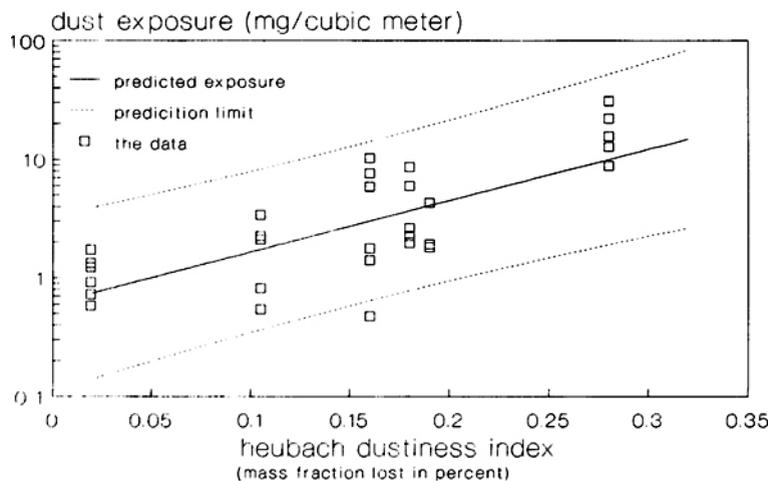


FIGURE 3. Predicted dust exposure and prediction intervals plotted as a function of weight % lost, Heubach test.

sion analyses were repeated twice using two different dependent variables: the geometric mean dust exposure and the individual dust exposures. A significant correlation was found between MRI and Heubach dustiness test results and geometric mean (GM) dust exposures. Statistical results for the analyses are listed in Table IV. In this table, the term "Probability of a larger F" expresses whether the model explains the dependent variable's behavior. A small significance (generally less than 0.05) indicates that the slope (the term 'b' in the regression equation) is significantly different than zero. The term R^2 , which ranges between 0 and 1, measures how much variation in the dependent variable is explained by the model.

The slope and intercepts determined by using individual exposure measurements and by using geometric mean dust exposures were essentially the same. However, the statistical results differ in predictable ways. The value of R^2 is higher for the regression analyses done using geometric means than the analyses based upon using individual values. This occurs because the geometric means have less error than individual values of concentration. However, the regression analyses based upon individual dust exposures have a higher level of significance because the error estimate has a greater number of degrees of freedom.

In Figures 3 and 4, the 95 percent prediction intervals for individual dust exposures are plotted as a function of dustiness test results. These plots are based upon the regression analyses for the logarithms of individual worker dust exposures. The pre-

diction intervals include 95 percent of the exposures which would be predicted from the regression model.⁽⁶⁾ For the Heubach dustiness tester, the ratio of the upper to lower prediction interval is no smaller than a factor of 25. For the MRI tester, this factor is no smaller than a factor of 35. The two standard deviation limits for air sampling data with a geometric standard deviation of 2.1 would have ranges which covers a factor of 17.6. Apparently, the width of these prediction intervals is caused mostly by the variability of the worker dust exposure measurements.

The prediction interval width is proportional to the standard error of estimate (S_e), which is essentially the standard deviation about the regression line. It is the result of two sources of error: 1) the lack of fit of the model to the data and 2) the sampling error in measuring the dust exposure. The significance of the first source of error was evaluated using the method described by Mendenhall.⁽⁶⁾ This method tests whether the error caused by the lack of fit is larger than the sampling error. The significance of this difference is stated as "the significance level for lack of fit" in Table IV. This indicates that the correlation between the MRI dustiness test and the worker dust exposure involves a significant lack of fit. Apparently, this source of error causes the wider prediction intervals for the MRI dustiness tester. For the Heubach dustiness test, the lack of fit was not significant. This means that the width of the prediction interval is caused by the variability in the workers' exposure data. Thus, the prediction intervals in Figure 3 cannot become much smaller.

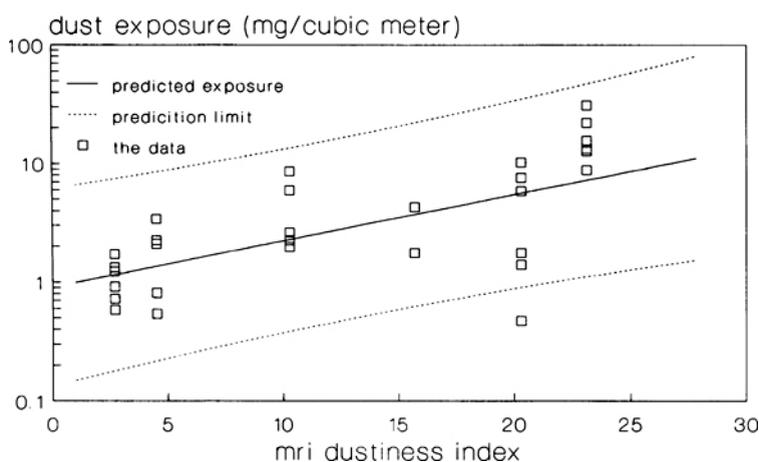


FIGURE 4. Predicted dust exposure and prediction intervals as a function of MRI Dustiness Index.

SAS regression diagnostics suggested that the data may contain an outlier. For material P3, one worker's dust exposure was only 0.47 mg/m³ as compared to a geometric mean of 2.8 mg/m³. In both the Heubach and MRI regression equations, the level of significance for this outlier was 0.01. Possibly, an outlier of this magnitude is to be expected. For a data set which contains 31 data points, there is about a one in four chance of such a large difference between the predicted and observed values. Also, this outlier could be real. There are a number of confounding factors present which were mentioned earlier in this paper. Whether this data point should be included or excluded is unclear. Excluding the outlier does affect the data analysis. For the regression analysis done on individual data points, the standard error of estimate for the Heubach and MRI regression equations are reduced to 0.66 and 0.72. As a result, the prediction intervals in Figures 3 and 4 would be smaller. In addition, the Lack of Fit Test would no longer be significant for the MRI tester.

Discussion

When dustiness test results are used to estimate actual dust exposures of individual workers, the prediction intervals in Figures 3 and 4 show that a large range of dust exposures is expected. The width of this prediction interval is, to a large extent, caused by the large variability in worker dust exposure. As a result, the prediction intervals for individual dust exposure cannot become much smaller.

Based upon regression analysis, some regression equations were developed which could be used to predict dust exposures and dustiness test results. These results are empirical and must be used carefully. The equations which predict worker dust exposure from dustiness test results are only valid to the extent that the conditions of this study are duplicated. There is no physical basis for regression equations: the slopes and intercepts were chosen to minimize the standard error of estimate. The regression results show that at one site a significant correlation between dustiness test results and dust exposures was observed. This suggests that significant correlations may also be observed at other sites and that dustiness tests provide an indication of a material's relative potential for causing dust exposure.

Recommendations

The fact that a significant correlation between dust exposures and dustiness test results was observed in an actual plant shows that addressing material dustiness is important in predicting and controlling worker dust exposure. It also suggests that significant correlations may be present at other plants and other processes. As a result of this, dustiness testers presently can be used to do predictive industrial hygiene (the estimation of exposures before they occur). For example, suppose a new product is being considered for production in a process or an operation where two or more different materials are being used. For this purpose or operation, one can develop a correlation between dustiness tester results and dust exposure. The correlation and dustiness test results from a small sample of this new material could be used to predict the dust exposures to within an order of magnitude. This could allow one to make dust control recommendations before the new product is produced or used on an industrial scale.

As mentioned above, the regression equations which are developed are totally empirical. The correlation between dustiness

test results and worker dust exposure needs to be evaluated for each operation for which it is being used. When a significant change in the operation occurs, the correlation needs to be re-evaluated. Because dust exposures need to be evaluated when significant process changes occur, re-evaluating the correlation should not pose much of an added burden.

Although a correlation cannot be established in cases where only one product is being used, the dustiness testers can still be used to compare the relative dust producing potential of new powders. Producers of powders could use dustiness testers to develop low dust formulations of their products. Powder consumers could use dustiness testers to compare the potential of different raw materials to cause dust exposure. The dustiness test results will indicate whether a change in the product will reduce or increase dust exposures.

Although this article reports that a significant correlation was observed between dustiness tester results and worker dust exposure, much more research is needed on dustiness tests and the actual mechanism of aerosol generation by powders during processing operations. More field studies are needed to evaluate the correlation between dustiness test results and dust exposures. In addition, a better understanding of airborne dust generation by industrial powder handling operations is needed. Presently, dustiness testers are empirical tests which are used to simulate the formation of airborne dust during powder handling operations. Unfortunately, the mechanism of aerosol generation during operations such as bag dumping is not well understood in terms of the identity and magnitude of the forces which affect dust generation. An improved fundamental understanding of airborne dust generation by powder handling operations would allow one to select and devise dustiness tests which closely simulate the actual process which generates the airborne dust.

For those who are reviewing the health and safety consequences of a new powder, dustiness testers can provide some insight into effect of this new powder upon dust exposures. If one ignores dustiness test results because they are empirical in nature, the alternatives are to either guess the magnitude of the potential exposure or to do nothing. The data in this article show that the use of dustiness tests is superior to the other two alternatives.

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