ABSTRACT

JEFFREY S. LANNING. Validating a Model for the Prediction of Dust Generation. (Under the direction of Dr. DAVID LEITH)

Modifications were made to a bench-top dustiness tester to allow for the simultaneous collection of dust generation and separation force data. Tests were performed on limestone, glass beads, titanium dioxide, and lactose. Their results were compared to a model developed from data measured in a previous study using a large-scale tester. The results of tests performed on four additional materials (instant tea mix, copier toner, baby powder, and fly ash) were also compared to predictions from the model. The data obtained in this study compared well to the data from the previous study. The data also compared well to the model with 94% falling within the 95% confidence interval.

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AR	Angle of Repose, degrees
c_w	Cone Width, m
d	Aerodynamic Particle Diameter, µm
d_{50}	Mass Median Particle Diameter, µm
$Frac_i$	Fraction of Particles with Size "i"
g	Gravitational Constant, 9.81 m/s^2
G_i	Dust Generation for Particles of Size "i"
H	Drop Height, m
M	Material Moisture Content, %
MRI	Midwest Research Institute
Q	Mass Flow Rate, kg/s
T_m	Melting Temperature, °C
ΔG	Deflection in Balance Reading Due to Material Drop, kg
ρ_p	Particle Density, kg/m^3

INTRODUCTION

The work presented in this technical report was performed in an attempt to meet three main objectives. First, the UNC bench-top dustiness tester needed to be modified to allow the simultaneous collection of separation force and dust generation data. The second objective was to show that data collected from the UNC bench-top tester is comparable to data obtained from a large scale tester used in previous work. The last goal of this work was to validate a model for the prediction of dust generation using data collected while studying the second objective and data from four previously untested materials.

The work included for this report included designing the modifications to the UNC bench-top tester that would allow for the collection of separation force data, modifying the standard operating procedure for the tester, testing the four granular materials used in a previous study on a large scale apparatus, examining three variables and one interaction, testing four new materials, and analyzing the experimental data for association to data from the previous study and the model for predicting dust generation.

Further research could be directed at towards two goals. Additional work could be done to develop a new material flow device. The current device does not work well with materials that flow poorly. Work could also be directed at developing models for processes other than the fall-type examined in this study. Models could be developed for the separation forces created during these processes. These models could then be used in the current model for the prediction of dust generation to determine if the model applies to non-fall-type processes.

BACKGROUND

The use of solids and powders is common in many industries. In handling these materials, there is potential for generating a dust that may jeopardize worker health or safety. Thus, it is beneficial to predict the amount of dust generated from a given source.

Several researchers have developed methods to determine the dustiness of a material. A Cassella apparatus was used by Bürkholz [1] to measure the dustiness of three materials with two different size distributions and four moisture contents. He determined that dustiness decreased with increasing moisture content. Additionally, he showed that particles smaller than 20μm in diameter did not generate as much dust as particles 20 to 40μm in diameter because the interparticle binding forces were greater in the smaller particles. Heitbrink et al. [2,3] used three different devices to measure dust generation and predict worker exposure. Results from these tests correlated to worker exposure sporadically, and therefore they concluded that the relevance of the tests had to be determined on a site by site basis.

Plinke [4] sought a unifying model for dust generation based on an understanding of the various principles involved in the generation of dust. He examined four commonly used materials with three size distributions and three moisture contents. Plinke rationalized that a model should be of the following form:

$$G_i = (Frac_i)^a \frac{(Separation\ Forces)^b}{(Interparticle\ Binding\ Forces)^c} \quad \textbf{(1)}$$

where G_i is the dust generation for particles of size i; $Frac_i$ is the fraction of particles with size i in the partent material; and a, b, and c are unknown coefficients. The dust generated and the size distribution were easily measured, but surrogates were needed for separation forces and interparticle binding forces. Material cohesiveness was chosen to represent interparticle binding forces, whereas impaction was used to represent separation forces for fall-type processes.

The cohesiveness (kPa) of the material was determined using a Peschl rotational shear tester. A model to predict the cohesion of materials was generated based on the composition; moisture content, M (%); and the mass median particle diameter, d_{50} (μm). The composition of the material was accounted for in the cohesion model by using the melting temperature, T_m (°C) [5,6]:

$$Cohesion = \frac{e^{1.3 \pm 0.56} M^{0.2 \pm 0.02} T_m^{\ 0.3 \pm 0.08}}{d_{50}^{\ 0.2 \pm 0.03}}. \tag{2}$$

A similar model was developed to predict the impaction force in fall-type processes. Statistical analysis showed that the following variables played a role in impaction: drop height, H (m); moisture content, M (%); particle diameter, d_{50} (μm); density, ρ_p (kg/m^3); the cone width of the receiving pile, c_w (m); and the angle of repose, AR (degrees). The impaction (m/s) was given as [7]:

$$Impaction = e^{-1.8 \pm 0.45} H^{0.4 \pm 0.10} M^{0.1 \pm 0.03} d_{50}^{\ 0.2 \pm 0.04} \rho_p^{\ 0.3 \pm 0.10} c_w^{\ 0.1 \pm 0.03} AR^{0.2 \pm 0.10}. \tag{3}$$

Then Plinke determined the coefficients a, b, and c for the dust generation model and obtained the following equation through statistical analysis:

$$G_i = e^{-9.1 \pm 0.96} Frac_i^{\ -0.2 \pm 0.03} \frac{(Impaction)^{1.0 \pm 0.27}}{(Cohesion)^{3.0 \pm 0.11}}. \tag{4}$$

Thus, he established a method to predict the generation of dust from a bulk material based on fundamental characteristics of the material and the process.

Cawley [8] developed a bench-top apparatus, the University of North Carolina bench-top dustiness tester, to overcome some of the disadvantages of the full-scale device used by Plinke. This apparatus is much smaller than the one used by Plinke. The bench-top apparatus is 0.25 m x 0.5 m x 1.1 m, whereas Plinke's tester was roughly 1 m x 2 m x 3m. The bench-top tester requires less test material than the full scale apparatus, therefore making it more cost-effective. In addition, the bench-top tester is self-enclosed which allows for the testing of hazardous and expensive materials.

The focus of this work was to determine if the model developed by Plinke is applicable to the UNC bench-top dustiness tester. Dust generation and separation force tests were run using the same materials as Plinke. The validity of Plinke's model was examined using four common commercial and industrial materials not involved in the development of his dust generation model.

EXPERIMENTAL METHODS

The present work was divided into three parts according to Equation 1, the separation force, interparticle binding force, and dust generation. The impaction and dust generation were measured simultaneously for every experiment. At the time of each experiment, two samples were taken for moisture content analysis from which cohesion was calculated using Equation 2.

Impaction Data

Cawley's apparatus was modified to allow simultaneous collection of separation force and dust generation data. Figure 1 shows a schematic diagram of the modified UNC bench-top tester. Modifications included the removal of the base of the dust generation section and replacement with temporary plastic wrap. Additionally, three legs were added to allow the placement of the dust generation section of the tester directly over a Mettler PM34-K balance (Mettler Instrument Corporation, Hightstown, New Jersey). The balance exported approximately four readings per second to an IBM computer. By allowing the plastic wrap to rest on the balance pan, impaction measurements coincided with the material drop for the dust generation tests.

As the test material fell onto the balance pan, the impact of the material caused the balance to read in excess of the actual weight resting on it. The difference between the highest weight recorded and the actual resting weight, Δg (kg), was determined. The mass flow rate, Q (kg/s); and the gravitational constant, g (m/s^2); were used in the following relationship:

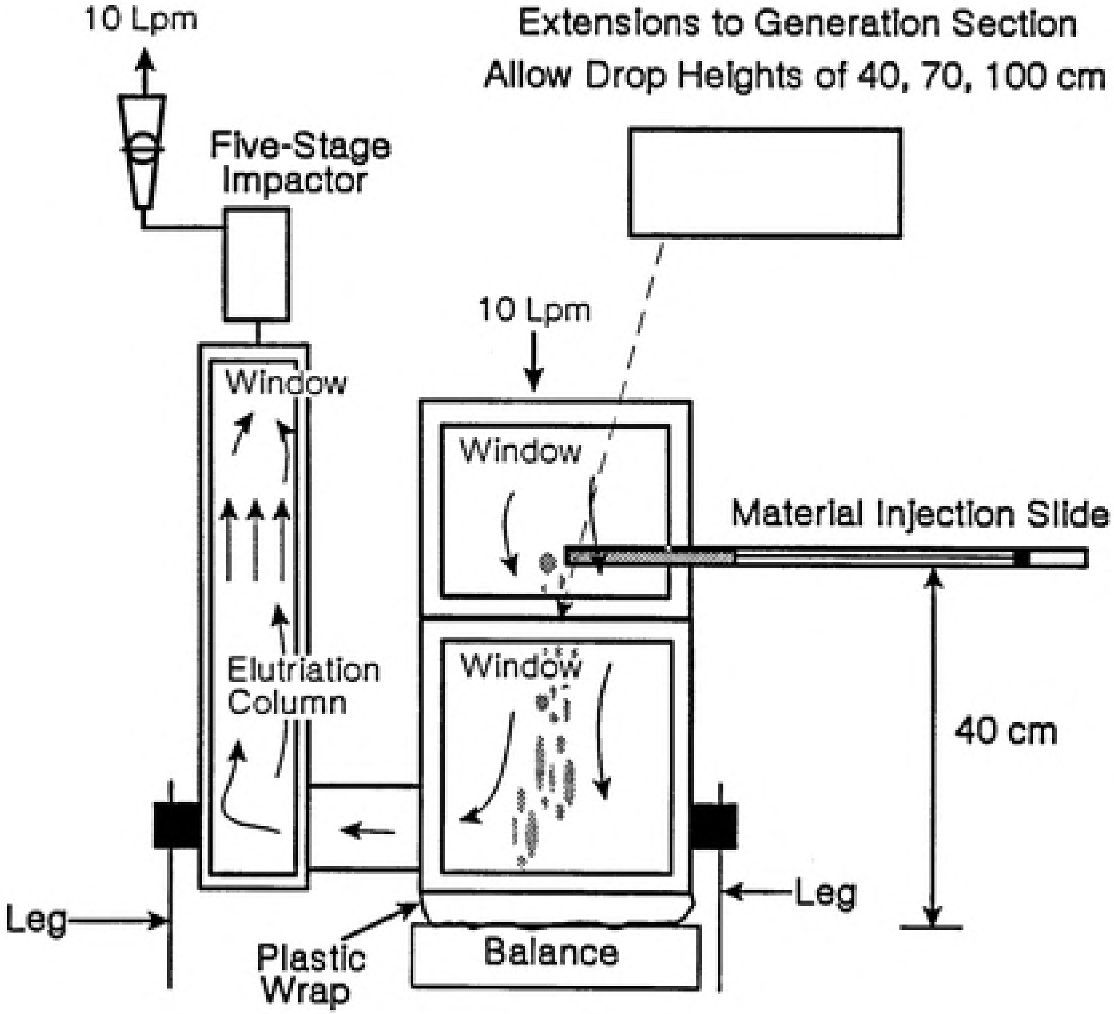

Figure 1: UNC Bench-Top Dustiness Tester Modified for Collection of Separation Force Data

$$Impaction = \frac{g \bullet \Delta g}{Q}. \tag{5}$$

This relationship was normalized for drop heights other than 0.7m by the following equation:

$$Impaction_n = Impaction_m \left(\frac{0.7}{Drop\ Height} \right)^{0.4} \tag{6}$$

where the subscripts n and m stand for normalized and measured results, respectively. Drop height was varied to show the effect of impaction on dust generation.

Measurement of Dust Generation Data

Dust was generated by dropping a known mass of test material with a known size distribution from a push-rod injection slide. This action caused the material to fall freely through the air. The material landed on the plastic wrap covering the balance pan. Dust was drawn upwards at 10 liters per minute through an elutriation column to remove large particles and collected on glass substrates in an Andersen Series 210 cascade impactor (Graseby-Andersen, Atlanta, GA). In this way, G_i values were measured under different operating conditions. Additionally, G_i values were calculated using Equation 4. A comparison was then made of the measured and calculated G_i values.

Test Materials

Glass beads, limestone, titanium dioxide, and lactose were used in the experiments. These were identical to the materials that Plinke used to develop his model. Instant iced tea mix (Thomas J. Lipton Inc., Englewood Cliffs, NJ), toner for a photocopier (Nashua Office Products, Nashua, NH), baby powder (Johnson & Johnson, Skillman, NJ), and fly ash from a coal fired power plant (UNC, Chapel Hill, NC) were used to verify the validity of the model for other substances. Iced tea mix, toner, and baby powder were chosen due to their widespread use in homes and businesses. Fly ash was selected due to the extensive use of coal in power plants and its role as an environmental pollutant as well as an industrial waste. These materials were unaltered before use.

Size Distributions

Size distributions for the four original materials were measured using a Helos (Sympatec GmgH, 3346 Remlingen, Germany) particle sizer and are reported in Table 1. The size distributions for the four additional materials were determined using an API Aerosizer (Amherst Process Instruments Inc., Hadley, MA) particle sizer and are also given in Table 1.

Drop Height

Materials were introduced into the tester via a push-rod injection slide at heights of 0.4, 0.7, and 1.0 m. The drop height was measured as the distance from the center of the injection slide to the balance pan. This height could be adjusted by inserting extensions in the dust generation section of the apparatus.

Moisture Content

The "base" moisture content of a material was defined as the moisture content upon arrival and was measured in a vacuum drying oven. The moisture content was considered as the weight lost during the drying process. Three levels of moisture content were prepared for each size distribution and material; these are shown in Table 2. For limestone, titanium dioxide, and glass beads, a fixed amount of water was added to create the high moisture content material. To increase the moisture content of the lactose, water was sprayed through an atomizer over a layer of the material. The moisture content of the inorganic materials was lowered by placing them in a convection drying oven for 24 hours at 170°C. The lactose was dried in the same oven at 60°C to reduce moisture

Table I -- Properties of Test Materials

Material and Aerodynamic Diameter Range in (um)		Mass Median Diameter, (um)	Geometric Standard Deviation	Density (g/cc)
Limestone	d<5	2.3	1.9	2.60
Limestone	5<d<25	8.7	2.2	2.60
Limestone	d>25	38.7	1.9	2.60
Titanium Dioxide	d<5	1.7	1.9	4.20
Titanium Dioxide	5<d<25	6.9	1.8	4.20
Titanium Dioxide	d>25	16.4	1.6	4.20
Glass Beads	d<5	3.6	1.8	2.45
Glass Beads	5<d<25	16.0	1.8	2.45
Glass Beads	d>25	39.9	1.6	2.45
Lactose	d<5	2.0	1.9	1.52
Lactose	5<d<25	6.7	2.4	1.52
Lactose	d>25	23.0	1.6	1.52
Instant Tea Mix		14.0	1.3	1.55
Toner		10.9	1.3	1.10
Fly Ash		14.4	1.3	2.40
Baby Powder		14.6	1.3	2.60

Table II -- Average Moisture Contents

Limestone

	$d<5$	$5<d<25$	$d>25$
High	1.40%	0.24%	0.23%
Base	0.59%	0.16%	0.13%
Low	0.33%	0.11%	0.06%

Titanium Dioxide

	$d<5$	$5<d<25$	$d>25$
High	1.50%	0.69%	0.88%
Base	1.17%	0.31%	0.17%
Low	0.32%	0.14%	0.11%

Lactose

	$d<5$	$5<d<25$	$d>25$
High	5.83%	5.97%	6.25%
Base	5.31%	4.61%	4.98%
Low	3.83%	1.73%	3.17%

Glass Beads

	$d<5$	$5<d<25$	$d>25$
High	0.64%	0.57%	0.63%
Base	0.41%	0.38%	0.10%
Low	0.13%	0.14%	0.04%

Instant Tea Mix	0.22%
Toner	14.1%
Fly Ash	0.92%
Baby Powder	0.21%

content. The actual moisture content was determined from two samples taken at the time of the experiment to account for any moisture lost to or gained from the environment.

Experimental Design

The two main factors in predicting dust generation from Equation 4 are cohesion and impaction. In this study, three variables were examined: moisture content, size distribution, and drop height. Moisture content and size distribution affect cohesion, and drop height affects impaction. Nine levels of cohesion were examined with the base level of cohesion taken as base moisture content and the $5\ \mu m < d < 25\ \mu m$ size distribution. An incomplete block design was created with the nine levels of cohesion and three levels of drop height. The four materials were designated as blocks, and each block contained 11 experiments. All of the experiments were replicated, thus giving 11 x 2 = 22 experiments per material for a total of 4 x 22 = 88 experiments. These 88 experiments were run in random order to reduce bias. Lastly, the four additional materials were tested once each for a grand total of 88 + 4 = 92 experiments. Table 3 shows this design graphically.

Table III -- Experimental Conditions
Drop Heights for Values of Moisture Content and Size Distribution

	Moisture Content		
Size Distribution	High	Base	Low
d>25	0.7 m	0.7 m	0.7 m
5<d<25	0.7 m	0.4, 0.7, 1.0 m	0.7 m
d<5	0.7 m	0.7 m	0.7 m

RESULTS

Figures 2-5 show the dust generation measured here and Plinke's dust generation measurements plotted against the predicted value of dust generation from Equation 4 for the base materials. Figure 2 shows that the limestone data gathered here are comparable with Plinke's data because both have the same trend and fit the model line very well. Figure 3 compares the dust generation for glass beads using the data from this study and Plinke's. The data from the bench-top study do not compare well with Plinke's data, for there is no discernible trend in these data. Figure 4 shows that the titanium dioxide data corresponds well to the model, but is not in the same range of predicted values as Plinke. Lactose data is shown in Figure 5. Although this data appears to parallel Plinke's model and the trend in his data, the model regularly overestimates the dust generation of the lactose.

Figure 6 compares all of the data from this study with predictions from Plinke's model and includes lines for one standard error. Although the plot contains a great deal of scatter, 67% of the data falls within one standard error of Plinke's model, while 93% of the data falls with in two standard errors. 21% of the data outside of a one standard error interval are below the predicted value and the majority of these points are lactose. Data for limestone and titanium dioxide agree the best with Plinke's model. 91% of the titanium dioxide and 86% of the limestone data were within one standard error of the model, while 45% of the glass beads and lactose data are in the one standard error interval. The data for the four additional materials is shown in Figure 7 along with predictions from Plinke's model and one standard error. Of these four materials, only the overestimated the dust generation. For all materials tested, 67% of the data fell within one standard error, and 94% fell within two.

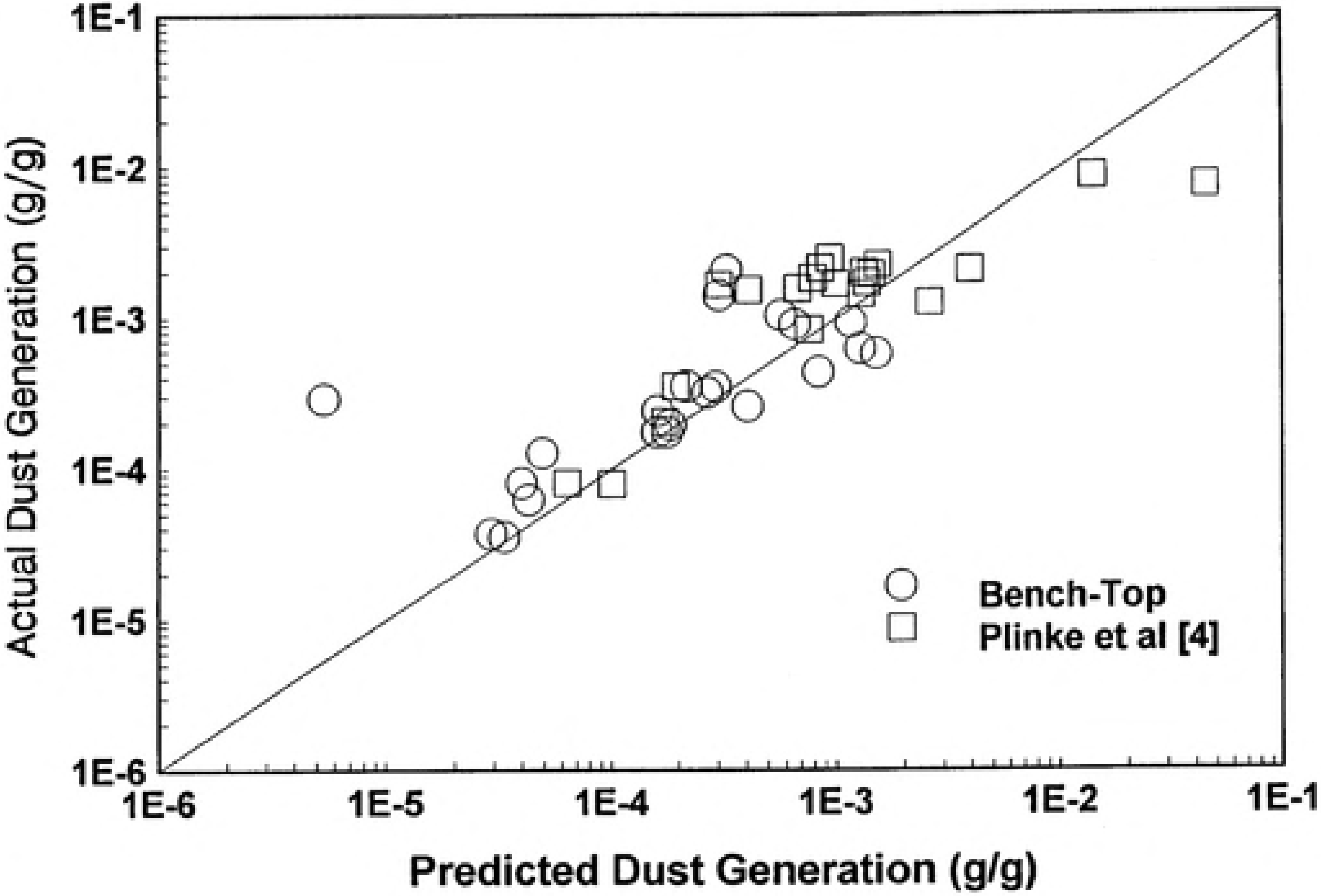

Figure 2: Actual dust generation from the bench-top apparatus and from the apparatus of Plinke et al [4] vs. predicted dust generation from Equation 4 for limestone tests.

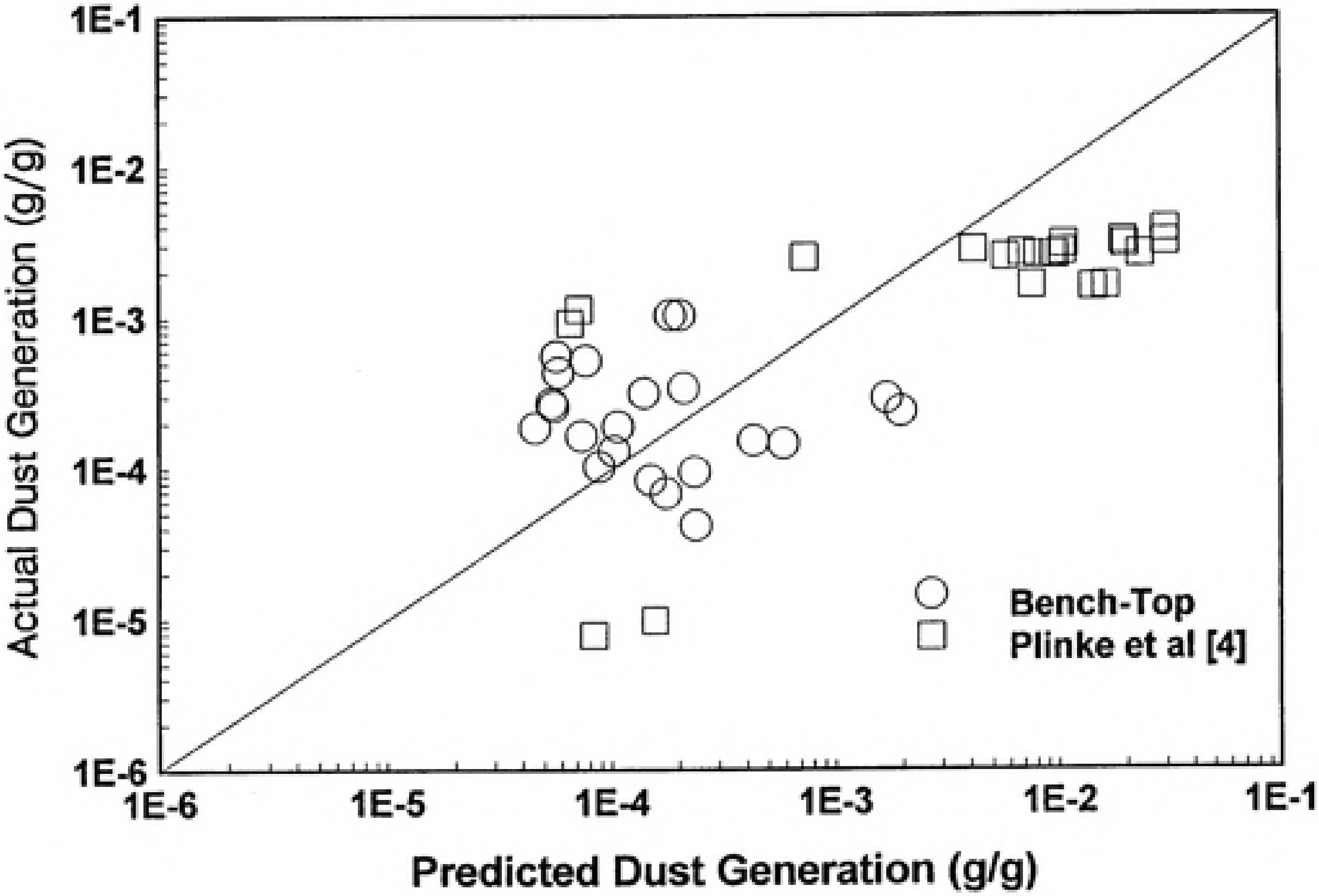

Figure 3: Actual dust generation from the bench-top apparatus and from the apparatus of Plinke et al [4] vs. predicted dust generation from Equation 4 for tests with glass beads.

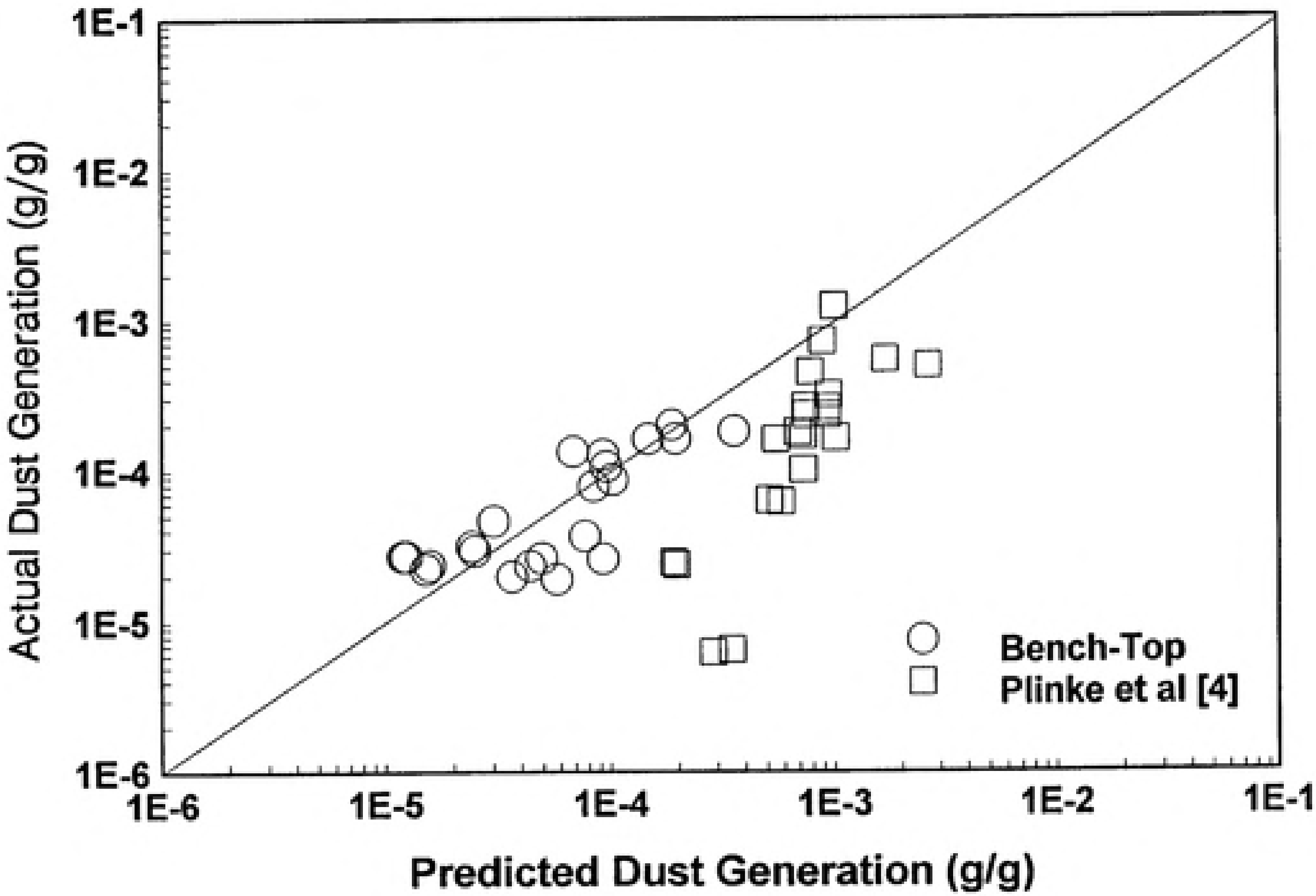

Figure 4: Actual dust generation from the bench-top apparatus and from the apparatus of Plinke et al [4] vs. predicted dust generation from Equation 4 for titanium dioxide tests.

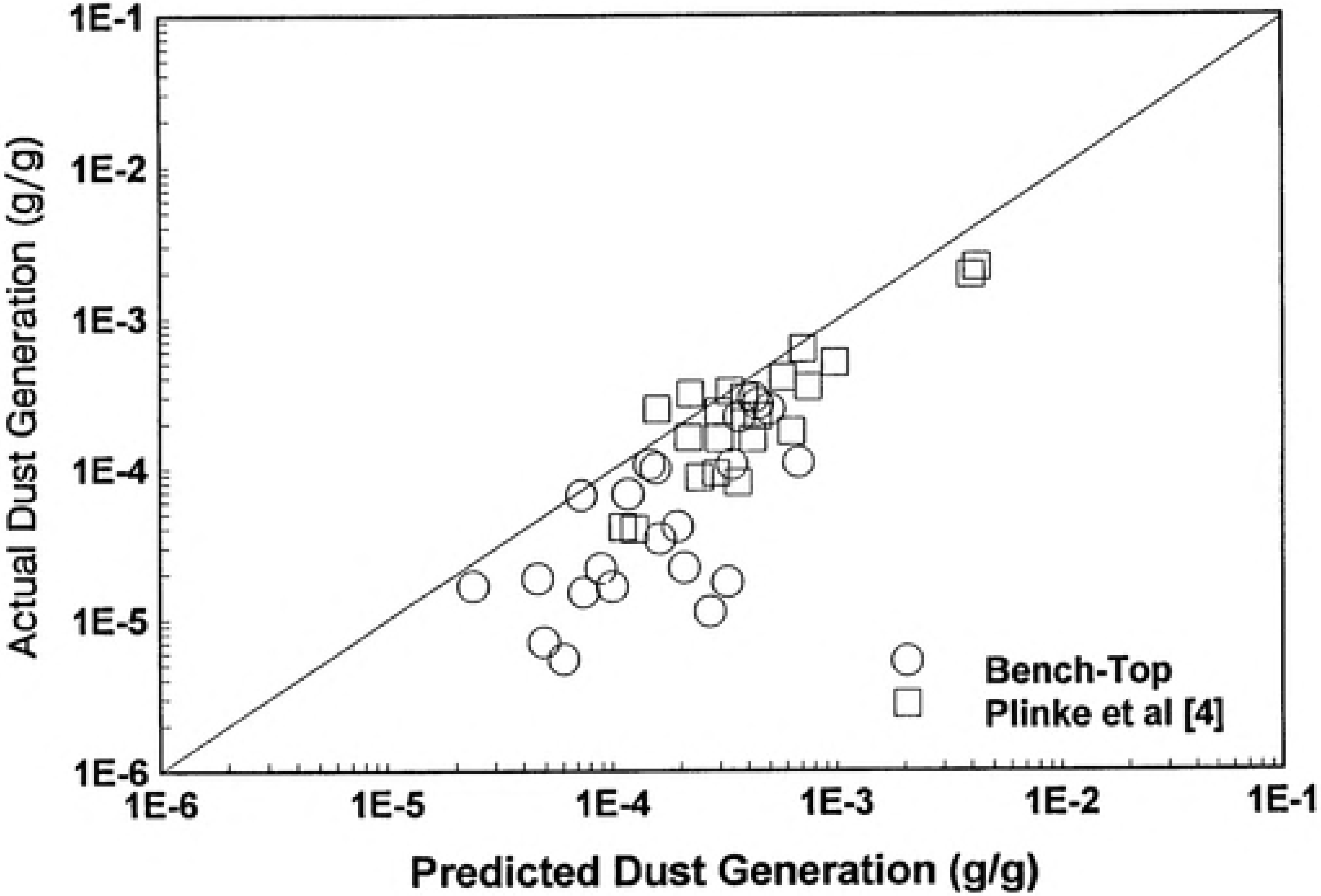

Figure 5: Actual dust generation from the bench-top apparatus and from the apparatus of Plinke et al [4] vs. predicted dust generation from Equation 4 for lactose tests.

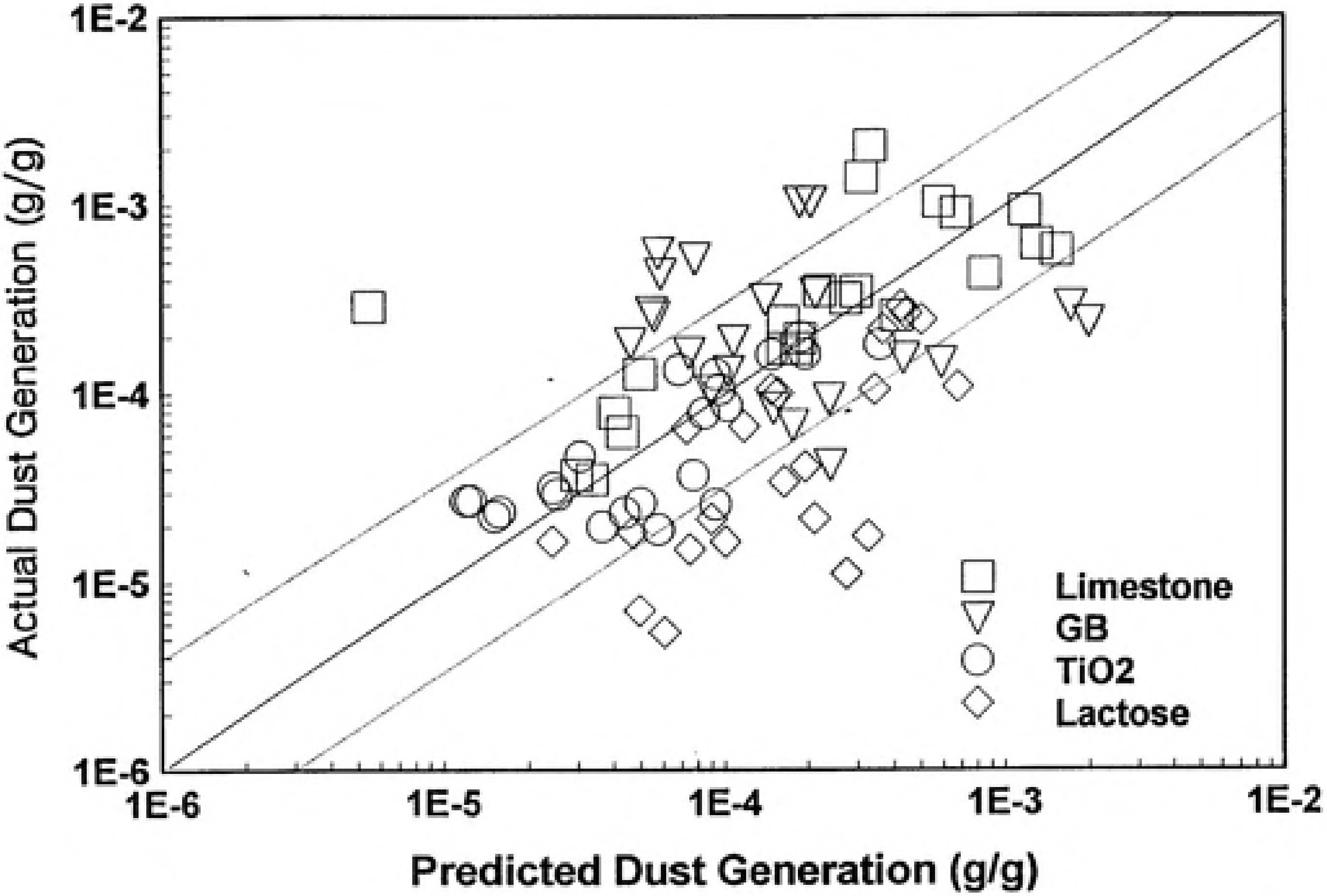

Figure 6: Actual dust generation from the bench-top apparatus vs. predicted dust generation from Equation 4 ± one standard error for the four materials Plinke used.

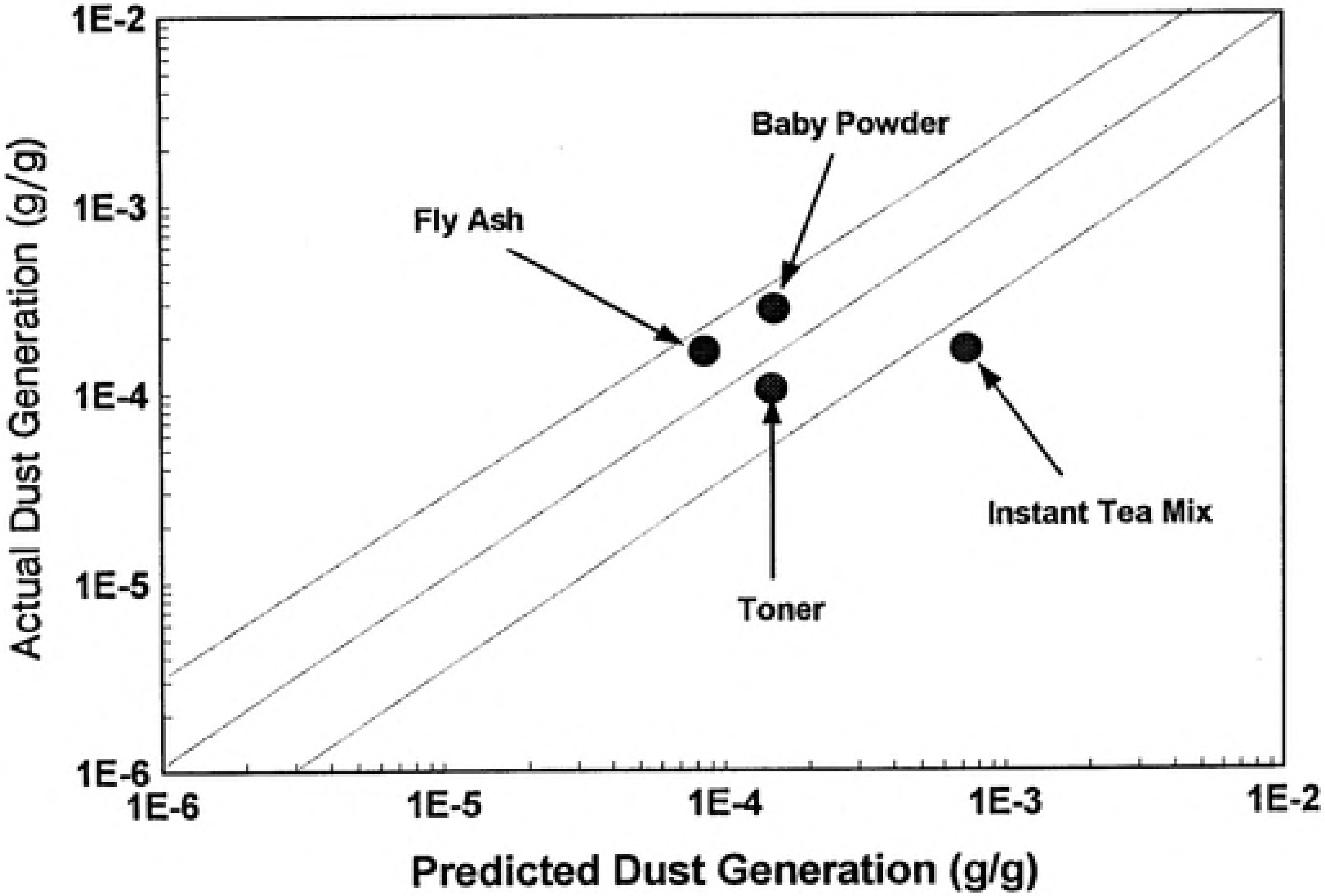

Figure 7: Actual dust generation from the bench-top apparatus vs. predicted dust generation from Equation 4 ± one standard error. Data for fly ash, baby powder, toner, and instant tea mix.

DISCUSSION

Figures 2 and 4 show good agreement between limestone and titanium dioxide data and Plinke's data and model. The data from these materials match the line of perfect agreement with the model relatively well. This is significant because each set is distributed over two orders of magnitude. Additionally, the titanium dioxide shows agreement with Plinke's model in a range not examined by Plinke with titanium dioxide.

The lack of agreement between the lactose data and Plinke's model is shown in Figure 5. The dust generation is overestimated by Plinke's model which assumes that the material contains no clumps. However, since lactose is very compressible, clumps were formed during the filling of the injection slide. When these clumps struck the balance pan, some of the energy input broke apart the clumps instead of generating dust. Therefore, the impaction measured during the experiment was greater than the impaction used to generate dust, and resulted in an overestimation of the dust generation.

Glass beads data did not compare well to the model or to Plinke's data. However, since Plinke's data for glass beads appears mostly as a cluster with a few points at lower predicted values and does not follow the model to any greater extent than our data, this could indicate that glass beads do not obey the model.

For the materials tested for verification, the model predicted the values for fly ash, baby powder and toner relatively well, but overestimated the dust generated by instant tea mix. This was most likely due to lack of knowledge about its melting temperature, which is necessary for calculating cohesion. The melting temperature of the instant tea mix was not made available to us by the manufacturer, therefore, an estimate was made based on the melting temperature of the main constituent of the instant tea mix, sugar. A 30%

increase in melting temperature from 178 to 230°C would lower the predicted dust generation and the one standard error interval enough to include the instant tea mix.

CONCLUSIONS

This study has shown that data collected from the UNC bench-top dustiness tester modified for separation force measurements is comparable to data from Plinke's large scale tester for limestone and titanium dioxide. Improvements to the injection mechanism to prevent materials from compressing would probably increase the similarity between Plinke's data and data collected from the bench-top device for lactose.

Glass beads may not follow the model of Plinke. Results from this study indicate that the dust generation of glass beads does not increase as the predicted value does. In fact, the dust generation appears to decrease as the predicted value increases. Plinke's data for glass beads do not appear to follow the model either.

Plinke's model gives a good first-estimate of dust generation for all materials studied. 67% of the 92 experiments fell within one standard error of the model. The model overestimated the dust generation more often than underpredicting the dust generation, thus leaving a margin of safety. This makes Plinke's model a viable tool in the prediction of dust generation from fall-type processes, and a basis for developing models to predict dust generation from other processes.

REFERENCES

1. Bürkholz, A: "Ein Verfahren zur Messung der Staubungsfähigkeit von Pulverförmigen Produkten", *Staub-Reinhaltung der Luft*, 49:433-438, 1989.

2. Heitbrink, WA, Todd, WF, Cooper, TC, and O'Brien, DM: "The Application of Dustiness Tests to the Prediction of Worker Dust Exposure", *Am. Ind. Hyg. Assoc. J.*, 51(4):217-223, 1990.

3. Heitbrink, WA, Baron, PA, Willeke, K: "An Investigation of Dust Generation by Free Falling Powders", *Am. Ind. Hyg. Assoc. J.*, 53(10):617-624, 1992.

4. Plinke, MAE, Leith, D, Boundy, MG, Löffler, F: "Dust Generation from Handling Powders in Industry", Submitted for publication *Am. Ind. Hyg. Assoc. J.*, 1994.

5. Plinke, MAE, Leith, D, Hathaway, R, Löffler, F: "Cohesion in Granular Materials", *Bulk Solids Handling*, 14(1):101-106, 1994.

6. Israelachivili, JN, Intermolecular and Surface Forces, London, Great Britain, Academic Press Inc, 1992.

7. Plinke, MAE, Leith, D, Goodman, RG, Löffler, F: "Experimental Examination of Particle Separation Mechanisms in Flow of Granular Material", *Particulate Science and Technology: An International Journal*, 12:71-87, 1994.

8. Cawley, B; Leith, D: "Bench-Top Apparatus to Examine Factors that Affect Dust Generation", *Appl. Occup. Environ. Hyg.*, 8(7):624-631, 1993.

APPENDIX A

EXPERIMENTAL DATA

Experiment	Material	Stage	Average DO	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
1	GB 5<d<25	1	12.2	37.8	3.166	2.848	0.1415	704	6.65	1.192	0.2486	2.76E-04	4.89E-05	8.28E-04	9.20E-05	0.0015
		2									0.5548	2.35E-04	1.58E-04	7.05E-04	7.83E-05	0.0106
		3									0.0514	3.76E-04	2.83E-03	1.13E-03	1.26E-04	0.0176
		4									0.0144	4.88E-04	1.43E-03	1.46E-03	1.63E-04	0.0025
		5 +BUF									0.0942	3.35E-04	6.32E-04	1.01E-03	1.12E-04	0.0072
		Total									0.9632	2.11E-04	3.38E-04	6.33E-04	7.03E-05	0.0394
2	GB 5<d<25	1	9.9	37.9	2.563	3.041	0.5692	704	6.65	1.574	0.2486	9.69E-05	5.73E-05	2.91E-04	3.23E-05	0.0018
		2									0.5548	8.26E-05	1.09E-04	2.48E-04	2.75E-05	0.0068
		3									0.0514	1.33E-04	9.70E-04	3.99E-04	4.43E-05	0.0058
		4									0.0144	1.71E-04	8.04E-04	5.13E-04	5.70E-05	0.0013
		5 + BUF									0.0942	1.18E-04	2.17E-04	3.54E-04	3.93E-05	0.0023
		Total									0.9632	7.39E-05	1.63E-04	2.22E-04	2.46E-05	0.0176
3	TiO2 d<5	1	18.2	35.4	5.034	2.998	1.4898	1830	1.7	3.338	0					0.0008
		2									0.1058	2.37E-05	6.33E-05	7.11E-05	7.90E-06	0.0024
		3									0.2621	1.98E-05	2.87E-05	5.94E-05	6.60E-06	0.0027
		4									0.2518	1.99E-05	1.32E-05	5.97E-05	6.63E-06	0.0011
		5 + BUF									0.3803	1.83E-05	7.33E-06	5.49E-05	6.10E-06	0.001
		Total									1	1.51E-05	2.23E-05	4.53E-05	5.03E-06	0.008
4	TiO2 d> 25	1	20.3	41.7	4.776	3.557	0.0891	1830	16.4	1.208	0.2888	3.88E-04	1.57E-05	1.16E-03	1.29E-04	0.0005
		2									0.1159	4.66E-04	1.49E-04	1.40E-03	1.55E-04	0.0019
		3									0.0116	7.38E-04	3.45E-03	2.21E-03	2.46E-04	0.0044
		4									0.0057	8.53E-04	2.29E-03	2.56E-03	2.84E-04	0.0014
		5 + BUF									0.0165	6.88E-04	2.75E-04	2.06E-03	2.29E-04	0.0005
		Total									0.4385	3.57E-04	1.80E-04	1.07E-03	1.19E-04	0.0087
5	Lactose d<5	1	11.7	32.2	3.575	2.644	4.1568	222	3.8	1.873	0.0098	1.53E-04	6.89E-05	4.59E-04	5.10E-05	0.0002
		2									0.476	7.04E-05	1.42E-06	2.11E-04	2.35E-05	0.0003
		3									0.2748	7.86E-05	4.92E-06	2.36E-04	2.62E-05	0.0004
		4									0.1317	9.11E-05	1.03E-05	2.73E-04	3.04E-05	0.0004
		5 + BUF									0.1077	9.48E-05	1.25E-05	2.84E-04	3.16E-05	0.0004
		Total									1	6.07E-05	5.41E-06	1.82E-04	2.02E-05	0.0016
6	GB d> 25	1	12.1	50.3	2.36	3.257	0.0945	704	23	0.858	0.1276	6.31E-04	3.29E-05	1.89E-03	2.10E-04	0.0011
		2									0.0103	1.04E-03	9.84E-04	3.12E-03	3.47E-04	0.0026
		3									0.0034	1.56E-03	5.16E-03	4.68E-03	5.20E-04	0.0019
		4									0.0099	1.05E-03	2.31E-04	3.15E-03	3.50E-04	0.0008
		5 + BUF									0.0366	8.10E-04	8.35E-05	2.43E-03	2.70E-04	0.0008
		Total									0.1958	5.85E-04	1.44E-04	1.76E-03	1.95E-04	0.007
7	TiO2 d<5	1	18.3	34.3	5.224	2.998	1.4888	1830	1.7	3.338	0					
		2									0.1058	2.46E-05	1.33E-05	7.39E-05	8.20E-06	0.0005
		3									0.2621	2.05E-05	2.66E-05	6.15E-05	6.83E-06	0.0025
		4									0.2518	2.07E-05	3.45E-05	6.21E-05	6.90E-06	0.0031
		5 + BUF									0.3803	1.90E-05	9.59E-06	5.70E-05	6.33E-06	0.0013
		Total									1	1.57E-05	2.36E-05	4.71E-05	5.23E-06	0.0084
8	Limestone 5<d<25	1	14.9	42.1	3.472	2.857	0.1469	900	8.7	1.228	0.2812	2.70E-04	2.81E-05	8.10E-04	9.00E-05	0.0008
		2									0.3833	2.56E-04	9.77E-05	7.68E-04	8.53E-05	0.0038
		3									0.0491	3.83E-04	2.79E-03	1.15E-03	1.28E-04	0.0139
		4									0.035	4.09E-04	2.20E-03	1.23E-03	1.36E-04	0.0078
		5 + BUF									0.0934	3.36E-04	3.27E-04	1.01E-03	1.12E-04	0.0031
		Total									0.822	2.18E-04	3.50E-04	6.54E-04	7.27E-05	0.0292
9	TiO2 5<d<25	1	12.5	37.2	3.283	3.675	0.6972	1830	6.9	2.187	0.2441	4.78E-05	3.22E-06	1.43E-04	1.59E-05	0.0002
		2									0.5466	4.06E-05	4.31E-06	1.22E-04	1.35E-05	0.0006
		3									0.1004	5.70E-05	5.47E-05	1.71E-04	1.90E-05	0.0014
		4									0.029	7.31E-05	1.76E-04	2.19E-04	2.44E-05	0.0013
		5 + BUF									0.0326	7.14E-05	1.57E-04	2.14E-04	2.38E-05	0.0013
		Total									0.9527	3.64E-05	1.68E-05	1.09E-04	1.21E-05	0.0048

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
10	Limestone	1	16.5	37.1	4.363	2.824	0.1325	900	8.7	1.2	0.2812	3.84E-04	2.90E-05	1.09E-03	1.21E-04	0.0009
	5 < d < 25	2									0.3633	3.46E-04	1.30E-04	1.04E-03	1.15E-04	0.0048
		3									0.0491	5.18E-04	2.80E-03	1.55E-03	1.72E-04	0.013
		4									0.035	5.52E-04	2.11E-03	1.66E-03	1.84E-04	0.0075
		5 + BUF									0.0934	4.53E-04	2.95E-04	1.36E-03	1.51E-04	0.0028
		Total									0.822	2.94E-04	3.46E-04	8.82E-04	9.80E-05	0.0289
11	Limestone	1	27.8	39.8	5.929	3.405	0.2067	900	8.7	1.311	0.2812	3.78E-04	1.39E-04	1.13E-03	1.26E-04	0.0031
	5 < d < 25	2									0.3633	3.60E-04	8.95E-04	1.08E-03	1.20E-04	0.0202
		3									0.0491	5.37E-04	1.14E-02	1.61E-03	1.79E-04	0.0448
		4									0.035	5.74E-04	8.04E-03	1.72E-03	1.91E-04	0.0169
		5 + BUF									0.0934	4.72E-04	9.77E-04	1.42E-03	1.57E-04	0.0073
		Total									0.822	3.05E-04	1.40E-03	9.15E-04	1.02E-04	0.0923
12	Lactose	1	9.2	30.2	2.999	3.125	1.8291	222	8.7	1.333	0.1852	1.97E-04	1.16E-05	5.91E-04	6.57E-05	0.0007
	5 < d < 25	2									0.1792	2.00E-04	4.73E-05	6.00E-04	6.67E-05	0.0027
		3									0.054	2.54E-04	1.05E-04	7.62E-04	8.47E-05	0.0018
		4									0.0313	2.83E-04	3.01E-05	8.49E-04	9.43E-05	0.0003
		5 + BUF									0.0353	2.76E-04	-1.78E-05	8.28E-04	9.20E-05	-0.0002
		Total									0.489	1.63E-04	3.40E-05	4.89E-04	5.43E-05	0.0053
13	TiO2	1	12.8	35.5	3.458	2.927	1.1808	1830	1.7	3.187	0					0.0005
	d < 5	2									0.1058	1.88E-05	5.70E-05	5.64E-05	6.27E-06	0.0018
		3									0.2621	1.56E-05	3.74E-05	4.69E-05	5.20E-06	0.0036
		4									0.2518	1.58E-05	2.99E-05	4.74E-05	5.27E-06	0.002
		5 + BUF									0.3803	1.45E-05	4.56E-06	4.35E-05	4.83E-06	0.0005
		Total									1	1.20E-05	2.71E-05	3.60E-05	4.00E-06	0.0072
14	GB	1	7	30.8	2.244	2.058	0.1254	704	2	1.479	0					0.0015
	d < 5	2									0.0858	1.27E-04	1.88E-03	3.81E-04	4.23E-05	0.0151
		3									0.3287	9.68E-05	7.47E-04	2.90E-04	3.23E-05	0.0257
		4									0.281	9.98E-05	2.62E-04	2.99E-04	3.33E-05	0.0077
		5 + BUF									0.3045	9.82E-05	1.29E-04	2.95E-04	3.27E-05	0.0041
		Total									1	7.75E-05	5.17E-04	2.33E-04	2.58E-05	0.0541
15	Limestone	1	12.9	39.2	3.218	4.031	0.2351	900	38.7	0.998	0.0451	6.71E-04	1.79E-04	2.01E-03	2.24E-04	0.0018
	d > 25	2									0.0209	7.82E-04	1.57E-03	2.35E-03	2.61E-04	0.0073
		3									0.0083	9.95E-04	6.77E-03	2.99E-03	3.32E-04	0.0095
		4									0.008	9.48E-04	1.69E-03	2.84E-03	3.16E-04	0.003
		5 + BUF									0.0185	8.02E-04	2.87E-04	2.41E-03	2.67E-04	0.0011
		Total									0.0988	5.74E-04	1.03E-03	1.72E-03	1.91E-04	0.0227
16	GB	1	5	35.4	1.398	2.855	0.3028	704	8.65	1.387	0.2488	7.66E-05	5.92E-05	2.30E-04	2.55E-05	0.0018
	5 < d < 25	2									0.5546	6.52E-05	2.77E-04	1.96E-04	2.17E-05	0.0167
		3									0.0514	1.05E-04	2.17E-03	3.15E-04	3.50E-05	0.0121
		4									0.0144	1.35E-04	1.53E-03	4.05E-04	4.50E-05	0.0024
		5 + BUF									0.0942	9.30E-05	1.19E-03	2.79E-04	3.10E-05	0.0122
		Total									0.9632	5.84E-05	4.30E-04	1.75E-04	1.95E-05	0.045
17	GB	1	18	52.1	3.006	3.939	0.6329	704	23	1.254	0.1278	2.57E-04	1.52E-05	7.71E-04	8.57E-05	0.0007
	d > 25	2									0.0103	4.25E-04	5.37E-05	1.28E-03	1.42E-04	0.0002
		3									0.0014	6.33E-04	1.19E-03	1.90E-03	2.11E-04	0.0006
		4									0.0099	4.28E-04	1.40E-04	1.28E-03	1.43E-04	0.0005
		5 + BUF									0.0368	3.30E-04	6.05E-05	9.90E-04	1.10E-04	0.0008
		Total									0.1858	2.38E-04	4.17E-05	7.14E-04	7.93E-05	0.0028
18	TiO2	1	17.8	41.9	4.175	4.494	0.9214	1830	16.4	1.927	0.2988	8.35E-05	8.72E-06	2.51E-04	2.79E-05	0.001
	d > 25	2									0.1159	1.00E-04	4.78E-05	3.00E-04	3.33E-05	0.0022
		3									0.0116	1.59E-04	5.00E-04	4.77E-04	5.30E-05	0.0023
		4									0.0057	1.83E-04	2.68E-04	5.45E-04	6.10E-05	0.0006
		5 + BUF									0.0169	1.48E-04	4.58E-05	4.44E-04	4.93E-05	0.0003
		Total									0.4395	7.68E-05	3.68E-05	2.30E-04	2.56E-05	0.0064

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
19	Lime d < 5	1	0.8	29.9	0.262	2.292	0.2349	900	2.3	1.755	0					0.0009
		2									0.231	7.27E-06	1.49E-04	2.18E-05	2.42E-06	0.0035
		3									0.2964	6.91E-06	3.87E-04	2.07E-05	2.30E-06	0.0117
		4									0.2153	7.37E-06	4.51E-04	2.21E-05	2.46E-06	0.0099
		5 + BUF									0.2573	7.11E-06	1.41E-04	2.13E-05	2.37E-06	0.0037
		Total									1	5.42E-06	2.91E-04	1.63E-05	1.81E-06	0.0297
20	GB 5 < d < 25	1	11	33.8	3.193	2.837	0.2841	704	6.65	1.37	0.2488	1.83E-04	4.30E-05	5.49E-04	6.10E-05	0.0011
		2									0.5548	1.56E-04	1.67E-04	4.68E-04	5.20E-05	0.0094
		3									0.0514	2.51E-04	2.03E-03	7.53E-04	8.37E-05	0.0106
		4									0.0144	3.24E-04	9.58E-04	9.72E-04	1.08E-04	0.0014
		5 + BUF									0.0942	2.23E-04	8.58E-04	6.69E-04	7.43E-05	0.0082
		Total									0.9632	1.40E-04	3.14E-04	4.20E-04	4.67E-05	0.0307
21	GB 5 < d < 25	1	7.4	39.4	2.305	2.318	0.3528	704	6.65	1.43	0.2488	1.16E-04	1.44E-05	3.48E-04	3.87E-05	0.0004
		2									0.5548	9.69E-05	4.35E-05	2.97E-04	3.30E-05	0.0027
		3									0.0514	1.59E-04	7.83E-04	4.77E-04	5.30E-05	0.0045
		4									0.0144	2.05E-04	4.35E-04	6.15E-04	6.83E-05	0.0007
		5 + BUF									0.0942	1.41E-04	3.56E-04	4.23E-04	4.70E-05	0.0027
		Total									0.9632	8.86E-05	1.02E-04	2.66E-04	2.95E-05	0.011
22	Lactose d > 25	1	13.2	39.2	3.299	4.431	2.8515	222	39.9	1.074	0.0171	6.70E-04	3.79E-04	2.01E-03	2.23E-04	0.0014
		2									0.0224	6.35E-04	1.97E-04	1.91E-03	2.12E-04	0.0013
		3									0.0148	6.92E-04	3.26E-04	2.08E-03	2.31E-04	0.0014
		4									0.01	7.46E-04	2.38E-04	2.24E-03	2.49E-04	0.0007
		5 + BUF									0.012	7.19E-04	1.98E-04	2.16E-03	2.40E-04	0.0007
		Total									0.0761	4.97E-04	2.46E-04	1.49E-03	1.66E-04	0.0055
23	Lactose d < 5	1	3.7	25.4	1.442	2.852	4.2858	222	3.6	1.885	0.0098	6.06E-05	2.77E-04	1.82E-04	2.02E-05	0.0008
		2									0.476	2.79E-05	6.41E-06	8.37E-05	9.30E-06	0.0009
		3									0.2748	3.11E-05	1.97E-05	9.33E-05	1.04E-05	0.0018
		4									0.1317	3.61E-05	1.80E-05	1.08E-04	1.20E-05	0.0007
		5 + BUF									0.1077	3.75E-05	2.83E-05	1.13E-04	1.25E-05	0.0009
		Total									1	2.40E-05	1.66E-05	7.20E-05	8.00E-06	0.0049
24	GB d > 25	1	8.1	45.5	1.738	3.257	0.0945	704	23	0.858	0.1276	4.64E-04	2.97E-05	1.39E-03	1.55E-04	0.0009
		2									0.0103	7.67E-04	1.15E-03	2.30E-03	2.56E-04	0.0039
		3									0.0014	1.14E-03	5.12E-03	3.42E-03	3.80E-04	0.0017
		4									0.0059	7.73E-04	2.13E-04	2.32E-03	2.58E-04	0.0005
		5 + BUF									0.0366	5.98E-04	8.06E-05	1.79E-03	1.99E-04	0.0007
		Total									0.1858	4.30E-04	1.52E-04	1.29E-03	1.43E-04	0.0067
25	TiO2 d > 25	1	10.4	50.2	2.032	3.842	0.1921	1830	16.4	1.408	0.2888	1.04E-04	1.20E-05	3.12E-04	3.47E-05	0.0004
		2									0.1159	1.25E-04	1.05E-04	3.75E-04	4.17E-05	0.0014
		3									0.0116	1.98E-04	1.87E-03	5.94E-04	6.60E-05	0.0025
		4									0.0057	2.29E-04	7.87E-04	6.87E-04	7.63E-05	0.0005
		5 + BUF									0.0165	1.85E-04	2.63E-04	5.55E-04	6.17E-05	0.0005
		Total									0.4385	9.50E-05	1.05E-04	2.87E-04	3.19E-05	0.0053
26	TiO2 d > 25	1	19.2	37.6	5.027	4.494	0.9214	1830	16.4	1.927	0.2888	1.01E-04	6.25E-06	3.03E-04	3.37E-05	0.0007
		2									0.1159	1.21E-04	3.79E-05	3.63E-04	4.03E-05	0.0017
		3									0.0116	1.91E-04	4.89E-04	5.73E-04	6.37E-05	0.0022
		4									0.0057	2.21E-04	2.28E-04	6.63E-04	7.37E-05	0.0005
		5 + BUF									0.0165	1.78E-04	4.89E-05	5.34E-04	5.93E-05	0.0003
		Total									0.4385	9.25E-05	2.59E-05	2.78E-04	3.08E-05	0.0044
27	Lactose 5 < d < 25	1	6.7	26.7	2.474	3.53	1.8291	222	16	1.16	0.1892	2.35E-04	1.61E-05	7.05E-04	7.83E-05	0.0009
		2									0.1792	2.37E-04	5.87E-05	7.11E-04	7.90E-05	0.0031
		3									0.054	3.02E-04	8.79E-05	9.06E-04	1.01E-04	0.0014
		4									0.0313	3.36E-04	2.17E-05	1.01E-03	1.12E-04	0.0002
		5 + BUF									0.0353	3.28E-04	2.88E-05	9.84E-04	1.09E-04	0.0003
		Total									0.489	1.94E-04	4.09E-05	5.82E-04	6.47E-05	0.0059

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
28	Limestone d > 25	1	21.5	57	3.7	3.665	0.0908	900	38.7	0.825	0.0451	1.37E-03	1.34E-04	4.11E-03	4.57E-04	0.0007
		2									0.0209	1.59E-03	1.15E-03	4.77E-03	5.30E-04	0.0028
		3									0.0063	2.03E-03	6.28E-03	6.09E-03	6.77E-04	0.0046
		4									0.008	1.93E-03	1.72E-03	5.79E-03	6.43E-04	0.0018
		5 + BUF									0.0185	1.63E-03	4.19E-04	4.89E-03	5.43E-04	0.0009
		Total									0.0988	1.17E-03	9.23E-04	3.51E-03	3.90E-04	0.0108
29	Lactose 5 < d < 25	1	20.8	33.8	6.047	3.761	3.4467	222	16	1.339	0.1892	3.92E-04	7.29E-06	1.18E-03	1.31E-04	0.0004
		2									0.1792	3.97E-04	9.80E-06	1.19E-03	1.32E-04	0.0005
		3									0.054	5.04E-04	8.37E-06	1.51E-03	1.68E-04	0.0001
		4									0.0313	5.62E-04	5.50E-05	1.69E-03	1.87E-04	0.0005
		5 + BUF									0.0353	5.49E-04	9.75E-05	1.65E-03	1.83E-04	0.001
		Total									0.489	3.24E-04	1.76E-05	9.72E-04	1.08E-04	0.0025
30	Limestone d > 25	1	16.6	50.7	3.193	3.515	0.0599	900	38.7	0.759	0.0451	1.51E-03	7.71E-05	4.53E-03	5.03E-04	0.0004
		2									0.0209	1.77E-03	8.73E-04	5.31E-03	5.90E-04	0.0021
		3									0.0063	2.24E-03	3.86E-03	6.72E-03	7.47E-04	0.0029
		4									0.008	2.14E-03	1.09E-03	6.42E-03	7.13E-04	0.001
		5 + BUF									0.0185	1.81E-03	3.29E-04	5.43E-03	6.03E-04	0.0007
		Total									0.0988	1.29E-03	6.16E-04	3.87E-03	4.30E-04	0.007
31	TiO2 5 < d < 25	1	18.3	37.3	4.173	3.638	0.2584	1830	6.9	1.777	0.2441	1.10E-04	2.51E-05	3.30E-04	3.67E-05	0.0007
		2									0.5468	9.37E-05	4.33E-05	2.81E-04	3.12E-05	0.0027
		3									0.1004	1.32E-04	3.14E-04	3.96E-04	4.40E-05	0.0036
		4									0.029	1.69E-04	3.32E-04	5.07E-04	5.63E-05	0.0011
		5 + BUF									0.0326	1.65E-04	1.07E-04	4.95E-04	5.50E-05	0.0004
		Total									0.9527	8.39E-05	7.81E-05	2.52E-04	2.80E-05	0.0085
32	Lactose 5 < d < 25	1	6.1	32.2	2.337	3.121	5	222	16	1.443	0.1892	1.21E-04	4.90E-06	3.63E-04	4.03E-05	0.0003
		2									0.1792	1.23E-04	2.24E-05	3.69E-04	4.10E-05	0.0013
		3									0.054	1.56E-04	3.43E-05	4.68E-04	5.20E-05	0.0008
		4									0.0313	1.74E-04	2.96E-05	5.22E-04	5.80E-05	0.0003
		5 + BUF									0.0353	1.70E-04	8.75E-06	5.10E-04	5.67E-05	0.0001
		Total									0.489	1.00E-04	1.64E-05	3.00E-04	3.33E-05	0.0028
33	TiO2 5 < d	1	11	29.5	3.059	2.529	0.2739	1830	1.7	2.379	0					0.0003
		2									0.1058	4.75E-05	5.79E-05	1.43E-04	1.58E-05	0.0007
		3									0.2621	3.97E-05	5.01E-05	1.19E-04	1.32E-05	0.0015
		4									0.2518	4.00E-05	8.26E-05	1.20E-04	1.33E-05	0.0018
		5 + BUF									0.3803	3.68E-05	2.30E-05	1.10E-04	1.22E-05	0.001
		Total									1	3.03E-05	4.64E-05	9.09E-05	1.01E-05	0.0053
34	Lactose 5 < d < 25	1	8.8	30.2	2.478	4.229	2.6702	222	16	1.272	0.1892	1.87E-04	6.53E-05	5.61E-04	6.23E-05	0.0027
		2									0.1792	1.89E-04	9.96E-05	5.67E-04	6.30E-05	0.0039
		3									0.054	2.41E-04	2.12E-04	7.23E-04	8.03E-05	0.0025
		4									0.0313	2.69E-04	1.46E-04	8.07E-04	8.97E-05	0.001
		5 + BUF									0.0353	2.62E-04	7.78E-05	7.86E-04	8.73E-05	0.0005
		Total									0.489	1.55E-04	1.00E-04	4.65E-04	5.17E-05	0.0107
35	Lactose 5 < d < 25	1	8.8	31.7	2.723	3.904	5	222	16	1.443	0.1892	1.41E-04	3.28E-05	4.23E-04	4.70E-05	0.0014
		2									0.1792	1.43E-04	7.92E-05	4.29E-04	4.77E-05	0.0032
		3									0.054	1.82E-04	1.48E-04	5.46E-04	6.07E-05	0.0018
		4									0.0313	2.03E-04	8.50E-05	6.09E-04	6.77E-05	0.0009
		5 + BUF									0.0353	1.98E-04	5.03E-05	5.94E-04	6.60E-05	0.0004
		Total									0.489	1.17E-04	6.71E-05	3.51E-04	3.90E-05	0.0074
36	Lime d < 5	1	12.6	35.8	3.456	2.059	1.038	900	2.3	2.363	0					0.0002
		2									0.231	3.92E-05	1.63E-05	1.18E-04	1.31E-05	0.0007
		3									0.2564	3.73E-05	4.89E-05	1.12E-04	1.24E-05	0.0027
		4									0.2153	3.98E-05	5.49E-05	1.19E-04	1.33E-05	0.0022
		5 + BUF									0.2573	3.84E-05	2.30E-05	1.15E-04	1.28E-05	0.0011
		Total									1	2.93E-05	3.71E-05	8.79E-05	9.77E-06	0.0069

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac I	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
37	Limestone	1	12.8	28.4	3.438	2.995	0.2384	900	8.7	1.349	0.2812	2.01E-04	2.28E-05	6.03E-04	6.70E-05	0.0014
	5<d<25	2									0.3633	1.91E-04	8.68E-05	5.73E-04	6.37E-05	0.0069
		3									0.0491	2.85E-04	1.12E-03	8.55E-04	9.50E-05	0.012
		4									0.035	3.05E-04	2.21E-03	9.15E-04	1.02E-04	0.0169
		5 + BUF									0.0934	2.51E-04	2.89E-04	7.53E-04	8.37E-05	0.0059
		Total									0.822	1.62E-04	2.40E-04	4.88E-04	5.40E-05	0.0431
38	Limestone	1	13.6	34	3.924	2.995	0.2384	900	8.7	1.349	0.2812	2.30E-04	2.01E-05	6.90E-04	7.67E-05	0.0009
	5<d<25	2									0.3633	2.18E-04	7.26E-05	6.54E-04	7.27E-05	0.0028
		3									0.0491	3.26E-04	9.21E-04	9.78E-04	1.09E-04	0.0048
		4									0.035	3.49E-04	1.76E-03	1.05E-03	1.16E-04	0.0066
		5 + BUF									0.0934	2.87E-04	2.22E-04	8.61E-04	9.57E-05	0.0022
		Total									0.822	1.86E-04	1.95E-04	5.58E-04	6.20E-05	0.017
39	Limestone	1	22.5	55.6	3.97	3.918	0.1772	900	38.7	0.943	0.0451	9.82E-04	5.54E-05	2.95E-03	3.27E-04	0.0003
	d>25	2									0.0209	1.14E-03	5.58E-04	3.42E-03	3.80E-04	0.0014
		3									0.0063	1.46E-03	2.25E-03	4.38E-03	4.87E-04	0.0017
		4									0.008	1.39E-03	4.17E-04	4.17E-03	4.63E-04	0.0004
		5 + BUF									0.0185	1.17E-03	5.88E-04	3.51E-03	3.90E-04	0.0013
		Total									0.0988	8.39E-04	4.30E-04	2.52E-03	2.80E-04	0.0051
40	Lactose	1	14.2	35.6	3.393	4.502	5	222	16	1.443	0.1092	1.76E-04	7.18E-05	5.28E-04	5.87E-05	0.003
	5<d<25	2									0.1792	1.78E-04	9.60E-05	5.34E-04	5.93E-05	0.0038
		3									0.054	2.26E-04	2.10E-04	6.78E-04	7.53E-05	0.0025
		4									0.0313	2.52E-04	1.88E-04	7.56E-04	8.40E-05	0.0013
		5 + BUF									0.0353	2.46E-04	8.98E-05	7.38E-04	8.20E-05	0.0007
		Total									0.409	1.46E-04	1.05E-04	4.38E-04	4.87E-05	0.0113
41	GB	1	9.9	31.1	3.123	2.303	0.3904	704	2	1.858	0					0.001
	d<5	2									0.0858	8.91E-05	6.18E-04	2.67E-04	2.97E-05	0.0062
		3									0.3287	6.81E-05	4.07E-04	2.04E-04	2.27E-05	0.0157
		4									0.281	7.03E-05	1.97E-04	2.11E-04	2.34E-05	0.0086
		5 + BUF									0.3046	6.93E-05	6.16E-05	2.08E-04	2.31E-05	0.0022
		Total									1	5.45E-05	2.69E-04	1.64E-04	1.82E-05	0.0318
42	Lactose	1	6.5	37.8	1.687	3.904	5	222	16	1.443	0.1092	8.75E-05	2.60E-05	2.63E-04	2.92E-05	0.0011
	5<d<25	2									0.1792	8.85E-05	8.32E-05	2.66E-04	2.95E-05	0.0033
		3									0.054	1.12E-04	1.17E-04	3.36E-04	3.73E-05	0.0014
		4									0.0313	1.25E-04	1.01E-04	3.75E-04	4.17E-05	0.0007
		5 + BUF									0.0353	1.22E-04	7.68E-05	3.66E-04	4.07E-05	0.0008
		Total									0.409	7.24E-05	6.56E-05	2.17E-04	2.41E-05	0.0071
43	Limestone	1	22.5	54.2	4.072	3.563	0.0685	900	38.7	0.79	0.0451	1.78E-03	5.60E-05	5.34E-03	5.93E-04	0.0003
	d>25	2									0.0209	2.08E-03	8.46E-04	6.24E-03	6.93E-04	0.0021
		3									0.0063	2.64E-03	2.94E-03	7.92E-03	8.80E-04	0.0022
		4									0.008	2.52E-03	1.26E-03	7.56E-03	8.40E-04	0.0012
		5 + BUF									0.0185	2.13E-03	4.10E-04	6.39E-03	7.10E-04	0.0009
		Total									0.0988	1.52E-03	5.71E-04	4.56E-03	5.07E-04	0.0067
44	GB	1	9.6	31.2	3.776	2.309	0.3392	704	6.65	1.419	0.2488	1.95E-04	1.33E-05	5.85E-04	6.50E-05	0.0004
	5<d<25	2									0.5546	1.66E-04	3.13E-05	4.98E-04	5.53E-05	0.0021
		3									0.0514	2.67E-04	5.63E-04	8.01E-04	8.90E-05	0.0035
		4									0.0144	3.44E-04	6.31E-04	1.03E-03	1.15E-04	0.0011
		5 + BUF									0.0942	2.37E-04	2.28E-04	7.11E-04	7.90E-05	0.0026
		Total									0.9632	1.49E-04	8.32E-05	4.47E-04	4.97E-05	0.0097
45	TiO_2	1	12.9	35.3	3.871	2.602	0.3637	1830	1.7	2.518	0					0.0003
	5<d	2									0.1058	3.91E-05	2.45E-05	1.17E-04	1.30E-05	0.0008
		3									0.2621	3.27E-05	3.46E-05	9.81E-05	1.09E-05	0.0021
		4									0.2518	3.29E-05	4.11E-05	9.87E-05	1.10E-05	0.0024
		5 + BUF									0.3803	3.03E-05	1.86E-05	9.09E-05	1.01E-05	0.0014
		Total									1	2.50E-05	2.93E-05	7.50E-05	8.33E-06	0.0068

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMAD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
46	TiO2	1	19.7	31.2	5.371	3.676	0.285	1830	6.9	1.812	0.2441	1.34E-04	2.54E-05	4.02E-04	4.47E-05	0.0006
	5 < d < 25	2									0.5466	1.14E-04	4.92E-05	3.42E-04	3.80E-05	0.0026
		3									0.1004	1.60E-04	4.12E-04	4.80E-04	5.33E-05	0.004
		4									0.029	2.05E-04	2.14E-04	6.15E-04	6.83E-05	0.0006
		5 + BUF									0.0326	2.00E-04	3.17E-05	6.00E-04	6.67E-05	0.0001
		Total									0.9527	1.02E-04	8.56E-05	3.06E-04	3.40E-05	0.0079
47	TiO2	1	7.8	44.4	2.156	2.657	0.255	1830	6.9	1.772	0.2441	5.73E-05	8.60E-06	1.72E-04	1.91E-05	0.0005
	5 < d < 25	2									0.5466	4.88E-05	1.46E-05	1.46E-04	1.63E-05	0.0019
		3									0.1004	6.85E-05	9.20E-05	2.06E-04	2.28E-05	0.0022
		4									0.029	8.78E-05	8.69E-05	2.63E-04	2.93E-05	0.0006
		5 + BUF									0.0326	8.56E-05	1.29E-05	2.57E-04	2.86E-05	0.0001
		Total									0.9527	4.37E-05	2.34E-05	1.31E-04	1.46E-05	0.0053
48	Limestone	1	16.4	30.7	5.241	2.757	0.1044	900	8.7	1.144	0.2812	5.04E-04	2.75E-05	1.51E-03	1.68E-04	0.0007
	5 < d < 25	2									0.3633	4.79E-04	1.16E-04	1.44E-03	1.60E-04	0.0038
		3									0.0491	7.14E-04	8.70E-04	2.14E-03	2.38E-04	0.0039
		4									0.035	7.65E-04	2.40E-03	2.30E-03	2.55E-04	0.0078
		5 + BUF									0.0934	6.28E-04	3.87E-04	1.88E-03	2.09E-04	0.0031
		Total									0.822	4.07E-04	2.57E-04	1.22E-03	1.36E-04	0.0191
49	Lactose	1	12.1	31.3	3.803	2.974	6.5	222	3.6	2.049	0.0098	1.25E-04	3.43E-05	3.75E-04	4.17E-05	0.0001
	5 < d	2									0.478	5.73E-05	2.12E-06	1.72E-04	1.91E-05	0.0003
		3									0.2748	6.39E-05	4.90E-06	1.92E-04	2.13E-05	0.0004
		4									0.1317	7.41E-05	2.04E-05	2.22E-04	2.47E-05	0.0008
		5 + BUF									0.1077	7.71E-05	1.56E-05	2.31E-04	2.57E-05	0.0005
		Total									1	4.94E-05	7.07E-06	1.48E-04	1.65E-05	0.0021
50	TiO2	1	12.3	33.5	3.602	2.927	1.1808	1830	1.7	3.187	0					0.0003
	5 < d	2									0.1059	1.95E-05	5.11E-05	5.85E-05	6.50E-06	0.0014
		3									0.2621	1.62E-05	4.12E-05	4.86E-05	5.40E-06	0.0029
		4									0.2518	1.64E-05	2.76E-05	4.92E-05	5.47E-06	0.0018
		5 + BUF									0.3803	1.51E-05	7.10E-06	4.53E-05	5.03E-06	0.0007
		Total									1	1.24E-05	2.70E-05	3.72E-05	4.13E-06	0.007
51	Lactose	1	16.8	45.4	3.587	4.275	1.9938	222	39.9	1	0.0171	9.04E-04	5.77E-05	2.71E-03	3.01E-04	0.0003
	d > 25	2									0.0224	8.57E-04	2.94E-05	2.57E-03	2.86E-04	0.0002
		3									0.0148	9.33E-04	2.93E-04	2.80E-03	3.11E-04	0.0013
		4									0.01	1.01E-03	1.32E-04	3.03E-03	3.37E-04	0.0004
		5 + BUF									0.012	9.71E-04	8.22E-05	2.91E-03	3.24E-04	0.0003
		Total									0.0761	6.71E-04	1.09E-04	2.01E-03	2.24E-04	0.0025
52	TiO2	1	18.3	52.1	3.446	3.754	0.1524	1830	16.4	1.345	0.2888	2.03E-04	1.12E-05	6.09E-04	6.77E-05	0.0004
	d > 25	2									0.1159	2.44E-04	2.03E-04	7.32E-04	8.13E-05	0.0029
		3									0.0116	3.86E-04	3.42E-03	1.16E-03	1.29E-04	0.0049
		4									0.0057	4.46E-04	2.58E-03	1.34E-03	1.49E-04	0.0018
		5 + BUF									0.0165	3.60E-04	3.44E-04	1.08E-03	1.20E-04	0.0007
		Total									0.4385	1.87E-04	1.98E-04	5.61E-04	6.23E-05	0.0107
53	Limestone	1	16.6	45.2	3.603	2.774	0.1109	900	8.7	1.158	0.2812	3.34E-04	1.93E-05	1.00E-03	1.11E-04	0.0006
	5 < d < 25	2									0.3633	3.18E-04	1.17E-04	9.54E-04	1.06E-04	0.0047
		3									0.0491	4.74E-04	2.23E-03	1.42E-03	1.58E-04	0.0121
		4									0.035	5.07E-04	1.66E-03	1.52E-03	1.69E-04	0.0064
		5 + BUF									0.0934	4.17E-04	4.95E-04	1.25E-03	1.39E-04	0.0051
		Total									0.822	2.70E-04	3.18E-04	8.10E-04	9.00E-05	0.0289
54	Lactose	1	16	31.9	4.91	2.897	5	222	3.6	1.944	0.0098	1.88E-04	3.39E-05	5.64E-04	6.27E-05	0.0001
	5 < d	2									0.478	8.66E-05	4.89E-06	2.60E-04	2.89E-05	0.0007
		3									0.2748	9.66E-05	1.21E-05	2.90E-04	3.22E-05	0.001
		4									0.1317	1.12E-04	3.03E-06	3.36E-04	3.73E-05	0.0008
		5 + BUF									0.1077	1.17E-04	5.86E-06	3.51E-04	3.90E-05	0.0019
		Total									1	7.46E-05	1.80E-06	2.24E-04	2.49E-05	0.0045

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
55	GB d > 25	1	19.9	38.4	5.084	3.024	0.0449	704	23	0.739	0.1278	2.12E-03	5.01E-05	8.36E-03	7.07E-04	0.0007
		2									0.0103	3.51E-03	5.32E-04	1.05E-02	1.17E-03	0.0008
		3									0.0014	5.24E-03	8.48E-03	1.57E-02	1.75E-03	0.0013
		4									0.0099	3.54E-03	1.29E-03	1.06E-02	1.18E-03	0.0014
		5 + BUF									0.0388	2.73E-03	2.00E-04	8.19E-03	9.10E-04	0.0008
		Total									0.1958	1.97E-03	2.38E-04	5.91E-03	6.57E-04	0.0048
56	Lactose 5 < d < 25	1	5.5	32.5	2.077	3.121	5	222	16	1.443	0.1892	1.08E-04	8.24E-06	3.24E-04	3.60E-05	0.0004
		2									0.1792	1.09E-04	2.97E-05	3.27E-04	3.63E-05	0.0018
		3									0.054	1.38E-04	3.29E-06	4.14E-04	4.60E-05	0.00006
		4									0.0313	1.54E-04	3.77E-05	4.62E-04	5.13E-05	0.0004
		5 + BUF									0.0353	1.51E-04	3.39E-05	4.53E-04	5.03E-05	0.0004
		Total									0.489	8.91E-05	2.17E-05	2.67E-04	2.97E-05	0.0038
57	Limestone 5 < d < 25	1	24.8	34.7	8.03	3.373	0.188	900	8.7	1.287	0.2812	4.07E-04	2.11E-04	1.22E-03	1.36E-04	0.0048
		2									0.3633	3.87E-04	1.10E-03	1.16E-03	1.29E-04	0.0322
		3									0.0491	5.76E-04	1.56E-02	1.73E-03	1.93E-04	0.0625
		4									0.035	6.18E-04	7.76E-03	1.85E-03	2.06E-04	0.022
		5 + BUF									0.0934	5.08E-04	2.07E-03	1.52E-03	1.69E-04	0.0156
		Total									0.822	3.29E-04	2.06E-03	9.87E-04	1.10E-04	0.1371
58	TiO2 5 < d < 25	1	9.3	40.8	2.797	2.716	0.3179	1830	6.9	1.952	0.2441	6.52E-05	6.73E-06	1.96E-04	2.17E-05	0.0004
		2									0.5488	5.55E-05	1.65E-05	1.67E-04	1.85E-05	0.0022
		3									0.1004	7.76E-05	1.10E-04	2.33E-04	2.59E-05	0.0027
		4									0.029	9.98E-05	5.66E-05	2.99E-04	3.33E-05	0.0004
		5 + BUF									0.0328	9.75E-05	5.03E-05	2.93E-04	3.25E-05	0.0004
		Total									0.9527	4.96E-05	2.63E-05	1.49E-04	1.65E-05	0.0061
59	TiO2 5 < d < 25	1	17.2	47.1	3.582	3.192	0.1703	1830	6.9	1.635	0.2441	1.21E-04	2.44E-05	3.63E-04	4.03E-05	0.0007
		2									0.5488	1.03E-04	6.23E-05	3.09E-04	3.43E-05	0.004
		3									0.1004	1.45E-04	5.09E-04	4.35E-04	4.83E-05	0.006
		4									0.029	1.86E-04	7.05E-04	5.58E-04	6.21E-05	0.0024
		5 + BUF									0.0328	1.82E-04	2.61E-04	5.46E-04	6.07E-05	0.001
		Total									0.9527	9.25E-05	1.26E-04	2.78E-04	3.08E-05	0.0141
60	Lactose d > 25	1	12.1	39.2	3.028	4.492	3.2749	222	39.9	1.104	0.0171	5.67E-04	2.52E-04	1.70E-03	1.89E-04	0.0014
		2									0.0224	5.37E-04	3.30E-04	1.61E-03	1.79E-04	0.0024
		3									0.0148	5.85E-04	4.43E-04	1.76E-03	1.95E-04	0.0021
		4									0.01	6.31E-04	2.77E-04	1.89E-03	2.10E-04	0.0009
		5 + BUF									0.012	6.09E-04	1.03E-04	1.83E-03	2.03E-04	0.0004
		Total									0.0761	4.21E-04	2.91E-04	1.26E-03	1.40E-04	0.0072
61	Limestone 5 < d < 25	1	8.7	42.9	2.489	2.271	0.1407	900	8.7	1.214	0.2812	2.00E-04	1.64E-05	6.00E-04	6.67E-05	0.0006
		2									0.3633	1.90E-04	2.12E-05	5.70E-04	6.33E-05	0.001
		3									0.0491	2.84E-04	1.14E-03	8.52E-04	9.47E-05	0.0073
		4									0.035	3.04E-04	1.43E-03	9.12E-04	1.01E-04	0.0065
		5 + BUF									0.0934	2.49E-04	2.55E-04	7.47E-04	8.30E-05	0.0031
		Total									0.822	1.61E-04	1.73E-04	4.83E-04	5.37E-05	0.0185
62	GB d < 5	1	12.7	33.1	3.764	2.356	0.4899	704	2	1.942	0					0.0013
		2									0.0858	9.37E-05	1.39E-03	2.81E-04	3.12E-05	0.0131
		3									0.3287	7.16E-05	6.08E-04	2.15E-04	2.39E-05	0.0219
		4									0.281	7.39E-05	2.19E-04	2.22E-04	2.46E-05	0.0067
		5 + BUF									0.3045	7.27E-05	5.34E-04	2.18E-04	2.42E-05	0.0178
		Total									1	5.74E-05	5.55E-04	1.72E-04	1.91E-05	0.0608
63	Lactose d > 25	1	12.3	39	3.167	4.492	3.2749	222	39.9	1.104	0.0171	5.93E-04	1.43E-04	1.78E-03	1.98E-04	0.0008
		2									0.0224	5.62E-04	3.27E-04	1.69E-03	1.87E-04	0.0024
		3									0.0148	6.12E-04	3.55E-04	1.84E-03	2.04E-04	0.0017
		4									0.01	6.60E-04	3.86E-04	1.98E-03	2.20E-04	0.0012
		5 + BUF									0.012	6.36E-04	1.27E-04	1.91E-03	2.12E-04	0.0005
		Total									0.0761	4.40E-04	2.84E-04	1.32E-03	1.47E-04	0.0068

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
64	Lactose	1	21	36.2	5.691	4.008	6.5	222	16	1.52	0.1892	2.53E-04	1.09E-05	7.56E-04	8.40E-05	0.0008
	5<d<25	2									0.1792	2.55E-04	1.54E-05	7.65E-04	8.50E-05	0.0008
		3									0.054	3.24E-04	4.46E-05	9.72E-04	1.08E-04	0.0007
		4									0.0313	3.62E-04	5.50E-05	1.09E-03	1.21E-04	0.0005
		5 + BUF									0.0353	3.53E-04	4.87E-05	1.06E-03	1.18E-04	0.0005
		Total									0.489	2.09E-04	2.18E-05	6.27E-04	6.97E-05	0.0031
65	GB	1	13.2	36.2	3.577	3.041	0.5692	704	6.65	1.574	0.2486	1.35E-04	4.65E-05	4.05E-04	4.50E-05	0.0014
	5<d<25	2									0.5546	1.15E-04	9.09E-05	3.45E-04	3.83E-05	0.0061
		3									0.0514	1.85E-04	7.89E-04	5.55E-04	6.17E-05	0.0049
		4									0.0144	2.39E-04	8.89E-04	7.17E-04	7.97E-05	0.0012
		5 + BUF									0.0942	1.64E-04	1.32E-04	4.92E-04	5.47E-05	0.0016
		Total									0.9632	1.03E-04	1.30E-04	3.09E-04	3.43E-05	0.0151
66	TiO2	1	19.3	36.3	5.216	3.675	0.6972	1930	6.9	2.167	0.2441	7.59E-05	1.58E-08	2.28E-04	2.53E-05	0.0001
	5<d<25	2									0.5466	6.46E-05	8.36E-08	1.94E-04	2.15E-05	0.0009
		3									0.1004	9.08E-05	5.39E-05	2.72E-04	3.02E-05	0.0014
		4									0.029	1.16E-04	1.47E-04	3.48E-04	3.87E-05	0.0011
		5 + BUF									0.0326	1.13E-04	1.07E-04	3.39E-04	3.77E-05	0.0009
		Total									0.9527	5.78E-05	1.91E-05	1.73E-04	1.93E-05	0.0047
67	Limestone	1	7.8	33.6	2.778	2.271	0.1407	900	9.7	1.214	0.2812	2.23E-04	1.77E-05	6.69E-04	7.43E-05	0.0006
	5<d<25	2									0.3633	2.12E-04	2.74E-05	6.36E-04	7.07E-05	0.0012
		3									0.0491	3.16E-04	1.20E-03	9.48E-04	1.05E-04	0.0071
		4									0.035	3.39E-04	1.33E-03	1.02E-03	1.13E-04	0.0056
		5 + BUF									0.0934	2.78E-04	2.31E-04	8.34E-04	9.27E-05	0.0026
		Total									0.822	1.80E-04	1.73E-04	5.40E-04	6.00E-05	0.0171
68	Lactose	1	13	38	3.365	4.687	5	222	39.9	1.202	0.0171	4.89E-04	1.79E-04	1.47E-03	1.63E-04	0.0009
	d>25	2									0.0224	4.63E-04	1.99E-04	1.39E-03	1.54E-04	0.0013
		3									0.0148	5.04E-04	3.03E-04	1.51E-03	1.68E-04	0.0013
		4									0.01	5.44E-04	2.38E-04	1.63E-03	1.81E-04	0.0007
		5 + BUF									0.012	5.25E-04	1.99E-04	1.58E-03	1.75E-04	0.0007
		Total									0.0761	3.63E-04	2.19E-04	1.09E-03	1.21E-04	0.0049
69	GB	1	24.9	33.6	6.303	3.443	0.4728	704	6.65	1.517	0.2486	2.67E-04	3.69E-04	8.01E-04	8.90E-05	0.0111
	5<d<25	2									0.5546	2.27E-04	8.12E-04	6.81E-04	7.57E-05	0.0545
		3									0.0514	3.65E-04	3.17E-03	1.10E-03	1.22E-04	0.0197
		4									0.0144	4.71E-04	3.04E-03	1.41E-03	1.57E-04	0.0053
		5 + BUF									0.0942	3.24E-04	2.60E-03	9.72E-04	1.08E-04	0.0298
		Total									0.9632	2.03E-04	1.03E-03	6.09E-04	6.77E-05	0.1202
70	TiO2	1	16.2	47.5	3.346	3.711	0.1361	1930	16.4	1.315	0.2988	2.11E-04	1.14E-05	6.33E-04	7.03E-05	0.0004
	d>25	2									0.1159	2.53E-04	1.48E-04	7.59E-04	8.43E-05	0.0021
		3									0.0118	4.01E-04	2.54E-03	1.20E-03	1.34E-04	0.0036
		4									0.0057	4.63E-04	1.74E-03	1.39E-03	1.54E-04	0.0012
		5 + BUF									0.0165	3.74E-04	6.46E-04	1.12E-03	1.25E-04	0.0013
		Total									0.4385	1.94E-04	1.61E-04	5.82E-04	6.47E-05	0.0086
71	Lactose	1	17	45.1	3.691	4.811	6.5	222	39.9	1.266	0.0171	4.59E-04	9.70E-05	1.37E-03	1.53E-04	0.0005
	d>25	2									0.0224	4.34E-04	1.04E-04	1.30E-03	1.45E-04	0.0007
		3									0.0148	4.73E-04	1.14E-04	1.42E-03	1.58E-04	0.0006
		4									0.01	5.10E-04	6.64E-05	1.53E-03	1.70E-04	0.0002
		5 + BUF									0.012	4.92E-04	1.38E-04	1.48E-03	1.64E-04	0.0005
		Total									0.0761	3.40E-04	1.05E-04	1.02E-03	1.13E-04	0.0024
72	Limestone	1	14.5	38.4	3.704	4.031	0.2351	900	38.7	0.998	0.0451	7.73E-04	2.05E-04	2.32E-03	2.58E-04	0.001
	d>25	2									0.0309	9.01E-04	1.37E-03	2.70E-03	3.00E-04	0.0031
		3									0.0063	1.15E-03	5.71E-03	3.45E-03	3.83E-04	0.0039
		4									0.009	1.09E-03	1.38E-03	3.27E-03	3.63E-04	0.0012
		5 + BUF									0.0185	9.24E-04	1.89E-04	2.77E-03	3.08E-04	0.0004
		Total									0.0988	6.61E-04	8.56E-04	1.98E-03	2.20E-04	0.0056

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
73	GB	1	12.8	31.3	4.012	2.471	0.79	704	2	2.137	0					0.0011
	d<5	2									0.0858	7.50E-05	6.72E-04	2.25E-04	2.50E-05	0.0065
		3									0.3287	5.73E-05	2.07E-04	1.72E-04	1.91E-05	0.0075
		4									0.281	5.92E-05	6.00E-05	1.78E-04	1.97E-05	0.0019
		5 + BUF									0.3045	5.82E-05	1.14E-04	1.75E-04	1.94E-05	0.0039
		Total									1	4.59E-05	1.85E-04	1.38E-04	1.53E-05	0.0209
74	GB	1	8.2	36.6	2.207	3.939	0.6329	704	23	1.254	0.1276	1.88E-04	1.80E-05	5.64E-04	6.27E-05	0.0008
	d>25	2									0.0103	3.12E-04	1.95E-04	9.36E-04	1.04E-04	0.0007
		3									0.0014	4.65E-04	2.86E-03	1.40E-03	1.55E-04	0.0014
		4									0.0099	3.14E-04	1.74E-04	9.42E-04	1.05E-04	0.0008
		5 + BUF									0.0366	2.42E-04	7.04E-05	7.26E-04	8.07E-05	0.0009
		Total									0.1858	1.75E-04	6.78E-05	5.25E-04	5.83E-05	0.0044
75	GB	1	25.7	35.3	6.193	3.486	0.5349	704	8.65	1.555	0.2486	2.43E-04	2.86E-04	7.29E-04	8.10E-05	0.0086
	5<d<25	2									0.5546	2.07E-04	8.78E-04	6.21E-04	6.90E-05	0.0589
		3									0.0614	3.33E-04	3.33E-03	9.99E-04	1.11E-04	0.0207
		4									0.0144	4.30E-04	2.35E-03	1.29E-03	1.43E-04	0.0041
		5 + BUF									0.0942	2.95E-04	2.40E-03	8.85E-04	9.85E-05	0.0274
		Total									0.9832	1.85E-04	1.03E-03	5.55E-04	6.17E-05	0.1197
76	GB	1	17.2	39.7	4.25	3.007	0.0425	704	23	0.731	0.1276	1.83E-03	4.48E-05	5.49E-03	6.10E-04	0.0005
	d>25	2									0.0103	3.04E-03	5.55E-04	9.12E-03	1.01E-03	0.0005
		3									0.0014	4.52E-03	9.81E-03	1.36E-02	1.51E-03	0.0012
		4									0.0099	3.06E-03	6.93E-04	9.18E-03	1.02E-03	0.0006
		5 + BUF									0.0366	2.36E-03	5.94E-04	7.08E-03	7.87E-04	0.0018
		Total									0.1858	1.70E-03	2.89E-04	5.10E-03	5.67E-04	0.0047
77	Lactose	1	7.5	28.3	2.785	2.852	4.2858	222	3.8	1.685	0.0098	1.17E-04	2.10E-04	3.51E-04	3.90E-05	0.0006
	5<d	2									0.476	5.39E-05	7.92E-06	1.62E-04	1.80E-05	0.0011
		3									0.2748	6.01E-05	2.50E-05	1.80E-04	2.00E-05	0.002
		4									0.1317	6.97E-05	1.30E-05	2.09E-04	2.32E-05	0.0005
		5 + BUF									0.1077	7.25E-05	3.82E-05	2.18E-04	2.42E-05	0.0012
		Total									1	4.64E-05	1.85E-05	1.39E-04	1.55E-05	0.0054
78	GB	1	10	29	3.383	2.327	0.4327	704	2	1.895	0					0.0011
	d<5	2									0.0858	9.07E-05	6.89E-04	2.72E-04	3.02E-05	0.0062
		3									0.3287	6.94E-05	3.74E-04	2.08E-04	2.31E-05	0.0127
		4									0.281	7.16E-05	1.82E-04	2.15E-04	2.39E-05	0.0047
		5 + BUF									0.3045	7.04E-05	5.72E-05	2.11E-04	2.35E-05	0.0018
		Total									1	5.55E-05	2.56E-04	1.67E-04	1.85E-05	0.0265
79	Lime	1	11.7	33.3	3.447	2.522	0.6128	900	2.3	2.126	0					0.0003
	d<5	2									0.231	5.37E-05	1.95E-04	1.61E-04	1.79E-05	0.0051
		3									0.2964	5.11E-05	5.07E-06	1.53E-04	1.70E-05	0.0002
		4									0.2153	5.44E-05	9.86E-05	1.63E-04	1.81E-05	0.0024
		5 + BUF									0.2573	5.25E-05	3.44E-05	1.58E-04	1.75E-05	0.001
		Total									1	4.00E-05	7.96E-05	1.20E-04	1.33E-05	0.009
80	GB	1	9.8	30.9	3.111	2.056	0.1254	704	2	1.479	0					0.0013
	d<5	2									0.0858	1.75E-04	5.01E-04	5.25E-04	5.83E-05	0.0043
		3									0.3287	1.34E-04	2.77E-04	4.02E-04	4.47E-05	0.0091
		4									0.281	1.38E-04	1.17E-04	4.14E-04	4.60E-05	0.0033
		5 + BUF									0.3045	1.36E-04	2.95E-05	4.08E-04	4.53E-05	0.0009
		Total									1	1.07E-04	1.89E-04	3.21E-04	3.57E-05	0.0189
81	Lactose	1	17.8	25.7	6.705	2.152	0.6261	222	2.3	1.403	0.0098	6.83E-04	3.34E-05	2.05E-03	2.28E-04	0.0001
	d<5	2									0.476	3.14E-04	3.44E-06	9.42E-04	1.05E-04	0.0005
		3									0.2748	3.51E-04	8.35E-06	1.05E-03	1.17E-04	0.0007
		4									0.1317	4.06E-04	1.49E-05	1.22E-03	1.35E-04	0.0008
		5 + BUF									0.1077	4.23E-04	4.56E-05	1.27E-03	1.41E-04	0.0015
		Total									1	2.71E-04	1.11E-05	8.13E-04	9.03E-05	0.0034

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Freq i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
82	GB 5<d<25	1	15.2	41.4	3.602	2.654	0.1461	704	6.65	1.199	0.2486	3.08E-04	9.97E-06	9.24E-04	1.03E-04	0.0003
		2									0.5548	2.62E-04	4.62E-05	7.86E-04	8.73E-05	0.0031
		3									0.0514	4.22E-04	8.84E-04	1.27E-03	1.41E-04	0.0055
		4									0.0144	5.45E-04	6.89E-04	1.64E-03	1.82E-04	0.0012
		5 + BUF									0.0942	3.74E-04	7.02E-05	1.12E-03	1.25E-04	0.0008
		Total									0.9632	2.35E-04	9.35E-05	7.05E-04	7.83E-05	0.0109
83	TiO2 5<d<25	1	7.8	40.5	1.889	3.585	0.544	1830	6.9	2.062	0.2441	3.19E-05	1.04E-05	9.57E-05	1.06E-05	0.0006
		2									0.5466	2.71E-05	1.55E-05	8.13E-05	9.03E-06	0.002
		3									0.1004	3.81E-05	1.30E-04	1.14E-04	1.27E-05	0.0031
		4									0.029	4.88E-05	1.60E-04	1.46E-04	1.63E-05	0.0011
		5 + BUF									0.0326	4.77E-05	3.89E-05	1.43E-04	1.59E-05	0.0003
		Total									0.9527	2.43E-05	3.15E-05	7.29E-05	8.10E-06	0.0071
84	Lime d<5	1	13.3	32.9	3.951	2.659	1.039	900	2.3	2.363	0					0.0004
		2									0.231	4.48E-05	1.81E-05	1.34E-04	1.49E-05	0.0009
		3									0.2964	4.27E-05	4.23E-05	1.28E-04	1.42E-05	0.0027
		4									0.2153	4.55E-05	5.60E-05	1.37E-04	1.52E-05	0.0026
		5 + BUF									0.2573	4.39E-05	1.80E-05	1.32E-04	1.46E-05	0.001
		Total									1	3.34E-05	3.53E-05	1.00E-04	1.11E-05	0.0076
85	TiO2 5<d<25	1	12.6	41.6	2.971	3.255	0.2072	1830	6.9	1.7	0.2441	8.95E-05	2.46E-05	2.69E-04	2.98E-05	0.0007
		2									0.5466	7.62E-05	4.08E-05	2.29E-04	2.54E-05	0.0026
		3									0.1004	1.07E-04	6.16E-04	3.21E-04	3.57E-05	0.0072
		4									0.029	1.37E-04	9.18E-04	4.11E-04	4.57E-05	0.0031
		5 + BUF									0.0326	1.34E-04	3.16E-04	4.02E-04	4.47E-05	0.0012
		Total									0.9527	6.82E-05	1.33E-04	2.05E-04	2.27E-05	0.0148
86	Lime d<5	1	12.1	33.5	3.543	2.505	0.5727	900	2.3	2.098	0					0.0002
		2									0.231	5.75E-05	2.96E-05	1.73E-04	1.92E-05	0.0008
		3									0.2964	5.47E-05	6.63E-05	1.64E-04	1.82E-05	0.0023
		4									0.2153	5.83E-05	9.52E-05	1.75E-04	1.94E-05	0.0024
		5 + BUF									0.2573	5.62E-05	5.31E-05	1.69E-04	1.87E-05	0.0016
		Total									1	4.29E-05	6.23E-05	1.29E-04	1.43E-05	0.0073
87	TiO2 5<d<25	1	14.4	40.5	3.488	2.942	0.0754	1830	6.9	1.389	0.2441	1.93E-04	1.68E-05	5.79E-04	6.43E-05	0.0005
		2									0.5466	1.64E-04	4.95E-05	4.93E-04	5.47E-05	0.0033
		3									0.1004	2.30E-04	7.52E-04	6.90E-04	7.67E-05	0.0092
		4									0.029	2.95E-04	1.19E-03	8.85E-04	9.83E-05	0.0042
		5 + BUF									0.0326	2.88E-04	3.52E-04	8.64E-04	9.60E-05	0.0014
		Total									0.9527	1.47E-04	1.60E-04	4.41E-04	4.90E-05	0.0186
88	Lime d<5	1	11	31.7	3.404	2.429	0.4209	900	2.3	1.972	0					0.0007
		2									0.231	6.64E-05	6.62E-05	1.99E-04	2.21E-05	0.0014
		3									0.2964	6.32E-05	1.44E-04	1.90E-04	2.11E-05	0.0039
		4									0.2153	6.73E-05	1.88E-04	2.02E-04	2.24E-05	0.0037
		5 + BUF									0.2573	6.50E-05	6.07E-05	1.95E-04	2.17E-05	0.0019
		Total									1	4.95E-05	1.27E-04	1.49E-04	1.65E-05	0.0118

Experiment	Material	Stage	Average DG	Average Q	Normalized Impaction	Estimated Impaction	Moisture Content	Tm	MMD	Cohesion	Frac i	Predicted Generation	Actual Generation	+ 1 SD	- 1 SD	Dust on Substrate
89	Talc	1	6.9	29.8	2.287		0.2079	930	14.8	1.195	0.0074	3.99E-04	2.68E-03	1.20E-03	1.33E-04	0.0024
		2									0.1202	2.28E-04	8.66E-04	6.84E-04	7.60E-05	0.0126
		3									0.1439	2.20E-04	7.29E-04	6.60E-04	7.33E-05	0.0127
		4									0.216	2.03E-04	1.76E-04	6.09E-04	6.77E-05	0.0046
		5 + BUF									0.5122	1.71E-04	2.26E-05	5.13E-04	5.70E-05	0.0014
		Total									0.9997	1.50E-04	2.79E-04	4.50E-04	5.00E-05	0.0337
90	Toner	1	4.3	12.7	3.321		14.1255	71	10.9	1.362	0.0511	2.66E-04	3.07E-04	7.98E-04	8.87E-05	0.0019
		2									0.6169	1.62E-04	8.98E-05	4.86E-04	5.40E-05	0.0067
		3									0.1956	2.03E-04	1.23E-04	6.09E-04	6.77E-05	0.0029
		4									0.055	2.62E-04	4.51E-05	7.86E-04	8.73E-05	0.0003
		5 + BUF									0.0815	2.42E-04	9.13E-05	7.26E-04	8.07E-05	0.0009
		Total									1	1.47E-04	1.05E-04	4.41E-04	4.90E-05	0.0127
91	Tea Mix	1	12.1	45.1	2.632		0.2167	178	14	0.74	0.007	1.96E-03	1.30E-03	5.88E-03	6.53E-04	0.0011
		2									0.1218	1.10E-03	2.51E-04	3.30E-03	3.67E-04	0.0037
		3									0.2192	9.82E-04	2.87E-04	2.95E-03	3.27E-04	0.0076
		4									0.3229	9.09E-04	1.54E-04	2.73E-03	3.03E-04	0.006
		5 + BUF									0.329	9.05E-04	5.53E-05	2.72E-03	3.02E-04	0.0022
		Total									0.9999	7.25E-04	1.70E-04	2.18E-03	2.42E-04	0.0208
92	Fly Ash	1	8.4	26.6	3.098		0.9169	900	14.4	1.597	0.0069	2.30E-04	1.44E-03	6.90E-04	7.67E-05	0.0012
		2									0.1263	1.28E-04	3.27E-04	3.84E-04	4.27E-05	0.005
		3									0.1589	1.23E-04	4.37E-04	3.69E-04	4.10E-05	0.0084
		4									0.2393	1.13E-04	1.35E-04	3.39E-04	3.77E-05	0.0039
		5 + BUF									0.5219	9.67E-05	2.53E-05	2.90E-04	3.22E-05	0.0016
		Total									1	8.49E-05	1.66E-04	2.55E-04	2.83E-05	0.0201

Explanation of Data Table

The material column lists the material that was dropped and its size distribution. Glass beads were abbreviated GB and titanium dioxide was abbreviated TiO2.

Stage refers to the impactor stage. BUF is the abbreviation for back-up filter.

Average DG is the average deflection of the balance reading during the impaction measurements.

Average Q is the average flow rate in g/s.

Normalized impaction is the impaction calculated using Equations 5 and 6.

Estimate impaction is the impaction calculated using Plinke's model for impaction, Equation 3.

Tm is the melting temperature in degree C.

MMD is the mass median particle diameter.

Cohesion was calculated using Plinke's model, Equation 2.

Frac i is the fraction of particles in the parent material with an aerodynamic diameter in the given size range.

Predicted Generation is the predicted value of dust generation from Plinke's model, Equation 4.

Actual Generation is the measured amount of dust generated from the experiment. Actual dust generation equals the amount of dust generated with a given size divided by the amount of material dropped of that size.

+ 1 SD is the value of predicted dust generation plus one standard deviation. The values for the standard deviation are given in Equation 4.

- 1 SD is the value of predicted dust generation minus one standard deviation. The values for the standard deviation are given in Equation 4.

Dust on Substrate is the measured mass of dust found on the impactor substrate in grams.

Cut Sizes for Andersen Series 210 Impactor

Impactor Stage	Size Range (μm)
1	9.2-15
2	3.7-9.2
3	2.2-3.7
4	1.4-2.2
5	0.76-1.4
BUF	<0.76

These values are for a flow rate of 10 liters per minute.

APPENDIX B

STANDARD OPERATING PROCEDURES

UNC BENCH-TOP DUSTINESS TESTER

1.0 EQUIPMENT SET UP

1.1 Experimental Parameters

1.1.1 Fill out experimental data sheet.

1.1.2 Label two test tubes for moisture analysis.

1.2 Material Preparation

1.2.1 Shake the air-tight container with the test material inside for 30 seconds. Wait at least one minute for the material to settle.

1.2.2 Weigh the container on the Sartorious balance and determine weight of the material.

1.2.3 Roughly determine the volume of the material inside the container by comparing with a similar container with marked volumes on the outside.

1.3 Preliminary Apparatus Set-up

1.3.1 Attach the extension section as needed with metal clips to obtain the desired drop height.

1.3.2 Wrap the bottom of the apparatus with plastic wrap and seal with tape.

1.3.3 Place apparatus on blocks so the plastic wrap rests on the balance pan.

1.3.4 Turn on data collection computer.

1.4 Impactor Preparation

1.4.1 Store the substrates, backup filter, and their respective blanks in the carrying box for a minimum of 24 hours to permit moisture equilibration.

1.4.2 Weigh the sample test tubes, substrates, backup filter, and blank in the aerosol chamber of the Mettler AE200 balance and record data in notebook.

1.4.3 Store the blank in labelled Petri dishes.

1.4.4 Mount the substrates and the backup filter in the impactor, starting with the backup filter followed by stage 5 proceeding to stage 1.

2.0 RUNNING AN EXPERIMENT

2.1 Apparatus Set-up

2.1.1 Attach the loaded impactor at the top of the elutriation column in an inverted position so that it rests firmly on the support pins. Connect the vacuum line to the impactor outlet.

2.1.2 Open the material container and fill the two sample test tubes with material for later analysis of moisture content. Quickly seal the test tubes with rubber stoppers.

2.1.3 Tare a large glass funnel on the balance. Quickly weigh out 100 g material and promptly seal the material container.

2.1.4 Fill the injection slide with this weighed material and lift the push-rod until the material is within one-half inch of the end of the slide.

2.1.5 Make sure the main power is off. Then set the Variac transformer to control the vibration to 70%. Set the motor setting of the injection rod to the desired value.

2.2 Equipment Start-up

2.2.1 Start vacuum to draw air at 10 LPM through the apparatus. Measure flow with a rotameter which has been calibrated with a spirometer. This flow should be monitored periodically throughout the test and corrected if deviations occur.

2.2.2 Insert the slide into the tester until the end is in the center of the soft sealant on the feeder pipe. This position centers the material drop in the middle of the apparatus.

2.2.3 Tare the balance.

2.2.4 Begin the data collection program.

2.2.5 Turn on the power supply which starts both the material flow and vibration. Time the injection period with a stopwatch starting when the material begins to leave the slide.

2.2.6 When the push-rod reaches the end of the slide, turn main power off and record the time.

2.2.7 Stop the data collection program one minute after turning the power off.

2.2.8 Continue to draw air through the tester for 25 minutes to assure that no dust remains.

2.2.9 During this time period measure and record room temperature, air pressure, and relative humidity.

2.3 Subsequent to Test

2.3.1 Disconnect the impactor from the tester and invert before stopping the air flow.

2.3.2 Disconnect the impactor from the vacuum line.

2.3.2 Reweigh the substrates, backup filter, and blanks and record on datasheet.

2.3.3 Use the samples discussed in Section 2.1.2 to determine the moisture content of the material. These samples will be analyzed at at later date.

3.0 CLEANING PROCEDURES

3.1 Tester - Stainless Steel Areas

3.1.1 Remove the plastic wrap and collect the used bulk material in a suitably marked container.

3.1.2 Wipe down the apparatus with dry paper towels. Next use a damp sponge followed by two separate wipe downs with dry paper towel. Allow a minimum of one hour to air dry.

3.2 Tester - Glass Area

3.2.1 Clean with a wet sponge and wipe off excess water with a dry paper towel. Allow a minimum of one hour to air dry.

3.3 Dust Injection Slide

3.3.1 Clean the plunger and the outside of the injection slide with a damp sponge.

3.3.2 To further clean the pipe apply air pressure at the mouth of the pipe while working the feeder arm in the forward and reverse positions.

3.3.2 Wrap several Kimwipes around the rubber tip of the cleaning rod to increase its diameter. Insert the rod several times into the feeder pipe to clean inside walls. Change Kimwipes often to remove moisture along the walls caused by the compressed air.

3.4 Impactor Stages

3.4.1 Clean the impactor stages after each experiment with a soft brush followed by Kimwipes soaked in ethyl alcohol. Wash the slots of the stages with ethyl alcohol using Kimwipes.

4.0 Corrective Action

4.1 If the airflow through the tester varies by more than 5% as measured with the rotameter, the flow will be corrected and the time of the adjustment will be recorded.

4.2 Experiments will be repeated by the investigator when the following occur:

4.2.1 The material flow rate cannot be determined because of time measurement errors.

4.2.2 The time elapsed from opening the material container to the start of the experiment exceeds 10 minutes. This delay will cause moisture changes to the material.

4.2.3 The average weight change of the substrate blanks varies by more than ± 0.2 mg.

4.2.4 Dust can be detected in the elutriation column after the 25 minutes.

4.3 When an experiment yields less than 5.0 mg of total dust or experience suggests than an experiment will not yield 5.0 mg with one material drop, the experiment will be repeated with multiple material drops.

4.3.1 The number of material drops to be performed will be based on previous experience and the goal of 5.0 mg of total dust.

4.3.2 The maximum number of drops in any experiment will be three. For relevant procedures, see Section 5.0, Repeated Material Drops.

5.0 Repeated Material Drops

5.1 Procedures

5.1.1 When four air changes have been achieved, remove the impactor from the tester and set it on a flat, level surface. Stop the airflow through the impactor and cover the inlet with Parafilm.

5.1.2 Withdraw the injection slide from the tester.

5.1.3 Fill the injection slide as described in Section 2.1.

5.1.4 Remove the Parafilm from the impactor and place the impactor at the top of the measurement section.

5.1.5 Perform subseequent material drops under the same conditions as the original.

5.2 Data Considerations

5.2.1 The total mass dropped will be the sum of the masses from the individual drops.

5.2.2 The material flow rate will be the total mass dropped divided by the sum of the material flow times.

5.2.3 The difference between the maximum balance reading and the rest mass of the dropped material is ΔG for use in impaction calculations.

5.2.4 If several drops are necessary, an average ΔG and mass flow rate are to be used for impaction calculations.

VACUUM OVEN PROCEDURE

1.0 To Pull a Vacuum and Begin Heating

1.1 Make sure both valves on top of the oven are turned completely clockwise. This closes them.

1.2 Turn on the vacuum pump. The switch is on the cord.

1.3 Hold the door closed, and open the valve on the right. Once the gauge reads over 5, you may let go of the door. If the needle stops below 29, open the valve more.

1.4 Turn the heating control knob (located at the bottom of the front panel) to desired setting.

2.0 To Repressurize

2.1 Turn heating control knob to 0.

2.2 Allow temperature to decrease to room temperature. This takes several hours.

2.3 Turn the right (vacuum line) valve clockwise until closed.

2.4 Turn off the vacuum pump. The oven should still be holding a vacuum.

2.5 Slowly open the left valve to allow purge air into the oven. The door will open when fully pressurized.

3.0 Notes:

3.1 The inorganic materials should be stay in the oven for 48 hours at 175° C. The lactose should be dried for 48 hours at 70° C.

3.2 A thermometer is in the oven to observe the temperature. Please note that there is a break in the Mercury. Therefore, you must add 10° C to the temperature you read.

3.3 To determine the moisture content use the following equation:

$$\%_{moisture} = 100 * \left(\frac{wt_{moist} - wt_{dry}}{wt_{dry}} \right)$$