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Comparison of a Direct-Reading Device to Gravimetric Methods for Evaluating Organic Dust Aerosols in an Enclosed Swine Production Environment

Craig D. Taylor and Stephen J. Reynolds
Institute for Rural and Environmental Health, University of Iowa, Iowa City, Iowa

The production of livestock in enclosed facilities has become an accepted practice, driven by the need for increased efficiency. Exposure to organic dusts, containing various bioactive components, has been identified an important risk factor for the high rate of lung disease found among workers in these environments. Assessment of organic dust exposure requires technical skills and instrumentation not readily available to most agricultural enterprises. Development of a simple, cost-effective method for measuring organic dust levels would be useful in evaluating and controlling exposures in these environments. The objective of this study was to evaluate the usefulness of the direct reading MIE PDM-3 Miniram for estimating organic dust concentrations in enclosed swine production facilities. Responses from the MIE PDM-3 Miniram were compared to gravimetric methods for total and inhalable dust. Total dust determinations were conducted in accordance with the National Institute for Occupational Safety and Health (NIOSH) method 0500. Inhalable particulate mass (IPM) sampling was conducted using SKC brand IOM (Institute of Occupational Medicine) sampling cassettes, which meet the American Conference of Governmental Industrial Hygienists ACGIH® criteria for inhalable dust sampling. This study design also allowed for the comparison of traditional total dust method to the IPM method, in collecting organic dusts in an agricultural setting. Fifteen sets of side-by-side samples (Miniram, total dust, and IPM) were collected over a period of six months in a swine confinement building. There were statistically significant differences in the results provided by the three sampling methods. Measurements for inhalable dust exceeded those for total dust in eleven of fifteen samples. The Miniram time-weighted average (TWA) response to the organic dust was always the lower of the three methods. A high degree of correlation was found among all three methods. The Miniram performed well under field conditions of varying temperature and humidity. The Miniram has the potential to predict the inhalable and total dust concentrations, assuming a correction factor for the organic dust being measured is applied.

Keywords Organic Dust, Direct-Reading Instruments, Instrument Calibrations, Photometers

Driven by the need for efficiency, production of livestock in enclosed facilities has become an accepted practice throughout North America and Europe. Especially during the winter season, confinement buildings tend to concentrate organic dusts, along with a variety of gases and other environmental contaminants. Exposure to these organic dusts, containing various bioactive components, has been identified an important risk factor for the high rate of lung disease found among workers in these environments.[2,3] More than 700,000 farmers and farm workers in the United States alone may be at risk for occupational lung disease from enclosed swine, poultry, and dairy operations.[4,5] Production efficiency itself can also be compromised when livestock are adversely affected by these exposures.[1]

Organic dusts found in swine confinement facilities are composed of feed components, urine, fecal material, swine dander, insect parts, bacteria, fungi, pollen grains, $(1 \rightarrow 3)$-β-D-glucans, endotoxins, and other bio-active materials.[1,4,6,7] Total organic dust levels found in U.S. farms vary greatly depending on the type of building, number of animals present, ventilation system, and ambient outdoor conditions. In general, total dust concentrations range from 1 mg/m^3 to more than 20 mg/m^3. In most cases, respirable dust, the portion that deposits in the small pulmonary passages and has an aerodynamic diameter less than 4 μm, accounts for 10 percent to 33 percent of total dust. The predominant particle size distribution of organic dust in swine facilities has been documented to be in the range of 9.6 μm to 26 μm.[8] The dose-response relationship between reduced pulmonary function and total organic dust levels has

been well documented by past studies.[2,3,5] Based on these studies, a guideline of approximately 2.4 mg/m^3 for total dust[4] (in comparison to the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®) of 10 mg/m^3)[9] has been recommended to prevent adverse work-related health effects in swine production environments.[2,3]

Determining the concentration of organic dust requires a considerable amount of time, material, and effort. Even the most basic gravimetric method requires several hours for sample collection assuming that air pumps, filter media, analytical balances, laboratory facilities, and trained technicians are available. There is a need to develop improved methods of determining organic dust concentrations in a quick, simple, and accurate manner. By providing immediate feedback to the operator, adjustments to work schedule and ventilation systems can be made, which will provide for better working conditions and reduce stress on livestock.

Aerosol photometry is widely accepted in the measurement of suspended dust particles. The principle of this method is based on Mie light scattering, as proposed by Gustav Mie[10] in the early 20th century. Light scattering technology is used in a variety of aerosol measuring instruments, including photometers, nephelometers, and particle counters. Photometers are a class of light scattering devices capable of detecting and analyzing multiple particles and converting this information to mass per unit volume. Industrial hygienists have often used photometers as direct-reading real-time dust monitors. Theoretical calibration curves derived for light scattering devices under controlled conditions are usually based on particles of spherical shape with a homogeneous size distribution. In contrast, real aerosol particulates have variable or irregular shapes and the size is distributed in a heterogeneous manner.[10] Photometers have certain limitations, which must be evaluated when considering their potential as direct-reading instruments. At very high concentrations, (> than 100 mg/m^3) they are limited by the effect of multiple scatterings in the sensing chamber and at low concentrations (< than 0.1 mg/m^3), the instrument may prove unreliable due to stray background light.[10]

The MIE PDM-3 Miniram is a type of light scattering photometer which is used for area or personal sampling. It continuously senses the combined scattering of all the particles in its sensing chamber and displays the concentration in mg/m^3 on the liquid crystal display (LCD). The value displayed on the LCD is continually updated at 10-second intervals. The device has the ability to calculate and display a time-weighted average (TWA) at any time during the sampling period. The Miniram does not require filtration of the aerosol or external pumps to operate. The sensing range is from 0.01 mg/m^3 to 100 mg/m^3, and is preferential to particles in the 0.1 to 10 μm range.[10]

The Miniram uses a pulsed Gallium Arsenide light-emitting source that generates a narrow band emission centered at 880 nanometers. Light scattered by airborne particles is collected over an angular range of between 45° and 90° from the forward direction by means of a silicon photo detector.[11] An optical interference filter is incorporated to screen out background light or wavelengths, which differ from the Gallium Arsenide source. The instrument will have a constant response at a zero concentration level due to the Raleigh (small particle) scattering of background or stray light. This response is taken into consideration during the instrument zeroing procedure.

The Miniram is considered to be a multiple-particle instrument and can give useful concentration estimates as long as certain requirements are met. Under ideal circumstances, there exists a linear relationship between the response of the instrument and the concentration of the aerosol to be measured. Previous research has shown this to be accurate (r = 0.99) at total dust levels at or below 20 mg/m^3 when calibrated with SAE fine dust.[11] Minirams show a tendency to overestimate or underestimate total dust at concentrations in excess of 6 mg/m^3 when tested with coal or quartz dust.[11] As the aerosol concentration increases it will eventually reach an upper limit where multiple scatterings will cause a deviation from the linear relationship of response versus concentration. As the diameter of the aerosol particle increases, the concentration at which the onset of multiple scatterings occur decreases.[10] The instrument should be operated within the linear range to obtain valid results.

The ACGIH TLV committee has expressed the intent to replace the existing total particulate TLVs with inhalable, thoracic, and respirable particulate TLVs. The ACGIH encourages research comparing the traditional total dust method to the newer inhalable, thoracic, and respirable methods, to assist their attempts to evaluate methodologies in their search for appropriate replacement methods for total dust sampling. The health effects associated with exposures to organic dusts show a close relationship to the inhalable dust fraction, particles capable of being inhaled through the nose or mouth during breathing. Even though the primary objective of this study was to compare the direct reading Miniram to gravimetric methods for total dust and inhalable dust, it also allowed for the comparison of inhalable and total dust methods in analyzing organic dust exposures.

METHODS

Samples were collected in a typical swine grower building in Iowa. The site was chosen from among the participants of an ongoing longitudinal rural health study.[12] The target confinement building was a totally enclosed swine grower building with a deep-pit manure handling system under the entire building. Feed was supplied by an overhead auger system, which brings ground feed into the building from an outside metal bulk bin. The feed ration is made from ground shelled corn, 38 percent soybean meal, a mineral supplement, and antibiotics as needed to control specific animal health conditions. No oil or other material was added to the feed to control or reduce dust levels from ground feed. Ventilation consisted of a system of 10 variable speed fans mounted in the exterior walls, with fresh air entering the building through a system of adjustable louvers mounted in the peak of the roof. Approximately 500 hogs were housed in the building.

Animal size ranged from 40 pounds to 140 pounds during the study.

A total of 15 sampling sessions were conducted throughout July 1995 to January 1996. Samples were collected in the center of the building by placing two sampling pumps for total dust, two sampling pumps for inhalable dust, and two Minirams in a wire basket suspended by a chain at five feet above the floor. Samples were collected over four to eight hours in each session. The Minirams were oriented downward in accordance with operating instructions. Both Minirams received factory calibrations and were zeroed prior to the collection of dust samples. Data was logged at one-minute intervals for the duration of each sampling period. A TWA was calculated at the end of each sampling period.

Total dust samples were collected and evaluated according to NIOSH method 0500, using 37-mm closed-faced polystrene cassettes and 37-mm polyvinylchloride (PVC) filters with a 5-μm pore size (SKC Inc., Eighty Four, PA). Total dust sampling pumps (MSA, Pittsburgh, PA) were calibrated to a flow rate of 2.0 liters per minute. Filters were pre- and post-weighed using a Mettler MT5 balance. (Mettler-Toledo, Inc.) Inhalable particulate matter (IPM) was collected using SKC sampling cassettes and 25-mm PVC filters with a 5-μm pore size (SKC Inc., Eighty Four, PA). These samplers, sometimes identified as IOM samplers, refer to the Institute of Occupational Medicine, where the device was originally developed. Personal sampling pumps (MSA, Pittsburgh, PA) were calibrated to a flow rate of 2.0 Lpm. Inhalable dust samples were analyzed by weighing the internal cassette and filter as a single unit.

Measurements for relative humidity, ammonia, carbon dioxide, and hydrogen sulfide were collected at the beginning of the sampling period. Wet bulb, dry bulb, and relative humidity were determined using a sling psychrometer (Bacharach Inc., Pittsburgh, PA.). Ammonia (Gastec No. 3L; range of 1–30 ppm), carbon dioxide (Gastec No. 2LL; range 300–5000 ppm), and hydrogen sulfide (Gastec No. 4LT; range 0.2–2 ppm) were measured using colorimetric detector tubes and a Gastec Model 800 multi-stroke sampling pump.

Statistical analysis of the data was performed using Sigmastat (Jandel Scientific). The Kolmogorov Smirnov test was used to test for deviation from normality for the replicate and the averaged samples for each sampling method. A paired t test, $\alpha = 0.05$, was used to test the hypothesis: that the mean of the differences in the replicated side-by-side samples was equal to zero. Analysis of variance and paired t tests were also used to test for significant differences between total dust, inhalable dust, and the Miniram methods, with $\alpha = 0.05$. Pearson correlation coefficients were calculated to evaluate the relationships between total dust, inhalable dust, and Miniram values. Spearman correlations coefficients were used to evaluate the relationships between dust measures and the other environmental measurements.

RESULTS

Individual sampling results for the IPM, total dust, and Miniram are presented graphically in Figure 1. Dust measurements ranged from 0.10 mg/m^3 (Miniram) to 20.02 mg/m^3 (IPM). The mean dust measurements averaged over 15 sampling sessions were 0.98 mg/m^3 (Miniram), 6.49 mg/m^3 (IPM), and 4.61 mg/m^3 (total dust) (Table I). The total dust and IPM measurements varied more from sample session to session, that is, had greater standard deviations than Miniram measurements.
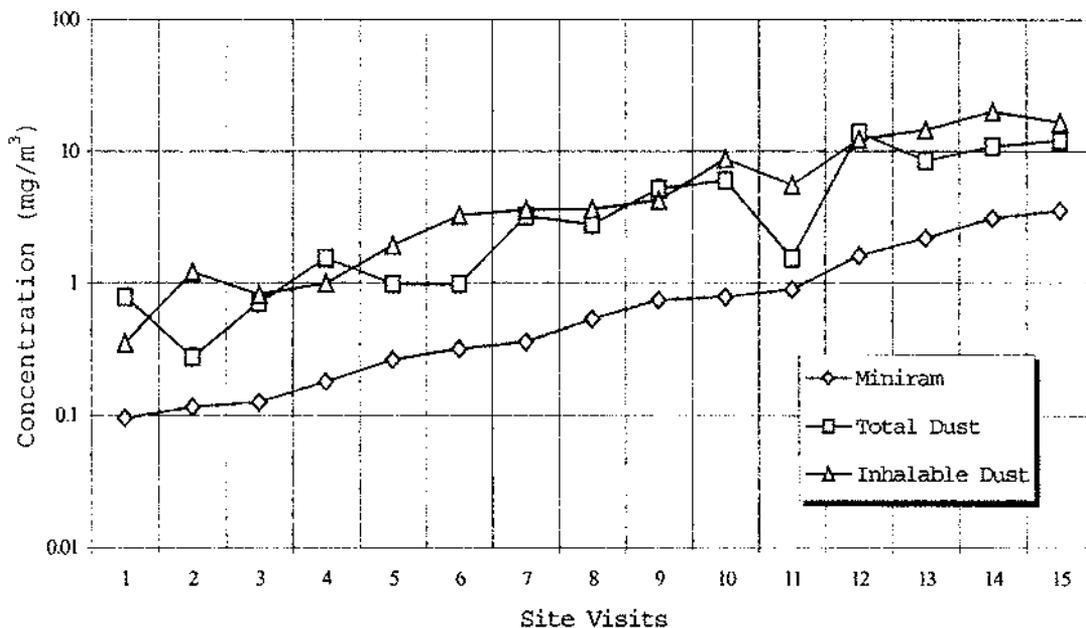

FIGURE 1

Comparison of sampler performance.

TABLE I

Mean dust concentrations, standard deviations, and pooled coefficients of variation
determined using Miniram, inhalable dust, and total dust methods

Device	Miniram	Inhalable dust	Total dust
Means	0.98 mg/m^3	6.49 mg/m^3	4.61 mg/m^3
Standard Deviations	1.11 mg/m^3	6.40 mg/m^3	4.60 mg/m^3
Pooled Coefficients of Variation	11.14	16.71	13.64

Pooled coefficients of variation $(\Sigma\,CV^2/n-1)^{1/2}$ were calculated to allow specific comparison of variability in measurements for each method. The IPM samples showed the greatest variation, while the Miniram showed the least.

The differences between replicates were normally distributed for all three sampling methods. At a significance level of $\alpha = 0.05$, no statistically significant differences were found between the two paired Minirams ($p = 0.1696$) or the two inhalable dust samplers ($p = 0.2563$). Total dust replicate samples did show a show statistically significant difference when the side-by-side replicate samples were evaluated ($p = 0.0078$).

The dust concentrations measured over 15 days were not normally distributed (Kolmogorov Smirnov test; inhalable dust $p = 0.022$, total dust $p = 0.048$, and Miniram $p = 0.0049$). After transforming the data to natural logarithms, a normal distribution was achieved. Analysis of variance was performed using Sigmastat (Jandel Scientific) using a design in which the day of sample collection and sampling device were considered independent variables, with the average of the replicate samples for each device used as the dependent variable. Normality and equal variance tests passed with their associated p-values of $p = 0.1600$ (normality) and $p = 1.000$ (equal variance). There was a statistically significant difference $p = <0.0001$ among the dust concentrations collected by the three sampling devices. There was no interaction between the date of the sample collection and the type of sampling device. Paired two-tailed t tests, $\alpha = 0.05$, confirmed that all three methods were significantly different from one another.

Pearson correlation coefficients were calculated for the log-transformed concentration data using Sigmastat (Jandel Scientific), (Table II). The Pearson correlation coefficients showed a strong, positive association among all three of the devices ($p < 0.001$ in all cases). Correlation coefficients were as follows: Miniram/IPM ($r = 0.95$); Miniram/total dust ($r = 0.90$); IPM/ total dust ($r = 0.88$).

TABLE II

Pearson correlation coefficients for sampling devices

Sampling devices	p-value	r_p
Miniram/total dust	<0.001	0.90
Miniram/inhalable dust	<0.001	0.95
Total dust/inhalable dust	<0.001	0.88

Prediction equations for the inhalable and total dust data were produced using Sigmastat (Jandel Scientific). The initial prediction equations were based on the regression equation identified as Formula 1:

$$Y = \beta_0 + \beta_1 x_1 + e \qquad (1)$$

where β_0 represents the y intercept, $\beta_1 x_1$ is the slope of a straight line, and e is the random error component. The equations for predicting gravimetric dust concentrations from Miniram measurements are presented in Figure 2.

Relationships between the dust measures and other environmental measurements (ammonia, humidity, carbon dioxide, and temperature) were evaluated using Spearman correlation coefficients (Table III). Ammonia measurements were made using dosimeter tubes and ranged from a high of 13 ppm to a low of 6 ppm. Depending on season, carbon dioxide concentrations ranged from a low of 600 ppm during the summer months, to a high of 2500 ppm during the winter. Indoor temperature ranged from 60°F in the winter to 92°F in the summer. Indoor relative humidity ranged from 54 to 96 percent. Surprisingly, carbon dioxide concentrations did not correlate with any of the dust measurements. Dry bulb temperatures exhibited a negative correlation to the total dust measurement. Most likely this was due to increased ventilation requirements during periods of high temperatures. Contrary to results of earlier research, a negative relationship was found between dust measurements and ammonia.[4,13] In this building, ammonia correlated strongly with increasing humidity levels.

DISCUSSION

The concentrations of organic dust aerosols measured in this study reflected the effects of seasonal variability and levels of livestock activity. With the onset of cool temperatures and the reduction of ventilation by mechanical devices, dust levels increased steadily and reached their highest concentrations in December and January. Based on the gravimetric dust measurements, exposures in this building could be expected to equal or exceed the ACGIH TLV (10 mg/m^3) for nuisance dust for about six months per year. Dust levels in this building may well exceed the recommended guideline for agricultural settings of 2.4 mg/m^3 total dust for much of the year.[2,3] Visual inspection of total dust cassettes showed significant quantities of particles adhering to the walls of the sampler cassettes, and it is likely
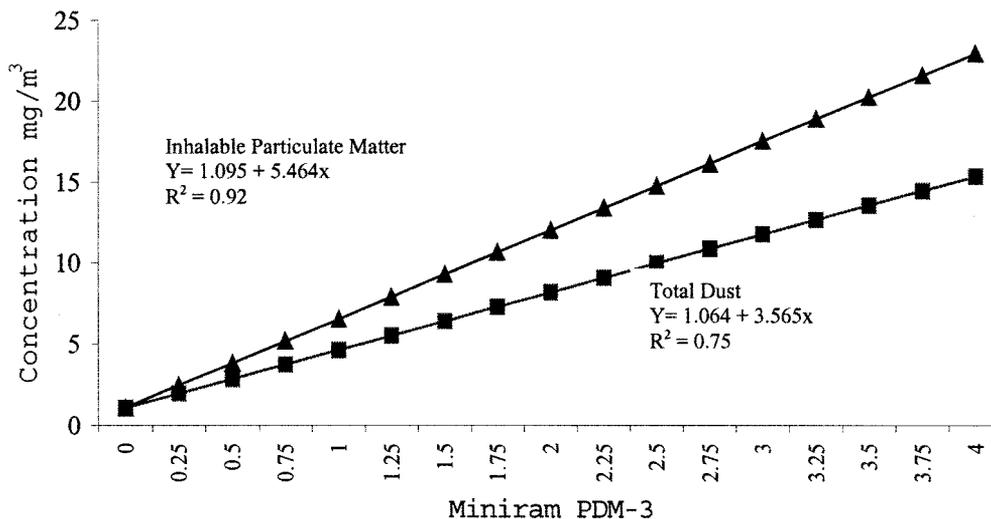
FIGURE 2
Regression lines for predicting inhalable and total dust concentrations.

that total dust measurements actually tend to underestimate total dust concentrations. SKC IPM samples collected a larger sample mass than the total dust samples in 11 of 15 sets. These finding were similar to those published in earlier IPM/total dust comparisons, sampling for wood dust and nickel.[14, 15] The SKC cassettes have the ability to efficiently collect particles of 100 μm. In agricultural settings, organic dust particles are characterized by large particles formed by conglomerates of smaller particles. At high concentrations the IPM samples may therefore tend to overestimate actual inhalable dust levels. The Miniram always provided the lowest dust concentration measurements, consistent with its characteristic response to dust particles of 10 μm or less.[10]

The Miniram was consistently highly correlated with both gravimetric methods. Based on the correlation coefficients, inhalable dust samples (r = 0.95) appeared to be slightly bet-

ter correlated to the Miniram data than the total dust samples (r = 0.90). The IPM and total dust samples were also positively correlated. In a prior study comparing the performance of the Miniram to respirable coal aerosols, the Miniram provided a reliable estimate of respirable coal dust.[16] In this study, correction factors were derived that can be applied to the Miniram TWA to estimate total or inhalable concentrations of organic dusts.

The Miniram has the potential to predict inhalable and total organic dust concentrations in livestock environments. It was also the most precise of the three methods (i.e., provided the lowest coefficient of variation). It is relatively easy to use and provides timely feedback. In addition, data logging capabilities allow analysis of dust levels over time, and the instrument could be interfaced to ventilation control systems and to exhaust particulates during periods of high concentrations. Application of this method assumes that the instrument is calibrated to a representative organic dust or a correction factor is applied to the Miniram TWA. Although easy to use, the performance of the Miniram is highly dependent on calibration and maintenance of the instrument before and after each sampling session. The internal sensing chamber required careful cleaning with compressed air to remove adhering organic dust particles that could greatly impact the instrument zero value and the ability of the instrument to operate correctly.

Although commonly used, the total dust sampling procedure presents some challenges in agricultural settings. Agricultural organic dusts tend to have lower densities and readily develop electrostatic charges.[7] This allows for the loss of substantial sample mass due to adherence to the walls of the cassette. The problem with adherence to the cassette walls may explain the statistically significant difference in the sample mass collected by the paired total dust samplers. Further studies are warranted to explore the possibilities of calibrating the Miniram or similar devices in other agricultural and industrial environments.

TABLE III
Spearman rank order correlation coefficient

Device	Measurement	p-value	r_s
Total dust	Ammonia	0.07	−0.48
Total dust	Carbon dioxide	0.21	.335
Total dust	Relative humidity	0.51	−0.18
Total dust	Dry bulb temp.	**<0.01**	**−0.82**
Inhalable dust (IPM)	Ammonia	**<0.01**	**−0.65**
Inhalable dust (IPM)	Carbon dioxide	0.59	0.15
Inhalable dust (IPM)	Relative humidity	0.30	−0.283
Inhalable dust (IPM)	Dry bulb temp.	0.19	−0.35
Miniram	Ammonia	**0.02**	**−0.58**
Miniram	Carbon dioxide	0.40	0.23
Miniram	Relative humidity	0.52	−0.18
Miniram	Dry bulb temp.	1.71	−0.37

CONCLUSIONS

The Miniram PDM-3 was compared to two gravimetric methods for measuring organic dust in a swine production environment. Dust measurements determined using Minirams were consistently lower than measurements provided by IPM and total dust methods. However, Miniram measurements were consistently strongly correlated with both gravimetric methods allowing calculation of correction factors. Direct-reading photometers such as Minirams offer several advantages compared to gravimetric methods. Minirams are simple to use and do not require laboratory analysis of dust samples. In addition to estimation of TWAs, data logging provides detailed information on variability in dust concentrations over time and real-time information, which can be used immediately. The Minirams performed well under field conditions of varying temperature and humidity. The Miniram has the potential to predict the inhalable, total, and respirable dust concentrations assuming an appropriate correction factor is applied.

ACKNOWLEDGMENTS

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