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DUST EMISSION RATES FROM FOOD PROCESSING

Steven E. Lacey[1], Lorraine M. Conroy[1], Todd M. Schoonover[1], John E. Franke[1], Donald R. Hedeker[2], Linda S. Forst[1]

[1]University of Illinois at Chicago, School of Public Health, Division of Environmental & Occupational Health Sciences, Chicago, IL, USA

[2]University of Illinois at Chicago, School of Public Health, Division of Epidemiology & Biostatistics, Chicago, IL, USA

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Abstract: A field study was performed to develop emission rates for dust exposure at a food processing facility. Eight 2-hour periods were monitored over 2 days. Area total suspended particulate samples were collected on 37 mm polyvinyl chloride filters with 5 µm pore size according to NIOSH Method 0500. Filters were analyzed gravimetrically. Ventilation and production activity data were collected during air sampling. Two mass balance models were used to calculate emission rates. The first was an experimental mass balance model, with the mass of contaminant generated determined by air flow and concentration measurements at room exit and entry points. The second treated the work environment as a completely mixed space, utilizing ventilation and area concentration measurements. Emission rates generated from mass balance models ranged from 2.09-542 mg/min for the various processing operations and food products. Process emission rates with production activity data allow estimation of dust exposure in similar facilities, and help direct development of exposure control strategies.

Address for correspondence: Steven E. Lacey, PhD, University of Illinois at Chicago, School of Public Health, Division of Environmental & Occupational Health Sciences, 2121 W. Taylor (M/C 922) Chicago, IL 60612 USA. E-mail: slacey@uic.edu

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INTRODUCTION

Determination of process emission rates, combined with production activity data, allows estimation of dust exposure in similar facilities. Emission rates may be used to mathematically estimate exposure, reducing the need for sampling, and to help direct development of exposure control strategies.

A limited amount of air sampling data have been reported for the food processing industry. Studies examining spice, animal feed, potato, and dried-foods processing reported area concentrations ranging from less than 0.5 mg/m^3 to 95.5 mg/m^3 [14, 15, 16, 17], with one study reporting personal dust exposures as high as 153 mg/m^3 [14]. Cross-shift changes in pulmonary function were noted in the spices and dried-food studies, and the dried-foods study reported acute symptoms including cough, dyspnea, throat irritation, throat dryness, eye irritation, nose dryness, nose bleeding, and headache [16].

Emission factors. With area total suspended particulate concentration measurements and room ventilation data, one may determine an emission rate; i.e. determination of mass of contaminant generated per unit time. The advantage of emission rates over area concentrations is that emission rates are more generalizable to other similar operations, whereas area concentration measurements alone are specific to the workplace where the measurements were taken. Emission rates may be applied to similar operations with measurements or estimates of

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room volume and ventilation rate to estimate area concentration.

Mass balance modeling to estimate emission rates has been employed to examine a variety of exposure environments: formaldehyde emission rates from cadavers in a gross anatomy laboratory [5]; Freon emissions from open-top vapour degreasers at an electronics manufacturing facility [10]; ethanol emissions for glazing during sweets production [11]; total volatile organic compounds and 13 hydrocarbons from a sheet-fed offset printing shop [12]; hexavalent chromium emissions from a chrome plating operation [2]; trichloroethylene and chromium emissions from degreasing and chrome plating processes at an automotive parts fabrication plant [13]; lead, chromium, and cadmium emissions during abrasive blasting on a bridge [3]; and toluene emissions from a parts-washing process at a metal part machining and assembly plant [4].

MATERIALS AND METHODS

Test location. A field study was performed to quantify personal exposures and to develop emission rates for dust exposure at a food processing facility. The processing area consisted of 4 rooms, connected via a closed-loop ventilation system, housed within a larger warehouse-type facility. The dimensions of each processing room were 6.10 m × 8.53 m × 3.65 m, for a volume of 190 m^3. Each room had an air supply located along the same wall near floor level, and an overhead exhaust hood from the ceiling near the centre of the room. Each room had one door for personnel access, and one overhead door for product and machinery access. A plan of the processing rooms is shown in Figure 1.

Personal exposure measurements for workers in the processing rooms are reported elsewhere [7]. Detailed area sampling for determination of emission rates was performed in Rooms 2 and 3 only (Fig. 1). Air sampling for total suspended particulate was conducted for eight 2-hour periods over 2 days. Continuous real-time dust monitoring, ventilation measurements, and production / worker activity data were also collected. To quantify total suspended particulate (food dust) exposure, low-volume air sampling pumps utilizing open-face 37 mm polyvinyl chloride (PVC) filters with 5 µm pore size (SKC Inc., Eighty Four, PA, USA) at a nominal flow rate of 2.0 l/min were used, in accordance with NIOSH Method 0500 [8]. Sampling flow rates were checked before, during, and after each sampling period using a pre-calibrated rotameter.

The mass of dust collected on each sampling filter was determined gravimetrically using a Sartorious model MC5 electronic balance. Filters were desiccated for 48 h prior to determination of pre- and post-sampling weight, and were weighed a minimum of 3 times before and after sampling to verify a constant weight; additional measurements were made as needed until measurement variance was limited to ± 5%.

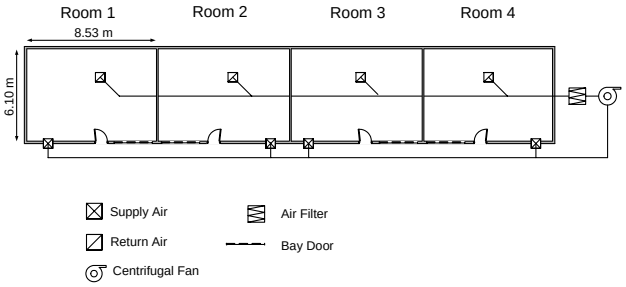

Figure 1. Plan of processing rooms.

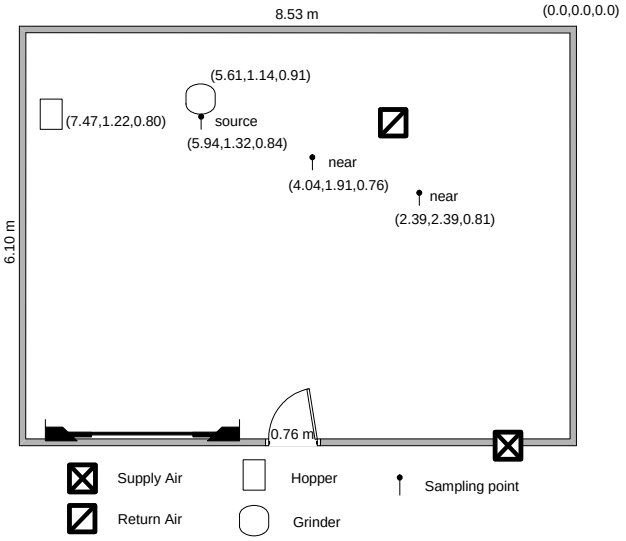

Figure 2. Example of coordinates of source sampling points in a processing room.

Area sampling. Sampling was conducted at air supply and exhaust locations in Rooms 2 and 3 on both days of sampling. An additional sampling pump was set outside the processing rooms to determine possible dust contribution from outside the process area.

Source sampling was performed for operations in Rooms 2 and 3. Simultaneous measurements were made at "source," "near," and "far" positions, with the source monitoring point being at the point of emission, the near position approximately 1 m from the source, and the far position approximately 2 m from the source. Ring stands were used to set sampling filters approximately 1 m off the floor. An example plan detailing the coordinate positioning of sampling locations within one of the processing rooms is shown in Figure 2.

Real-time monitoring. Real-time air monitoring instruments collected dust concentration data during the course of the work shift in selected processing rooms. A DataRam 2000 (MIE, Foxboro, MA, USA), programmed for a logging period of 10 s, collected continuous air contaminant concentration data in Room 3. A Personal DataRam (MIE, Foxboro, MA, USA), programmed for a logging period of 60 s and set to sample in active mode, was used in Room 2. These data were used to determine the effective ventilation rate in the processing room via examination of concentration decay rate during idle work

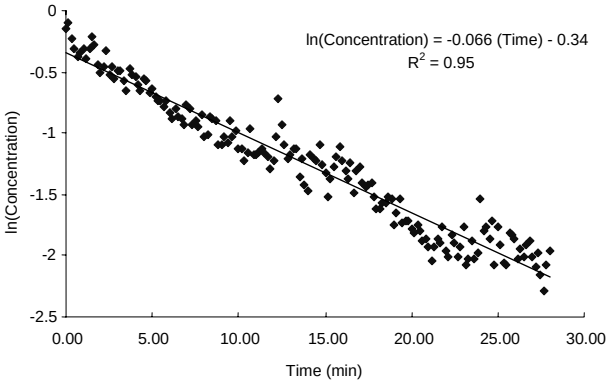

Figure 3. Example of log transform of decay curve concentration data.

periods. Additionally, these data were used to estimate instantaneous concentration, C_s, within a space at the beginning of the time period of interest. The instantaneous concentration of a given space is needed to solve the Completely Mixed Space model, discussed later.

Ventilation measurements. Ventilation measurements were taken at all air supply and exhaust openings using an Alnor Balometer swinging vane anemometer (Alnor Corp., Shoreview, MN, USA). Dimensions of the supply and exhaust openings were noted. The air flow direction between the process rooms and the surrounding factory area was determined using a piece of tissue paper held at the gap between each personnel access door and the floor. A series of velocity measurements of air entering or exiting the room via the door gap were made using a TSI Velocicalc thermal anemometer (TSI Inc., Shoreview, MN, USA), and dimensions of the openings were measured.

Determination of Mixing Factor, k. The room ventilation mixing factor, k, was determined from the real-time air sampling data. At times of known inactivity in the processing area (i.e., break time, lunch time), the processing room had time to be cleared of airborne dust by means of the general exhaust ventilation system. For a completely mixed space without a source of contaminant generation, the decay of an initial concentration within a space due to exhaust ventilation is described by [11]:

$$C = C_0 \exp(-kq/V)t \quad (1)$$

where,

C - concentration of contaminant in the space at time, t;
C_0 - concentration of contaminant at t = 0;
k - mixing factor;
q/V - air change rate.

This decay of dust concentration within the room may be graphically demonstrated by plotting the ln(concentration) during the time period of inactivity. The effective ventilation rate (kq/V) is the slope of the decay curve. An example of a decay curve used to determine the effective ventilation may be seen in Figure 3. The mixing factor, k, is the ratio of effective ventilation to mechanical ventilation.

Experimental Mass Balance Model. An Experimental Mass Balance (EMB) model may be used to determine mass emission rate of contaminant. Emission rate is the difference between the mass of contaminant exiting the space and the mass of contaminant entering the space. The difference is the amount of contaminant generated by the process within the space of interest. This is expressed mathematically by [12]:

$$S_{emb} = \sum_{i=1}^{T_{exp}} Q_{exit\ i} \times C_{exit\ i} - \sum_{i=1}^{T_{enp}} Q_{entry\ i} \times C_{entry\ i} \quad (2)$$

where,

S - emission rate [mass/time];
Q - air flow at room exit and entry [volume/time];
C - concentration at room exit and entry [mass/volume];
T_{exp} - total exit points
T_{enp} - total entry points

The EMB model is well suited for an environment with contaminant contribution from multiple sources. The model assumes that sampling accounts for all of the mass of the pollutant entering and exiting a space. Additionally, it is assumed that the facility contains a limited number of accessible air supply and exhaust points, and assumes no deposition of contaminant in space. This model was applied to Rooms 2 and 3, each of which has 1 air supply and 1 air exhaust location. Air may also enter or exit the room at the gap where the access door meets the facility floor. Air flow rates were measured at these 3 locations in each room, as described earlier. Total dust concentration samples were taken at the air supply and air exhaust locations, and at a single point just outside the processing rooms. An estimate of the emission rate was developed for each 2-hour sampling period for the two processing rooms.

Completely Mixed Space Model. The Completely Mixed Space model is most useful when many sources are contributing to the area concentration, so that the environment is assumed to be a nearly homogenous mixture. Correction for incomplete mixing is made by adjusting the air flow rate using a mixing factor, k. An estimate of room concentration at the start of the sampling period must be known, as well as the air change rate within the space, q/V. The completely mixed space model is expressed as [12]:

$$S_{cms} = \frac{C_{av}kq - \left[C_s\left(V/t_{av}\right)\right]\left[1 - \exp\left(-kq/Vt_{av}\right)\right]}{1 + \left[V/kqt_{av}\right]\left[\exp\left(-kq/Vt_{av}\right) - 1\right]} \quad (3)$$

where,

S - emission rate [mass/time];
C_{av} - average concentration in the space [mass/volume];

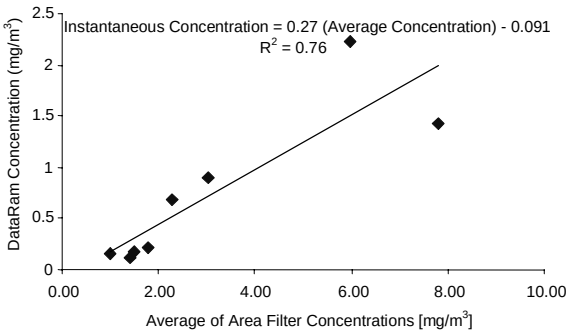

Figure 4. Example of calibration curve, correcting real-time data to primary sampling device.

t_{av} - sampling time [time];
C_s - concentration at start of sampling period [mass/volume];
V - volume of the space [volume];
q/V - air change rate/time; and
k - mixing factor, which varies between 0-1 [unitless].

The instantaneous concentration, Cs, was determined with real-time data from the Personal DataRam and DataRam dataloggers. The Personal DataRam and DataRam data obtained in Room 2 and Room 3, respectively, consistently estimated concentrations lower than the 37 mm PVC filters; a calibration curve was therefore developed to translate real-time data values into filter equivalent values. Average real-time concentration measurements in a room during a sampling period were correlated to the average of all 37 mm PVC filter area samples for the same room and sampling period (Figure 4). An equation for the line of best fit was determined and used to calculate filter equivalent values for the instantaneous concentration.

Statistical Analysis. Area concentration measurements were analyzed to investigate mean differences due to operation using a 1-way analysis of variance (ANOVA). For this analysis, the data were natural log-transformed to better satisfy the normality assumption of the model and to minimize differences in variances. Following the overall test from the ANOVA, comparisons of all pairs of operations (e.g., sieving vs. grinding, sieving vs. blending, and blending vs. grinding) were made using Tukey's Honestly Significantly Different (HSD) multiple comparison procedure. This procedure controls the overall significance level for this set of specific comparisons [6]. We present the Tukey HSD pairwise comparison of means results at an overall significance level of $\alpha = 0.05$. Tukey's method was also applied to sieving operations to examine area sampling concentrations relative to product.

Similarly, emission rate estimates were analyzed using Tukey's HSD multiple comparison procedure to investigate mean differences due to operation. Within sieving operations, too few estimates of emission rate were available for each product to warrant further comparison.

RESULTS

Area sampling. Total dust concentrations at supply and exhaust locations are presented in Table 1. Source, near, and far sampling location results are also presented in Table 1, together with the concentration measurements made outside of the processing rooms.

Ventilation measurements. Supply and exhaust air flow rates are based on the average of 1 morning and 1 afternoon measurement made on Day 2 with an Alnor

Table 1. Dust concentrations (mg/m^3) at supply, exhaust, source, near, far, and outside sampling locations.

Day	Room	Period	Operation	Material Processed	Concentration (mg/m^3)					
					Supply	Exhaust	Source	Near	Far	Outside
1	2	1	Grinding	Vanilla	0.21	1.29	—[a]	—[a]	—[a]	—[b]
1	2	2	Grinding	Vanilla	1.98	4.37	3.31	2.26	2.16	2.26
1	2	3	Grinding	Vanilla	—[c]	1.65	2.24	1.60	4.55	0.45
1	2	4	Grinding	Vanilla	1.08	0.30	7.35	5.43	5.99	0.42
1	3	1	Sieving	Cilantro	0.33	14.7	7.31	4.93	4.19	
1	3	2	Sieving	Basil	—[d]	3.01	2.58	2.26	1.29	
1	3	3	Sieving	Basil	0.41	3.09	4.68	2.85	1.51	
1	3	4	Sieving	Basil	0.10	5.82	8.07	5.42	4.65	
2	2	1	Sieving	Coconut	0.32	0.63	0.80	0.48	3.18	0.25
2	2	2	Sieving	Spinach	0.51	1.25	1.95	0.66	0.44	0.51
2	2	3	Sieving	Spinach	0.07	0.58	0.82	0.73	0.37	0.43
2	2	4	Sieving	Strawberry	0.13	11.0	7.28	14.6	6.57	0.93
2	3	1	Blending	Jalapeno	0.23	0.33	2.15	3.17	1.19	
2	3	2	Blending	Jalapeno	0.09	1.27	0.98	1.22	0.75	
2	3	3	Blending	Jalapeno	0.18	1.63	1.48	2.56	0.59	
2	3	4	Blending	Jalapeno	2.31	2.03	2.11	2.95	0.96	

[a]No source sampling performed during this time period; [b]Filter lost mass from pre- to post-weight, giving a negative concentration of -0.27 mg/m^3; [c]Filter lost mass from pre- to post-weight, giving a negative concentration of -1.05 mg/m^3; [d]Filter lost mass from pre- to post-weight, giving a negative concentration of -0.20 mg/m^3; Sampling Period 1: ~7:00AM to 9:00AM; Period 2: ~9:00AM to 11:00AM; Period 3: ~11:00AM to 1:00PM; Period 4: ~1:00PM to 3:00PM

balometer. Table 2 shows average flow rates at each location. One estimate of air direction and air velocity was made at the space below each personnel access door (door closed, the normal position) for each processing room on Day 2. Mechanical ventilation rates were used in the EMB model and effective ventilation rates were used in the CMS model.

Six estimates of the room ventilation mixing factor, k, were calculated based on DataRam concentration decay curves in Room 3 on both days during the worker's morning break, lunch break, and afternoon break. The mixing factor values ranged from 0.14-0.42, and the average k = 0.30 was used in the calculations involving the Completely Mixed Space model.

Calculated emission rates using both the EMB and CMS models are presented in Table 3. Since no estimate of instantaneous concentration was available on Day 1 in Room 2 during Periods 1 and 2, it was not possible to determine emission rates with the CMS model for these periods. It was also not possible to determine emission rates on Day 1 during Period 4 due to a facility ventilation system failure that occurred during data collection, causing supply air flow to stop.

Analysis of area concentrations was performed to examine the effect of operation and product relative to concentration. The same type of analysis was performed on estimates of emission rate generated from the EMB and CMS models. Since all of the processing rooms were connected via a closed-loop ventilation system, with generally balanced supply air and exhaust air flow, and each of the processing rooms were of the same volume and dimensions, it is assumed that the individual rooms do not affect the concentration measurements, i.e., each measurement is independent from other measurements.

Analysis of area sample concentrations relative to operation. The area concentrations (source, near, far and exhaust locations) were examined. The data were first sorted by operation: grinding, sieving, and blending. Within these groups, the data were then sorted by product. In our 2 days of sampling, we only observed the grinding of a single product, vanilla. For blending, we only observed jalapenos. Because each of these operations was only observed processing 1 product, differences seen by operation may in actuality be related to the product. Sieving was performed on several products: cilantro, basil, coconut, spinach, and strawberry.

Tukey's HSD procedure was used to examine the difference among the arithmetic means of area sample concentrations for the 3 operations. The data were natural log-transformed for the test procedure. The arithmetic mean and median of area concentrations relative to operation and Tukey's HSD procedure results are reported in Table 4. Sieving (3.99 mg/m^3) produced mean dust concentrations higher than blending (1.59 mg/m^3); while this difference was not significant at $\alpha = 0.05$, it was significant at $\alpha = 0.054$. Though the difference between the means of grinding (3.27 mg/m^3) and blending (1.59 mg/m^3) were notable, the difference was not statistically significant at $\alpha = 0.05$.

Table 2. Exhaust air and supply air flow measurements.

Room	Mechanical Ventilation[a] (m^3/min)			Effective Ventilation[b] (kq/V)
	Exhaust	Supply	Door Gap	
2	23.7	28.6	2.27 out of room	0.045
3	37.5	30.6	3.57 into room	0.048

[a]Used with concentration measurements in EMB model
[b]Used with concentration measurements in CMS model

Table 3. Emission rates (mg/min) of total suspended particulate determined by experimental mass balance and completely mixed space models.

Day	Room	Period	Operation	Product	Emission Rate (mg/min)	
					EMB Model	CMS Model
1	2	1	Grinding	Vanilla	24.4	—[a]
1	2	2	Grinding	Vanilla	51.9	—[a]
1	2	3	Grinding	Vanilla	40.2	19.6
1	2	4	Grinding	Vanilla	—[b]	—[b]
1	3	1	Sieving	Cilantro	542	70.2
1	3	2	Sieving	Basil	84.0	23.8
1	3	3	Sieving	Basil	102	26.5
1	3	4	Sieving	Basil	—[b]	—[b]
2	2	1	Sieving	Coconut	6.18	16.5
2	2	2	Sieving	Spinach	16.1	12.2
2	2	3	Sieving	Spinach	12.8	4.99
2	2	4	Sieving	Strawberry	258	102
2	3	1	Blending	Jalapeno	4.66	18.7
2	3	2	Blending	Jalapeno	42.6	9.05
2	3	3	Blending	Jalapeno	54.1	13.5
2	3	4	Blending	Jalapeno	2.09	18.4

[a]No estimate of instantaneous concentration available for this sampling period, thus unable to apply CMS model; [b]Facility ventilation system failure.

Table 4. Arithmetic mean and median of area sample concentrations (mg/m^3) relative to operation and Tukey's HSD results.

Operation	N	Mean	Median
Sieving	32	3.99	2.93
Grinding	13	3.27	2.26
Sieving	32	3.99*	2.93
Blending	16	1.59	1.38
Grinding	13	3.27	2.26
Blending	16	1.59	1.38

*Not significant at $\alpha = 0.05$ level, but significant at $\alpha = 0.054$

Analysis of area sample concentrations relative to product. The arithmetic means of natural log-transformed area sample concentrations for sieving were examined to test for differences in dust concentration generated from each product. The mean, median, and results of Tukey's HSD procedure are reported in Table 5.

Table 5. Arithmetic mean and median of area sampling concentrations (mg/m^3) relative to product for sieving operations and Tukey's HSD results.

Product	N	Mean	Median	Tukey's HSD[a]
Cilantro	4	7.79	6.12	—
Basil	12	3.77	3.05	
Cilantro	4	7.79	6.12	***
Coconut	4	1.27	0.72	
Cilantro	4	7.79	6.12	***
Spinach	8	0.85	0.70	
Cilantro	4	7.79	6.12	—
Strawberry	4	9.86	9.14	
Basil	12	3.77	3.05	***
Coconut	4	1.27	0.72	
Basil	12	3.77	3.05	***
Spinach	8	0.85	0.70	
Basil	4	3.77	3.05	—
Strawberry	4	9.86	9.14	
Coconut	4	1.27	0.72	—
Spinach	8	0.85	0.70	
Strawberry	4	9.86	9.14	***
Coconut	4	1.27	0.72	
Strawberry	4	9.86	9.14	***
Spinach	8	0.85	0.70	

[a]Comparisons significant at $\alpha = 0.05$ level indicated by ***

Table 6. Arithmetic mean and median of EMB and CMS model emission rates (mg/min) relative to operation and Tukey's HSD results.

Operation	Mass Balance Model	N	Mean[a]	Median
Sieving	EMB	7	146	84.0
Grinding		3	38.8	40.2
Sieving	EMB	7	146	84.0
Blending		4	25.9	23.6
Grinding	EMB	3	38.8	40.2
Blending		4	25.9	23.6
Sieving	CMS	7	36.6	23.8
Blending		4	14.9	16.0

[a]No comparisons were significant at $\alpha = 0.05$ level

Mean concentrations from sieving cilantro, basil, and strawberry were not significantly different. Sieving coconut and spinach were not significantly different from each other. Sieving cilantro, basil, and strawberry each resulted in significantly higher dust concentrations than sieving coconut or spinach.

Analysis of EMB and CMS emission rates relative to operation. Estimates of the emission rate were developed by use of EMB and CMS models. The data were natural log-transformed for comparison of means testing. The emission rate data were sorted by operation, and the mean and median emission rates and Tukey's HSD results are reported in Table 6. Though the EMB mean emission rate for sieving (146 mg/min) was notably higher than for grinding (38.8 mg/min) or blending (25.9 mg/min), Tukey's HSD determined no significant difference of emission rate among the 3 operations at $\alpha = 0.05$.

Only 1 estimate for CMS emission rate was available for grinding operations, and therefore was excluded from comparison using Tukey's HSD. The CMS mean emission rate for sieving was higher than blending, but Tukey's HSD determined no significant difference of emission rate between the operations at $\alpha = 0.05$.

DISCUSSION

Summary of emission rates from EMB and CMS models. Estimates of emission rate concur reasonably well within a specified operation with a single product. Emission rates vary, sometimes drastically, based on the "dustiness" of each product. Emission rates and their relationship to product dustiness are consistent with qualitative observations noted during sampling; i.e. operations performed on a product that resulted in visible dust generation resulted in higher measured dust concentrations.

These emission rate estimates, like the personal exposure measurements [7], lend support to the idea that dust generation is dependent on at least 2 primary variables: 1) the operation being performed and 2) the product being processed. Operations that dictated high energy input into the product, or high impact forces, resulted in greater dust generation. The energy input from the blades of the grinder and vibrational energy used to shake particles through a sieve resulted in relatively high emission rates. Alternately, the slow tumble of a product through a corkscrew auger imparts less energy on the product, and subsequently results in lower emission rate estimates. The extent of enclosure of the equipment also probably affected dust generation. Sieve surfaces and hoppers were completely open. The extent of shrouding with plastic sheeting between material transfer points also probably influenced dust generation.

The energy input alone, however, does not dictate a high or low dust generation rate. The type of product being processed seems to have comparable importance. The tendency for a particle to fall apart into smaller particles, thus more likely to become airborne, is dependent on the cohesive properties of the product being processed. Cohesion forces are largely dependent on product moisture content, particle size distribution, and melting temperature [9]. With all of the products the facility encounters being freeze-dried, or occasionally air-dried, moisture content is likely to be low for all products, thereby decreasing cohesion forces for all products.

Within operation/product groups, the emission rates appear fairly consistent, i.e. grinding vanilla provides a relatively tight range of 19.6-51.9 mg/min. Sieving operations reflect the influence of product on emission rate, as the emission rates ranged from 4.99-542 mg/min. Blending operations were only observed for processing jalapenos, providing a relatively tight range of emission rate estimates of 2.09-54.1 mg/min based on estimates from both models.

Both the EMB and the CMS models have strengths and limitations. The CMS emission rate estimates are based on the average of several area concentration measurements within the workspace, and therefore are less influenced by sample analysis error on a single sample; however, the mixing characteristics of the space and the initial concentration need to be measured or estimated. The EMB model is more sensitive to error in concentration measurements (e.g., weighing error) since it only relies on 2 area concentration measurements, but is a simpler model to apply to a space with a limited number of air entry and exit points. This study is the first attempt to develop emission rates for this type of operation, and reflects the range of emission rates from this type of work.

More sampling is needed to gain greater confidence in dust concentrations generated for specific operation/ product combinations, and subsequently greater confidence in emission rate estimates. For example, in our study only 1 sampling period was observed where the workers were sieving strawberries, so we only have 1 set of observations regarding this product. Additionally, only 1 sampling period was observed where the workers were grinding vanilla. The ability to collect data for grinding of other products would permit better understanding of the impact of product during such operations.

If more data points had been collected, it is possible that a relationship between emission rate and production would have emerged. A sampling strategy that was more comprehensive in the number of days sampled may have provided more data points to establish emission factors for these operations and products. Real-time monitoring over many days or weeks of data collection would require a less intensive staff effort, and would gain the quantity of data points needed to more fully understand exposure as it varies with operation and product.

CONCLUSIONS

Emission rates generated from mass balance models ranged from 2.09-542 mg/min for the various processing operations and products. Though emission rates were higher for sieving relative to grinding and blending, the differences were not statistically significant for either model. Additional data collection specifically for grinding and blending operations is necessary to better characterize emission rates for these processes.

Area concentrations at the source, near, far and exhaust locations ranged from 0.33-14.7 mg/m^3, with an average of 3.21 mg/m^3 for the various operation/product combinations. If workers were exposed to such concentrations over their entire shift, it is possible that the time-weighted average would exceed the Threshold Limit Value for particulates not otherwise classified (PNOC) of 10 mg/m^3 for inhalable particles [1]. Though the TLV for inhalable PNOC is a reasonable comparison for evaluating such exposures, it is recognized that the PNOC TLV has limited protective ability due to the irritant nature of certain dusts, e.g., jalapeno peppers, aloe vera.

Dust exposures for this type of food processing facility are influenced by both the operation being performed and the product being processed. Grinding and sieving produced higher dust concentrations than blending, but this difference was only statistically significant for sieving ($\alpha = 0.05$). Within sieving operations, cilantro, basil, and strawberry resulted in statistically significant higher concentrations than coconut or spinach.

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