Size Distribution and Identification of Aerial Dust Particles in Swine Finishing Buildings


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ABSTRACT

The sizes of aerial starch, grain meal and all particles present in swine finishing houses were described by the log normal distribution. Respirable fractions by mass and by number were 3.7 and 76.1%, respectively, as estimated from the particle size distribution. Most starch and grain meal particles identified were larger than 5 μm diameter. Fifty percent of all particles were less than 2.6 μm diameter. Higher total mass concentrations were not associated with similar increases in respirable mass concentrations. The aerial dust originated primarily from feed, based on particle identification using optical and electron scanning microscopy.

INTRODUCTION

The adverse environment inside confinement units is one of the primary problems facing the swine production industry. Aerial dust in swine shelters causes respiratory distress symptoms in both humans and pigs, deterioration of buildings and equipment, unreliability in sensors, electronic instrumentation and controls, and an increase in objectionable odors. These detrimental effects depend, to a greater or lesser degree, on the quantity, size, and composition of dust particles. Optical methods for monitoring aerosol concentrations depend on light scattering and absorbing characteristics of the particles. These are influenced by particle size, shape, and composition. Little quantitative data are available on the morphology, composition, and origin of dusts occurring in swine confinement buildings. For this reason, characteristics of dust particles from commercial swine finishing houses were studied.

Initially, a survey was conducted to evaluate the environment inside 11 commercial swine finishing buildings (Heber et al., 1988). Dust samples were collected eight times over a 9-month period from each unit to analyze particle size distribution, particle identification, and particle morphology.

LITERATURE REVIEW

Particle Size Distribution

The size of particles influences their sedimentation rate (Janni et al., 1984) and the location of their deposition in the respiratory tract (Mercer, 1978). Both factors depend on particle aerodynamic diameter. A particle's size also influences its ability to pass through filters (Carpenter et al., 1986). Measurements of total mass concentration would probably not detect changes in the number concentration of respirable particles (those particles less than 5 μm diameter). The respirable fraction by mass (RFM) should also be measured with total mass concentration to more adequately assess the effects of smaller particles.

Aerial dust particles typically follow a log normal size distribution (Stockham and Fochtman, 1977). The geometric median diameter and geometric standard deviation of these particle size distributions can be estimated from the cumulative percentage of particles plotted on log probability paper (Noble et al., 1963). Nilsson (1982) noted that although 80% of the dust in a swine finishing house were between 0.5 and 2.5 μm, the mass of these particles was less than 10% of the total mass. The mass median diameter of dust from four finishing buildings was 10.7 μm, and 66% of the observed particles were less than 4.6 μm (Donham et al., 1986). Ventilation preferentially removes the smaller particles, so that the geometric mean diameter normally becomes greater with increased ventilation (Noble et al., 1963).

The concentration of particles above the respirable range is also important to control. The 5 to 20 μm diameter particles are primarily responsible for the odor-carrying ability of aerial dust (Honey and McQuitty, 1979; Burnett, 1969). Noxious gases adhere to the surface of aerosol particles, thus, increasing the gas concentrations several-fold (Janni et al., 1984). Donham et al. (1986) measured ammonia gas adsorbed on settled particulates and found it in the range of 3.9 mg adsorbed ammonia per gram of dust. A majority of airborne bacteria adhere to particles larger than 4 μm (Robertson and Frieben, 1984). Viable particles may carry harmful microorganisms and endotoxins (Donham et al., 1986).

Particle size measurements are usually expressed as a single number based on area, volume, or a linear dimension. Single vertical or horizontal linear dimensions tend to falsely spread a narrow size distribution of irregular particles (which are abundant in...
swine dust) because of the large number of random orientations possible when viewed with a microscope. For this reason, an areal comparison with an ocular reticle is a better method (Annis, 1972). A Coulter Counter was used to measure the volume of dust extracted from cotton lint fibers and dispersed in filtered electrolyte. The volume concentration and an assumed constant particle density were used to determine a mass concentration (Parnell et al., 1984).

**Particle Analysis Using Microscopy**

A polarizing microscope is one of the best instruments for identifying and classifying individual particles collected on membrane filters (Chatigny et al., 1983; McCrone, 1986). Donham et al. (1986) examined dust from four swine houses with a polarizing, phase contrast, and fluorescence microscope. Iodine and Nile blue sulfate stains were used to identify starch and fecal material, respectively.

A scanning electron microscope (SEM) facilitates the most detailed particle size determination of any direct method. While SEM can resolve particles several times smaller than those resolved by optical microscopy, it can reveal only shape, surface characteristics, and sometimes elemental composition. The SEM cannot be used to identify organic compounds, unless they are biological and have typical external forms (McCrone, 1986). In spite of these limitations, Nilsson (1982) used the SEM to size swine house particles.

**Particle Identification**

Among 11 to 16 μm diameter swine dust particles, about 1 and 10% were identified on photomicrographs as hair and skin, respectively. Skin comprised 5% of the 7 to 9 μm particles (Honey and McQuitty, 1979). Both aerial and settled dust were primarily feed particles. This agreed with previous studies (Chiba et al., 1985; Curtis et al., 1975). Several researchers noted that many large airborne particles were actually agglomerates of smaller particles caused by electrostatic attraction (Koon et al., 1963) and the attachment of viruses and bacteria (Harry, 1978; Dyment, 1976).

A comprehensive analysis of the dust from swine houses (Donham et al., 1986) identified feed (starch granules, grain meal, trichomes, and corn silk); fecal material (bacteria, gut epithelial cells, and undigested feed); dander; mold (hyphae, spores, and sporangia); pollen; insect parts; and mineral ash. The predominant components were feed among particles larger than 5 μm diameter, and fecal material among particles between 1 and 2 μm diameter.

Aerial dust in finishing units was coarse and tannish. It was also more fluffy than dust from farrowing, nursery, and growing buildings because of higher quantities of feed used in the finishing units. The fraction respirable was primarily fecal material, probably generated by animal movements (Donham et al., 1986).

**RESULTS AND DISCUSSION**

**Particle Size Analysis**

Cumulative, log-probability, particle size distributions were determined for each sample analyzed with the resistive-pulse particle-analyzer. Linear regression was used to estimate the geometric mean diameter (GMD), geometric standard deviation (GSD), and mass median diameter (MMD) according to a procedure outlined by Stockham and Fochtman (1977). Sphericity and constant density of particles were assumed. The particle size distributions by number and by volume for a sample from Unit F is shown in Fig. 1. The particle size distributions of the 75 dust samples were quite similar as indicated by the low standard deviations for GMD, MMD, and GSD (Table 1).

Higher dust concentrations by mass (Table 2) and by number (Heber et al., 1988) were associated with greater GSD and smaller GMD, indicating that respirable fraction by mass was not proportional to TMC. Respirable dust increased at a lower rate than total dust. Multiple regressions (P<.01) of total mass concentration (TMC) and number concentration (N) on GSD and GMD were as follows:

**PROCEDURE**

**Sample and Data Collection**

Indoor dust samples were collected from 11 commercial swine finishing buildings (Heber et al., 1988). Each unit was surveyed eight times, approximately once per month. Dust samples were collected on two, 37 mm membrane filters (0.45 μm pore size) at 34 to 51 Lpm airflow rate with a Sierra-Misco Model 3000 Constant Flow Air Sampler. An open-faced cassette held each membrane filter horizontally at 1.5 m above the floor. The air sampler was placed near the center of the building in the service alley.

The measurement of particle volume with a resistive-pulse particle-analyzer over a range of 1.76 to 7.01 μm diameter on the first sample was described by Heber et al. (1988). Number concentrations from these samples collected over a 15 to 30 min period were also reported. The size distributions as determined by the resistive-pulse particle-analyzer are presented here.

The collection time of the second sample ranged from 1 to 5 min. A Porton globe and circle graticule was installed in the eyepiece of a polarizing, phase contrast microscope for sizing, counting, and identifying particles on these membrane filters. SicHEL's multiple traversing technique (Sichel, 1957) and NIOSH Method 7400 (NIOSH, 1984) were used to calibrate the graticule and to prepare the microscope slides, respectively. Photomicrographs of dust particles from soil, feces, soybean meal, corn, grain sorghum, wheat, swine premix, and pig skin flakes were used to supplement the McCrone's Particle Atlas (McCrone and Delly, 1973) for identifying particles. All observations were made at 160X magnification. Differentiation between birefringent starch and mineral particles less than 5.4 μm diameter was not possible at this magnification. Bright field identification of grain meal and skin was also limited to particles greater than 5.4 μm.

A 5 × 5 mm piece of the second membrane filter was mounted onto an SEM stub with double-sided tape for SEM analysis. Particles were sized and identified at 1000X magnification with a Porton globe and circle graticule placed over the video display.
Microscopic Observations

Optical Microscope: Starch, skin, and grain meal particles larger than 5.4 \(\mu m\) were readily identified with a polarizing microscope. Bright and dark (polarized) field images of particles collected from Unit K are shown in Fig. 2. The non-starch or grain meal particles were irregular in shape, generally denser than skin particles, and not birefringent. Birefringent starch particles displayed a dark center in the unpolarized field (Fig. 2a) and projected a Maltese cross in the polarized field (Fig. 2b). Most of the other particles in Fig. 2a were grain meal. Skin particles were flat and quite transparent. It could not be determined whether particles were partially digested or of fecal origin.

Although not identified, particles smaller than 5.4 \(\mu m\) were counted in size ranges between 3.8 and 5.4 \(\mu m\), 2.7 and 3.8 \(\mu m\), and smaller than 2.7 \(\mu m\). More than 50% of

![Fig. 2—Photomicrographs (400X) of airborne dust particles collected inside unit K in December, taken using a polarizing microscope. (a) Bright field. (b) Polarized field.](image-url)
TABLE 3. NUMBER OF PARTICLES BY IDENTIFICATION AND SIZE DISTRIBUTION FROM 86 DUST SAMPLES AS DETERMINED BY OPTICAL MICROSCOPY. ALL PARTICLES SMALLER THAN 5.4 μm AND SOME LARGER PARTICLES COULD NOT BE IDENTIFIED

<table>
<thead>
<tr>
<th>Particle type</th>
<th>Diameter at upper limit of each size class, μm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;2.7</td>
</tr>
<tr>
<td>Total</td>
<td>8544</td>
</tr>
<tr>
<td>Starch</td>
<td>64</td>
</tr>
<tr>
<td>Grain meal</td>
<td>885</td>
</tr>
<tr>
<td>Skin</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Numbers do not sum to total because not all particles were identified.

the total number of particles in eight size classes were less than 2.7 μm (Table 3). A similar microscopic investigation of swine dust with an SEM reported the mode of the particle size distribution to be between 2.0 and 3.0 μm, with only 3.3% less than 1.0 μm (Nilsson, 1982). Therefore, it was assumed that most of the particles between 1.0 and 2.0 μm were counted in this study. However, the smallest of these particles were difficult to distinguish from tiny air bubbles under the slide.

A cumulative, log-probability, size distribution was plotted for the total number of particles from 86 samples (Fig. 3). The geometric median diameter (GMD) and geometric standard deviation (GSD) were 2.56 μm and 2.58, respectively. A mass median diameter (MMD) of 18.9 μm was determined from the volume distribution, assuming constant density. The respirable fractions by mass and by number were 3.7 and 76.1%, respectively, according to the particle size distribution for all particles. Particle size was estimated from a direct comparison of the projected area. Diameter and volume were then calculated from the observed area, assuming sphericity of each particle.

The particle size distributions by number and by volume of the 2,317 grain meal and 489 starch particles above 5.4 μm are plotted in Fig. 3. A majority of starch particles was greater than 5.4 μm, with the mode occurring in the 10.8 to 15.3 μm class. The mode of the grain meal particles was not readily apparent, since the highest count occurred in the smallest observed size class (Table 3). From linear regressions of these particle size distributions (Fig. 3), the GMD, GSD, and MMD for starch particles were 12.4 μm, 1.56, and 21.4 μm, respectively. The GMD, GSD, and MMD for grain meal particles were 8.6 μm, 1.65, and 17.9 μm, respectively.

Particle size distribution parameters were determined for all particles observed from each confinement unit (Table 2). The average GSD was 2.61 and 2.43 (significantly different at P<0.03) for the naturally ventilated and mechanically ventilated units, respectively, indicating a steeper slope for particle size distributions from naturally ventilated buildings. Larger GSD’s corresponded to higher total mass concentration (TMC) in naturally ventilated units, since more mass is attributed to greater relative numbers of larger, non-respirable particles. A larger average starch GMD of 13.1 μm from naturally ventilated units as compared to 11.6 μm from mechanically ventilated units (P<0.03) also corresponded to the greater TMC and larger particles in naturally ventilated units.

**Scanning Electron Microscopy:** Particles identified with SEM ranged in diameter from 1 to 30 μm. Shape and surface texture were the primary criteria for identification. The micrographs (Fig. 4) show three, 10 to 15 μm starch particles with smooth surfaces and spherical or polygonal shapes; a flat, 20 μm, skin particle with folds near the edges; and several large, irregular, grain meal particles and agglomerates with plated or layered surfaces. The 1-2 μm sporelike particles are shown as an individual sphere (Fig. 4a); a group of four spheres (Fig. 4b); and a cylindrical or oblong particle attached to a starch particle (Fig. 4a).

Agglomerates of up to several dozen, 1.0 μm diameter spheres were frequently seen on the filters but were assumed to be filter artifacts during the observations. After comparing these micrographs with a photomicrograph of *Bacillus subtilis* spores (Robertson and Frieben, 1984), it is believed that these were similar, aerosolized, viable particles, perhaps cells of *Staphylococcus*, a common bacterium (Buchanan and Gibbons, 1974). Fig. 4 shows these viable particles existing alone, in combination with four others, and adhered to larger particles.

About 65% of the 1518 particles observed with SEM were identified as grain meal, 13.5% as starch, and 1% as skin (Table 4). Only 17 starch particles were observed below 6.7 μm. Particle shape was recorded and summarized for particles whose identification was questionable. Particles less than 1.5 μm were difficult to distinguish from the sponglike filter surface, and particles greater than 20 μm were generally avoided. The particle size distribution in Table 4 was developed by an
TABLE 4. SUMMARY OF PARTICLE IDENTIFICATION AND SIZE DISTRIBUTION OF 76 DUST SAMPLES AS DETERMINED BY SCANNING ELECTRON MICROSCOPY. THESE NUMBERS DO NOT REPRESENT A TRUE SIZE DISTRIBUTION BECAUSE OF SMALL NUMBERS PER FIELD OF VIEW AND BIAS TOWARD CERTAIN SIZES AND NUMBERS PER FIELD

<table>
<thead>
<tr>
<th>Size class (Upper limit, μm)</th>
<th>Identified particles</th>
<th>Unidentified particles in shape categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total number</td>
<td>Starch</td>
</tr>
<tr>
<td>&lt;1.5</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>2.1</td>
<td>118</td>
<td>1</td>
</tr>
<tr>
<td>3.0</td>
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<td>3</td>
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<td>4.2</td>
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<td>13</td>
</tr>
<tr>
<td>5.9</td>
<td>330</td>
<td>52</td>
</tr>
<tr>
<td>8.4</td>
<td>209</td>
<td>54</td>
</tr>
<tr>
<td>11.8</td>
<td>151</td>
<td>30</td>
</tr>
<tr>
<td>16.7</td>
<td>163</td>
<td>29</td>
</tr>
<tr>
<td>&gt;16.7</td>
<td>115</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td>1518</td>
<td>206</td>
</tr>
</tbody>
</table>

were described by the log normal distribution. Most starch and grain meal particles had diameters larger than 5 μm. Fifty percent of all particles were less than 2.6 μm diameter.

2. The respirable fraction by mass was 3.7%, as estimated from the particle size distribution. Fifty percent of the mass was due to particles smaller than 18.9 μm. The respirable fraction by number was 76.1%.

3. Higher total mass concentrations were not associated with similar increases in respirable mass concentrations. As total mass concentrations increased, the log-probability particle size distributions became less homogeneous, with smaller geometric mean diameters.

4. Feed was the major source of airborne dust. Dust control measures should include reduction of feed dust emissions. Enclosing feed delivery and reducing feed wastage are suggested measures.

5. The relatively inexpensive, optical microscope was more cost-effective in sizing and identifying dust particles than the scanning electron microscope.

6. Digested or fecal particles could not be identified with an optical microscope without a suitable stain.

References

CONCLUSIONS
1. The sizes of starch, grain meal, and all particles
   arbitrary counting method and too few particles were observed (20 per sample) to draw conclusions about overall particle size. The particle size distributions for all particles, starch particles, and grain meal particles were plotted (Fig. 5). The particle size distribution of all particles collected from a swine finishing house in Sweden and sized by SEM (Nilsson, 1982) was plotted for comparison with the particle size distribution for all particles from this survey. The GSD and MMD were similar. The geometric median diameter from this study was 5.7 μm as compared to 3.8 μm in Nilsson's study, because of the bias toward larger particles.

Fig. 4—Scanning electron micrographs (2000X) of dust particles collected on membrane filters inside swine finishing buildings. (a) Unit E. (b) Unit D.

Fig. 5—Compiled particle size distributions of 76 samples of starch, grain meal, and all particles observed with a scanning electron microscope. Also shown is the size distribution of particles collected in a swine finishing building in Sweden (Nilsson, 1982).


