Effect of Additives on Aerodynamic Segregation of Dust from Swine Feed

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ABSTRACT

A simple, low-cost method for rapidly measuring aerodynamic dust segregation (ADS) from feeds was developed. ADS were measured from 9 and 12% moisture content corn-, wheat-, and grain sorghum-based swine feeds treated with 0.0, 0.5, or 1.0% levels of animal fat or crude soybean oil. Soybean oil was more effective in reducing ADS than animal fat at the same levels. ADS of swine feed was 22% less at 12% m.c. than at 9% m.c. Corn feed was 12.3% and 5.8% less dusty than milo and wheat feeds, respectively. Large geometric diameters were associated with low ADS (P<0.001).

INTRODUCTION

An important engineering challenge in livestock housing is improvement of air quality in confined swine buildings. A serious air quality problem is the high concentration of suspended solid particles (Donham et al., 1986). Smaller airborne particles will remain suspended while larger particles tend to settle on surfaces in the facility.

Swine dusts have both feed and fecal components but most airborne and settled particles in finishing units originate from feed (Heber et al., 1988). Swine feed rations contain large numbers of fine particles as a result of grinding of whole grains and adding vitamins and minerals. Some feed particles become airborne dust when aerodynamically segregated during feed delivery, winnowed by pigs, and mechanically agitated by pigs and workers.

The management of dusts in swine buildings is primarily based on ventilation and housekeeping practices. Adding dust-suppressing liquids to feed appears to be an excellent alternative for finishing units (Chiba et al., 1985). Many swine producers in Kansas report good results from the practice of adding about 1.0% soybean oil or animal fat to enrich the swine diet and enhance dust control. The selection of additive type is dictated by price, and additive levels are usually selected after observing results (Henry, 1986). The objectives of this research were to: (a) develop a simple low-cost method for rapidly measuring aerodynamic dust segregation from feeds, and (b) evaluate the effects of grain type, feed moisture content, additive type, and additive level on aerodynamic dust segregation from feeds.

LITERATURE REVIEW

Grain and Feed Additives

The use of additives to control grain dust emissions (production of aerial dust) during grain handling has been studied by several researchers. Mineral oil applications up to 0.06% were tested on corn, wheat, and soybeans (Jones and Parnell, 1985). A saturation point was reached with wheat at 0.04% of added oil. Corn was less dusty than wheat or soybeans. Lai et al. (1981) found that the effects of vegetable oil and mineral oil on grain dust emissions decreased with grain storage time, but that as little as 0.02% mineral oil was effective for short time intervals. The addition of 0.07% hydrocarbon-base oil to wheat in a laboratory experiment reduced dust emissions by more than 92% (Cocke et al., 1978). Reductions in aerial dust concentrations of 60 to 80% were obtained when corn and soybeans were treated with additive levels between 0.08 and 0.36%.

The addition of oils and fats to swine feed for dust control has been researched. Additive levels needed in feed is generally much higher than in whole grains due to the larger number of fine particles. Jericho and Harries (1975) used fish oil to reduce dust emissions in a pig building, while feeding an artificially dusty ration. Fifty percent soybean oil reduced settled dust by 46% and reduced total aerial bacterial colony counts by 27% in pig nurseries (Gore et al., 1986). Concentrations of aerial dust and amounts of settled dust in a swine finishing building were lower when dietary fat was added to the feed at a 5% level (Chiba et al., 1985). Results indicated that adding 5% tallow was superior to adding 2.5% for reducing dust emissions from feed.

Dustiness Measurements

Greenaway (1972) developed a fundamental test and a rapid empirical test for measuring residual dust in corn. The percentage of residual dusts in corn was determined with the fundamental method by filtering, drying, and weighing separated dust trapped in distilled water. In the rapid empirical method, the conductivity of the distilled
water was measured instead of weighing the dust. Corn 
with less than 0.05% dust was normal, but corn with 
more than 0.12% dust was very dusty according to 
laboratory and field studies. Residual dusts were related 
to dust emissions during handling of corn, soybeans, and 
wheat in a headhouse (Martin and Lai, 1978). Grain 
sorghum and wheat will typically contain 1 to 5 g of 
residual dust (<100 μm) per kg of grain (Jones and 
Parnell, 1985).

Cocke et al. (1978) used a 43 cm dia., 68 cm long, 
rotating cylinder to agitate 1.8 kg of grain for up to 10 
min to test the effects of additives on grain dust emission. 
A dust sample collected on a membrane filter inside the 
cylinder was used to determine the mass concentration of 
airborne dust.

A laboratory test for grain dustiness developed by 
Martin (1985) involved dropping a sample of whole corn 
through a vertical cylinder. An experiment was 
conducted with this tester to study the aerodynamic 
segregation of dust from corn as influenced by the 
amount of residual dust added, corn moisture content, 
drop height, amount of broken kernels, and amount of 
mixing. Aerodynamic dust segregation was positively 
related to the amount of fine dust added and drop height 
but negatively related to corn moisture content. Aerial 
dust concentrations in commercial grain elevators were 
proportional to test results on field samples (Lai et al., 
1982).

DEVELOPMENT OF AERODYNAMIC DUST 
SEGREGATION TESTER

Martin Grain Dustiness Tester

The equipment used in this experiment was 
constructed according to a modified design of the grain 
dustiness tester developed by Martin (1985). This tester 
was developed to simulate aerodynamic dust segregation 
(ADS) occurring during grain handling. It was originally 
designed to segregate, contain, and measure grain dust 
segregation from 20 g corn samples. The tester consisted of 
three basic components: (a) a 3.5 cm dia., 6 cm long 
steel cylinder with a spring-driven drop gate and manual 
release to drop the sample, (b) a 4.2 cm dia., 40 cm long 
steel column to contain the dust cloud, and (c) a 3 cm 
dia., 35 cm³ plastic catch cup with a removable 0-ring 
seal.

The test was conducted by: weighing the sample and 
container; placing the sample on the drop gate; weighing 
the empty container and placing it under the column as 
the catch cup; and weighing the sample and container 60 
seconds after dropping the sample. The ADS by mass was 
calculated as the difference between initial and final 
sample weights divided by the initial sample weight, and 
was expressed as a percentage. The time expired between 
dropping the sample and removing the cup is referred to 
as the catch time.

ADS Test Parameters

A metal cutoff gate was installed at the bottom of the 
column to separate the aerodynamically segregated dust 
cloud from the catch cup, rather than removing the cup 
after the catch time expired (Fig. 1). A microcomputer 
sequenced the operation of the drop and cutoff gates. 
Each gate inside the column was held shut with a spring 
and instantly opened with a solenoid relay. A steel cup 
holder was sealed around the bottom of the column with 
0-rings. The column was sealed with a rubber stopper on 
the top and with the tightly fitted plastic cup at the bottom.

Ground feed has significantly different characteristics 
than whole grain and behaves differently in an ADS test. 
Therefore, effects of physical and procedural parameters 
of the ADS tester for ground feeds would need to be 
investigated. It was also hypothesized that the 
cumulative segregation after 2, 3, or 4 drops might 
provide a better measurement than after just one drop.

An experiment was conducted to determine the effects 
of column height, catch time, sample size, and the 
number of sequential drops used for each sample. A 
glass tube was used in this experiment to allow visual 
observation of the falling sample. Three tube lengths 
were used to produce column heights of 88, 100, and 112 
cm. Catch times were 900, 1000, and 1100 ms and 
and sample sizes were 7, 14, and 21 g. Two observations 
were made on each column. Feed samples were prepared 
from a typical swine finishing ration consisting of milo, 
soybean meal, minerals, and premix.

The statistical R² value in the analysis of variance was 
0.92 for the cumulative segregation after the 2nd, 3rd, or 
4th drops. However, an R² of 0.91 was obtained for a 
single drop, thus, sacrificing little statistical precision or 
power and requiring less time to run. An analysis of 
variance was conducted with ADS after a single drop as 
the dependent variable. The effects of catch time (T), 
sample size (S), and column height (H) on ADS were 
statistically significant (P<0.01) with no significant
interactions (Figs. 2, 3, and 4). A multiple linear regression of ADS as a function of column height, catch time, and sample size was:

$$\text{ADS} = 18.7 - 0.15 S + 0.16 H - 0.02 T \quad R^2 = 0.78$$

ADS decreased from 10.4 to 8.3% as sample weight increased from 7 to 21 g (Fig. 2). Percentages of segregated particles are related to the area to volume ratios of a sample of falling feed. Large samples break up less than the small samples. These effects bring fewer particles per unit weight of the falling sample in direct contact with the air stream. ADS increased from 7.3 to 11.0% as column height increased from 88 to 112 cm (Figs. 3 and 4). Tall columns segregate many particles but short columns are more convenient to use. ADS decreased from 11.6 to 7.0% as catch time increased from 900 to 1100 ms. It was observed, however, that the dust cloud created by the impact in the catch cup was partly captured by the cutoff gate at the short catch time. This did not appear to be a problem at 1000 ms. This experiment with ADS test methods indicated that it would be reasonable to use a single drop, a 1 m column height, a 1 s catch time, and a 10 g test sample.

**EXPERIMENTAL PROCEDURE**

**Experimental Design**

This experiment tested the effects of three types of swine feed, two moisture contents, and five additive treatments. The additive treatments consisted of no additives, and two levels each of two types of additives. Four lots of each combination of feed type, moisture content, and additive treatment were prepared. Each lot was sampled and tested three times.

**Sample Preparation**

Wheat, corn, and grain sorghum (milo) finishing swine rations were ground with a hammermill (4.8 mm screen) to an average geometric median diameter (GMD) by weight of 822 μm and an average geometric standard deviation of 1.76 (ASAE, 1984). The rations were mixed as follows:

- Wheat, corn or grain sorghum: 75.85%
- Soybean meal: 20.85%
- Dicalcium phosphate: 1.40%
- Lime stone: 0.95%
- Stock salt: 0.50%
- Vitamin premix: 0.25%
- Trace mineral: 0.10%
- Antibiotics: 0.10%

| Total | 100% |

Initial moisture contents (w.b.) of the corn, wheat, and milo feed batches were 12.6, 11.7, and 11.9%, respectively. The moisture content of each batch was determined by oven-drying approximately 5 g of feed for 1 h at 130 °C. The fat contents (w.b.) of the corn, wheat, and milo feeds were 2.5, 1.7, and 2.4%, respectively, as determined by the Soxhlet ether extract procedure.

Experimental lots consisted of 500 g of feed in 0.95 L (1 qt) jars. Forty lots were prepared from each of the three batches of feed. The moisture content was reduced to 11.8% in 20 lots of corn feed by drying at 60 °C in a laboratory oven. Twenty lots of each feed type were similarly dried to 9.0% by removing the required weight of moisture. Several lots were checked for moisture.
content to verify the dry-down procedure. Each set of 20 lots consisted of four lots each of five treatments: no additives (control), 0.5 or 1.0% of added animal fat, and 0.5 or 1.0% of added crude soybean oil. Fat and oil percentages were based on weight. Feed was removed from each jar and mixed with additives using a spatula and a U.S. No. 6 sieve. Fat was heated to 60 °C before being poured into the feed. All lots were stored at room temperature for 24 h before testing. The ADS tests were conducted between the 6th and 12th day following feed grinding.

Test Procedure
The aerodynamic dust segregation (ADS) was defined in this work as the separation of fine particles (in 1 s) from a free-falling 10 g sample of feed in a 1 m high, 5 cm diameter column. An observation consisted of the average ADS of three test samples from each lot. Each individual test sample was randomly selected from among the 120 lots.

An ADS test was conducted according to the following procedure:
1. Shake a randomly selected jar of feed vigorously at least 10 times by hand.
2. Add approximately 10 g of feed to a tared plastic cup and weigh.
3. Pour sample from cup onto the closed drop gate (Fig. 1).
4. Insert emptied cup into the bottom of the column.
5. Seal top of the column with a rubber stopper.
6. Open drop gate.
7. Close cutoff gate after 1 s.
8. Weigh cup with remaining feed sample.
9. Clean column using compressed air.
10. Calculate ADS as percent mass of original sample.

Particle Size Analysis
The particle size distribution of each treatment was determined for evaluation of its effect on ADS. The particle size distribution of segregated feed particles captured by the catch gate after 1 s was determined to show what size range of particles were segregated by the test procedure. This was compared with the particle size distribution of settled dust from commercial swine buildings, which primarily consists of particles aerodynamically segregated from swine feed under field conditions.

A standard sieving procedure (ASAE, 1984) was conducted on (a) 200 g of feed (consisting of 50 g per lot) from each treatment, (b) a 75 g composite sample of fine particles segregated from milo feed by the ADS tester during the developmental experiment, and (c) a 100 g composite sample of settled dust collected from building surfaces during a 9-month survey of 11 commercial swine finishing units (Heber et al., 1988). The geometric median diameter (GMD) by weight was defined as the diameter at which 50% of the particles were smaller and 50% were greater. The geometric mean standard deviation was determined by dividing the diameter at 84.1% of the cumulative weight by the GMD.

Table 1. Analysis of variance of aerodynamic dust segregation of swine feed*

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F1</th>
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</thead>
<tbody>
<tr>
<td>Moisture Content, MC</td>
<td>1</td>
<td>257</td>
<td>256.5</td>
<td>201.0*</td>
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<tr>
<td>Additive Treatment, AT</td>
<td>4</td>
<td>230</td>
<td>57.5</td>
<td>45.0*</td>
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<tr>
<td>Control vs. Others</td>
<td>(1)</td>
<td>(137)</td>
<td></td>
<td>107.1*</td>
</tr>
<tr>
<td>Low vs. High</td>
<td>(1)</td>
<td>(45)</td>
<td>35.3</td>
<td>35.3*</td>
</tr>
<tr>
<td>Oil vs. Fat</td>
<td>(1)</td>
<td>(45)</td>
<td>35.3</td>
<td>35.3*</td>
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<td>Interaction</td>
<td>(1)</td>
<td>(2)</td>
<td>1.9</td>
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<td>GRAIN</td>
<td>2</td>
<td>51</td>
<td>25.4</td>
<td>19.9*</td>
</tr>
<tr>
<td>GRAIN X MC</td>
<td>2</td>
<td>29</td>
<td>14.6</td>
<td>11.4*</td>
</tr>
<tr>
<td>GRAIN X AT</td>
<td>8</td>
<td>34</td>
<td>4.3</td>
<td>3.3*</td>
</tr>
<tr>
<td>MC X AT</td>
<td>4</td>
<td>10</td>
<td>2.4</td>
<td>1.9</td>
</tr>
<tr>
<td>GRAIN X MC X AT</td>
<td>8</td>
<td>9</td>
<td>1.2</td>
<td>0.9</td>
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<tr>
<td>Experimental error</td>
<td>90</td>
<td>115</td>
<td>1.28</td>
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<tr>
<td>Sampling error</td>
<td>240</td>
<td>344</td>
<td>1.43</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>359</td>
<td>1078</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Additive treatments included a control, and two levels (low and high) each of fat and oil. Grain types were wheat, corn, and grain sorghum.
†Experimental error mean square used in denominator.
‡Significant at the 0.01 level.

RESULTS AND DISCUSSION
This experiment investigated the effects of grain type, additive type, additive level, and moisture content on aerodynamic dust segregation (ADS) of swine feed. All single effects were significant (P<0.01). Interactions of grain type with moisture content and with additive type were also significant (Table 1).

Moisture Content
The mean aerodynamic dust segregation (ADS) was 7.8 ±0.1% at 9% m.c. and 6.1 ±0.1% at 12% m.c., or a decrease of 22%. Milo feed was affected the most (27% decrease) and wheat feed the least (13% decrease) by higher moisture content. ADS was significantly higher (P<0.05) at 9% m.c. than at 12% m.c. for each experimental treatment, except for wheat feed with no additives and with soybean oil (Fig. 5).

Fig. 5—Aerodynamic dust segregation, ADS, of wheat-based swine finishing feed as influenced by moisture content and two levels of added soybean oil and animal fat. The 95% confidence interval is shown for each treatment mean (n=12).
TABLE 2. MEANS AND STANDARD ERRORS OF MEANS OF AERODYNAMIC DUST SEGREGATION*

<table>
<thead>
<tr>
<th>Additive level</th>
<th>Grain type (n=8)</th>
<th>All (n=24)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Corn</td>
<td>Milo</td>
</tr>
<tr>
<td>Control 0.0%</td>
<td>BCD 7.32 ± 2.28</td>
<td>A 8.80 ± 4.2</td>
</tr>
<tr>
<td>Fat 0.5%</td>
<td>E 6.52 ± 2.7</td>
<td>B 7.79 ± 3.8</td>
</tr>
<tr>
<td>1.0%</td>
<td>CDE 6.79 ± 2.8</td>
<td>BCE 6.99 ± 2.8</td>
</tr>
<tr>
<td>Oil 0.5%</td>
<td>F 6.62 ± 3.1</td>
<td>BC 7.40 ± 4.0</td>
</tr>
<tr>
<td>1.0%</td>
<td>F 5.48 ± 2.5</td>
<td>E 6.30 ± 2.8</td>
</tr>
</tbody>
</table>

*Treatments are given for each additive treatment on individual grain types and for all grain types. The same letter indicates that the means were not significantly different (P<0.05).

Additive Treatment
The mean ADS for the additive treatments were 8.2 ± 0.3%, 7.4 ± 0.2%, 6.8 ± 0.2%, 6.8 ± 0.3%, and 5.8 ± 0.2% for no additives, 0.5 and 1.0% fat, and 0.5 and 1.0% oil, respectively, and were significantly different (P<0.05). At the 0.5% additive level, reductions in ADS from the control were 10.3 and 17.7% for fat and oil, respectively. Reductions in ADS from the control were 17.7 and 29.6% at 1.0% added fat and oil, respectively. Reductions in ADS with higher additive levels in each feed type were statistically significant (P<0.05), except for fat in corn- and milo-based feed (Table 2 and Figs. 6 and 7). Overall, doubling the amount of additive reduced the ADS 1.7 times. The law of diminishing returns appeared to affect additive levels above 5.0 kg/T of feed, because 10.0 kg/T did not provide twice the benefit.

It appears from this study that crude soybean oil at half the rate is as effective as animal fat in reducing dust emissions from swine feed. This fact should be taken into account when comparing prices. The current prices for soybean oil and animal fat are $2.03 and $4.70 per 100 kg, respectively.

Grain Type
The mean ADS of 7.5 ± 0.2%, 6.9 ± 0.2%, and 6.5 ± 0.1% for milo, wheat, and corn-based swine feeds, respectively, were significantly different (P<0.05).

Particle Size Distributions
The average feed GMD for the 30 treatments in this experiment was 809 μm and ranged from 687 to 875 μm (Fig. 8). Large GMDs were correlated with low ADS (P<0.001). The effect of GMD on ADS was less than effects of other factors, such as moisture content, but...
results show that smaller feed particles will be somewhat dustier than larger particles. Feed dustiness should be considered in the selection of screen size used to grind the feed.

Average GMDs for the 10 treatments of each feed were 782, 803, and 842 μm for milo, wheat and corn feeds respectively. These GMDs corresponded with the mean ADS for each grain type. The average geometric standard deviations for the milo, wheat, and corn feeds were 1.76, 1.78, and 1.72, respectively.

The particle size distributions of the 12% m.c. controls of each type of feed were compared to the particle size distributions of settled dust and segregated particles from ADS tests (Fig. 9). The GMD of the settled dust was assumed to be 100 μm by interpolation between two data points in Fig. 9. Most of the mass occurred between 75 and 150 μm. Most of the mass at diameters larger than 150 μm was due to caked agglomerations and miscellaneous particles (bird and mouse feces, etc.) which were scraped off building surfaces along with genuine settled dust. The particle size distribution of settled dust represents the size of feed particles that become airborne and carried by air movement some distance from their source before settling. Small particles will be carried greater distances than large particles. The GMD of the feed particles segregated by the ADS tester was 259 μm. The particle sizes of the segregated feed particles followed a log normal distribution (R²=0.97). Large fractions of chaff accounted for the weight of the larger particles. These chaff particles have a much smaller aerodynamic diameter than indicated by sieving.

CONCLUSIONS

1. Adding animal fat or soybean oil to grain sorghum-, wheat-, and corn-based swine feeds significantly decreased the aerodynamic dust segregation.

2. Twice as much animal fat as soybean oil was required in feed to attain the same reduction in aerodynamic dust segregation.

3. Corn feed was 12.3% and 5.8% less dusty than milo and wheat feeds, respectively.

4. The aerodynamic dust segregation of swine feed at 12% m.c. was 22% less than that at 9% m.c.

5. Doubling the additive level reduced aerodynamic dust segregation by a factor of 1.7.

6. The influence of additive levels on aerodynamic dust segregation was less in corn—than in milo—or wheat-based feeds.

7. Large geometric median diameter of feed was correlated (P<0.001) with low aerodynamic dust segregation.

References


