Factors affecting the Release and Concentration of Dust in Pig Houses

G. Gustafsson

Department of Agricultural Biosystems and Technology (JBT), Swedish University of Agricultural Sciences, P.O. Box 86, S-230 53 Alnarp, Sweden; e-mail: Gosta.Gustafsson@jbt.slu.se

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Dust in pig confinement buildings may create negative health effects on humans as well as on the animals. Measures to reduce the dust concentration in the air are therefore urgent. The mass balance of dust as well as the efficiency of different dust-reducing measures have been investigated and analysed. The investigations have shown that the generation of dust is affected by activity, number of pigs and also by the weight of the pigs. Increased ventilation rate, electrostatic air cleaning and removal of dust by vacuum cleaners have had limited effect on the dust concentration. It has been observed that the type of ventilation technique but also the type of housing system influence the generation of dust. Spraying of small water droplets as well as an oil mixture have resulted in a significant reduction of the dust concentration.

Notation

\begin{align*}
A & \text{ floor area, m}^2 \\
ah, b & \text{ regression coefficients} \\
C_{av} & \text{ average dust concentration, mg/m}^3 \\
C_i & \text{ dust concentration in inlet air, mg/m}^3 \\
C_o & \text{ dust concentration in outlet air, mg/m}^3 \\
C_{resp} & \text{ respirable dust concentration, mg/m}^3 \\
C_{tot} & \text{ total dust concentration, mg/m}^3 \\
G & \text{ removal by air cleaning, mg/h} \\
n & \text{ number of pigs} \\
p_d & \text{ dust production, mg/h} \\
q & \text{ ventilation rate, m}^3/h \\
S & \text{ settling rate of dust, mg/m}^2 h \\
t & \text{ time, h} \\
u & \text{ ratio of exhausted dust, \%} \\
V & \text{ building volume, m}^3 \\
v & \text{ value depending on the properties of the dust, m/h} \\
w & \text{ pig weight, kg} \\
\eta & \text{ air cleaning efficiency} \\
\theta & \text{ relation between airflow rate of an air cleaner and the building ventilation rate}
\end{align*}

1. Introduction

The presence of dust in pig houses may create working environmental problems (Donham, 1987; Tielen et al., 1995; Takai and Iversen, 1990; Larsson et al., 1993; Malmberg et al., 1993) as well as depressed health status of the animals (Donham, 1991; Robertson et al., 1990; Robertson, 1993; Hamilton et al., 1993). Donham (1987) and Tielen et al. (1995) reported acute respiratory illness common among swine confinement workers but also among veterinary surgeons specialized on pigs (Tielen et al., 1995). Frequent symptoms are coughing, sputum of phlegm, soar throats, runny noses, burning or watering of eyes, shortness of breath, chest wheezing, etc (Donham, 1987; Tielen et al., 1995). Takai and Iversen (1990) showed that work in pig houses caused acute reduced lung function (FEV1 and FVC) both among farmers with respiratory symptoms as well as among farmers without any symptom. The reduced lung function was specially pronounced among farmers with asthma. Investigations by Larsson et al. (1993) and Malmberg et al. (1993) showed that exposure to swine dust of non-smoking subjects who
had never visited a swine confinement building resulted
in an intense airway inflammatory reaction and general
symptoms as fever.

Donham’s (1991) investigations on swine have shown
correlation between percentage of swine with scars on
livers and the concentration of dust and endotoxin in the
air. These investigations also showed increased mortality
and reduced gain among piglets exposed to dust concen-
trations higher than 5·2 mg/m³ but also elevated mortality
and prevalence of pneumonia and pleuritis among fattening
pigs exposed to dust concentrations higher than 3·7 mg/m³. Studies by Robertson (1992) have also shown
a relationship between the air quality in pig houses and
the severity of both atrophic rhinitis and enzootic pneu-
monia of pigs. Hamilton et al. (1993) reported that the
combination of dust, ammonia and P. Multocida induced
turbulent atrophy on pigs, combinations of which result-
ed in an accumulative effect.

Measures to reduce the contamination of the air in
swine confinement houses are therefore urgent. The pur-
pose of this investigation has therefore been to analyse
the mass balance of dust but also the efficiency of differ-
ent dust-reducing measures.

2. The characteristic of pig house dust

The major part of pig house dust is organic (Aarnink
et al., 1999). Originally, the dust was considered to origin
from feedstuffs. However, investigations by Hartung
(1992) and Aarnink et al. (1999) have indicated that there
are also other components of the dust as particles from
skin, hair, faeces and urine. Investigations by Angst
(1984) and Hinz and Krause (1988) have shown that the
composition of settled dust and feedstuffs in pig houses
differ considerably regarding crude protein and crude
ashes.

Hinz and Krause (1988) also reported that dust par-
ticles may function as carriers for different types of
microbes as Staphylococcae, Streptococcae, Escherichia
Coli, Pseudomonas Spec. and different species of fungi.
They identified the following species of fungi in swine
house dust: Scopulariopsis, Cladosporium, Mucor. It has
also been reported that dust particles may absorb differ-
ent gases which may contribute to odour (Janni et al.
1984; Bundy and Hazen, 1973).

Nilsson (1982) reported that the major part of the dust
particles are respirable (less than 5 μm in diameter).
However, it should be observed that the major part of the
weight of the dust is not respirable. Donham (1986)
reported that 7% of the total weight of the dust was
respirable, while Gustafsson et al. (1990) found that the
respirable fraction varied between 9 and 13% in growing-
finishing pig houses.

3. Factors affecting the generation and concentration
of dust

3.1. Feeding

Nilsson (1982) found that the type of feed (dry or wet)
had limited influence on the daily averages of total dust
concentrations in growing-finishiing pig houses. He con-
cluded that a considerable proportion of the dust there-
fore originate from the pigs themselves. However, both in
cases with wet and dry feed the dust concentrations
increased during the feeding time due to an increased
activity.

Takai et al. (1986) found a dust concentration of
1·8 mg/m³ at dry feeding and 1·4 mg/m³ for wet feeding.

It has been found in several investigations (Gore et al.,
1986; Gast & Bundy, 1986; Chiba et al., 1987; Heber
& Martin, 1988; Takai & Pederson, 1994) that the addi-
tion of oil or fat to the feedstuff may decrease the amount
of dust in pig houses.

The influence of feeding technique on the activity of
the pigs may have an indirect effect on the dust concen-
tration. Robertson (1992) has presented results which
show significantly higher dust concentrations at restrict-
ive feeding compared to ad libitum feeding.

3.2.Activity

Several investigations (Nilsson, 1982; Gustafsson,
1994; Pedersen, 1993; van’t Klooster et al., 1993) have
proved that the activity in swine houses has a strong
influence on the concentration of dust in the air. The
concentration normally increases during periods when
the activity is high, such as during feeding, weighing of
the pigs. The variation in number of particles of different
sizes during a day with constant ventilation rate is pre-
sented in Fig. 1 (Gustafsson, 1994). The figure shows an
increase in the number of dust particles during the day
when the activity is higher than at night.

Pedersen (1993) has shown that the number of dust
particles in the air varies with the same pattern as the
signal from an activity sensor.

3.3. Ventilation

There is little concensus among investigations about
the influence of ventilation on dust concentration. How-
ever, investigations by Bundy and Hazen (1975)
and Bundy (1984) about the influence of ventilation
rate on the number of dust particles show a decrease
in the number of dust particles at increasing airflow
rate.
FACTORS AFFECTING THE RELEASE AND CONCENTRATION OF DUST IN PIG HOUSES

The influence of ventilation rate on the total mass concentration of dust in the air has been less pronounced (Nilsson, 1982; Gustafsson, 1994). However, influence of temperature difference between the barn and outside air (indirect indicator of ventilation rate) have been found by Heber et al. (1988). Some investigations have also indicated influence of ventilation technique on dust concentrations (van’t Klooster et al., 1993; Heber et al., 1988).

3.4. Source surpression

Several investigations (Takai et al., 1993; Zhang et al., 1995; Zhang et al., 1996; Zhang, 1999; Jacobson et al., 1999; Lemay et al., 1999; Osman et al., 1999; Nonnenman et al., 1999) have shown that fogging, spraying or sprinkling not only oil mixtures but also pure water may reduce the concentration of dust in the air. However, there is still a need for more design data regarding techniques, amounts and frequency for the application of these fluids.

4. Theory

The mass balance of generated dust has been described by Nilsson and Gustafsson (1987) as

\[
V \frac{dC_{av}}{dt} = p_d - q(C_o - C_i) - SA - G
\]

where \( V \) is the building volume in m\(^3\), \( C_{av} \) is the average dust concentration, \( C_o \) and \( C_i \) are the total dust concentrations in outlets and inlets in mg/m\(^3\), \( t \) is time in h, \( p_d \) is the production of dust in mg/h, \( q \) is the ventilation rate in m\(^3\)/h, \( S \) is the settling rate of dust in mg/m\(^2\) h, \( A \) is the area of the floor in m\(^2\), and \( G \) is the amount of dust removed by air cleaning devices in mg/h.

The settling of dust may be described by

\[
S = vC_{av}
\]

where \( v \) is a value depending on the properties of the dust in m/h.

If stationary conditions are maintained, is it possible to determine the generation of dust from

\[
p_d = q(C_o - C_i) + SA + G
\]

The fraction removed by air cleaning devices is described by:

\[
G = \theta q \eta C_{av}
\]

where \( \theta \) is the relation between the airflow rate of an air cleaner and the ventilation rate of a barn and \( \eta \) is the air cleaning efficiency of an air cleaning device. The concentration in the inlet of the air cleaner is assumed to be the average dust concentration in the air \( C_{av} \).

5. Materials and methods

5.1. Buildings and equipment

The investigations have been carried out in three piggeries for growing-finishing pigs at the research station Alnarp Södergård. One of the piggeries (No 1) is equipped as a climate chamber (Fig. 2) which provides the opportunity to control and simulate the following parameters: outside climate (temperature and relative humidity), inside climate (temperature and relative humidity), ventilation rate, and design and location of air inlets and outlets.

Piggery No. 2 (Fig. 3) is equipped with a breathing ceiling as air inlet but also with possibilities for manure gas exhaustion through a slatted floor.

Piggery No. 3 (Fig. 4) is an uninsulated building where the pigs were kept on straw bedding. The building is equipped with automatical controlled natural ventilation in combination with a minor proportion mechanical ventilation through a slatted floor.

The influence of the following factors in the building environment has been investigated, namely, number and weight of animals, activity, settling of dust, ventilation rate, ventilation technique, and animal housing system.

The following methods to reduce the generation and concentration of dust have also been investigated, namely, electrostatic air cleaning, dust removal by vacuum
5.2. Measurements

The efficiency of different treatments have been analysed by:

- gravimetric measurements of the amount of total dust in mg/m³ with 37 mm diameter dust filters (Millipore) at a flow rate of 1·91/min located in the middle of the barn at 1·5 m height but also in the exhaust air;
- gravimetric measurements of the amount of respirable dust (mg/m³) with dust filters (Millipore) after separation of particles larger than 5 μm with a cyclon (SKC cyclon) at the same locations as for total dust;
- counting the number of particles of different sizes with an optical particle counter (Rion) which counted the number of particles of size larger than 0·3, 0·5, 1·0, 2·0, and 5·0 μm;
- weighing settled dust on five 0·230 m² settling plates located at a height of 2·0 m with the collected amount of dust measured by weighing the plates on a balance;
- measuring the ventilation rate with a hot wire anemometer (Alnor) in the exhaust air ducts.

Each measurement was carried out over a period of 3–4 days in order to collect enough dust on the settling plates. Ventilation rate was kept constant during each measurement. Different treatments have been compared with reference values measured before and after the treatments.

5.3. Analyses

Different measures to reduce the generation and concentration of dust have been analysed by using the following properties in the mass balance equation [Eqn (1)]: averages of total and respirable dust concentrations $C_{\text{tot}}$ and $C_{\text{resp}}$ measured in the middle of the barn and in the exhaust air; average of settling rate of dust on settling plates $S$; generation of dust $p_d$ as defined by Eqn (3); relation between settled amount of dust and dust concentration $S/C_{\text{tot}}$; and fraction of respirable dust $C_{\text{resp}}/C_{\text{tot}}$. 
Measurements of the number of particles have mainly been used to get a picture of the particle size distribution and influence of activity and ventilation rate.

The settling rate of dust varies to a large extent between different locations inside the buildings. However, it has also been found that the variations in the settling rate

### 6. Results and discussion

The influence of number of pigs on the production of dust was investigated by changing the number of pigs when their average body weight was in the range of 86–98 kg. The measurements showed that the generation of dust is proportional to the number of animals (Fig. 5).

The influence of pig weight on the dust production was also investigated during 15 production batches with fattening pigs. The production of dust increased with the body weight in all batches. The influence of body weight on dust production has therefore been analysed by linear regression which is presented in Table 1.

These facts indicate that a considerable part of the dust is generated from the animals themselves.

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**Fig. 4.** Design and location of instrumentations in piggery No. 3; (1) air inlet, (2) air outlet, (3) settling plate, (4) sampling with dust filter; all dimensions in mm

**Fig. 5.** Relation determined between the production of dust $p_d$ and the number of pigs $n$; $p_d = -0.61 + 0.248n$; coefficient of determination is 0.99
Table 1
Regression coefficients determined for the production of total dust per pig \( p_d \) in mg/h as a function of weight \( w \) in kg during different batches; \( p_d = a + bw \) where \( a \) and \( b \) are regression coefficients

<table>
<thead>
<tr>
<th>Piggery</th>
<th>Coefficients ( a, \text{mg/h} )</th>
<th>Coefficient of determination ( r^2 )</th>
<th>Coefficient of No. of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.3</td>
<td>0.87</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>5.6</td>
<td>0.91</td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td>22.1</td>
<td>0.62</td>
<td>17</td>
</tr>
<tr>
<td>1</td>
<td>24.7</td>
<td>0.92</td>
<td>11</td>
</tr>
<tr>
<td>1</td>
<td>38.8</td>
<td>0.68</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>101.2</td>
<td>0.68</td>
<td>17</td>
</tr>
<tr>
<td>1</td>
<td>21.2</td>
<td>0.90</td>
<td>12</td>
</tr>
<tr>
<td>1</td>
<td>9.5</td>
<td>0.83</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>51.1</td>
<td>0.82</td>
<td>16</td>
</tr>
<tr>
<td>1</td>
<td>38.4</td>
<td>0.80</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>-9.5</td>
<td>0.93</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>41.2</td>
<td>0.81</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>75.2</td>
<td>0.75</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>53.7</td>
<td>0.93</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>103.6</td>
<td>0.72</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 2
Relationship determined between the settling rate of dust and the total dust concentration \( S/C_{tot} \) in the air during different batches

<table>
<thead>
<tr>
<th>Piggery</th>
<th>( S/C_{tot} ), m/h</th>
<th>( x )</th>
<th>S.D.</th>
<th>CV</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59</td>
<td>11</td>
<td>0.19</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>58</td>
<td>17</td>
<td>0.30</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>52</td>
<td>10</td>
<td>0.20</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>48</td>
<td>9</td>
<td>0.18</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>56</td>
<td>8</td>
<td>0.14</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>65</td>
<td>26</td>
<td>0.40</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>86</td>
<td>24</td>
<td>0.28</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>77</td>
<td>20</td>
<td>0.26</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>72</td>
<td>24</td>
<td>0.34</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>59</td>
<td>25</td>
<td>0.42</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>67</td>
<td>40</td>
<td>0.60</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>85</td>
<td>35</td>
<td>0.41</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>56</td>
<td>21</td>
<td>0.38</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>26</td>
<td>0.44</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

\( x \), average of \( S/C_{tot} \); S.D., standard deviation; CV, coefficient of variation; \( n \), number of measurements.

Follow the same pattern over the entire production period (Fig. 6). This fact indicates that the airflow patterns inside the buildings could have an influence on the dust conditions.

The relation between settling rate \( S \) and the total dust concentration \( C_{tot} \) was determined (Table 2) in order to see if Eqn (2) is valid. Although the variation is quite high, the determinations indicate that the settling rate of the dust is influenced by the concentration of dust in the air.

Increased ventilation rate is often recommended as a method to reduce the concentration of air pollutants in buildings. Unfortunately, the ventilation rate has a limited diluting effect on dust at those ventilation rates recommended for insulated swine houses in temperate areas. The reason is that the settling of dust on different surfaces is a more important mechanism to remove dust particles from the air than the ventilation rate in pig houses. The major part of the dust settles on different surfaces inside the buildings. Figure 7 shows an example
Fig. 8. Ratio \( u \) of dust extracted by the ventilation system to dust production: \( u = 100/(1 - 1.54/q) \) where \( q \) is the ventilation rate per pig.

Fig. 9. Influence of ventilation rate on the number of dust particles of different sizes; \( x \) – – – \( x \), 0–3–0.5 \( \mu m \); \( o \) – – – \( o \), 0.5–1.0 \( \mu m \); + – – – + , 1.0–2.0 \( \mu m \); \( o \) – – – \( o \), 2.0–5.0 \( \mu m \); \( o \) – – – \( o \), > 5.0 \( \mu m \).

of the limited effect on the total dust concentration at different ventilation rates. The dilution of the dust by increased ventilation will increase the heating requirement in temperate regions.

The fraction of the generated dust which is exhausted by the ventilation air is presented in Fig. 8. The fraction of the dust which is exhausted is limited at those ventilation rates which occur in swine confinement houses in temperate areas. The low fraction of exhausted dust shows that the settling of dust is more important than the ventilation rate in the mass balance of dust.

Out of the measurements and the mass balance equations [Eqns (3) and (4)], it is possible to estimate the influence of animal density (pig per floor area) and ventilation rate on total dust concentration (weight) as

\[
C_{\text{tot}} = \frac{4.6w}{(q/n) + 64.3(A/n)}
\]

where \( w \) is body weight and \( n \) is the number of pigs. In this relation, animal density is of more importance than ventilation rate due to the influence of settling of dust.

The influence of ventilation rate on the number of dust particles of different sizes when air has been supplied with a high-speed recirculating air inlet is presented in Fig. 9.

Table 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High speed air inlet + high exhaust</th>
<th>Breathing ceiling + low exhaust</th>
<th>Difference, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( x )</td>
<td>S.D.</td>
<td>( n )</td>
</tr>
<tr>
<td>Total dust conc., mg/m(^3)</td>
<td>1.29</td>
<td>0.57</td>
<td>10</td>
</tr>
<tr>
<td>Resp. dust conc., mg/m(^3)</td>
<td>0.26</td>
<td>0.095</td>
<td>6</td>
</tr>
<tr>
<td>Dust prod. per pig, mg/h</td>
<td>253</td>
<td>104</td>
<td>11</td>
</tr>
<tr>
<td>( S/C_{\text{tot}} ), m/h</td>
<td>86</td>
<td>41</td>
<td>11</td>
</tr>
<tr>
<td>( S/C_{\text{resp}} ), m/h</td>
<td>392</td>
<td>86</td>
<td>6</td>
</tr>
<tr>
<td>Ratio of resp. dust, %</td>
<td>18.8</td>
<td>3.5</td>
<td>6</td>
</tr>
<tr>
<td>Exhausted dust, %</td>
<td>25.9</td>
<td>7.3</td>
<td>9</td>
</tr>
</tbody>
</table>

\( x \), average; S.D., standard deviation; \( n \), number of batches; NS, non-significant difference; * , significant difference 0.05 > \( p \) > 0.01; \( p \), probability
The ventilation has had a diluting effect mainly on particles larger than 1.0 μm. The ventilation rate had no effect for particles smaller than 1.0 μm for this particular ventilation system.

Two very different ventilation principles have been compared, namely, high-speed recirculating air inlets in combination with an exhaust fan located at roof level (high exhaustion), and a breathing ceiling as the air inlet in combination with manure gas ventilation (low exhaustion).

The recirculating air inlets create considerable air mixing and air movements in the stable while the air movements from the breathing ceiling are extremely small.

Experimental data for dust concentration and production, settling rate, ratio of respirable dust and fraction of exhausted dust are presented in Table 3. Significant differences occurred regarding respirable dust concentration \( C_{\text{resp}} \) and \( S/C_{\text{resp}} \). These results indicate that the ventilation technique (mainly air velocities and air movements) may have an influence on small particles.

Two different housing systems were compared, namely, climate-controlled confinement in the insulated piggery No. 2; and cold confinement in the uninsulated piggery No. 3 with straw bedding and natural ventilation.

In all investigated batches except one, significant differences occurred between the different piggeries, see Table 4. The presence of dust was much lower in the

### Table 4
Total and respirable dust concentration \( C_{\text{tot}} \) and \( C_{\text{resp}} \) and settling rate of dust \( S \) at five comparative production batches with growing-finishing pigs in two different housing systems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Piggery No. 2</th>
<th>Piggery No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial</td>
<td>x</td>
</tr>
<tr>
<td>Total dust conc., mg/m(^3)</td>
<td>1</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.37</td>
</tr>
<tr>
<td>Resp. dust conc., mg/m(^3)</td>
<td>2</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.15</td>
</tr>
<tr>
<td>Settling of dust, mg/m(^3)h</td>
<td>1</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>55</td>
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<td></td>
<td>4</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>71</td>
</tr>
</tbody>
</table>

\( x, \) average; S.D., standard deviation; \( n, \) number of measurements; \( \Delta, \) difference between housing systems, %; NS, non-significant difference; *, significant difference 0.05 > \( p > 0.01 \); **, significant difference 0.01 > \( p > 0.001 \); ***, significant difference 0.001 > \( p \); \( p, \) probability

### Table 5
The influence of air cleaning on total dust concentration

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Dust concentration, mg/m(^3)</th>
<th>Difference, %</th>
<th>Air flow in air cleaner, m(^3)/pig h</th>
<th>Vent. rate, m(^3)/pig h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air cleaner</td>
<td>Ref.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.94</td>
<td>1.24</td>
<td>-24</td>
<td>17.3</td>
</tr>
<tr>
<td>2</td>
<td>0.92</td>
<td>1.28</td>
<td>-28</td>
<td>10.3</td>
</tr>
<tr>
<td>3</td>
<td>1.39</td>
<td>1.77</td>
<td>-21</td>
<td>10.3</td>
</tr>
<tr>
<td>4</td>
<td>1.21</td>
<td>1.45</td>
<td>-17</td>
<td>17.2</td>
</tr>
<tr>
<td>5</td>
<td>1.60</td>
<td>1.74</td>
<td>-8</td>
<td>11.6</td>
</tr>
<tr>
<td>6</td>
<td>1.09</td>
<td>1.41</td>
<td>-23</td>
<td>11.6</td>
</tr>
</tbody>
</table>
uninsulated stable with straw bedding. The reasons to the large differences between the different systems are difficult to explain. Possible explanations may be more moisture in the cold environment with straw bedding, and very high ventilation rates during spring, summer and autumn in the uninsulated building.

The use of an electrostatic air cleaner had a limited effect on the dust concentration in the air (Table 5), although it has been proved that the equipment removed a large fraction of the particles in the air which passed through the device. Considering the mass balance of the dust, it is obvious that air cleaning devices need large airflow capacities if the dust concentration in the air is to be affected. The airflow through an air cleaner has the same influence on the dust concentration as an equally large increase in ventilation rate in the building.

The use of a vacuum cleaner designed for industrial purposes, as well as a central vacuum cleaning system, have been investigated. Both devices have been used to clean floor surfaces but also other surfaces such as pipes, etc., at different cleaning intervals. Although most surfaces looked cleaner after the treatments, no significant effect could be measured regarding total and respirable dust concentrations, settling rate or generation of dust (Table 6).

Water showering of floor surfaces has resulted in a limited non-significant decrease in dust generation and concentration (Table 7).

Three types of spraying nozzles have been investigated in an automatic spraying system namely, high-pressure (ultra-sound) nozzles, flat-fan nozzles, and full cone nozzles. The nozzles have been operated automatically in short sequences. They were operated twice per hour from 8 a.m. until 6 p.m. and once per hour during the rest of the day. Spraying water droplets have given different results dependent on the type of nozzles which have been used. The use of ultra-sound nozzles which created droplets in the size range between 5 and 10 μm resulted in a significant increase of both total and respirable dust concentrations during nine comparative trials (Table 8). The reason for the increased dust concentrations was probably the ultra-sound (frequency 30 kHz) created by the nozzles. This sound was beyond the human hearing range. However, observations of the pigs clearly showed that the pigs reacted in an abnormal way the first times the nozzles were in operation. The increased dust concentrations may only be explained by an increased activity of the pigs due to the ultra-sound.

The use of the flat-fan nozzles operated with a pressure of 0.35 MPa gave a reduction in both total and respirable

---

### Table 6

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Difference, %</th>
<th>S.D.</th>
<th>Number of measurements</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dust concentration, mg/m³</td>
<td>−13</td>
<td>24</td>
<td>7</td>
<td>NS</td>
</tr>
<tr>
<td>Resp. dust concentration, mg/m³</td>
<td>−18</td>
<td>28</td>
<td>5</td>
<td>NS</td>
</tr>
<tr>
<td>Dust production per pig, mg/h</td>
<td>−1</td>
<td>20</td>
<td>8</td>
<td>NS</td>
</tr>
<tr>
<td>S/Ctot, m/h</td>
<td>+8</td>
<td>20</td>
<td>7</td>
<td>NS</td>
</tr>
<tr>
<td>Ratio of resp dust, Cresp/Ctot</td>
<td>+2</td>
<td>26</td>
<td>5</td>
<td>NS</td>
</tr>
</tbody>
</table>

S.D., standard deviation; NS, non-significant difference

### Table 7

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Difference, %</th>
<th>S.D.</th>
<th>Number of measurements</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dust concentration, mg/m³</td>
<td>−9</td>
<td>26</td>
<td>16</td>
<td>NS</td>
</tr>
<tr>
<td>Dust production per pig, mg/h</td>
<td>−9</td>
<td>13</td>
<td>16</td>
<td>NS</td>
</tr>
<tr>
<td>S/Ctot, m/h</td>
<td>+6</td>
<td>34</td>
<td>16</td>
<td>NS</td>
</tr>
</tbody>
</table>

S.D., standard deviation; NS, non-significant difference
The influence of water spraying with supersonic nozzles (without sound attenuation) on total and respirable dust concentrations $C_{tot}$ and $C_{resp}$, dust production $p_d$, ratio between settling rate $S$ and total concentrations in relation (difference in %) to the situation without any water spraying

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Difference, %</th>
<th>S.D., %</th>
<th>Number of measurements</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dust concentration, mg/m$^3$</td>
<td>+ 33</td>
<td>23</td>
<td>9</td>
<td>**</td>
</tr>
<tr>
<td>Resp. dust concentration, mg/m$^3$</td>
<td>+ 138</td>
<td>85</td>
<td>9</td>
<td>***</td>
</tr>
<tr>
<td>Dust production per pig, mg/h</td>
<td>+ 7</td>
<td>11</td>
<td>8</td>
<td>NS</td>
</tr>
<tr>
<td>$S/C_{tot}$, m/h</td>
<td>− 34</td>
<td>16</td>
<td>9</td>
<td>***</td>
</tr>
</tbody>
</table>

S.D., standard deviation; NS, non-significant difference; **, significant difference 0.01 > $p$ > 0.001; ***, significant difference 0.001 > $p$; $p$, probability

dust concentrations. In these trials, each pen was equipped with four (horizontal spraying direction) flat-fan nozzles in combination with a full-cone nozzle (oriented downwards).

The use of full-cone nozzles operated at 0.3 MPa pressure also reduced both the total and respirable dust concentrations. The settling rate and the generation of dust were also affected. The efficiency was improved with increasing length of the spraying periods, see Fig. 10.

It has earlier been proved by Takai et al. (1993) that the spraying of mixtures of oil and water in pig houses will give a significant reduction in dust concentrations. However, it has not been verified whether the reduction of dust is due to less generation of dust from the pigs skin surfaces or if the oil functions as a dust binding agent on different building surfaces.

In these investigations, 10% rape seed oil in a water solution was used. The mixture has been applied in two different ways, namely, manually spraying directly on the pigs with a knapsack sprayer, and automatically with a spraying system with full-cone nozzles parallel to the feeding troughs. In the latter case, the oil mixture was applied once per day during the feeding time. The efficiency of manual spraying is presented in Table 9.

The manual treatment affected all the parameters measured. In order to see if the oil affected the release of dust from the skin, one treatment was carried out outside the building so that no oil should cover any building surfaces. In this treatment, the total dust concentration was reduced to 84% of the reference level. The treatment had a significant reduction on settling rate (63% of the reference level) and generation of dust (72% of the reference level). It can be concluded that the treatment with oil has reduced the generation of dust from the skin to some extent but also that the oil treatment functions as a dust-binding agent on surfaces in the building.

An automatic system for spraying of oil has also been investigated. The automatic spraying system consists of two full-cone nozzles per pen located parallel to the feeding troughs. The oil mixture was sprayed over the pigs back once per day during the feeding of the pigs. The reduction on total dust concentration at different amounts of oil is presented in Fig. 11. The treatments resulted in a considerable reduction in the total dust concentration. The reduction levels in the range of 75–80% has earlier been reported by Takai et al. (1993) with a high-pressure spraying system.

7. Conclusions

The investigations have shown that the generation of dust is influenced by the number and the weight of the
pigs. Settling of dust is a more important mechanism in the mass balance of dust than ventilation rate. The settled amount of dust stands in relation to the floor area of a building.

Another factor which has a strong influence on the concentration of dust is the activity in the buildings. Dust concentrations are higher in the daytime than at night. A major part of the generated dust settles on different surfaces inside the buildings. The settling rate of dust is affected by the concentration of dust in the air. An increased ventilation rate has a limited effect on the concentration of dust due to the importance of the settling of the dust.

Dust-reducing measures, such as electrostatic air cleaning of the air and removal of dust with vacuum cleaners, gave no significant reduction in the dust concentration. Automatic spraying of small droplets of water reduced the dust concentration with two types of spraying nozzles. For another type of nozzle, the generation of dust increased due to an ultra-sound which created an increased activity of the pigs. Spraying with a mixture of rape seed oil was also effective with manual spraying as well as with an automatic spraying system. The oil seems not only to have an effect on the generation of dust from the skin but also to function as a dust-binding agent for settled dust.

Acknowledgements

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Table 9

Relative levels of total and respirable dust concentrations Ctot and Cresp, dust production rate, and settling rate S when a rape seed oil mixture was sprayed manually directly on the pigs in relation to no oil spraying (reference level is 100%)

<table>
<thead>
<tr>
<th>Trial no</th>
<th>Total dust concentration, %</th>
<th>Respirable dust concentration, %</th>
<th>Settling rate, %</th>
<th>Dust production, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>9</td>
<td>87</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>4</td>
<td>75</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>51</td>
<td></td>
<td>38</td>
<td>61</td>
</tr>
</tbody>
</table>

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