CHANGING THE ENVIRONMENT IN SWINE BUILDINGS USING SULFURIC ACID

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ABSTRACT. Ammonia and dust concentrations in swine confinement buildings were reduced by spraying a mixture of water and sulfuric acid, by adding sulfuric acid to the swine manure, and by oxidizing the manure. The system was composed of a sprinkling system, spraying fluid at pH 5.5, and a sulfuric acid pump in the swine manure collection channel, ensuring that the pH in the swine manure never exceeded 5.5. In that way, the nitrogen, which usually escapes as ammonia gas, was kept as ammonium fluid. Above the manure collection channel was a gas monitor ensuring that the level of hydrogen sulfide did not rise to levels associated with danger to pigs or humans. Short-term observations in the swine confinement building showed a reduction of ammonia concentrations from 8 to 10 ppm down to 1 to 2 ppm and a reduction of respirable and total dust concentrations from 1.00 mg/m³ down to 0.28 mg/m³ and from 2.70 mg/m³ down to 1.20 mg/m³. Pig performance was improved, verified by an increase in weight gain of 1074 g/day (SD = 774 g/day). There was a subjective improvement in the working environment reported by two swine confinement workers and a better utilization of swine manure as fertilizer. This suggests that a substantial improvement in the environment of swine buildings can be achieved by installing this system in swine confinement buildings.

Keywords. Ammonia, Dust, Swine production, Work environment, Animal housing, Sulfuric acid.

Through the last 20 years, there has been concern about the working environment of swine confinement workers. An increase in the number of pigs in confinement buildings has raised concentrations of dust, ammonia, and other gases to levels associated with pulmonary function decrement and pulmonary symptoms in swine confinement workers (Brautbar, 1998; Donham et al., 1995; Von Essen and Donham, 1999; Larsson et al., 1994). Additionally, ammonia and dust concentrations in swine confinement buildings have increased the frequency of pneumonia and pleuritis in pigs registered at slaughter (Beskow et al., 1998).

Several hypotheses and pathogenic explanations have been proposed, but none has stated a mechanism for the development of headache, fatigue, asthma, coughing, and dizziness in swine confinement workers. Some of the hypotheses are ammonia exposure leading to acute inflammation in the lower respiratory tract (Brautbar, 1998), constituents of dust acting as allergens (Larsson et al., 1994), use of disinfectants in swine buildings (Preller et al., 1995), and multiple exposures (Von Essen and Donham, 1999).

People living in the vicinity of swine buildings have complained of odors. They claim to suffer more from respiratory symptoms such as asthma and pneumonia and report a low quality of life (Wing and Wolf, 2000; Schiffmann et al., 1995).

Although there have been many studies dealing with the subject, only a few have proposed methods preventing the hazard. In 1997, the use of canola oil sprinkling was shown to modify the level of inhalable dust, ammonia, carbon dioxide, and hydrogen sulfide, reducing the acute health effects in swine confinement workers (Senthilvelan et al., 1997). Before that, a preliminary study was conducted in which mineral oil was sprinkled and found to reduce the respirable and inhalable dust concentrations by 75% (Zhang et al., 1994). Earlier methods for reducing dust in swine confinement buildings include application of fogging (Nilsson, 1982), air filters (Carpenter and Fryer, 1990), feed additives (Chiba et al., 1987), and ionization (Bundy, 1984; Möller, 1991). None of these have been widely adopted as on-farm applications.

OBJECTIVES

In order to prevent emission of ammonia into the atmosphere, a simple technical procedure was invented in which the ammonia was trapped in the form of ammonium, keeping the nitrogen in the manure pit. By adding sulfuric acid into sprinkling water and ultimately the swine manure, the pH was lowered to 5.5, keeping the ammonia in the swine manure as ammonium. The manure was also oxidized by recirculating it through a drainage pump and oxygen injector system. Effects of this method on ammonia concentrations, dust concentrations, pigs, working environment, and on nitrogen concentrations in the swine manure were studied.

MATERIALS AND METHODS

The study was conducted on a private property with a herd of pigs in the northern part of Jutland, Denmark, over eight weeks in June and July, 2000. The study was approved by the
National Working Environment Authority and by the County of North Jutland Advisory Committee on Ethics in Human Experimentation.

ANIMAL FACILITIES AND MANAGEMENT

The exposure studies were conducted in two identical swine buildings. Each building measured 75 m × 8 m × 3.5 m. The pen floor was totally slotted (100%). A 0.5 m deep manure collection channel was located beneath the slotted area of the floor. Interior walls had concrete sheathing on both sides of a stud wall frame. Manure was removed from the barn every day and collected in the manure pit. Propeller fans (each with a maximum air delivery capacity of 68,000 m³/hour) were placed in the roof of the buildings, one for every 8.5 m. Fresh air entered the barns through windows along the building. There was no heating because of the summer temperature outside the buildings. An automatic controller regulated the sequencing and speed of the exhaust fans, ensuring a temperature ≤ 20 °C. A total of 725 pigs were housed in each of the buildings. The average body mass of the animals was 25 ± 5 kg per pig when beginning the exposure and approximately 95 kg when slaughtered. Pellet feed was filled daily to a single–space dry feeder in each of 33 pens. Management of the two buildings was identical, and production methods conformed to those recommended by the Society of Agriculture in Denmark. The sprinkling and manure oxidizing system was installed in the treatment building; it was not installed in the control building.

TECHNICAL PROCEDURE

The manure treatment system was in two parts, as shown in figure 1. First, the manure was collected under the slots in a collection channel. The channel transferred the manure to a manure pit. A mixture of water and sulfuric acid (pH = 5.5) was sprayed from the ceiling of the building and eventually flowed into the manure collection channel. Manure in the manure pit was recirculated with a drainage pump to mix it uniformly. Sulfuric acid and oxygen were added to the manure in the recirculation process. Both are essential in changing air quality. If only sprinkling with acid were used, then the level of hydrogen sulfide in the manure would rise. If only oxidizing were used, then the ammonia would escape as a gas.

The system consists of a sprinkling system on the ceiling of the barn connected to a jet (Lowara S.G.M. 7, 0.55 kW). The sprinkling system was connected to a water supply and a sulfuric acid pump that was controlled by a flow monitor. To reach a pH level of 5.5 in the swine manure, a pH monitor was placed in the manure and connected to a sulfuric acid dose pump. At this pH, the nitrogen was kept in the form of ammonium. The sprinkling schedule was set to 1 min/h with a sprinkling capacity of 1.35 L/min. Because the pH in the sprinkling fluid was kept at 5.5, it never became too acid for human or animal health. In the manure collection channel of the treatment barn, a drainage pump (Flygt model 3127–490, 5.9 kW) was connected with an oxygen injector in order to oxidize the manure to a maximum extent. A gas monitor (Duotec AS model H2S 200) above the manure collection channel ensured that the level of hydrogen sulfide did not rise above 30 ppm. The gas monitor was connected to a central alarm system (Duotec AS model GMC 8022) that alerted the owner of the property of any malfunction. The manure channel collection was connected with the manure pit in a channel system that circulated the swine manure, creating uniform alkalinity.

MEASUREMENT OF CONSTITUENTS OF SWINE MANURE

Manure samples were collected every three weeks from each of the manure pits and sent to the Central Laboratory of Agriculture Science, Foulum, Denmark, for analyses. Total nitrogen, nitrate nitrogen, total ammonium nitrogen, urea nitrogen, and dry matter constituent were measured.

MEASUREMENT OF AIR QUALITY AND ENVIRONMENT

Environmental assessment for ammonia and hydrogen sulfide gases was done using colorimetric test tubes (Dräger versions 6733231 and 6728041) connected to a gas detection hand pump (Accuro version 6400000). One representative area of each barn was identified and used for the sampling location at 2:00 p.m. every day for 43 days.

Personal dust samples were measured continuously by using personal aerosol samplers (SKC 224–50), with a 37 mm membrane filter of 0.8 μm porosity at a flow rate of 1.91 L/min, which were carried by the study subject for one work day. Dust filters from each barn were sent to Miljø–kemi, Dansk Miljøcenter A/S, Galten, Denmark, for analyses.

Aerial dust samples were obtained using an air sampler (SKC 224–50). An air sample was drawn into the sampler through a 37 mm membrane filter of 0.8 μm porosity. The air sampler was placed in the barns at comparable locations at a height of 1.3 m. Dust filters were sent to Miljø–kemi, Dansk Miljøcenter A/S, Galten, Denmark, for analyses.

Total dust and respirable dust in the treatment barn and the control barn were measured during a 2.5–hour period. Dust concentrations were only measured once at the end of the study.

EFFECT ON LUNG FUNCTION IN A FARMER DURING WORK

One swine confinement worker was recruited for the study. He was a lifetime nonsmoking male, 56 years of age, who was normally exposed to the work environment in swine buildings. He had no known allergy history or any symptoms of dyspnea, coughing, sputum, or chest pain. In 1999, he had a successful coronary bypass surgery due to arteriosclerosis of the coronary arteries. He received no medication.

Baseline peak flow measurement was taken at the property. The subject was instructed in using the peak flow meter (Ercopharm Easy Peak, pocket version). The peak flow meter measures the maximal rate of flow that is achieved during a forced expiration. The schedule was set to take peak flow measurements four times a day: at 7:00 a.m. (before entering the barn), 9:00 a.m. (during a normal working period in the barn for two hours), 12:00 noon (two hour after leaving the barn), and 9:00 p.m. (11 hours after leaving the barn).
The design was set up as a crossover trial. It was not possible to blind the subject because of the visibility of the sprinkling system and the difference in air quality.

An Ercopharm Easy Peak pocket version (with a maximum peak flow at 700 L/min) that was made according to the “International Consensus Report on Diagnosis and Treatment of Asthma” (NIH, 1992) was used for lung function measurements. The subject performed the lung function tests in an upright position. The best peak flow score of three was recorded at each measurement. Because there was only one worker available for testing, the data will need to be interpreted with caution.

The owner of the herd, who suffered from asthma related to staying in swine buildings, was included part-time in the study. He usually had to use a respirator during work. He reported the difference in his use of the respirator in between the two barns. Both subjects were informed of the scope of the study, and consent agreements were established.

**Effect on Pigs**

Weight gain of 21 pigs in the treatment barn was compared to weight gain of 21 pigs reared in the control barn. Measurements were taken every second week over a period of 39 days.

**Results and Discussion**

The analyses of the swine manure from each barn are shown in figures 2 and 3. The amount of organic nitrogen was smaller in the treatment barn than in the control barn. The amount of ammonium was higher in the treatment barn, suggesting that more of the ammonia in the swine manure was captured as ammonium. The plant–available nitrogen was increased in the swine manure of the treatment barn, making the treatment swine manure a better fertilizer.

The normal reaction that happens in the swine manure inside the manure pit at pH 7 is:

\[
\text{CO}(\text{NH}_2)_2 (l) + \text{H}_2\text{O}(l) \Rightarrow \text{NH}_4^+(l) + 2\text{HCO}_3(l) \\
\text{E: urease (1)}
\]

\[
\Rightarrow 2 \text{NH}_3(g) + \text{CO}_2(g) + \text{H}_2\text{O}(l)
\]

At pH 7, the following equilibrium exists:

\[
\text{NH}_4^+(l) \Leftrightarrow \text{NH}_3(g) + \text{H}^+(l) \tag{2}
\]

By sprinkling the slotted area with fluid at pH 5.5, the urease–producing bacteria were inhibited. In that way, reaction 1 was reduced. By lowering the pH to 5.5 in the manure pit with sulfuric acid, a new reaction began (Fog–Petersen, 1960):

\[
2 \text{NH}_3(\text{aq}) + \text{H}_2\text{SO}_4(l) \Rightarrow 2\text{NH}_4^+(l) + \text{SO}_4^{2-}(l) \tag{3}
\]

In this way, the emission of ammonia was reduced. Depending on the amount of ammonia, an equivalent amount of sulfuric acid was added, keeping the ammonia as ammonium. Oxidizing was necessary for preventing hydrogen sulfide development.

**Effect on Air Quality and Environment**

Figure 4 and table 1 show the differences in ammonia concentration between the two barns \((p < 0.001, t\text{ test})\). In the control barn, the ammonia concentration fluctuated between 8 and 12 ppm. In the treatment barn, it fluctuated between 1 and 2 ppm. The normal level of ammonia in swine confinement buildings is between 15 and 25 ppm (Donham et al., 1995; Senthilvelvan et al., 1997), depending on the number of pigs, the ventilation rate, and the size of the building. The hydrogen sulfide concentration was below the detection limit of the test tubes on all days in both buildings (not shown).

There were substantial differences in ammonia concentrations between the treatment barn and the control barn (fig. 4 and table 1). The threshold of smell of ammonia is 5 ppm (Stasey, 1993), a level never exceeded in the treatment barn and always exceeded in the control barn.

Dust concentrations were only measured on one day, so results must be interpreted with caution. The results are shown in table 2. There was a reduction in dust in the treatment barn compared to the control barn. The largest reduction was seen in the personal samplings, where there was a 4– to 6–fold reduction in the treatment barn.
The reduction in dust as a side effect of ammonia reduction was also found by Senthilselvan et al. (1997). By sprinkling with rapeseed oil, they reduced the dust concentration and with that most gas concentrations, including ammonia. It is a well–known phenomenon that gases are absorbed by dust particles (Stasey, 1993), which could possibly explain our finding. Another explanation could be that sprinkling with water caught the dust particles in the aerosol (Stasey, 1993). Sprinkling with sulfuric acid provides a hydrogen ion that reacts with the ammonia and a negatively charged sulfate ion that could possible trap the dust particles.

An air environment in the treatment barn was achieved that met the guidelines recommended by Donham et al. (1995). Guidelines for worker health state that total dust exposure should be no greater than 2.8 mg/m³ and ammonia should be no greater than 7.5 ppm.

**EFFECT ON LUNG FUNCTION IN A FARMER DURING WORK**

A definite decrement in peak flow was not measured after working in the control barn (fig. 5) because the test subject was expiring air at a level that was at least at the maximum 700 L/min capacity of the peak flow meter. A change between the two barns was seen, since peak flow was steady when the subject was working in the treatment barn (fig. 6) and fluctuated slightly below the 700 L/min maximum while the subject was working in the control barn (p < 0.001). An explanation could be that 8 to 12 ppm ammonia, as measured in the control barn, served as a local irritant to the airways there by constricting the airways. Differences in dust levels could also explain this change. Peak flow scores outside the barn (at 7:00 a.m., 12:00 a.m., and 9:00 p.m., not shown) were 700 L/min for the 42–day period, indicating that the environment did not have a long–term effect on lung function. The subject suffering from asthma never reported that he had to use a respirator while working in the treatment barn. He had to wear it the whole time when working in the control barn.

**EFFECT ON PIGS**

Twenty–one pigs were weighed in each barn and the average weight was calculated. The same pigs were weighed every second week over a period of 39 days, and the results are shown in table 3. The daily growth rate was higher in the treatment barn, with an average of 1074 g/day, compared to 959 g/day in the control barn. Daily growth increased 12% (p < 0.05, t test) in the treatment barn.

<table>
<thead>
<tr>
<th>Week</th>
<th>Treatment barn</th>
<th>Control barn</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>42.2 kg[a]</td>
<td>34.5 kg[a]</td>
</tr>
<tr>
<td>2</td>
<td>55.7 kg[a]</td>
<td>45.8 kg[a]</td>
</tr>
<tr>
<td>3</td>
<td>65.9 kg[a]</td>
<td>58.4 kg[a]</td>
</tr>
<tr>
<td>4</td>
<td>84.1 kg[a]</td>
<td>71.9 kg[a]</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean</th>
<th>1074 g/day</th>
<th>959 g/day</th>
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<tbody>
<tr>
<td>Standard error</td>
<td>169 g/day</td>
<td>75 g/day</td>
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</table>

[a] An average of the 21 pigs weighed in each barn.
Unfortunately, the 21 pigs were not comparable in their initial weight, and that might give the results an element of uncertainty. The average initial weight in the control barn was 34.5 kg, and the final average weight was 71.9 kg. In the treatment barn, the average initial weight was 42.2 kg, and the final average weight was 84.1 kg. The results should not be underestimated, since the difference in weight gain is statistically significant.

The weight gain might express an improvement in swine health in the treatment barn. This suggests that installing the manure treatment system could improve pig performance, giving the farmer a profit.

CONCLUSIONS

- The technical procedure described reduced ammonia concentrations and dust concentrations in a swine confinement building.
- The prevention of ammonia emission kept the nitrogen in the swine manure, improving the manure as fertilizer.
- The average weight gain in the treatment barn was increased by 12% compared to the control barn in a 39–day period.
- Expenses for the environmental improvement could be at least partially covered by improved pig performance and by improvement of swine manure as fertilizer.
- A substantial improvement in the working environment in swine confinement buildings seemed to be achieved by installing the technical procedure described.

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