Drainage Properties and Ammonia Emissions in Slatted Floor Systems for Animal Buildings

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Drainage properties of and ammonia emissions from slatted floors and drainage channels were investigated using a laboratory arrangement development for the purpose. The arrangement consists of a steel-framed box with two levels in order to simulate different slatted floor systems. The slatted floor under test is laid on the top level and manure is dropped on to it from various heights. The lower level consists of a drainage channel, the top of which is covered by a lid perforated with holes of different shapes.

Drainage experiments on slatted floors for cows with slits from 30 to 45 mm wide showed an average total drainage value for faeces and urine of 72% and an average urine drainage value of 82%. Drainage experiments on slatted floors for pigs showed results varying between 38 and 46% for total drainage depending on different drainage arrangements. The best drainage capacity was obtained when the drainage channel cover had holes giving a large drainage area.

The ammonia experiments on slatted floors for cows with 2 and 30 mm spacing showed an accummulated ammonia emission of about 8 and 3 g respectively, during the 20 h testing period. On slatted floors for fattening pigs, the accumulated ammonia emission was calculated to be about 2 g during the 20 h testing period. These ammonia emission results are related to the mass quantities and the nitrogen contents of faeces and urine, which normally are dropped to slatted floor surfaces in animal buildings.

1. Introduction

Slatted floors for animal buildings have been used for several years in Sweden. Many years ago, slatted floors were manufactured of wood but currently they are also made of plastic and aluminium. Most slatted floors with openings of different sizes are now made of concrete. The main application areas of slatted floors are in dairy cow housing and pig houses. Slatted concrete floors are mostly used in loose-housing systems on dairy farms.

The purpose of using slatted floors inside animal buildings is to get the best possible environment by obtaining good drainage of manure through the floor, such that the floor is cleaner and more hygienic. In practical use, slatted floor systems show different degrees of manure drainage and as a rule, the drainage properties are poorer in animal buildings for pigs than for cows.

In order to achieve the best possible drainage properties, the concrete beams should be designed with a V profile (Fig. 1). The underside of the beam should be smaller than the upper side to decrease the risk of manure lodging in the openings between the concrete beams. The protruding edge of the left side in Fig. 1 decreases that risk even more.

One alternative to concrete floors with rectangular openings is a concrete floor with round or semi-circular openings (Fig. 2). However, in such floors the holes easily become clogged with residues of hay, straw and silage. The semi-circular holes give much better drainage than round ones.

Nitrogen emissions consist of nitrogen oxides and ammonia and contribute substantially to environmental pollution and cause severe acidification. Most of the emissions of nitrogen oxides are caused by the combustion process in motor vehicles and in energy production but the main source of ammonia emissions is animal manure. Ammonia emission from animal manure is divided between animal buildings, manure storages and manure spreading and, in Sweden, about 20–25% of the total ammonia emission derives from manure in animal buildings.

Ammonia emissions in animal buildings originate when urine in contact with faeces is present on the floors.
The urea from the urine is converted into ammonia by
the urease enzyme, which is produced by bacteria in the
faeces. Urine is generally the main source of ammonia
emissions from animal buildings, because hydrolysis of
urea proceeds at a fast rate compared with mineralization
of nitrogen from faeces. Different measures can be
applied to decrease emissions in animal buildings.

During the 1980s, the drainage properties of slatted
floor systems were studied at the Technical University of
Munich-Weihenstephan, where it was found that there
was a strong relationship between the drainage area and
the manure drainage ability of the floor. After a series of
drainage experiments it was concluded that the optimal
slatted floors for cows should have beam widths between
100 and 130 mm with a 30 mm slat opening. This floor is
shown in Fig. 2a.

At the beginning of the 1990s, field experiments were
made in the Netherlands to study the ammonia emission
from concrete and steel slatted floors in pig houses. Once
a day, urine and faeces were spread on the tested
slatted floors and the ammonia concentrations were
measured. The results showed that a maximum value of the
ammonia emission was reached after about 1–2 h testing
time. The ammonia emission then decreased and reached
equilibrium after about 22 h. The accumulated ammonia
emission varied between 18 and 22 g NH₃ over the test
period.

In an experiment in Denmark, the ammonia emission
from slatted floor surfaces of a pig house was investigated
during several growing periods of fattening pigs. In
measurements made on fattening pigs growing from 30 to
95 kg, the accumulated ammonia emission varied
between 5 and 15 g/d of NH₃ for each fattening pig.

In the middle of the 1990s, a research project was
carried out at the Department of Agricultural Biosystems
and Technology, Swedish University of Agricultural
Sciences, Alnarp to simulate and study normally draining
floor systems for cows and pigs in a laboratory arrange-
ment. The object of the study, reported here, was to
investigate the drainage properties of and ammonia emis-
sions from slatted floors and drainage channels in animal
buildings for cows and pigs.

2. Materials and methods

2.1. Test arrangement

The main investigation method was to measure the
drainage properties and ammonia emissions of slatted
floor systems in the laboratory using an experimental
arrangement designed to simulate different slatted floor
systems.

The arrangement consists of a steel-framed box with
two levels (Fig. 3). Each level has an experimental test
area of 1·2 m × 1·2 m. The slatted floor under test is laid
on the top level. A bucket containing test manure upside
down and closed with a cover is placed in a ring fastened
to a steel frame, which can be adjusted to different heights
(Fig. 3). When the cover is opened, the manure is dropped
on to the slatted floor. At the lower level, there is a urine
drainage channel 1·2 m long × 0·2 m wide × 0·2 m deep.
The channel slopes gently (0·5%) towards an outlet at
one end. The top of the drainage channel is covered with
a lid with holes of different shapes. The channel can be
placed in different positions in the test arrangement. The
most common test positions were in the middle and at the side. The drainage channel is enclosed by sloping sides made of plywood.

2.2. Testing drainage properties

When testing the drainage properties with the laboratory arrangement, a real situation is simulated, using standard masses of faeces and urine from cattle and pigs. Each test was started by dropping a sample of faeces, followed by a sample of urine. The solid manure and urine samples were dropped onto the floor system from 1.2 m and 0.6 m, representing cattle and pigs, respectively.

To provide a measure of drainage properties, the percentage of the total drainage and the urine drainage was used. The total drainage percentage is that amount of faeces and urine, which drain through the floor gaps and through the holes of the urine channel lid within a certain time period, compared with the total amount of the solid manure mixture and the total liquid quantity dropped onto the floor. The urine drainage percentage is that amount of urine, which collects in the urine channel within a certain time period, compared with the total urine quantity dropped onto the floor. Each drainage experiment was replicated four times. The laboratory arrangement was cleaned between each drainage test.

2.3. Testing ammonia emission

When testing the ammonia emission, the test arrangement was completely enclosed with plywood sheets, as shown in Fig. 4. Between 10 and 15 min after the solid manure and the urine samples were dropped against the slatted floor under test, the inner air volume was divided by a horizontal sheet in the middle of the test arrangement. The purpose of the horizontal sheet was to secure measurement results from only one level. The surface of the slatted floor placed on the top level was covered by a hood containing a fan, which mixes the air inside. On the sides of the hood there were four inlet holes (45 mm dia.) and one outlet hole (75 mm dia.). The inside air was sucked through the outlet hole to the ammonia measuring device.

The ammonia concentrations were measured by a MIRAN 203 instrument. This device continuously measures the ammonia component of the air by exposing it to infrared light and analysing the result. The airflow rate was indirectly measured for each experiment using an orifice plate, mounted in the exhaust duct and a pressure gauge. The measurements of the ammonia concentrations started between 15 and 20 min after the manure samples had been dropped and the test arrangement had been enclosed. All the parameters were continuously recorded by a personal computer via data loggers.

To calculate the ammonia emission from the floor surfaces the following formula was used:

\[ E = (C_{ia} - C_a) \varphi (F/A) \]

where \( E \) is the ammonia emission in kg/m\(^2\)h, \( C_{ia} \) is the ammonia concentration in the inner air volume of the test arrangement in p.p.m., \( C_a \) is the ammonia concentration in the incoming air in p.p.m., \( \varphi \) is the density of ammonia in the exhaust air in kg/m\(^3\), \( F \) is the airflow rate.
Each ammonia experiment was replicated two or three times and each was run for about 20 h. Between each ammonia test, the laboratory arrangement was cleaned. The ammonia emissions shown in this paper originated only from the release of ammonia from the manure and urine mixture remaining on the slatted floor surfaces. The emissions were related to the size of only the floor element because of the horizontal sheet in the middle of the laboratory arrangement.

2.4. Slatted floor tested

The slatted floor for cows was made of concrete with a V profile as shown in Fig. 5. The width of the slat openings $d$ varied between 2 and 45 mm, which is equivalent to opening areas between 1.4 and 24.3%. The slatted floor for pigs was made of plastic material and was built of modules as shown in Fig. 6. The modules are 0.6 m long $\times$ 0.4 m wide $\times$ 0.05 m thick and have a drainage area of 40%.

For the drainage experiments with the slatted floor for cows, the floor was placed on the top level of the testing arrangement. At the bottom level, the urine drainage channel was fixed in the middle position covered by a lid with an opening area of 0.9%. The sides sloping into the drainage channel had a relatively large slope (on average 5%). For the drainage experiments with the slatted floor for pigs, the floor was placed on the top level of the testing arrangement. At the bottom level, four alternative arrangements for drainage were tested in order to find the best capacity for urine drainage.

In the ammonia experiments, slatted floors for cows and pigs were of the same type as in the drainage experiments. The sides sloping down into the urine drainage channel had a relatively large slope (on average 5%). The ammonia experiments with slatted floors for cows at the top level were limited to slat openings of 2 mm and 30 mm, respectively. At the bottom level, the urine drainage channel was fixed in the middle position covered by a lid with an opening area of 0.9%. The ammonia experiment with a slatted floor for fattening pigs on the top level was performed with the urine drainage channel fixed in the middle position covered by a lid with an opening area of 0.9%.

2.5. Manure and urine samples

The standard mass of cattle manure was estimated to be 8 kg, containing 5 kg of solid manure and 3 kg of urine. The standard manure mass for fattening pigs was estimated to be 2 kg, containing 1 kg of solid manure and 1 kg of urine. Samples of the standard manure masses were analysed for dry matter content and total nitrogen content using the Kjeldahl laboratory equipment.

3. Results

3.1. Drainage experiments with slatted floor for cows

Table 1 shows results of drainage experiments using slatted floors for cows. The average total drainage percentage $\bar{x}$ varied between 32.2 and 74.9. Slatted floors with openings from 35 to 45 mm showed a rather constant average total drainage value of about 73.5%. Tests with a slat opening of 30 mm showed a total drainage of approximately 67%. With narrower openings, the total
Table 1
Results of drainage experiments using slatted floors for cows with various sizes of drainage slit openings

<table>
<thead>
<tr>
<th>Width of openings, mm</th>
<th>Total drainage, %</th>
<th>Urine drainage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\bar{x})</td>
<td>(s)</td>
</tr>
<tr>
<td>45</td>
<td>74.9</td>
<td>2.5</td>
</tr>
<tr>
<td>40</td>
<td>73.2</td>
<td>1.3</td>
</tr>
<tr>
<td>35</td>
<td>72.4</td>
<td>1.4</td>
</tr>
<tr>
<td>30</td>
<td>66.6</td>
<td>2.4</td>
</tr>
<tr>
<td>12</td>
<td>38.4</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>32.2</td>
<td>2.1</td>
</tr>
</tbody>
</table>

\(\bar{x}\), mean value; \(s\), standard deviation.

drainage decreased dramatically. The standard deviation values \(s\) of the total drainage varied between 1.3 and 4.5%.

The average urine drainage value varied between 75.1 and 87.6% with an average value of 82%. The standard deviation of the urine drainage varied between 0.8 and 9.1%.

3.2. Drainage experiments with slatted floor for pigs

Table 2 shows results of drainage experiments using a slatted floor for fattening pigs. The average total drainage percentage \(\bar{x}\) varied between 37.6 and 46.4%. These total drainage values are lower than those for the tests with slatted floors for cows. The standard deviation values \(s\) of the total drainage varied between 1.8 and 7.6%.

The average urine drainage value varied between 58.0 and 75.2%. The best drainage capacity seems to be when

Table 2
Results of drainage experiments using slatted floors for fattening pigs with varying urine drainage alternatives at the bottom level

<table>
<thead>
<tr>
<th>Test arrangement</th>
<th>Total drainage, %</th>
<th>Urine drainage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\bar{x})</td>
<td>(s)</td>
</tr>
<tr>
<td>1</td>
<td>37.6</td>
<td>7.6</td>
</tr>
<tr>
<td>2</td>
<td>43.4</td>
<td>5.2</td>
</tr>
<tr>
<td>3</td>
<td>37.8</td>
<td>4.8</td>
</tr>
<tr>
<td>4</td>
<td>46.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

\(\bar{x}\), Mean value, \(s\), Standard deviation; 1 Middle position of drainage channel and 0.9% opening area of the cover; 2 Middle position of drainage channel and 1.8% opening area of the cover; 3 Side position of drainage channel and 0.9% opening area of the cover; 4 Side position of drainage channel and 1.8% opening area of the cover.

3.3. Ammonia experiments using slatted floors for cows

Figures 7 and 8 show results from ammonia experiments with slatted floors for cows. The maximum ammonia emissions were calculated to be 900 and 200 mg/m² h, on average, for the 2 and 30 mm slat openings, respectively. These maximum values were reached within about half an hour from the start of the ammonia measurements. The ammonia experiments showed an accumulated ammonia emission of about 8 and 3 g, respectively, during the 20 h testing period.

The dry matter content of the cattle manure used in the experiments was 14.3 and 14.2%, respectively. Analyses of the experimental manure showed a total nitrogen content of 0.41 and 0.47% and a pH value of about 8.2 and 8.0, respectively. During the experiments the air temperature and the air flow inside the experimental device were measured, on average 11.0 and 11.5°C and 30.1 and 32.1 m³/m² h, respectively.
3.4. Ammonia experiment using slatted floors for pigs

Figures 9 and 10 show results from an ammonia experiment using slatted floors for fattening pigs. The maximum ammonia emission was estimated to be about 130 mg/m\(^2\) h, on average, and was reached within about 2 h from the start of the measurements. The accumulated ammonia emission was calculated to be about 2 g during the 20 h testing period.

The dry matter content of the experimental pig manure was measured and found to be about 20%. Analysis of the experimental manure showed a total nitrogen content of 0.39%, on average. The pH value of the experimental manure was about 7.1. During the experiment, the measured air temperature and the airflow inside the experimental device were, on average, 18.4°C and 30.5 m\(^3\)/m\(^2\) h, respectively.

4. Discussion

The drainage and ammonia experiments were carried out in the laboratory arrangement in a standardized way in order to diminish the great variations of different parameters. Each drainage experiment was repeated four times and each ammonia experiment was repeated two or three times.

This standardized testing performance resulted in standard deviation values in the drainage experiments, that were rather moderate. One factor, which influences the drainage experiments, is the quality and the mixture of the manure samples. Analysis of the experimental pig and cattle manure showed higher dry matter content for the pig manure than for the cattle manure. This indicates a greater straw content in the solid part of the pig manure samples than in the solid part of the cattle manure samples, which could have influenced the drainage results.

Results from different ammonia experiments show the same development with time of the ammonia emission. After the manure samples were dropped, the ammonia emission reached a peak value between 30 min and 2 h after the start of the experiment. The ammonia emission then decreased slowly to relatively low values, which were reached after about 20 h.

The results from the ammonia experiments show differences in calculated ammonia emission between the cow and the pig experiments, 900–200 and 130 mg/m\(^2\) h, respectively. One reason for the differences is the variation in the standard mass and the nitrogen content of the faeces and urine samples, which were dropped onto the experimental surfaces. The total faeces and urine sample for the cow experiments was 8 kg, while for the pig experiments about 3 kg was used. These mass quantities have been chosen to simulate a real situation. The total nitrogen content of the experimental manures varied between 0.39 and 0.47%,
which is a rather normal variation in total nitrogen content.

Another reason for the differences is the climatic factors, which influence the ammonia emission under the experiments. It is well known that the higher the air temperature, the greater the ammonia emission. The air temperature was about 11 °C for the cow experiments and about 18 °C for the pig experiments. This difference could have influenced the ammonia emission during the experiments. Another climatic factor, which influences the ammonia emission, is the air flow. During the experiments, the airflow has varied between 30.1 and 32.1 m³/m² h. This difference is too small to have had a main effect on the ammonia emission during the experiments.

5. Conclusions

Drainage experiments on slatted floors for cows with slits from 30 to 45 mm wide showed an average total drainage value for faeces and urine of 72% and an average urine drainage value of 82%. Drainage experiments on slatted floors for pigs showed results varying between 38 and 46% for total drainage depending on different drainage arrangements. The best drainage capacity was obtained when the drainage channel cover had holes giving a large drainage area.

Analyses of drainage data show correlations between total drainage percentage and size of the openings in the tested slatted floors. The test data also show that drainage ability of the urine drainage channel depends on the size of the openings in the cover of the drainage channel.

The ammonia experiments on slatted floors for cows with 2 and 30 mm spacing showed an accumulated ammonia emission of about 8 and 3 g, respectively, during the 20 h testing period. On slatted floors for fattening pigs, the accumulated ammonia emission was calculated to be about 2 g during the 20 h testing period. These ammonia emission results are related to the mass quantities and the nitrogen contents of faeces and urine, which normally are dropped to slatted floor surfaces in animal buildings.

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