International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July
Ref: C0175

# Influence of the frequency of emptying wash waters on the efficiency of a bioscrubber in reducing ammonia, odours and dust emitted by fattening pig units

*Nadine Guingand, IFIP Institut du Porc, La Motte au Vicomte, FR-35651 le Rheu Cedex*

## Abstract

This study was conducted on two successive batches of 120 pigs each between 25-110kg live weight, divided into two rooms equipped with identical bioscrubbers. In both rooms, sixty pigs were group-housed in 6 pens on fully slatted floor. Slurry was stored in pit underneath during the whole fattening period. Fresh air entered via a ceiling of perforated plastic sheeting. The set-point temperature was fixed at 24°C during the whole period. For both rooms, air exhaust air was entirely treated by bioscrubber. During the first batch, a partial emptying of wash water (≈50%) was carried out twice for the first bioscrubber while the emptying was complete for the second one. For the second batch, a complete emptying was carried out four times for the first bioscrubber while no emptying was applied for the second one. During both batches, ammonia, odours and dust were measured in the air before and after each bioscrubber. The gas concentrations were continuously measured by photoacoustic infrared absorption spectrometry using a gas analyser (Innova 1412) coupled to a sampler dosimeter (Innova 1303) sampling air before/after the bioscrubber and outside. Air samples for olfactometric analyses were conducted in the extraction duct for each room and odour concentrations were determined in accordance with the European standard (CEN 13725). After each emptying, wash water samplings were achieved for analyses (dry matter, pH, total and ammonium nitrogen). Ammonia, odour and dust emissions measured in exhaust air before being treated by the bioscrubber were in accordance with previously published data. Efficiency of bioscrubbers on ammonia, dust and odours emissions varied depending on the emptying modalities applied. A partial emptying compared to a complete emptying led to a higher efficiency of the bioscrubber on odours and ammonia. No difference was observed on ammonia and dust emissions between the four-time emptying and no emptying modalities. Conversely, the efficiency on odours was sharply deteriorated. Data collected during this study led us to determine the part played by the biological action in bioscrubbing the ammonia, enabling us to confirm the biological action of scrubbing on odours.

**Keywords: pigs, bioscrubber, ammonia, odours, dust**

## 1 Introduction

Bioscrubbing techniques meet a great success with breeders who care about the environment of theirs farms and who want to comply with new regulatory constraints, especially those concerned by the Directive on industrial emissions 2010/75/EU (IED). Because of its double efficiency on ammonia and odors, this end-of-pipe technique begins to have a large development in French pig production. Nevertheless, some restrictions limit the expansion of this technique to a larger number of farms. Among these restrictions, the need to centralize extracted air on existing buildings is a main technical limit. But some technical questions still remain, especially on the management of washing water. The basic principle of the scrubbing is laid down in the chemical action of water on soluble compounds such as ammonia but also in the development of a bacterial flora implanted in the packed bed, able to destroy non soluble compounds. Increasing the removal of water could be an important lever to increase scrubber efficiency. The main aim of this experiment is to study the frequency of emptying wash water on the efficiency of a bioscrubber in reducing ammonia, odors and dust emitted by fattening pig units.

# 2 Materials and methods

## 2.1 Rooms and scrubber

This study was achieved on two successive batches of 120 crossbred (PPxLW)x(LWxLD) pigs between 25-110 kg live weight (first batch called B1 from July to October 2011 and second batch called B2, from February to June 2012). Each batch was divided into two rooms of 60 pigs organized in 6 pens of 10 pigs on fully slatted floor. Slurry was stored underneath the pit for the duration of the whole fattening period. Fresh air entered via a ceiling of perforated plastic sheeting and the air exhaust was an under-floor extraction chimney ended by a bioscrubber. Crude gas was directly ducted to a horizontal scrubbing unit specially designed for the experiment and sized to ensure the treatment of a maximum rate of 3600 cubic meter per hour. Crude gas was firstly moistened by a set of nozzles installed in front of the filter wall. The wall was also permanently kept moist from above using water stored in the water basin. The filter wall consisted of a plastic packing with a specific surface of 125 $m^2/m^3$ and a layer thickness of 0.45m. A submerged pump permanently sprinkled water from the water basin on the filter wall. Because of evaporation during the scrubbing process, the submerged pump was equipped with a constant level permitting the water supply. The water consumption was recorded by a water meter.
Modalities and frequencies of emptying were:

- For the first batch (B1): the first scrubber (S1) was half emptied twice during the fattening period (D64 and D78) while the second scrubber (S2) was fully emptied twice at the same times.
- For the second batch (B2), S1 was fully emptied four times (D29, 50, 72 and 92) while no emptying was applied to S2.

*Table 1: Experimental design*

| Batch | Scrubber | Number of emptying | Days of emptying |
|---|---|---|---|
| **B1 – from July to October** | S1 | 2 | D64 and D78 |
| | S2 | 2 | |
| **B2 – from February to June** | S1 | 4 | D29, 50, 72 and 92 |
| | S2 | 0 | - |

## 2.2 Measurements and recording

### 2.2.1 Ambient parameters

Thermo-hygro sensors (Konrad) placed inside and outside the two fattening rooms and on the clean air allowed to continuously monitor temperature and hygrometry during the whole fattening period. The ventilation rate was continuously recorded (every 15 mn) by measuring the rotation speed of a full-size free-running impeller unit coupled with the exhaust fan of each room.

### 2.2.2 Ammonia, odors and dust

Ammonia concentration in the crude gas (exhaust air of both rooms), in the clean gas (after each scrubber) and outside were measured by infrared photoacoustic spectroscopy analyser (PAS; e.g. INNOVA® 1412) coupled with a sampler dosimeter (INNOVA® 1303). Emission factors were validated by the mass balance method. Air samples for odour measurements were achieved on the crude and the clean gas. Samples were analysed by the CERTECH Laboratory (Seneffe – Belgium) by olfactometric method for the determination of the odour threshold. Equipment and procedures are conformed to current recommendations (NF EN 13725). Dust measurement was achieved on the crude and the clean gases during five periods defined during the fattening period. Dust concentration was measurement using the gravimetric method. Collections were achieved on the crude and the clean gases.

### 2.2.3 Washing water

For each emptying (intermediary and final emptying at the end of the fattening period) and for both batch, water sampling were achieved in the water basin for chemical analysis (pH, Dry Matter, total and ammonium nitrogen).

## 2.3 Mass balance

Mass balances are calculated on the nitrogen quantities associated to each scrubber. Inputs were the sum of nitrogen contents at the entry of the scrubber, corresponding to the nitrogen content in the crude gas. Outputs were the sum of nitrogen contents in the clean gas and the nitrogen contents in water stored in the basin. The nitrogen content of the wash waters was calculated on the water volume monitored (volume) and the results of chemical analysis per period (concentration).

# 3 Results

Animal performance is not presented in this article. Nevertheless, no significant difference was observed between rooms for the two batches. Pig performance was totally in accordance with these already obtained in similar conditions.

## 3.1 Temperature and ventilation rate

Average temperature of the crude and the clean gas for both batch are given in Table 2. Temperature of the crude gas was representative of the ambient temperature of fattening rooms. Average temperatures of the crude gas were lower for the second batch (B2) than for the first one (B1) illustrating the season effect. The reduction of temperature between the crude and the clean gas (between 3.3 and 4.6°C) is due to the evaporative cooling achieved by the scrubbing process.

*Table 2: Temperatures of the crude and the clean gas (°C)*

| **Batch/Place** | | **S1** | **S2** | **Outside** |
|---|---|---|---|---|
| B1 | Crude gas | 26.5±0.8 | 26.0±0.8 | 15.9±5.1 |
| | Clean gas | 22.4±1.4 | 21.4±1.5 | |
| B2 | Crude gas | 25.8±1.4 | 24.8±1.4 | 11.8±5.5 |
| | Clean gas | 20.1±1.8 | 21.5±1.0 | |

For B1, the ventilation rate per pig was 37.8 ±6.6 $m^{-3}.h^{-1}$ for the room equipped with S1 and 43.5±6.5 $m^{-3}.h^{-1}$ for the second room equipped with S2. For B2, the ventilation rate was respectively 30.6±9.1 $m^{-3}.h^{-1}$ for the room equipped with S1 and 33.1±9.9 $m^{-3}.h^{-1}$ for the room equipped with S2. In accordance with the reduction of temperature mentioned in table 2, ventilation rates during the second batch (from February to June) were lower than those measured during the first one (from July to October).

## 3.2 Water consumption

Average water consumptions per animal are given in the following table (Table 3) – volumes dedicated to emptying are integrated in the average values. Water volume for both scrubbers was higher for the first batch in comparison to the second one. The main reason was the increase of the outside temperature fostering the water evaporation from the basin and then the fresh water supply.

*Table 3: Average water consumptions (liters per pig) per scrubber and per batch*

| Batch | Scrubber 1 | Scrubber 2 |
|---|---|---|
| B1 | 351 (7.6) | 421 (19.1) |
| B2 | 315 (34) | 303 (-) |

*() volume dedicated to emptying – in litre per pig*

## 3.3 Ammonia

Before treatment, on the crude gas, average ammonia emissions varied between 0.32±0.15 g/h per pig and 0.41±0.17 g/h per pig (Table 4). For both batch, those values were similar and in accordance with average ammonia emissions listed in the literature for fattening pigs (Guingand et *al.*, 2010 ; Philippe et *al.*, 2007).

*Table 4: Ammonia emissions before and after treatment per batch (g/h per pig)*

| **B1** | **S1<br>2 partial emptying** | **S2<br>2 total emptying** |
|---|---|---|
| Before | 0.32±0.15 | 0.39±0.13 |
| After | 0.16±0.06 | 0.31±0.14 |
| Efficiency(%) | -50 | -21 |
| **B2** | **S1<br>4 total emptying** | **S2<br>No emptying** |
| Before | 0.41±0.17 | 0.39±0.12 |
| After | 0.16±0.06 | 0.12±0.03 |
| Efficiency(%) | -64 | -69 |

On the clean gas, after the treatment by the scrubbing process, efficiency on ammonia varied in relation with the kind of emptying (Table 4). In our experiment, whatever kind of emptying applied, ammonia emission was always reduced on the clean gas. The lower efficiency (21%) was measured during the first batch with two total emptying. At the opposite, the higher efficiency (69%) was measured with no emptying during the second batch.
In our trial, the achievement of two partial emptying led to a higher efficiency of the treatment on ammonia in comparison to two total emptying (50% vs 21%). Nevertheless, applying four total emptying permitted to improve up the efficiency to 64% and to be close to the maximum value obtained with no emptying (64% vs 69%).

## 3.4 Mass balance

Nitrogen input, namely the nitrogen content in the crude gas, should be equivalent to nitrogen outputs, that is to say the sum of the nitrogen content in the clean gas and the nitrogen content of water stored in the basin. In the following table, the difference of nitrogen content measured both in the crude and the clean gas (Air) was compared to the nitrogen content of water (Water). For B1, the difference between nitrogen trapped in the wash water and the difference of nitrogen between the crude and the clean gas was lower than 30%. For B2, the difference was higher for the first scrubbing unit probably due to the increase of water removal. Indeed, the rise of emptying frequency increased directly the number of samples and then the impact of sampling on results. This fact was also confirmed with S2 during the second batch with a 2% difference between Air and Water.

*Table 5: comparison of nitrogen quantities (kg) in the wash water and in the air per scrubber and per batch*

| **B1** | **S1**<br>**2 partial emptying** | **S2**<br>**2 total emptying** |
|---|---|---|
| Water | 28.1 | 18.5 |
| Air | 20.3 | 13.7 |
| Difference Air/Water (%) | -28 | -26 |
| **B2** | **S1**<br>**4 total emptying** | **S2**<br>**No emptying** |
| Water | 25.3 | 32.9 |
| Air | 33.4 | 32.2 |
| Difference Air/Water (%) | +32 | -2 |

## 3.5 Odours

For B1, odours emitted by the fattening rooms were respectively 9.7 $10^5$±7.0 $10^5$ odour units per pig per day for S1 and 9.2 $10^5$±7.9 $10^5$ odour units per pig per day for S2. For B2, odour emissions were higher with 14.0 $10^5$±8.2 $10^5$ odour units per pig per day for S1 and 22.0 $10^5$±1.3 $10^5$ odour units per pig per day for S2. Those value were relatively lower to the values given in the literature. Odours were not affected by the type (partial or total) and the frequency of water removal. But, only the absence of removal led to a significant reduction of odours with an efficiency rate varying between 20 and 37% (Figure 1).

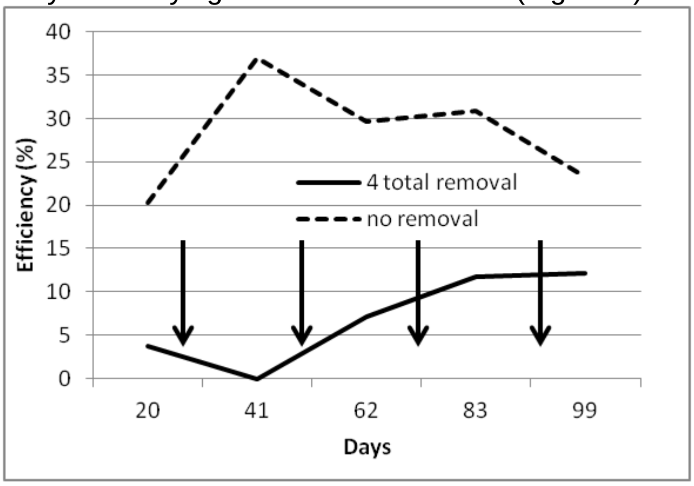


*Figure 1: Odour efficiency (%) in relation with the frequency of removal (B2 only) – the arrows indicate the emptying*

## 3.6 Dust

For B1, the scrubbing process led to a reduction of 30% with 2 partial emptyings (1.21±0.3 vs 0.86±0.1 mg.m$^{-3}$) while the reduction was 60% with 2 total emptying (2.31±1.17 vs 0.91±0.36 mg.m$^{-3}$). For B2, the efficiency of the scrubbing process was 52% with 4 full emptyings (1.65±0.1 vs 0.79±0.6 mg.m$^{-3}$) and 61% with no emptying (3.6±1.1 vs 1.4±1.2 mg.m$^{-3}$). Dust concentrations measured in the crude gas were in accordance with literature in similar conditions (Guingand and Courboulay, 2007). The efficiency of the treatment appeared to be more affected by the type than by the frequency of water removal. The scrubbing process was less efficient with a partial removal (-30%) than with a full removal (-60% for B1). The increase of the number of removal had no real effect in comparison with no removal (-52% vs -61%).

## 3.7 Wash water

The pH of wash water varied between 7.1 and 7.7 with no link with the type and frequency of removal for both batch. Dry matter (figure 2a) did not vary with the kind of emptying while it increased with the pig weight, illustrating the accumulation of dust in the bioscrubber. These particles came from the increase of the pig weight but also from the increasing part of food-borne particles.

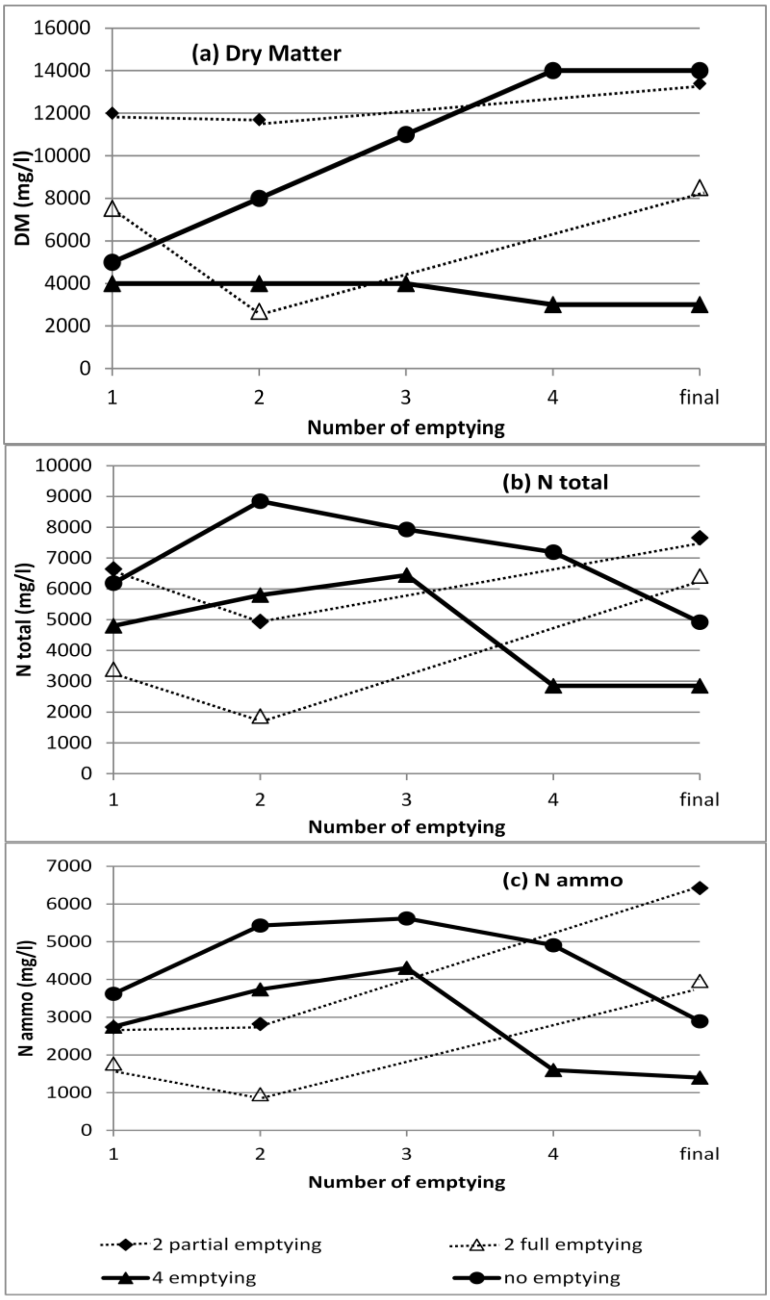


*Figure 2: Composition of wash water (a – Dry Matter  b- Total N c – Ammo N)*

Evolution of nitrogen (total and ammonium nitrogen – figure 2b and c) were totally equivalent with a drastic decline of the nitrogen content in the wash water stored during the whole fattening period at the end of the fattening.
With 2 or 4 full emptying, the decline of the nitrogen content is notable and was only observed on the finishing period (for B1, the two removals were applied at D64 and D78).

## 4 Discussion

The bioscrubbing process is based on the combination of three action modes: chemical, physical and biological. Thus, certain chemical compounds, like ammonia, due to their solubilisation capacity in water, are directly targeted by this technique. By it (physical) action on the particle sedimentation, the bioscrubbing process enable also to act on ammonia fixed on particles. The last action mode is the biological one: because of the development of a bacte-

rial population on the filter wall resulting from the accumulation of particles (mainly organic – Heber et al., 1988), the bioscrubbing process has a biological action on ammonia.
With a partial emptying and despite the mixing of water before removal, the quantity of particles removed was less than half the quantity of particles before emptying. The reduction of the dry matter varied between 16 and 32% corresponding to a lower value than expected (around 50% of DM reduction). Particles were the principal sources of bacterial plating. The partial removal of wash water has surely led to a lower modification of the bacterial flora implemented in the filter in comparison with full emptying. The biological action of the bioscrubber was essentially maintained and the efficiency rate on ammonia was 50% (table 3 – B1 S1). At the opposite, the implementation of two full emptying on the same period (B1) led to a real washing of the filter resulting in a massive destruction of the bacterial population. The bacterial plating was drastically altered. For the final removal, particles were massively eliminated (reduction of 60% of DM in the sample achieved one week after the first removal). So, the biological action of the scrubbing on ammonia was strongly altered and the efficiency of the scrubbing dropped by 20% (table 3 – B1 S2). Two full removals did not appear to be sufficient to increase the chemical action of the scrubber on ammonia but sufficient to alter its biological action.
While difference on ammonia efficiency was measured between the types of removals (B1), no effect on odours was observed. Since the removal of half of wash water with around the third of the particles quantity, the biological action of the scrubber on odours was strongly altered. In fact, during B1, no effect of the scrubbing on odours was observed. In the same way, the comparison of the efficiency between 4 and no removal showed the importance of the bacterial plating of the filter and the stability of the bacterial flora in the filter. With 4 full emptying, the scrubbing had no efficiency on odours while the absence of removal led to a reduction of 30%.
The biological action on ammonia and odours appears to be more important than the chemical action of the bioscrubbing based on the solubilisation of ammonia in the water and the physical action on particles sedimentation.
For ammonia, the comparison between 4 and no removal (B2) resulted in same efficiencies : 65 and 70%. A higher frequency of wash water removal led to a better solubilisation of ammonia resulting in a better chemical action of the bioscrubbing process. Nevertheless, the washing of the filter occurred by a higher frequency of water removal led to a degradation of the bacterial population resulting to no effect on odours abatement and a massive reduction of the biological action of the bioscrubber on ammonia destruction. Equivalent efficiencies were obtained with both modalities of removal (4 or no removal) but the action modes were different:

- With more frequent removal, the chemical action is the main one leading to an important reduction of ammonia on the clean air but with no effect on odours
- With no removal, the biological action is the main one leading to, both, an important reduction of ammonia and odours.

The solubility of ammonia in water can varied between 198 and 895 grams per litre in relation temperature (INERIS, 1999). In our study, the temperature of the air extracted from the bioscrubber varied between 20 and 26°C (table 3). For those temperatures, the solubility of ammonia in water is around 530 grams per litre. The quantity of ammonia, which could be solubilised in the water stored in the basin (around 500 litres)was around 265 kg. Ammonia emitted per batch was around 60 kg. That means that water in the bioscrubber could be kept during 4 batches before removal or during around 18 months. Nevertheless, this would mean that since the first batch, the totality of ammonia emitted by pigs would be absorbed by the clean water of the treatment unit. In our study, the best efficiency rate was never over 70%. Therefore, there were some parameters in the bioscrubber design or in the water composition that should limit the ammonia solubility. The design of the scrubber was analysed and no major issues were identified. Previous works (Guingand, 2009) suggested the main importance of air speed to optimise the contact between air and water with a limit value fixed at 1,5 $m.s^{-1}$. In our study, the maximum speed measured at the entry of the bioscrubber was 0,9 $m.s^{-1}$. It appears more likely to study the composition of water and its impact on bioscrubbing efficiency. Firstly, pH of wash water was relatively stable over the whole experiment for both scrubbers and batches and did not appear to have any influence on efficiency in our study.

Data analysis on S2B2 (no removal) has permitted to identify a positive correlation (r=0.9) between dry matter content and the efficiency on ammonia. The accumulation of dry matter in the wash water was the result of the sedimentation of the particles emitted by pigs and food. For the bioscrubber with no removal, the mass balance default on particles was very small. Pigs emitted 16.7 kg of particles and only 6.5 kg of particle have been measured in the extracted air after treatment. The quantity of particles in the wash water should be 10.2 kg. Chemical analysis of water stored in the basin gave a value of 9.8 kg of dry matter which resulted in a mass balance default of 0.4 kg (around 4% of the input).
The relation between the efficiency on ammonia and the dry matter content of wash water was the illustration of the importance of the biological action of the scrubber at the expense of the chemical action of solubilisation.

## 5 Conclusions

The primary importance of the biological action of the bioscrubbing on ammonia was the main result of our study. If, most of the times, the solubilisation of ammonia in the water is considered as the main action mode of the scrubber, this study has shown the importance of the dry matter accumulation in the wash water and the necessity to keep the bacterial population in the filter, core activity of the scrubber. Keeping wash water during at least a fattening period also allows the biological action of the scrubber on odours. To date, this technique which should be assessed as a Best Available Technique in the context of the Industrial Emission Directive (2010/75/EU), has largely based its development on its ability to reduce odours in pig production.

## 6 Acknowledgements

The author wish to thank ADEME, the French Environment and Energy Management Agency (contract n°0974C0086 – www.ademe.fr) and the French Ministry of Agriculture (CASDAR funds - www.casdar.fr) for their contributions to the funding of this work.

## 7 References

Guingand N, Courboulay V. (2007). Reduction of the number of slots for concrete slatted floor in fattening buildings : consequences for pigs and environment. In the Proceedings of the International Conference on Ammonia in Agriculture , Wageningen. The Netherlands. 19-21 March, 147

Guingand N. (2009). Wet scrubber : one way to reduce ammonia and odors emitted by pig units. In the Proceedings of the 60$^{th}$ EAAP Meeting, Barcelona. Spain. 24-27 August.

Guingand N., Quiniou N., Courboulay V.(2010). Comparison of ammonia and greenhouse gas emissions from fattening pigs kept either on partially slatted floor in cold conditions or on fully slatted floor in thermoneutral conditions. In the Proceedings of the International conference ASABE, Dallas, Texas, USA. 13-15 September.

Heber A.J., Stroik M., Faubion J.M., Willard L.H. (1988). Size distribution and identification of aerial dust particles in swine finishing buildings. *Transactions of ASAE*; 882-887

INERIS (1999). Ammoniac : essais de dispersion atmosphérique à grande échelle. Rapport final. 113 pages

Phillipe F.X., Laitat M., Canart B., Vandenheede M., Nicks B. (2007). Comparison of ammonia and greenhouse gas emissions during the fattening of pigs kept either on fully slatted floor or on deep litter. *Livestock Science*, 111,144-152