

Assessment of NH₃ Reduction and N₂O Production during Treatment of Exhausted Air from Fattening Pigs Building by a Commercial Scrubber

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Abstract

The use of air scrubbers to reduce ammonia (NH₃) emissions from buildings on pig farms is one of the most promising techniques in the Göteborg protocol and other European regulations including the Industrial Emission Directive. In France, some air scrubbers are currently used on pig farms, mainly to reduce odours from livestock buildings. However, recent research revealed the production of N₂O resulting from the treatment of air from pig buildings. In this context, a two-month study was conducted on a pig farm with 750 places for fattening pigs to check the abatement of NH₃ emissions and to assess the possible production of N₂O during treatment of exhausted air from buildings housing fattening pigs by a air scrubber. Concentrations of NH₃ and N₂O in the inlet and outlet air of the scrubber were continuously monitored using an Innova 1412 infrared analyzer. With the scrubber operating parameters (airflow, design, size), our results confirmed the production of N₂O in the order of 5% of NH₃-N reduced. N₂O was produced by biological nitrification and/or denitrification inside the air scrubber. Statistical analysis (Pearson's test) showed that the production of N₂O was strongly influenced by the rate of airflow and the outside temperature. The abatement of NH₃ emissions from the building was only 33%, *i.e.* much lower than the 70% - 90% usually cited in the literature.

Keywords

Wet Scrubber, Ammonia, Nitrous Oxide, Piggery, Air Treatment

1. Introduction

Livestock production is one of the human activities that has a negative impact on the

environment through the emission of ammonia (NH_3) and greenhouse gases (GHG), especially methane (CH_4) and nitrous oxide (N_2O) from livestock housing and manure management [1]-[4]. Among other livestock activities, pig housing is a serious source of NH_3 [5].

France has to respect a series of international protocols, European directives and national regulations aimed at reducing the environmental impacts of livestock farming. Limitation of ammonia emissions is part of the Gothenburg Protocol (United Nations Convention on Long-range Transboundary Air Pollution—CL RTP [6] and the EU National Emissions Ceilings Directive [7]. The Kyoto Protocol under the United Nations Framework Convention on Climate Change—UNFCCC [8] targets the emissions of methane and nitrous oxide. An even stricter approach to implementing abatement measures had emerged from the Integrated Pollution Prevention and Control Directive (IPPC) 96/61/EC [9], which was recently incorporated in the Industrial Emissions Directive (IED) 2010/75/EU [10].

According to this legislative framework, ammonia limitation can be achieved by several available abatement options that are described in official documents: 1) “Guidance document for preventing and abating ammonia emissions from agricultural sources” [11] under the Gothenburg Protocol and 2) “Reference Document on Best Available Techniques for The Intensive Rearing of Poultry and Pigs” or BREF [12] emerging from the IED directive.

One of the main techniques used to reduce ammonia emissions from pig housing is to treat the exhaust air with an air scrubber. The principle of this technique, described in more detail elsewhere [13] [14], consists of passing the exhaust air from livestock buildings through a trickling bed filter which retains certain pollutants, including ammonia, as well as dust and odours [14] [15].

Different types of air scrubber are recommended for the removal of ammonia from exhaust air of piggery buildings. Most are classified in three types [16] [17]: wet scrubbers (also referred to water-only scrubbers or biotrickling filters), chemical scrubbers (acid for example) and air scrubber filters. Under certain conditions, a wet scrubber could have the same function as a biotrickling filter when a bacterial population develops on the inorganic packing material due to the accumulation of dust contained in the exhaust air from pig buildings [16] [17]. The use of an air scrubber is expected to reduce NH_3 emissions from buildings by at least 70% [11] [12] [14]. However, some recent studies showed that at the farm level, the actual reduction in NH_3 by a biotrickling filter could in fact be less than 50% and, furthermore, that N_2O is also produced [17] [18]. Indeed, the efficiency of an air scrubber depends to a great extent on the characteristics of the equipment (design, maintenance, renewal of the washing water, etc.) and on the operating conditions (ammonia loading rate, air ventilation, etc.) [17] [19] [20]. N_2O is generally a by-product of nitrification/denitrification processes [21]. The production of N_2O also depends on different parameters linked to the air scrubber including the ammonia loading rate, air humidity, temperature, and the composition of the washing water [20]-[22]. In a comparison of different studies, Van der Heyden *et al.*

[20] reported that an increase in the residence time of the air in the scrubber appeared to increase the production of N_2O .

Air scrubbers are currently mainly used in French pig farms to reduce odours from livestock buildings to avoid possible conflicts with neighbors [23]. A recent French survey has estimated that air scrubbers are installed in about 5% of pig farm buildings [24]. According to the operating parameters of commercial scrubbers (airflow, design, size, etc.) the ammonia removal rate is lower than that targeted [19] [23].

In this context, a two-month study was conducted on a pig farm with 750 fattening pigs to assess the reduction in NH_3 emissions and the possible production of N_2O by a commercial air scrubber that had been installed to reduce efficiently odours from the pig building.

2. Material and Methods

2.1. Pig Housing

The study was carried out from September to November 2012 on a pig farm in Brittany (France). The air scrubber is installed to treat the air of a total of 750 fattening pigs in seven sections of one building. The floor of each section is slatted with a manure storage space underneath for the fattening period. Each room is mechanically ventilated by two fans with variable speed regulation to keep a constant inside temperature of around 26°C . All the outlet air from all seven sections is combined in a depressurized air corridor and directed towards the inlet of the air scrubber by two large fans.

2.2. Air Scrubber

The commercial air scrubber at the pig farm surveyed had been installed outside the building to reduce obnoxious odours. This air scrubber seems to meet the needs because, according to the farmer, no complaints of local residents have been recorded since the installation process. The air scrubber ($3.5\text{ m} \times 3.6\text{ m} \times 3.9\text{ m}$; **Figure 1**) is a counter-current plastic packed-bed (900 mm thick plastic honeycomb cores with a 1 mm mesh). The outlet air from the seven sections of the fattening building was extracted and directed to the air scrubber unit through a central depressurized duct (at 50 Pa). According to the manufacturer's instructions the air scrubber is configured to operate at a maximum airflow rate of $2 \times 27400\text{ m}^3\cdot\text{h}^{-1}$. This maximum flow rate corresponds to the recommended ventilation rate for the number of pigs in the seven sections ($70 - 80\text{ m}^3\cdot\text{h}^{-1}\cdot\text{pig}^{-1}$). The empty bed residence time calculated with the maximum airflow ($\text{EBRT} = \text{scrubber volume}/\text{scrubber airflow rate}$) is 3.2 seconds. The flow rate of the air entering the filter at a given time, which is automatically applied and recorded by the manufacturer's data logger, is linked to the flow rate of the outlet air from the pig building which depends on the outside temperature. In these conditions, the flow rate of the scrubber fluctuates resulting in fluctuating loading conditions. The air enters the air scrubber and passes through the plastic packed-bed and is continuously moistened by 16 water spraying nozzles (spray rate = $1\text{ m}^3\cdot\text{h}^{-1}$ per nozzle). Finally, the air passes through a demister (thickness: 30 cm) before leaving the air scrubber. The

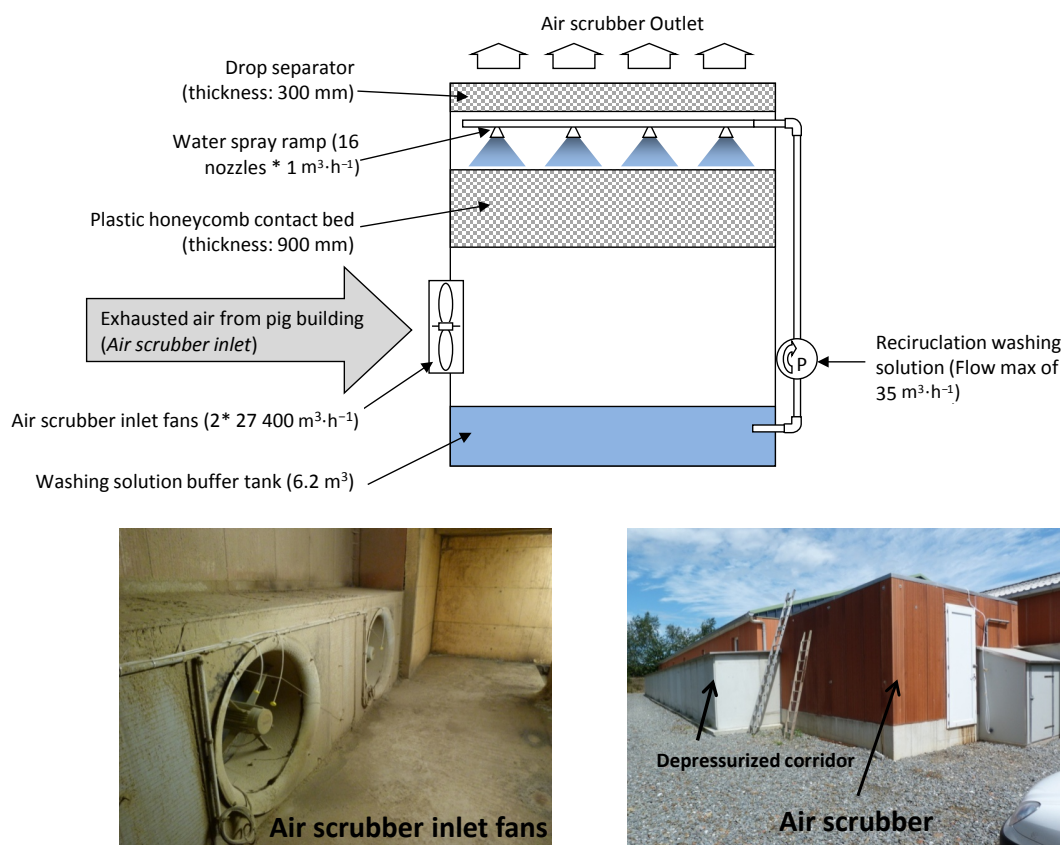


Figure 1. Characteristics of the air scrubber monitored on the farm.

washing water (tap water) is stored in a buffer tank (6.2 m^3) and is continuously recirculated. A volume-controlled valve allows fresh water to be added automatically to supplement evaporated and discharged water. The discharge water is evacuated every six months to the slurry store and applied to arable land as fertilizer.

2.3. NH_3 and N_2O Measurement

The abatement of NH_3 and the production of N_2O by the air scrubber were estimated by measuring the concentration of the gases in the inlet and outlet air of the scrubber. The concentration of NH_3 and N_2O at the inlet was calculated as the mean of four sampling points located by the two scrubber inlet fans. The concentration at the outlet was calculated as the mean of three sampling points positioned on the diagonal of the scrubber outlet (**Figure 2**). This design was used to avoid the problem of potential preferential pathways. In addition, chimneys (300 mm in diameter) equipped with a cap were used to protect the outlet sampling points from wind and rain (**Figure 2**). Each sampling point at the inlet and outlet was fitted with a 0.45 micron dust filter. The filters were replaced twice a week. The inlet and outlet air of the scrubber were continuously sampled by a system of pumps connected to a multiplexer (Secan 2800, EMS). The multiplexer connected a selected inlet or outlet monitoring point sequentially with a photoacoustic infrared gas analyzer (1412 Photoacoustic Field Gas Monitor, Innova

Table 1. Main characteristics of the commercial air scrubber.

Number and type of animal	750 fattening pigs
Scrubbing principle	Counter current
Packing bed	Plastic honeycomb cores 900 mm thick, 1 mm mesh
Scrubber dimensions (l × w × h)	3.6 m × 3.9 m × 3.5 m
Packing bed volume	12.64 m ³
Specific surface area ^a	125 m ² ·m ⁻³
Maximum air flow rate	54,800 m ³ ·s ⁻¹
Maximum air speed	1.1 m·s ⁻¹
Minimum EBRT ^b	3.2 s
Plastic demister	0.3 m
Water recirculation	Permanent
Volume washing water tank	6.32 m ³
Flow rate of recycling pump	16 m ³ ·h ⁻¹
Spray density	1.14 m ³ ·m ⁻² ·h ⁻¹
Water discharge	Every 6 months
Loading of water tank	volume controlled valve

^aIn dry clean condition; ^bEmpty bed residence time; calculated as air scrubber volume (m³) divided by the maximum airflow rate (m³·s⁻¹).



Figure 2. Chimney system for measurement of the concentration of N₂O and NH₃ at the outlet of the air scrubber.

Luma-Sense Technologies) with filter numbers UA973, UA982, UA985, UA969 and UA0988. The multiplexer was set up to connect one inlet or outlet air point every 8 min 30 s, which corresponds to the time required to measure the concentration of five gases eight times. But, because of possible interference in the detection of NH₃ and N₂O due to the presence of other gases [21] [25] only the last three measurements (*i.e.* those

made after six minutes) of the eight recorded measurements were averaged and used for data analysis. According to the measurement specifications provided by the manufacturer, the measurement uncertainty in air was $\pm 0.07 \text{ mg } [\text{NH}_3] \text{ m}^{-3}$ and $0.027 \text{ mg } [\text{N}_2\text{O}] \text{ m}^{-3}$. To check for possibly wrong quantification of gas concentrations by the IR-photoacoustic setup [25] the concentrations of NH_3 were also measured with acid impingers, and the concentrations of N_2O by gas chromatography (GC). To check concentrations of NH_3 , a fraction of the inlet and outlet air was continuously monitored for four days. The acid impingers were replaced at 24 hour intervals. The NH_3 in the sampled air was trapped by passing through the impinger containing 50 mL H_2SO_4 (1 N) at a flow rate of $5 \text{ L}\cdot\text{min}^{-1}$. The ammonia in the total acid solution of the impinger was determined by alkaline distillation and titration. The concentration of NH_3 in the sampled air was thus time averaged. To check the concentration of N_2O , approximately 15 mL of inlet and outlet air were randomly sampled with a gas syringe and stored in a 4 mL glass tube sealed with a rubber stopper. Over-pressure protected the contents of the vial in the case of imperfect sealing or possible pollution from ambient air. The concentration of N_2O was determined with an Agilent 6890 N GC chromatograph (Agilent Technologies, USA) equipped with an electron capture detector (ECD), a 3 m 1/8 stainless steel pre-column filled with 90/100 Porapack N followed by a 4 m 1/8 stainless steel column filled with 4M Porapack Q. Nitrogen was the carrier gas at $44 \text{ mL}\cdot\text{min}^{-1}$ and temperatures of the column oven and ECD detectors were 70°C and 300°C . The injection port temperature was 100°C .

2.4. Results and Statistical Analysis

Based on the monitored concentration of gas and the recorded airflow rate, the efficiency of the air scrubber was assessed according to the NH_3 loading rate, NH_3 removal rate, and NH_3 removal efficiency (%) as described by Melse *et al.* [16]. N_2O production was expressed either as the N_2O production rate ($\text{g } [\text{N}_2\text{O}] \text{ h}^{-1}$) or as the percentage of N_2O production.

Pearson's correlation coefficient (r) was used to identify significant relationships between the N_2O or NH_3 emission rates and environmental and air scrubber working factors with a 95% confidence interval ($P < 0.05$, $r = 0 - 0.25$ weak correlation, $0.251 < r < 0.500$ moderate correlation, $0.501 < r < 0.750$ strong correlation, $0.751 < r < 1.00$ strongest correlation).

3. Results

3.1. Data Analysis

NH_3 concentrations obtained with the photoacoustic analyzer were of similar magnitude to those obtained using the acid impinger method taking the difference in the sensitivity of the two techniques into account. This similarity between the two methods was also observed by Dumont *et al.* [21]. Consequently, the photoacoustic analyzer was used to monitor all the NH_3 concentrations. Likewise, no significant differences were found between measurements of the concentrations of N_2O by GC-ECD and the pho-

toacoustic analyzer. The response of the photoacoustic analyzer was sufficiently sensitive for the concentrations of N_2O present at the inlet or outlet of the air scrubber.

Concerning the efficiency of the removal of NH_3 , the results were sometime negative due to significantly higher concentrations of NH_3 at the outlet than at the inlet. Even though already observed [14] [26], these negative results accounted for 4% of the total results and were not retained for subsequent analyses. These results are questionable because no major differences in the scrubber operating parameters (outside temperature, airflow rate, NH_3 inlet concentration) were found that could explain this phenomenon. Other erratic or outlier data due technical problems that are inherent to on-site measurement campaigns, e.g. instrument failure; malfunction of the measuring equipment (pump, analyzer etc.) were also excluded from subsequent analyses. The results discussed hereafter are based on data from the infrared analyzer after the exclusion of the previously described values. **Table 2** summarizes these results.

3.2. Air Scrubber Operating Parameters

Over the study period, the airflow rate of the air scrubber ranged from 37,538 to 54,800 $\text{m}^3\cdot\text{h}^{-1}$ with an overall average of 45,708 $\text{m}^3\cdot\text{h}^{-1}$. Fluctuations in the air scrubber flow rate closely mirrored fluctuations in the outside temperature (**Figure 3**), which ranged

Table 2. Summary of air scrubber operating parameters, and NH_3 and N_2O emissions over the 2 months of monitoring of the commercial air scrubber.

	Min	Mean	Max	SD
Outside Temperature ($^{\circ}\text{C}$)	5.6	13.7	22.8	3.3
Inlet Temperature ($^{\circ}\text{C}$)	9.2	15.4	21.8	2.5
Scrubber airflow rate ($\text{m}^3\cdot\text{h}^{-1}$)	37,538	45,708	54,800	4297
Air speed ($\text{m}\cdot\text{s}^{-1}$)	0.7	0.9	1.1	0.1
EBRT (s)	3.2	3.9	4.7	0.4
NH_3				
Inlet concentration ¹ ($\text{mg}\cdot\text{m}^{-3}$)	7.5	12.1	20.6	1.2
Outlet concentration ² ($\text{mg}\cdot\text{m}^{-3}$)	5.2	8.0	13.6	1.3
NH_3 loading rate ($\text{g} [\text{NH}_3] \text{h}^{-1}$)	323	552	1035	81
NH_3 loading rate ($\text{g} [\text{NH}_3] \text{m}^{-3}\cdot\text{h}^{-1}$)	26	44	82	6.4
NH_3 removal rate ($\text{g} [\text{NH}_3] \text{h}^{-1}$)	5.6	187	535	68
NH_3 removal rate ($\text{g} [\text{NH}_3] \text{m}^{-3}\cdot\text{h}^{-1}$)	0.4	15	42	5.4
NH_3 removal efficiency (%)	1.4	33.5	57.1	10.7
N_2O				
Inlet concentration ¹ ($\text{mg}\cdot\text{m}^{-3}$)	0.24	0.55	1.06	0.17
Outlet concentration ² ($\text{mg}\cdot\text{m}^{-3}$)	0.61	0.93	1.52	0.16
N_2O production rate ($\text{g} [\text{N}_2\text{O}] \text{h}^{-1}$)	5.1	17.6	31.6	3.9

(1) Average value of 4 sampling points (2) Average of 3 sampling points.

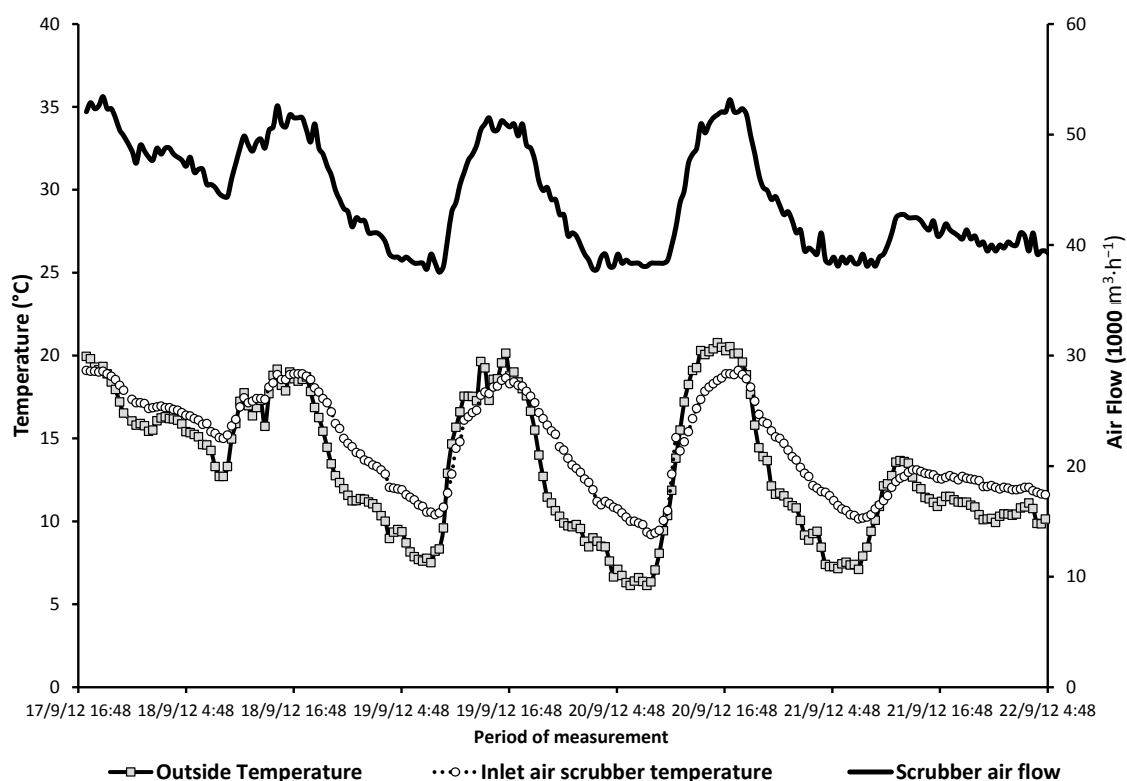


Figure 3. Fluctuations in outside temperature, inlet air scrubber temperature and air flow rate.

from 5.6°C to 22.8°C. The outside temperature impacted the ambient temperature of the pig room, which ranged from 23.5°C to 28.5°C. Similarly, the temperature of the inlet air of the scrubber fluctuated over the study period from 9.2°C to 21.8°C. This trend was expected as the flow rate to the air scrubber corresponds to the total exhaust air from the seven sections of the piggery, which are regulated individually depending on the outside temperature. Consequently, the EBRT in the scrubber ranged from 3.2 to 4.7 seconds with an overall average of 3.9 seconds and the air speed ranged from 0.7 to 1.1 m·s⁻¹ with an overall average of 0.9 m·s⁻¹. The fluctuations of the airflow rate meant that the air scrubber operated under fluctuating NH₃ loading conditions, as reported in the study of Melse *et al.* [17].

3.3. Efficiency of Ammonia Removal

Figure 4 partially illustrates fluctuations in the concentration of NH₃ at the scrubber inlet, outside temperature, and airflow rate.

The concentration of NH₃ at the inlet fluctuated widely from 7.5 to 20.6 mg [NH₃] m⁻³ with an overall average of 12.1 mg [NH₃] m⁻³. The concentration of NH₃ at the outlet mirrored this trend and fluctuated between 5.2 and 13.6 mg [NH₃] m⁻³ with an overall average of 8.0 mg [NH₃] m⁻³. The concentrations of NH₃ at the inlet and outlet are in the same order of magnitude as those reported in the literature [17] [27].

The fluctuations in the concentrations of NH₃ at the inlet combined with the fluctuations in the airflow rate resulted in fluctuations in the NH₃ loading rate and in the NH₃

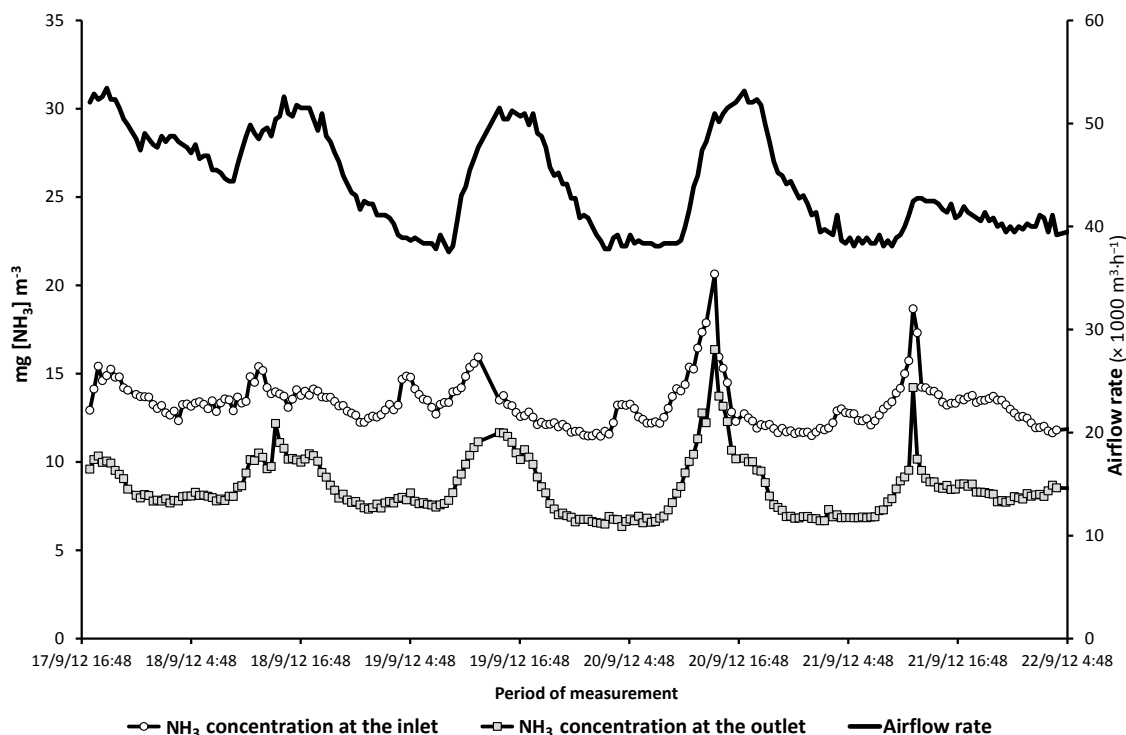


Figure 4. Fluctuations in the concentrations of ammonia at the inlet and outlet of the scrubber and in the air flow rate during air scrubber monitoring.

removal rate. The NH_3 loading rate ranged from 323 to 1035 $\text{g} [\text{NH}_3] \text{h}^{-1}$ with an overall average of 552 $\text{g} [\text{NH}_3] \text{h}^{-1}$. The NH_3 removal rate ranged from 5.5 and 535 $\text{g} [\text{NH}_3] \text{h}^{-1}$ with an overall average of 187 $\text{g} [\text{NH}_3] \text{h}^{-1}$.

Based on these data, the NH_3 removal efficiency ranged from 1.4% to 57% with an overall average of 33%. The rate of NH_3 removal by the scrubber recorded in this study is thus lower than the 70% - 90% range usually cited when a scrubber is recommended for the reduction of ammonia produced in livestock farming [11] [14]. However, the 33% removal found in our study is in agreement with the results of other French experiments on commercial scrubbers set up to reduce odours [19] [23]. It is well established that the efficiency of air scrubbers in removing NH_3 is strongly dependent on the characteristics of the equipment (ammonia loading rate, airflow rate, etc.) and the operating conditions (design, maintenance, renewal of washing water, etc.) [14] [17] [19] [20].

Some general trends emerged from our monitoring of the air scrubber over the whole period. Over time, our results showed an increase in the concentrations of NH_3 at the inlet and the concentrations of NH_3 ammonia at the outlet with an increase in the airflow rate. This resulted in an increase in the NH_3 loading rate, a reduction in the NH_3 removal rate ($\text{g} \cdot \text{h}^{-1}$) which in turn reduced the efficiency of the NH_3 removal rate (%) with an increase in the air scrubber flow rate (Figure 5).

Statistical analysis (Pearson's test, $P = 0.05$) of the overall data highlighted some interesting facts. Our results indicated a significant but weak positive effect of airflow rate

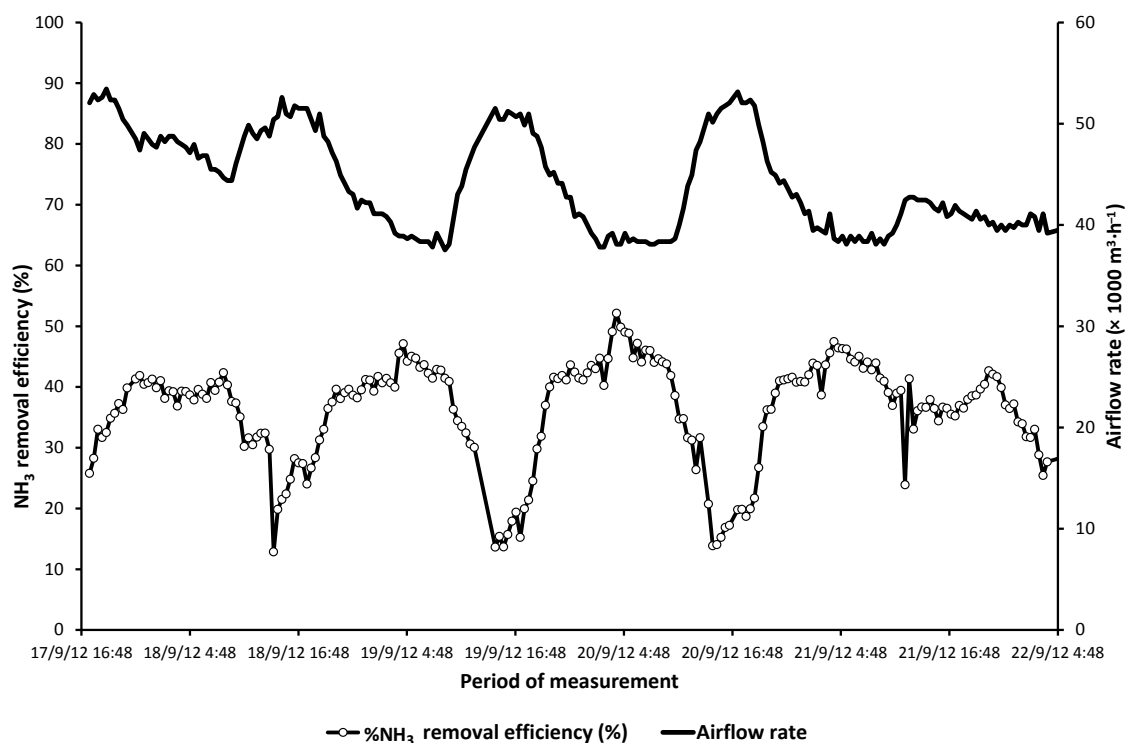


Figure 5. Fluctuations in NH_3 removal rate (%) and in the air flow rate during air scrubber monitoring.

on the concentration of NH_3 at the inlet ($r = 0.22$, $P < 0.05$). This does not correspond to the effects observed by Melse *et al.* [17] who observed a daily pattern between the airflow rate and the concentration of NH_3 at the inlet due to the activity of the pigs, which influenced NH_3 emissions. In the same way, the strong positive link between the efficiency of NH_3 removal and the concentration of NH_3 at the inlet observed in other studies [27] [28] was not observed in our study ($r = 0.21$, $P < 0.05$). Our result might be due to the central ventilation system, which mixed the exhaust air from several sections of the piggery, thereby reducing fluctuations in the concentration of NH_3 at the inlet and hence in fewer fluctuations in the loading rate of NH_3 [29]. Another explanation for these different results might be the deposits of dust in the duct that could “smooth” the concentrations at the inlet. Indeed, a significant proportion, (up to 40%) of the NH_3 in the exhausted air from the piggery could be fixed on dust [21] [30]. The NH_3 loading rate is closely correlated with the outside temperature and the airflow rate ($r = 0.7$, $P < 0.05$) meaning that more NH_3 enters the air scrubber. An increase in the outside temperature thus implies an increase in the airflow rate to maintain satisfactory conditions in the piggery. In turn, this affects NH_3 emissions in the pig rooms [5]. However, in our study, there was a very weak correlation between NH_3 removal rate and outside temperature or airflow rate ($r < 0.1$, $P < 0.05$). The parameters that most strongly influenced NH_3 removal efficiency (%) were outside temperature ($r = -0.5$, $P < 0.05$) and airflow rate, which determined the air contact time between NH_3 and the washing solution ($r = -0.4$, $P < 0.05$). An increase in the airflow rate reduced the contact time (EBRT) between the air and the washing solution thereby reducing the mass transfer of

NH₃ from the air to the water. This is consistent with the results of previous studies, underlining the link between the efficiency of the air scrubber and the air-liquid contact time [19] [20] [23]. However, according to the NH₃ removal rate (figure and statistical data), one could assume that the commercial air scrubber parameters only enable the transfer of a certain mass of NH₃. Beyond this NH₃ mass value, the NH₃ is not transferred to the washing solution. This maximum transfer value is thus reduced by an increase in airflow, which reduces the contact time needed for the transfer of NH₃. All these factors contributed to the reduction of NH₃ removal efficiency (%).

Other parameters that could influence the efficiency of NH₃ removal are the characteristics of the washing water (not measured in this study). The fluctuations in the air scrubber in removing NH₃ could be associated with the accumulation of ammonia and nitrate/nitrite in the solution produced over time [31]. Melsea and Ogink [14] (2005) reported that up to 90% of the ammonia-N removed was discharged or accumulated in the water as ammonium and nitrate. According to different authors [14] [15] [32], the accumulation of nitrogen compounds in washing water could modify the equilibrium between the concentration of ammonia in the outlet air and the concentration of dissolved ammonia in the water [17]. Such an equilibrium is usually influenced by fluctuations in the composition of the air and of the water, which occurs when the air scrubber is overloaded or when the flow rate of the discharge water is set too low [17] [20].

From our study, it appears that the air scrubber installed at a commercial farm to reduce the odours emitted by the exhausted air from the piggery was less effective in reducing the NH₃ than values normally cited in the literature. It would be possible to enhance the removal of NH₃ by reducing the accumulation of nitrogen in the washing solution [17] [19] without modifying the operating parameters (airflow rate, water flow rate) of the air scrubber used in this experiment. This could be done by discharging water [26]. However, Guingand [33] observed no difference in the ammonia reduction rate between an option in which the washing water was emptied four times and a no emptying option. Another possible way to enhance the removal of NH₃ would be to add a biological treatment step of the washing water [22] [34]. It would also be useful to include a control and monitoring process of the washing water. This could be achieved by installing an electrical conductivity meter [14] which is positively linked to the ammonia in solution [19]. From a scientific viewpoint, identifying the parameters responsible for the low NH₃ removal would require a more in-depth analysis than was planned in the present study. In particular, analyzing the washing water would be necessary.

3.4. N₂O Production

As shown in **Figure 6**, the concentration of N₂O at the air scrubber outlet was systematically higher than that measured at the inlet. The concentration of N₂O at the inlet ranged from 0.24 to 1.06 mg [N₂O] m⁻³ with an overall average of 0.55 mg [N₂O] m⁻³. The concentration of N₂O at the outlet fluctuated between 0.61 and 1.52 mg [N₂O] m⁻³ with an overall average of 0.93 mg [N₂O] m⁻³. The statistical analysis of all the data revealed a significant difference ($P < 0.05$) between the concentration of N₂O at the inlet

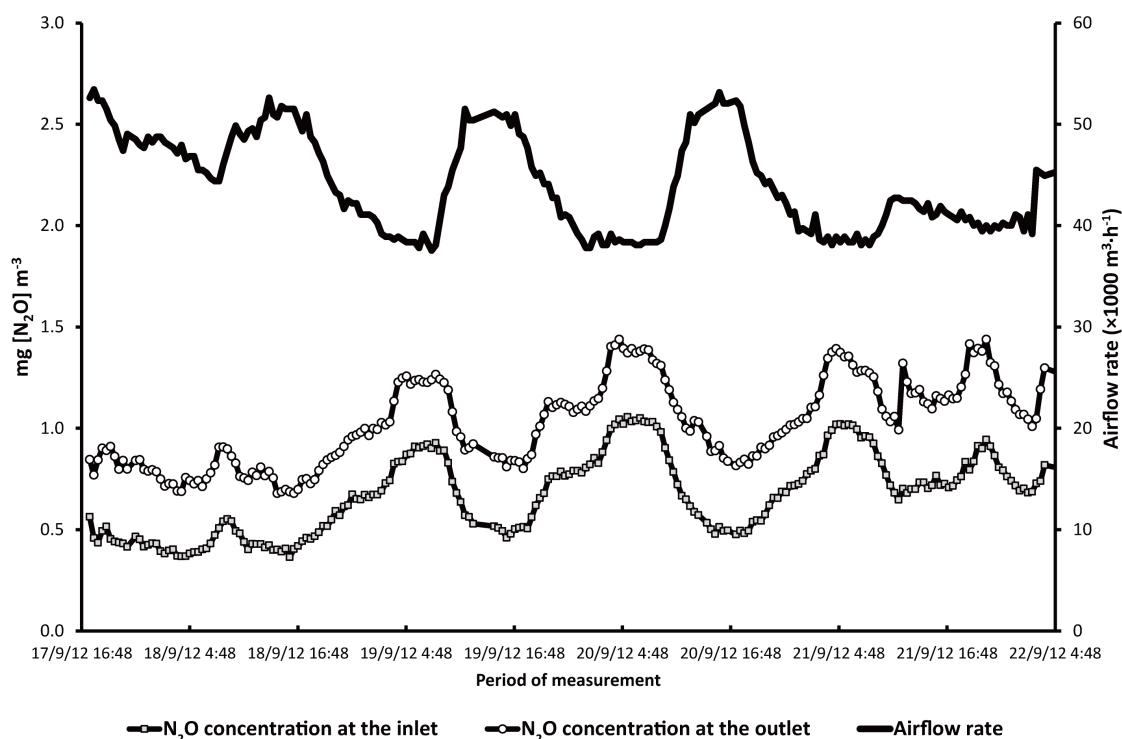


Figure 6. Fluctuations in the concentration of N_2O at the inlet and outlet and in the air flow rate during monitoring of the air scrubber.

and at the outlet of the air scrubber. Our results indicate production of N_2O by the air scrubber ranging from 14 to 233% with an overall average of 78% compared to the concentration in the air at the inlet. N_2O production fluctuated from 5.1 to 31.6 g $[\text{N}_2\text{O}] \text{ h}^{-1}$ with an overall average of 17.6 g $[\text{N}_2\text{O}] \text{ h}^{-1}$.

These results confirm the production of N_2O reported in other studies [17] [27] with similar air scrubbers to reduce ammonia from exhausted air originating from pig buildings. The production of N_2O -N observed in this study corresponds to an average of 5% of NH_3 -N eliminated. This mean value is equivalent to that reported by Melse *et al.* [17] for an average scrubber efficiency of 70% for NH_3 . Figure 7 clearly reveals fluctuations in the production of N_2O -N (% NH_3 -N removal) with fluctuations in the outside temperature and in the airflow rate. An increase in the outside temperature and in the airflow rate resulted in an increase in N_2O -N production. Statistical analysis revealed a strong statistical correlation between N_2O production (g $[\text{N}_2\text{O}] \text{ h}^{-1}$) and air temperature (outside or inlet air, $r = 0.6$, $P < 0.05$), airflow rate and implicitly the EBRT and air speed ($r = 0.6$, $P < 0.05$) and NH_3 loading rate ($r = 0.5$, $P < 0.05$).

Several authors assume that N_2O production in the air scrubber is due to biological degradation (nitrification/denitrification) of the nitrogen present in the washing solution by a biomass developing in the packed-bed plastic or in the washing solution due to dust deposition [17] [21] [31]. N is biologically degraded by ammonia-oxidizing bacteria such as *Nitrosomonas* and by nitrite oxidizing bacteria such as *Nitrobacter* and *Nitrospira* [35]. The carbon required for nitrification can be obtained from the organic

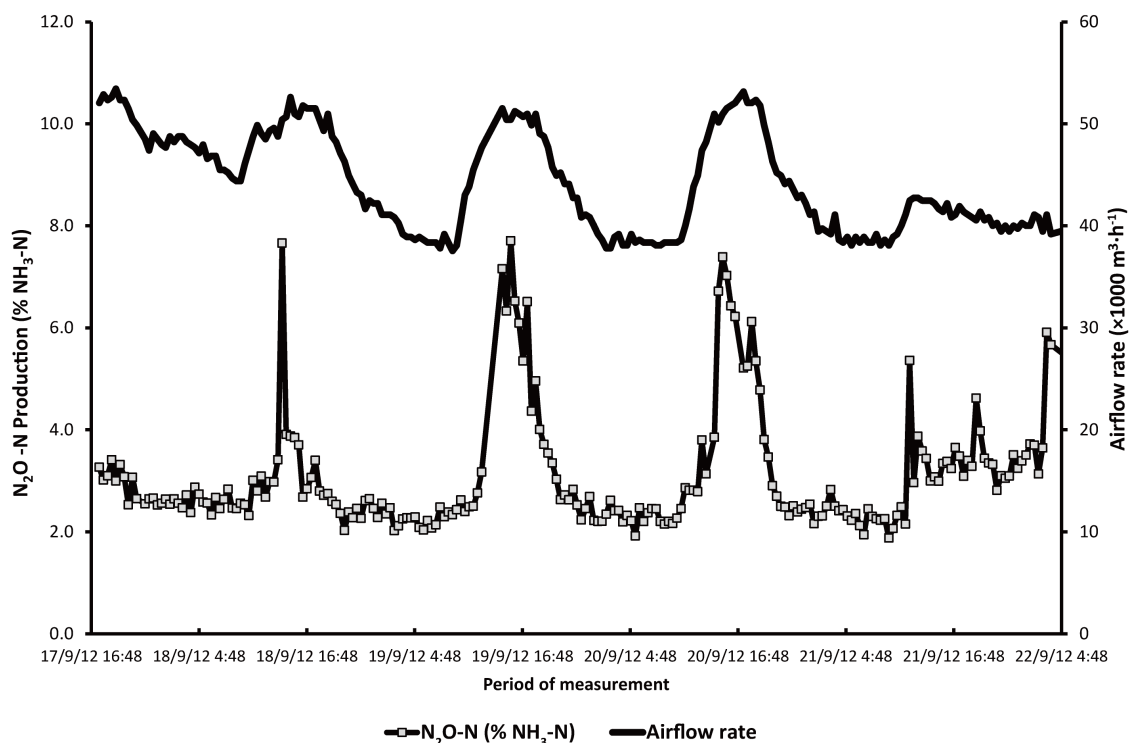


Figure 7. Fluctuations in N_2O -N production ($\%\text{NH}_3\text{-N}$ removal) and air flow rate during monitoring of the air scrubber.

materials in the dust particles entering the air scrubber. In general, complete nitrification and denitrification requires the control of pH, temperature, substrate and chemical oxygen demand (COD), dissolved oxygen, etc. as well as preventing the accumulation of inhibitory metabolites such as free ammonia. As mentioned above, up to 90% of the NH_3 removed from piggery air was discharged or accumulated in the washing solution and hence available for bacterial oxidation to nitrite (NO_2^-) and subsequently from nitrite to nitrate (NO_3^-). It is therefore likely that high concentrations of NH_4^+ and NO_2^- in the washing solution affected the activity of *Nitrosomonas* and *Nitrobacter*. Moreover, N_2O production is highly dependent on biodegradable carbon, which is expressed as a low COD:N ratio during denitrification [22]. This implies that fluctuations in the NH_3 loading rate of the air scrubber might have an influence on the measured N_2O production rate, as a change in NH_3 loading rate could change the COD:N ratio. A too low COD:N ratio may increase the production of N_2O during denitrification. Finally, other parameters can also influence the production of N_2O including the temperature of the air to be treated, and the NH_4^+ content, temperature, level of oxygen dissolved and pH of the washing water [19] [20].

However, based on our results alone, it is difficult to establish a link between N_2O production and the operating conditions of the scrubber or the climatic conditions, as these factors are inter-correlated [17]. At commercial scale, the washing dynamics is complex because the physical-chemical reactions and biological reactions occur simultaneously and due to the different media (gas, water, biofilm, and solids) involved. In

the same way as for the efficiency of NH_3 removal, data on the washing solution during the monitoring period would be required for analysis.

A complete understanding and interpretation of the data could be done with certitude only by making the N balance of the process (including the concentrations of NO_2^- and NH_4^+ as they may inhibit nitrifying bacteria depending on pH value). However, this was not possible because of the configuration of the commercial air scrubber.

4. Conclusions

The aim of this study was to assess the reduction in NH_3 emissions and the possible production of N_2O by a commercial air scrubber installed to reduce odours from a building housing fattening pigs. The results of a 2 month period of monitoring of a building holding 750 pigs indicated that with the operating parameters of the scrubber concerned (airflow, design), the reduction in NH_3 emissions was about 33%, which was much lower than the 70% - 90% reported in the literature. Statistical analysis (Pearson's test) indicated that the parameters defining the air contact time (airflow, air speed, EBRT) between NH_3 and the washing solution had the strongest influence on the efficiency of NH_3 removal (%). Another parameter that could influence the efficiency of NH_3 removal is the composition of the washing solution (not measured in this study). The instability of the results achieved by the scrubber could be associated with the accumulation of ammonia and nitrate/nitrite in solution produced over time.

This study supported the findings of other studies concerning the production of N_2O , which expressed in $\text{N}-\text{N}_2\text{O}$, was of the order of 5% of $\text{N}-\text{NH}_3$ removed by the air scrubber. This N_2O is certainly produced by the biological degradation that takes place inside the air scrubber by nitrification/denitrification of the nitrogen present in the washing solution. The biomass that develops in the packed-bed plastic or in the washing solution due to dust deposition is certainly the cause of this biological activity. $\text{N}_2\text{O}-\text{N}$ production (% NH_3-N removal) was strongly correlated with fluctuations in the outside temperature and in the airflow rate. An increase in the outside temperature and airflow rate increased $\text{N}_2\text{O}-\text{N}$ production.

This study shows that the use of air scrubbers to reduce odours for NH_3 regulatory purposes requires some modifications to optimize the efficiency of NH_3 removal and to limit the production of N_2O . This could be achieved, for example, by setting up a control and monitoring process for the washing water, for example an electrical conductivity meter positively linked to the ammonia in the washing solution. From a scientific viewpoint, exploration of the parameters responsible for the low rate of NH_3 removal and N_2O production requires more comprehensive analysis than that is planned in the present study, in particular, analysis of the washing water. In conclusion, this study shows that air scrubbers need to be characterized under farm conditions to avoid overestimating the expected efficiency in reducing NH_3 and to control the production of N_2O , when the target is to reduce odours.

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