Progress in Research into Ammonia and Greenhouse Gas Emissions from Animal Production Facilities

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INTRODUCTION

On 1-4 June 2003, the Danish Institute of Agricultural Sciences (DIAS) hosted the International Symposium on Gaseous and Odour Emissions from Animal Production Facilities. This symposium can be considered a follow-up of the first special symposium on gaseous and odour emissions, held in 1997 in Vinkeloord, the Netherlands (Voermans and Monteny, 1997). The organizers of the 2003 symposium were Section II (Buildings) of the Commission International du Genie Rurale (CIGR), the European Association of Agricultural Engineers (EurAgEng), and the Nordic Association of Agricultural Scientists (NJF). A total of 93 participants from 22 nations got together to share the latest advancement in research and development into the important issues of gaseous emissions from animal production facilities, including odour. They presented 40 papers and 22 posters on various issues concerning gaseous emissions from animal production facilities.

This paper describes the major progress in the field of ammonia, methane and nitrous oxide emissions from livestock production. Statements, data and findings are referred to between parentheses (author – page number of the symposium proceedings).

LEGAL ASPECTS

Odour nuisance is probably the oldest environmental issue related to animal husbandry. Since the 70'es of the last century, it has received much attention from politicians and researchers. Olfactometry, with the human nose used as sensor for odours, was developed in those early days (Takai *et al.* – 62) and is still the most important device for measurement of odour concentrations in air deriving from agricultural sources. In recent years, ammonia (NH_3; acidification and eutrophication), dust (health related), hydrogen sulphide (H_2S), and the non-CO_2 containing greenhouse gases methane (CH_4) and nitrous oxide (N_2O) have been added to the list of polluting gaseous emissions from animal husbandry. As a result, animal producers of today are facing an increasingly complex job of dealing with that kind of emissions in order to maintain their licenses for operation (Jongebreur *et al.* – 11). This license is necessary to comply with sustainability related demands from the society, expressed in a number of governmental regulations and legislations. Table 1 shows the most important legal frameworks per type of gas regarded.

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Table 1. Overview of regulatory frameworks on gaseous emissions in various parts of the world

	EU	USA
NH_3	NEC-Gothenborg; IPPC	ATSDR, EPA, CERCLA, NIOSH and state specific
Odour	Distances	Vary by state (e.g. 7:1 ODT)
CH_4	Kyoto protocol	–
N_2O	Kyoto	–
Dust	EU Directive 96/62/EC	PM2.5/PM10, EPA and state specific
H_2S	–	ATSDR, EPA, NIOSH and state specific

ATSDR Agency for Toxic Substances and Disease Registry, Center for Disease Control
EPA Environmental Protection Agency
NIOSH National Institute for Occupational Safety and Health

In the EU-member states, the Gothenborg-protocol and the National Emission Ceilings (NEC-guidelines), dealing with the NH_3 emissions, seem to be in the process of superseding national legislation. Measures to reduce NH_3 emissions are listed in an international document (European Commission, 2002) with Best Available Techniques (BAT) for the below issues:

- housing systems
- outdoor storages
- manure spreading
- feeding and management

It is clear that these measures cost money, although (slight) benefits are to be expected by preventing losses of N from manure to the atmosphere (saving fertilizer value). An Italian study (Valli and Bonazzi – 49) clearly demonstrated that optimized housing systems for pigs (€ 0-3.5 in additional cost per kg reduced NH_3 emission) and poultry (€ 0.5-10 in additional cost per kg reduced NH_3 emission) are cost ineffective. Furthermore, it has been shown that covering of outdoor manure storages can be very effective (> 80% emission reduction, e.g. by using oil, peat, floating foil, granules, bubble film, straw crust), but a reduction of 1 kg of NH_3-N would cost up to € 3/m^2 (Williams – 283). An assessment of combined measures has been conducted in Germany (Eurich-Menden *et al.* – 33). Results showed that combining measures like low-N feed, covering of outside storages, drying of excrements, and low-emissions manure application may cost € 5.2-6.3 per kg of NH_3 reduced.

MEASUREMENT TECHNOLOGY

Sources of gaseous emissions in livestock production can be a point source (animal houses with mechanical ventilation), a pseudo-point source (animal houses with natural ventilation, manure storage), or a non-point or surface source (land spread of slurry or grazing cattle). Various methods exist to determine the amount of gases emitted from each source type. Indirect methods using N-balances require detailed information on the amounts of N that are introduced (e.g. by feed, animals, litter), accumulated (in manure), and exported (animal products, manure), with the difference being the amount of gaseous N lost to the environment. In direct methods, often used for point sources, the emission (flux; g h^{-1}) can be calculated from separately measured gas concentrations (g m^{-3}) and air exchange rates (m^3 h^{-1}) at the source. A novel method for flux measurements from mechanically ventilated buildings was presented (Mosquera and Hofschreuder – 529). Results from the passive flux sampler method showed good agreement with the direct method. Direct methods for pseudo-point and non-point sources may comprise the use of trace gases released near the emitting source, combined with concentration measurement away from the source, to determine the rate of dilution of the trace gas (combination with dispersion model) as a measure of source strength (= flux) of the polluting gas (Stout *et al.* – 96). Results showed that these types of measurement require much attention to get reliable results, depending on the source characteristics (design of ventilation system, quality of air mixing) and the configuration (multiple sources).

Various devices were presented in the emission research to measure gas concentrations, varying from ammonia sensors (Burns *et al.* – 88; Liang *et al.* – 203; Pedersen – 257) to infrared spectrophotometers (Gustafson *et al.* – 239), NO_x-analyzers (Demmers *et al.* – 249; Heber *et al.* –161), and multi-gas monitors (Müller *et al.* – 172). Air exchange rates from point sources are usually measured by anemometers or measurement ventilators placed in the ventilation shafts or by monitoring the runtime of *in-situ* calibrated ventilation fans (Casey *et al.* – 213). Natural (e.g. CO_2; Sousa and Pedersen – 114) or introduced (e.g. SF_6) trace gases are used for both point and pseudo-point sources. For these situations, specific equipment (CO_2-analyzer, gaschromatograph) or multi-gas monitors (CO_2, CH_4 and NH_3 measured simultaneously) will be required to measure gas concentrations.

Formal, legal or standard protocols for determination of emission factors often exist for measurement equipment, boundary conditions (e.g. feeding and management), and duration of the measurements. Claes *et al.* (359) clearly demonstrated that process or empirical models could be used to describe the development of gaseous emissions over time, thereby reducing the need for intensive measurement schemes (e.g. 14 strategically chosen one-day measurements distributed over the year to replace the continuous year-round measurements).

EMISSION DATA

Various papers have been dealing with research into potential low-emission housing systems for fattening pigs, poultry (laying hens, broilers) and dairy cows. In these studies, low-emission housing systems were compared with traditional housing systems. Traditional housing systems for fattening pigs are, in general, pens where the animals are kept in groups on fully slatted floors. Slurry is usually stored beneath the slats. Laying hens are commonly kept in battery cages, with manure storage beneath the cages or removal through a belt system. Broilers are kept in groups on litter in almost any part of the world. For dairy cows, tying stalls (animal fixated) and free-stall cubicle houses are commonly used.

Low emission housing systems are based upon one of the following reduction mechanisms:

- diets with reduced nitrogen (protein) content (reduced urea concentration in urine)
- preventing NH_3 formation (relevant for poultry; drying of droppings to reduce degradation of uric acid)
- reduced emitting surface area of floors (minimize evaporation of NH_3)
- reduced emitting surface area of slurry in the pit (minimize evaporation of NH_3)
- slurry or floor cooling (minimization of evaporation of NH_3)
- reduced pH of urine (diet induced) and slurry (use of acids) or litter (use of litter additives) (reduced NH_3 volatilization)

In Table 2, a summary of the research findings on ammonia emissions in pig husbandry is presented, whereas Tables 3 and 4 summarize the emission information for poultry and diary cows, respectively. The tables contain information about the measurement system used to determine emissions, a description of the studied housing systems, the measured emission levels, and some comments.

Table 2. Summary of emission levels from pig housing systems as reported in the proceedings of the 2003 international symposium held in Denmark

Animal Species	Measurement principle[1)]	System description	NH_3 emission Mg d^{-1} pig^{-1}	CO_2 emission mg d^{-1} pig^{-1}	Remarks	Reference
Fattening pigs	VR: measurement fan C: Wet chemical (sulphuric acid)	Fully slatted	10 000		Major impact of fouling of pen and animal on emission level. Compare: Aarnink *et al.* (1996): 6 400 ± 2 400	Guingand (France)
		Partly slatted – 8 pigs per pen	12 200			
		Partly slatted – 24 pigs per pen	12 500			
	VR: measurement fan C: infrared spectroscopy	Fully slatted – 9 pigs per pen	14 000-20 000	6 000-15 000	Seasonal variation	Gallmann *et al.* (Germany)
		Kennel system, (free range), partly perforated/solid – 24 animals per pen	10 000-12 000	2 000-5 000		
	VR: anemometer C: infrared analyzer	Deep litter – 25 pigs per pen	5 500-15 600		Increase with growth	Jeppson (Sweden)
	VR: measurement fan C: Infrared multigas montor	Fully slatted with pit overflow – 200 pigs per pen	7 100 ± 3 600	43 000 ± 19 200	Frequent slurry removal reduces emissions	Guarino *et al.* (Italy)
		Fully slatted with frequent slurry removal – 200 pigs per pen	4 700 ± 2 500	36 700 ± 14 800		
	VR: measurement fan C: NO_x analyzer	Fully slatted – 12 pigs per pen	12 400-12 800			Demmers *et al.* (UK)
		Fully slatted, 50% covered with rubber mats – 12 pigs per pen	11 200-12 100			
		Fully slatted, 50% paved, curtains in pits – 12 pigs per pen	10 600			
		Partly slatted – 12 pigs per pen	6 400-6 700			
		Partly slatted, convex solid area, sloping channel sides – 12 pigs per pen	5 800-7 000			

[1)] VR = measuring methods of ventilation rate; C = Measuring methods of gas concentration

The reported range in NH_3 emission from traditional pig housing systems with fully slatted floors is 7 100-20 000 mg d^{-1} per pig. For systems aiming at an emission reduction, like partly slatted floors, the German Kennel system, and systems with frequent slurry removal, the reported range is 6 400-12 500 mg d^{-1} per pig. These data show that reduction of the NH_3 emission can be achieved by reducing the emitting surface area of the floor and the slurry stored in the pits. It should be noticed that the emission data from the UK study with 'simulated' (use of rubber mats and pavement) and real partly slatted floors are markedly lower than the French data for the same system. This difference is mainly caused by pen fouling, due to poor climatization and management (Guingand – 80), which may strongly reduce the emission reduction potential of the system.

Table 3. Summary of ammonia emission from poultry housing systems as reported in the proceedings of the 2003 international symposium held in Denmark

Animal species	**Measurement principle [1)]**	**System description**	**NH_3 emission mg day^{-1} bird^{-1}**	**Remarks**	**References**
Ducks	VR: krypton concentration C: infrared multi-gas monitor	Grid/slurry or floor/straw (n = 8)	850	Body mass: 2 kg	Müller *et al.* (Germany)
Turkeys		Straw/litter (n = 6)	1 700	Body mass: 8 kg	
Layers		Battery cages, manure drying (n = 6)	90		
		Aviary system with manure drying (n = 6)	270		
	VR: CO_2 balance C: NH_3 sensor	Battery cages with manure belt system	170	Body mass 1.5 kg	Liang *et al.* (USA)
		Battery cages with manure storage (high rise)	1 040		
Broilers	VR: krypton concentration C: infrared multi-gas monitor	Straw/litter (n = 3)	120	Body mass: 0.8 kg	Müller *et al.* (Germany)
	E: N-balance VR: pressure drop over fans C:electro-chemical gas sensor	Litter based, free range system (indoors); fresh litter at beginning of fattening round; 6 rounds measured	930	Much higher than stated by e.g. Wathes *et al.* (1997) and Demmers *et al.* (1999). Major effect of suspected litter management	Burns *et al.* (USA)
	VR: anemometers C: electro–chemical sensors	Litter based system; re-use for 1 year (building up) (n = 8)	500	Variability between farms >> day-to-day variability; impact of litter management	Casey *et al.* (USA)
	VR: anemometers C: electro-chemical sensors	Litter based system; reuse for 1 year (n = 2)	610		Wheeler *et al.* (USA)
		Litter based system; new litter per flock (n = 2)	360		

[1)] VR = measuring methods of ventilation rate; C = measuring methods of gas concentration.

In the source articles for Table 3, different authors have used different units for ammonia emission, e.g. g d^{-1} per livestock unit (LU), where 1 LU is 500 kg body mass. In cooperation with the authors, the emission in Table 3 was translated to the same unit, mg d^{-1}bird^{-1}. The values presented in the tables only included the average figure from each author, although great variations might exist from one experiment to the other.

Measured NH_3 emissions for laying hens and broilers show a broad range. The emission from laying hen battery cage systems with storage beneath the cages (high-rise housing) is roughly 10 times higher than the average emission from systems with belt drying and frequent removal of droppings. It is obvious that direct drying of droppings will slow down the degradation process of uric acid, being very effective as a means for NH_3 emission reduction. Emissions from aviary systems are higher than from battery cage housing, even when both systems are equipped with belt drying. This is related to the increased surface area in the aviary systems, where the animals are allowed to move around freely, leaving droppings in the litter part of the system.

For broilers, litter management (e.g. removal frequency) is crucial to achieve emission reduction. In re-used litter there will be a build up of droppings, and decomposition processes (composting) will enhance the production of NH_3. Therefore, frequent refreshment of litter should be considered in order to reduce NH_3 emissions.

Table 4. Overview of dairy cow emission research

Animal species	**Measurement principle** [1)]	**System description**	**NH_3 emission mg day^{-1} cow^{-1}**	**Remarks**	**References**
	VR: Measuring fan C: Infrared spectrophotometer	Tying stall with rubber slats; separate urine and faeces collection/ discharge	15 600	Losses from urine (trailing hose) and faeces (broadcast) after spreading: 10.4	Sannö (Sweden)
	VR: Measuring fan C: Infrared spectrophotometer	As in J-O. Sannö; additional channel cooling	19 000	Improved indoor climate	Gustarsson *et al.* (Sweden)

1): VR = meas. methods of ventilation rate; C = gas concentr.

Both reported studies on dairy cow housing systems used improved slurry management (scraping, cooling) as a means to reduce NH_3 emissions. The reported data refer to tying stalls for dairy cows where the animals are fixed. Ammonia emissions are reduced by around 30%, compared with the situation without the improvements (not shown in Table 4). It has to be noticed that the suggested measures only apply for tying stalls. For cubicle housing systems, where the animals can move around freely, and consequently, there is no defined areas for urinating and defecating , different measures have to be taken to reduce emissions.

Emission levels are expressed differently in the papers. The applied units vary from g d^{-1} per animal to kg y^{-1} per livestock unit (LU). It is recommended to standardize the units used for emission levels, taking into account the nature of the production cycle (e.g. 6 weeks for broilers, 4 months for fattening pigs, > 1 year for laying hens, sows, cattle). Furthermore, expression of emission levels per LU will have the advantage of offering possibilities to compare emissions per 500 kg of live weight), but it will offer no basis for (national) emission inventories that use animal numbers or emissions per animal as a basis (Reidy and Menzi – 395).

Measurement systems also vary greatly. In this paper, the reported emission levels were not analyzed for the applied measurement system. In general, proper calibration procedures may assure optimal and realistic quality of the data. Still there is a need for standardization of measurement systems used for various source types. This need will increase when emission data are used for national and international emission inventories.

EMISSION REDUCTION OPTIONS

In the tables presented previously, various emission reduction options were studied. For pig housing systems, reduction of the emitting surface area combined with optimal climatization can substantially reduce NH_3 emissions. Poultry system emissions can best be reduced by slowing down the decomposition of uric acid (drying of droppings), and by means of optimal litter/dropping management (frequent removal). Specific technological options for emission reduction will influence one or more parameters that play a role in the formation and release of NH_3. Ammonia emission is influenced by the following parameters: urea concentration in the urine, NH_3 content of manure, urease activity, temperature, air velocity, moisture content and pH (Monteny, 2000). The sensitivity for pH is probably the highest, since pH determines the ratio between the soluble ammonium (NH_4^+) and the volatile ammonia (NH_3). Lowering the pH will reduce the content of NH_3 in the manure, and increasing the NH_4^+ concentration. The addition of sulphuric acid to slurry stored in pits in pig houses (Pedersen – 257) to a pH level of 5.5 led to a reduction of the NH_3 emission from the house by 50%, compared with that from an untreated situation. Aeration had to be used to prevent the transfer of sulphate to hydrogen sulphide, which may pose health risks and/or nuisance (odour). Slurry acidification was also studied by Berg and Pasciszki (460), who performed a laboratory test with lactic acid and saccharose applied to a straw induced crust. The effect of lowered pH and covered surface resulted in NH_3-emission reductions by 94% and 55% for lactic acid and saccharose, respectively, compared to untreated slurry. Besides straw, other types of floating covers were found to be effective for slurry storage. Williams (283) reported NH_3 emission reductions of up to 80% (compared with uncovered storage) by using rapeseed oil, peat layer, floating foils, granules, bubble film, and Leca nuts. However, the cost effectiveness is low (up to € 3 /m^{-2} per kg NH_3 reduced).

Haussermann *et al.* (452) reported initial results from an extended survey into the effect of various options for reduction of gaseous emissions from pig housing systems. Both management (feeding strategies, climatization taking animal weight, animal activity, and indoor climate into account) and technique (cooling of incoming air) seem to offer good potentials for reduction of emissions.

EMISSION DATA IN A BROADER FRAMEWORK

Table 5 shows the state-of-the-art in the nineties in Northern Europe. The first source in the table refer to an EU project on measuring gaseous emissions, comprising 118 cattle buildings, 130 pig buildings and 81 poultry buildings in Northern Europe (GB, D, NL and DK). Very great variations were found, both among buildings in the same country and among the countries. The presented data are the average of all data collected for each type of housing system. The second source is the 'Ammonia List', being a part of the formal legal framework, 'Regeling Ammoniak en Veehouderij' (Regulations on Ammonia and Animal Husbandry; see: www.infomil.nl).
The data and information presented during the conference have to be regarded as a next step in the process of increased understanding of the level of and variation of NH_3 emissions from various types of animal husbandry, including the factors responsible for certain levels and variations.

Table 5. Summary of emission data compared with data from other selected sources

Animal type	**Ammonia emission mg/animal/day**		
	This paper	Groot Koerkamp *et al.*, 1998	Dutch list of housing systems
Dairy cows, litter		11 300	
Dairy cows, tying stall	19 000		11 780
Dairy cows, cubicles		33 300	26 000-30 100[1)]
Beef cattle, litter		8 900	
Beef cattle, slats		12 900	
Calves, litter		4 800	6 850
Calves slats/group		10 100	
Sows, litter		19 200	
Sows, slats		12 600	11 500
Weaners, slats		700	1 650
Finishers, litter	4 700-15 600	6 000	
Finishers, slats	10 000-17 000	7 200	8 220
Laying hens, deep litter/perchery	1 040	850	465
Laying hens, battery cages	90-170	350	125
Broilers, litter	120-930	350	220

1) Depending on grazing system (low values: with full time grazing; high values: with zero grazing)

Need for future research

Animal producers are facing increasing pressure from the society to comply with environmental legislation, i.e. to produce in an environmentally friendly and sustainable way. In Europe, there is a development towards international guidelines and emission ceilings, especially for NH_3. But also non-CO_2 greenhouse gases, odour, and dust will become important issues from an international perspective. Agricultural engineers are challenged to develop integrated solutions; future housing systems will have to comply with as the lowest possible levels for all gaseous emissions (Jongebreur *et al.* – 11), leaving enough room for producers to expand their production to be economically sound. Social scientists, farmers and industries will have to be included to create solutions that can be managed and accepted by producers.

Growing international awareness of the problems associated with gaseous emissions from agriculture will lead to a broad exchange of emission data, reduction options, measurement technology and tools for emission assessments. Scientists and policy makers are facing the challenge of standardization of procedures and protocols for measuring, reporting and assessing emissions (e.g. models).

CONCLUSIONS

Information from different literature sources is difficult to compare, because the reported emission data are usually expressed in many different terms, such as mg, g or kg per animal, livestock unit (LU, 500 kg) or heat production unit (HPU, 1000 W total heat production) per hour, day, year or production circle. Furthermore, different measurement techniques are used, being a potential source of variation. Other important sources of variation may be details of similar systems regarded, climate and management practices.

Ammonia emissions may range for the different types of animals as follows:

Dairy cows:	15 600-19 000 mg per day per cow
Layers:	90-1 040 mg per hen per day, where 90 refers to battery cages and manure drying, and 1 040 refers to long-term storage below cages)
Broilers:	120-930 mg per broiler per day (mainly depending on litter management)
Fattening pigs:	4 700-17 000 mg per pig (multiple sources of variation)

Many investigations on low emission housing systems are in process throughout the world, and it may be expected that lower NH_3 emissions will be realized within the next decades. This will contribute to a more sustainable animal husbandry from an ecological perspective, although the greatest challenge will be to reduce the additional costs to acceptable levels and to assure economic sustainability.

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