We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Greenhouse Gas Emissions from Non-Cattle Confinement Buildings: Monitoring, Emission Factors and Mitigation

S. Godbout[1,2], F. Pelletier[1], J.P. Larouche[1], M. Belzile[1], J.J.R. Feddes[1,3],
S. Fournel[1,2], S.P. Lemay[1,2] and J.H. Palacios[1]
[1]Research and Development Institute for the Agri-Environment, Québec City, QC,
[2]Department of Soil Science and Agri-Food Engineering, Université Laval, Québec City, QC,
[3]Department of Agricultural, Food and Nutritional Science,
University of Alberta, Edmonton,
Canada

1. Introduction

Worldwide environmental issues are dominated by climate change, especially by the increase in greenhouse gas (GHG) emissions (UNDP, 2007). The rise in of GHG concentrations in the atmosphere has become a major environmental concern as revealed in the Kyoto Protocol (AAFC, 2000). Besides contributing to global warming by absorbing infrared radiation, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have been declared the most harmful gases for ecosystems, apart from ammonia (NH_3) (Pain, 1998; Copeland, 2009).

Agricultural practices account for 10 to 12% of world total GHG emissions, however, it could reach between 17 and 32% (8,5-16,5 Pg CO_2-eq) by including all agriculture-related emission sources (Bellarby et al., 2008). Agricultural GHG emissions can be divided into three main groups: a) CH_4 emissions from cattle enteric fermentation; b) CH_4 and N_2O emissions due to manure management practices; and c) N_2O emissions from cultivated fields, including direct emissions from crop land and pasture and indirect emissions resulting from the use of nitrogen fertilizer in agriculture.

Manure management alone is responsible for 13% of GHG emissions from the agricultural sector with CH_4 and N_2O accounting for 33 and 67% of CO_2-eq, respectively (Steinfield et al., 2006). Current trends suggest that this level will substantially increase over the coming decades as the intensification of livestock activities continues. On the other hand, CH_4 and N_2O have a global warming potential of 21 and 310 times over hundred years greater than CO_2, respectively, based on their ability to contribute to climate change (Houghton et al. 1995). Hence, the environmental impact of livestock operations can not be considered negligible.

Currently, many countries have to use internationally agreed values to evaluate their GHG emissions. By describing the GHG emission sources and presenting the emission factors from non-cattle production, this chapter will improve the knowledge of scientists and

politicians about the contribution of agriculture to global warming. Moreover, this chapter provides quick information on monitoring and mitigation of GHG emissions.

2. Gas emissions from animal confinement buildings

2.1 The source of contaminants

Contaminants exhausted from animal confinement buildings include various gases, dust particles, micro-organisms and odours. The most important gases are CO_2, NH_3, hydrogen sulphide (H_2S), CH_4, N_2O and some trace gases (aldehydes, amines, aromatics, organic acids, sulphur compounds, etc.). NH_3, CH_4 and N_2O are produced from manure decomposition while CO_2 is primarily a product of animal metabolism (Hartung & Phillips, 1994).

In most confinement buildings, manure is stored as a liquid or semi-solid beneath the animals for a short or long period of time. Both the manure attached to the flooring material and the manure stored under the animals produce these gases.

Manure decomposition begins in the stomach of the animal where the consumed feed undergoes early anaerobic decomposition by the intestinal flora at a temperature between 38 and 40 °C. Once the manure is excreted and exposed to air, a new type of bacteria grows according to the manure management method practiced. Depending on ambient temperature, this change takes 12 to 24 h (Barrington, 1999).

In the case of solid manure to which straw is added, animal manure is decomposed by aerobic bacteria. These bacteria break down organic matter and stabilize the manure. Once stabilized, almost no gas or odorous compounds will be produced (Barrington, 1999).

In liquid manure, a population of facultative bacteria (aerobic or anaerobic) grows rapidly. These bacteria decompose organic matter and produce gases and odorous compounds. The emission of these contaminants is thus carried throughout storage (Barrington, 1999). Figure 1 presents a schematic view of the emission mechanisms from anaerobic decomposition of liquid manure.

The production of N_2O during storage and treatment of animal manure occurs during nitrification and denitrification of nitrogen contained in the manure. Nitrification is the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), and denitrification is the reduction of NO_3^- to N_2O or atmospheric nitrogen (N_2). Generally, as the degree of aeration of the waste increases, so does the amount of N_2O produced (Olsen et al., 2003).

2.2 Emission calculation

Two parameters are very important in determining gas emission rates, namely the gas concentration (inlet and outlet) and the air exchange rate (Fig. 2). Gas emissions are calculated by multiplying the difference in concentration by the mass flow of gas, which is calculated from the mass flow of air. The GHG emissions can be calculated for each sampling period using Equation 1. In this equation, the specific volume of air ($v = (P_{atm} – P_v)/(287 \times T)$; ASABE, 2010) is used to obtain the mass flow of air from the volumetric flow rate.

$$E_{GHG} = (C_{out} - C_{in}) \times \frac{Q}{N_{animals}} \times \frac{P_{atm} - P_v}{287 \times T} \times \frac{M_{GHG}}{M_{air}} \times 525,6 \qquad (1)$$

where E_{GHG} represents CO_2, CH_4 or N_2O emissions for one animal space during one sampling event (g yr^{-1} animal^{-1}), C_{out} is the GHG exhaust concentration from the animal space (ppmv), C_{in} is the incoming GHG concentration to the animal space (ppmv), Q is the average room air exchange rate during the sampling event (m$^3_{air}$ min^{-1}), $N_{animals}$ is the number of animals in the room, P_{atm} and P_v are respectively the atmospheric pressure at sea level and the vapour pressure (Pa), T corresponds to the temperature (K), M_{GHG} characterize the molar masses of CO_2 (44 g mol^{-1}), CH_4 (16 g mol^{-1}), or N_2O (44 g mol^{-1}), M_{air} signifies the molar mass of air (29 g mol^{-1}), 287 is the thermodynamic constant of air (J kg^{-1} K^{-1}) and 525,6 is a conversion factor (mg min^{-1} to g yr^{-1}).
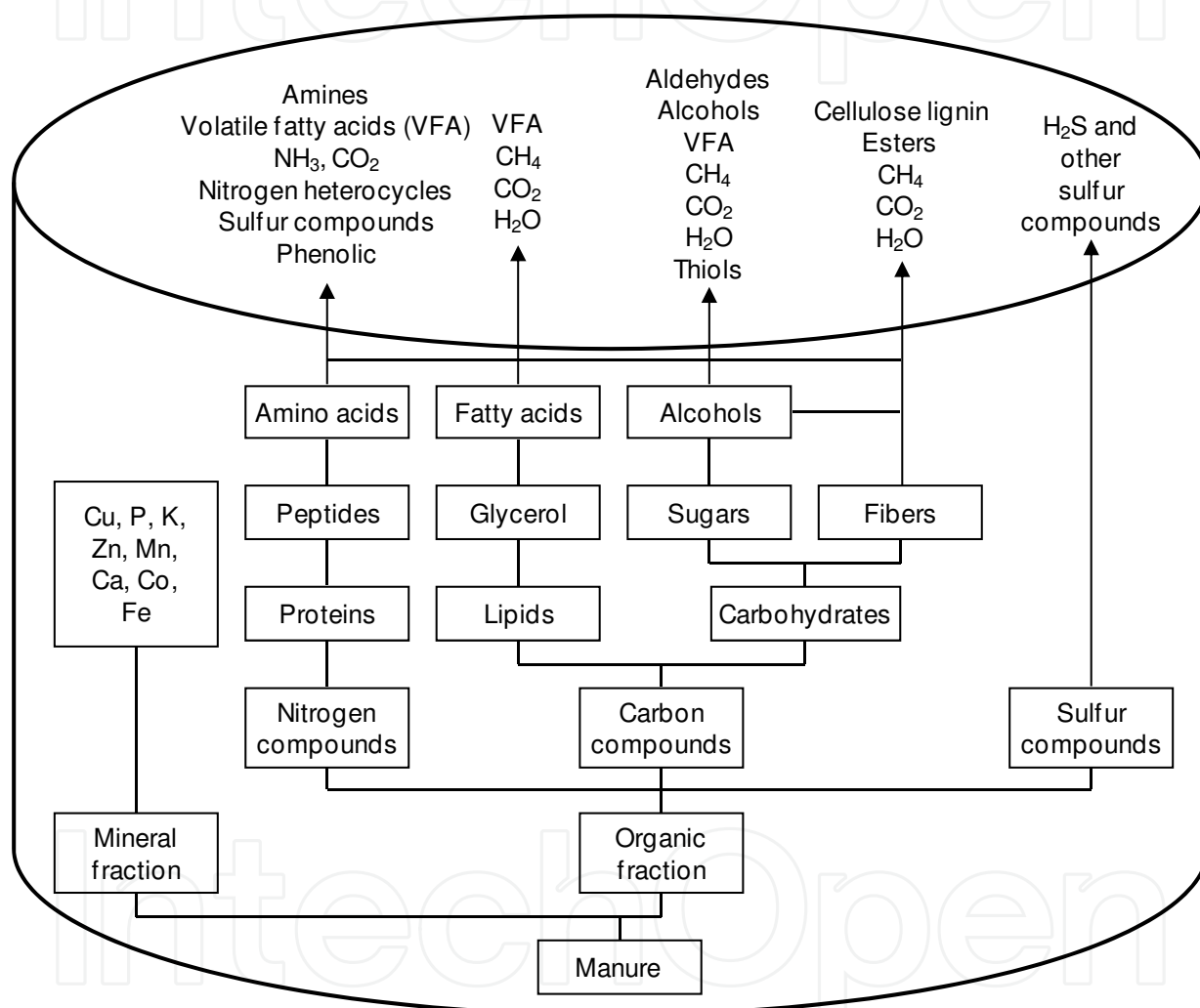

Fig. 1. Emissions from anaerobic decomposition of liquid manure (adapted from de la Farge, 1978; IPT, 1998; Taiganides, 1987; UGPVB, 1996; O'Neill & Phillips, 1992)

The majority of the pig and poultry operations are mechanically ventilated whereas confined cattle facilities are primarily naturally ventilated. The methodology to estimate gas emissions depends on wind speed, direction, building opening orientation and outside-inside temperature differential.

The inlet and outlet gas concentrations play an important role. Monitoring methodologies differ among countries. The air exchange rate of an animal housing facility must be

measured accurately. This would apply to both mechanically ventilated (MV) buildings and naturally ventilated (NV) facilities or a combination of the two ventilation systems. Buildings with combined systems are commonly referred to as hybrid ventilation systems (HV). Many methods have been developed to measure ventilation rates from animal housing facilities.

The following sections will address these topics with a complete description of an experimental setup used by the authors for sampling and analysis of GHG emitted by a number of non-cattle confinement buildings. Also best methods for measuring the air flow rate in both MV and NV barns are suggested.
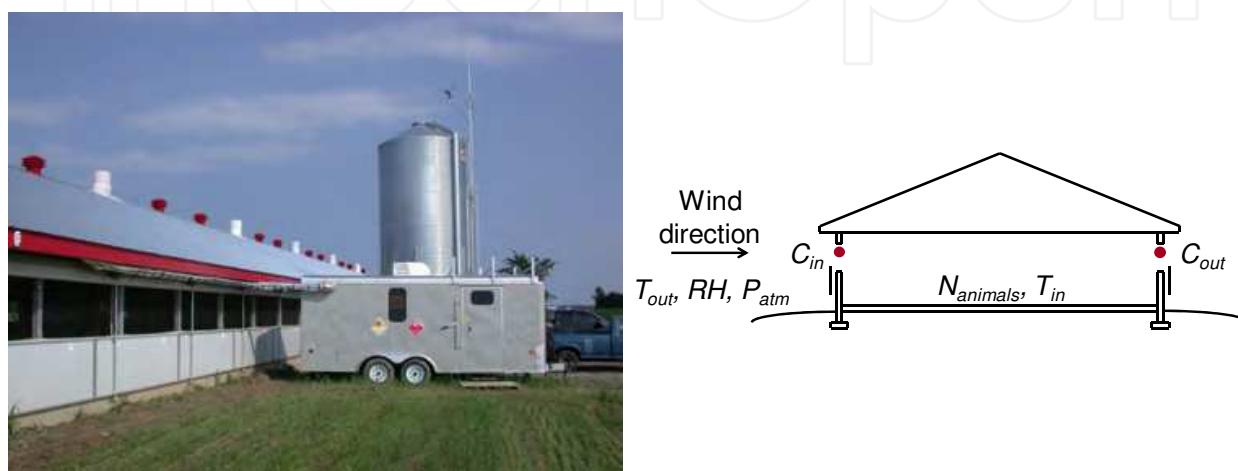

Fig. 2. View of an emission measurement set up on a naturally ventilated barn.

3. Concentration measurements: gas sampling and analysis

3.1 Atmospheric concentration gas analysis

Since the ambient air is used for ventilation of animal buildings, the determination of gas emissions from agricultural activities initially requires a measurement of the ambient air concentration. The contribution of farming systems under study may affect the GHG ambient concentrations near the facility. The measurement of atmospheric concentration need to use equipment having great sensitivity and selectivity like those utilizing optical properties of gas such as Fourier transform infrared spectroscopy (FTIR), photoacoustic spectroscopy (PAS) and non dispersive infrared analyser (NDIR) or separation techniques like chromatography with selective detectors (Neftel et al., 2006).

Since agricultural and forest soils are involved in gas exchange with the atmosphere and many agricultural activities like animal husbandry are significant sources of CH_4 and N_2O, several studies were conducted to quantify emissions from soils and livestock buildings. In those projects, a number of researchers primarily interested in the characterization of emissions from livestock buildings often work with PAS in the infrared (Blanes-Vidal et al., 2008; Cabaraux et al., 2008; Philippe et al., 2007). While for other authors interested in analytical development or atmospheric flux measurements from soils, separation by chromatography seems to be the preferred means of detection and quantification of trace gases in ambient air (Loftfield et al., 1997; Sitaula et al., 1992; Weiss, 1981; Blackmer & Bremner, 1977).

The air is mainly composed of N_2, oxygen (O_2) and argon (Ar) with several others gases in trace concentrations like CO_2, CH_4 and N_2O. These components can be separated by chromatography and detected by different detectors more or less specific to the target gas. The technique is simple, proven and allows the simultaneous quantification of CO_2, CH_4 and N_2O in the gaseous effluents discharged to the atmosphere. Compared to other techniques having the required sensitivity, like most modern spectroscopic techniques, the chromatography is known to produce reliable results and can be envisaged as a moderate to low cost technique with easy apparatus implementation.

These three GHG are easily separated at low temperature on a column filled with porous polymers Porapak Q or Chromosorb 102 (Cowper & DeRose, 1983). However, the analysis strategy depends on the detectors used and additional gases to be separated and quantified in the sample. Methane can be precisely measured by a flame ionization detector (FID) on a wide range of concentrations ranging from parts per million to volume percent (Cowper & DeRose, 1983) which is suitable for measuring emissions from a livestock building where CH_4 concentrations will range from atmospheric pressure of 1,7 ppmv (Brasseur et al., 1999) to less than 5 000 ppmv for most of the time. To measure atmospheric concentrations of CO_2, a particular approach should be implemented. The approach involves the reduction of CO_2 to CH_4 with hydrogen over a nickel catalyst and detection by the FID (Cowper & DeRose, 1983).

In order to obtain the required sensitivity for the quantification of N_2O at concentrations found in ambient air, the electron capture detector (ECD) is commonly used to measure atmospheric concentrations. Some work has been done with N_2 alone as a carrier gas (Jiang et al., 2007; Arnold et al., 2001; Loftfield et al., 1997) while others were performed with an Ar/CH_4 mix (95/5) as carrier gas or as make-up gas to the detector (Jiang et al., 2007; Heinemeyer & Kaiser, 1996; Sitaula et al., 1992; Weiss, 1981; Mosier & Mack, 1980). It was also noted that impurities in a carrier gas can strongly influence the response of the ECD (Phillips et al., 1979) and that the addition of O_2 in the carrier gas increases the sensitivity of ECD to allow the determination of atmospheric concentrations of CO_2 (Cowper & DeRose, 1983). Even if the dynamic range of the ECD is limited, the range of concentration for CO_2 and N_2O encountered for most confinement buildings are limited. The typical measured concentrations range from atmospheric concentration (360 ppmv for CO_2 and 0,31 ppmv for N_2O; Brasseur et al., 1999) up to 5 000 ppmv for CO_2 and up to 10 ppmv for N_2O.

3.2 Sampling and management of gas samples

The system developed for the quantification of gas emissions from the agricultural sector has two main functions, first the collection and management of the sample and second the analysis of the sample. Samples are taken sequentially from several sampling points and continuously transported to the analysis system. CO_2, CH_4 and N_2O are analyzed with a gas chromatograph (GC). An example of the gas sample collection system is shown in Fig. 3.

For each sample location, gases are pumped through a membrane filter made of polytetrafluoroethylene (50 mm diameter, 0,2 μm pore size) and routed in a Teflon tube (6,4 mm OD, 0.8 mm wall) of variable length depending on the distance between the sampling location and the analysis system. The Teflon tubes are connected to a rotary valve allowing the sequential sampling and analysis of up to 16 locations. A purge diaphragm pump allows
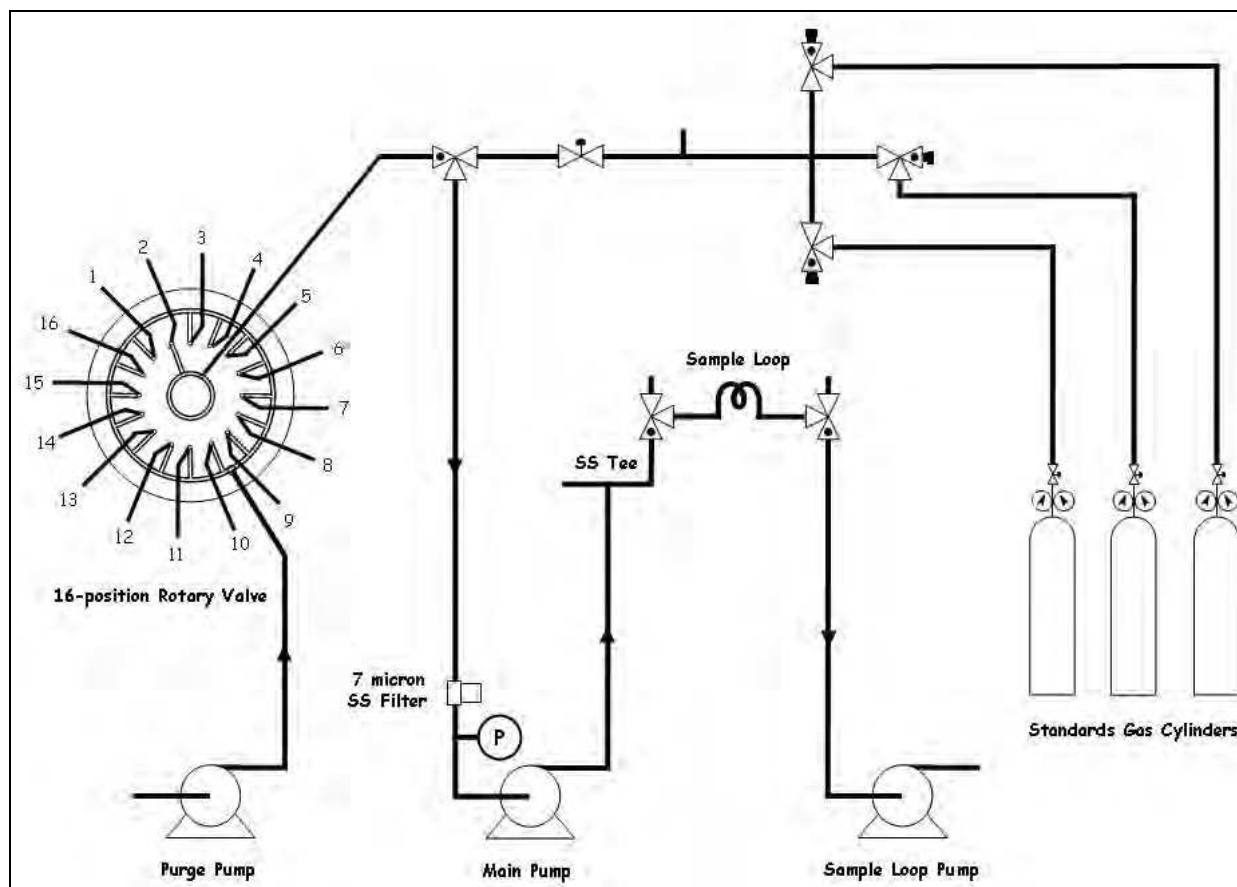
Fig. 3. Gas sample collection system

for back flowing of ambient air through the Teflon gas lines that are not under analysis to minimize stagnation of sample in the tubes.

The gas flow from the source to the analyser is provided by the main diaphragm pump which delivers the gas to a stainless steel tee fitting. A small filtering sleeve made of sintered stainless steel (7 µm pore size) placed upstream of the main pump provides extra equipment protection against fine dust. The stainless steel tee allows the diaphragm pump to draw a fraction of the sample to flow continuously through the 1 000 µL sample loop of the GC. Two solenoid valves are used to isolate the sample loop in order to balance the pressure of the sample with atmospheric pressure before injection. The sample excess is exhausted to the atmosphere.

The solenoid valve placed between the 16-position rotary valve and the main pump allow for selecting the sample gas analysed from the rotary valve or a selection of calibration gases including ambient air and pressurized gas cylinders controlled by solenoid valves.

All components of the sample collection system that are in contact with the sample gas are either Teflon (ex.: sample tubes), Teflon coated (ex. : pump diaphragms) or stainless steel 316 (ex.: rotary valve, fittings, etc.).

The Teflon sampling tubes from the sampling locations to the analyzer are placed inside a series of ducts maintained by circulating air at approximately 35 °C. The complete system including the 16-position rotary valve, the GC and the pumps are installed in a temperature

controlled mobile laboratory. T-type thermocouples are used to monitor the temperature in the heated ducts and the temperature inside and outside the mobile lab. A data logger controlled by the computer of the GC can acquire and archive various parameters measured during periods of analysis. It also controls the electric actuator of the 16-position rotary valve and the various solenoid activated valves of the gas collection system of the samples.

3.3 Chromatographic analysis of greenhouse gases

The strategy for the chromatographic analysis is the separation of the three gases on packed columns filled with the porous polymer Porapak Q 80/100 mesh. A pre-column (3,2 mm OD, 1 m long) connected in series before the analytical column (3,2 mm OD, 3 m long) removes some substances that may be present in the gas samples. These substances, which are retained longer than N_2O in the pre-column, can include water, NH_3 and some sulphur compounds that may have adverse effects on the detectors or on the columns.

CH_4 is quantified with a FID, while CO_2 and N_2O are measured with an ECD. However following the initial set-up of the chromatographic analysis, CO_2 was quantified with the FID after reduction with hydrogen over a nickel catalyst. Subsequently, following the chance observation of the detection of CO_2 by the ECD, the quantification of CO_2 is transferred to the ECD. This minimises the gradual loss of the effectiveness of the nickel catalyst and also allows a better separation of CO_2 and N_2O which is not affected by the disruption of the baseline caused by the actuation of the detector valve.

Figure 4 shows a schematic of the tubing configuration of the GC used for the separation and quantification of the greenhouse gases and Fig. 5 shows a picture of the column arrangement inside the GC oven and a picture of the outside of the GC.

The oven of the GC is maintained at 60 °C for the duration of the analysis. The 10-port injection valve and the 6-port detector valve are mounted on top of the GC. The zero grade nitrogen is used as carrier gas and is introduced at the three entry points of the pneumatic system of the GC at an equal flow rate of 25 ml min^{-1}. The two detectors are maintained at 325 °C and the FID is supplied with 30 ml min^{-1} of hydrogen UHP and with 300 ml min^{-1} of zero grade air produced by a commercial generator. All the necessary tubing, fittings and valves installed in the GC are made of stainless steel.

The sequence of the analysis begins when the injection valve is actuated to allow the carrier gas to flow through the sample loop and thus transfer the sample gas into the pre-column and the analytical column. After elution of the N_2O from the pre-column, the injection valve returns to its original position to allow the back flush of the pre-column and further elution of the analytical column. After detection of CH_4 on the FID, the detector valve is actuated to allow quantification of the CO_2 and N_2O on the ECD. The retention times are 2,9 min for CO_2, 1,6 min for CH_4 and 3,8 min for N_2O. Examples of chromatograms obtained for analysis of standard calibration gases and ambient air are presented in Figs. 6 and 7, respectively. With an analysis time of 5 min for the chromatographic analysis and a turnover of less than 7 min between analyses, the chromatographic system allows continuous acquisition of sufficient data to adequately describe agricultural process.

Normal operation of the GC is provided in part by the control software for the electrical parameters and also by periodic checks of the pressure on low pressure gauges on the

cylinder gas regulators and on the pressure gauges mounted on three controls of the carrier gas admission in the GC which operate near 234 kPa.
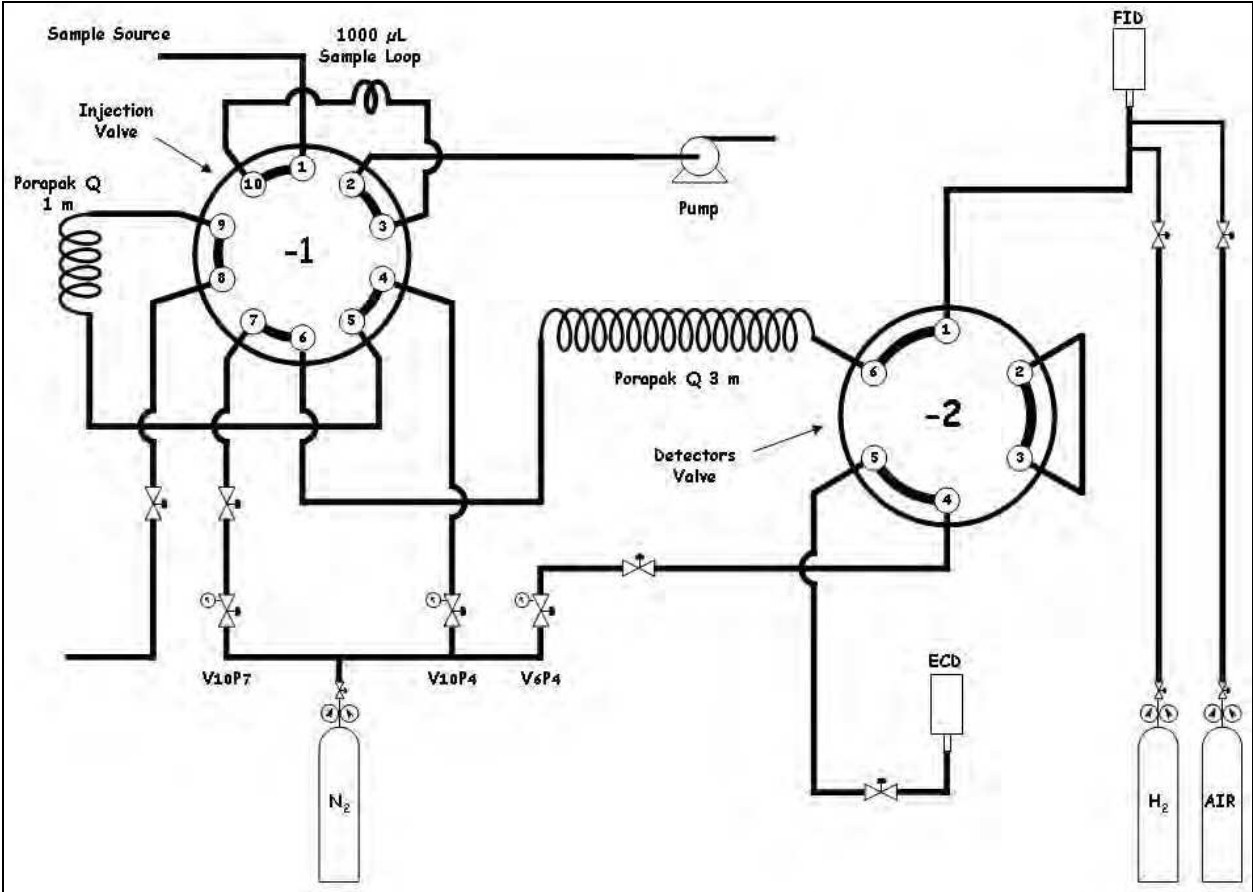

Fig. 4. Tubing configuration of the chromatograph

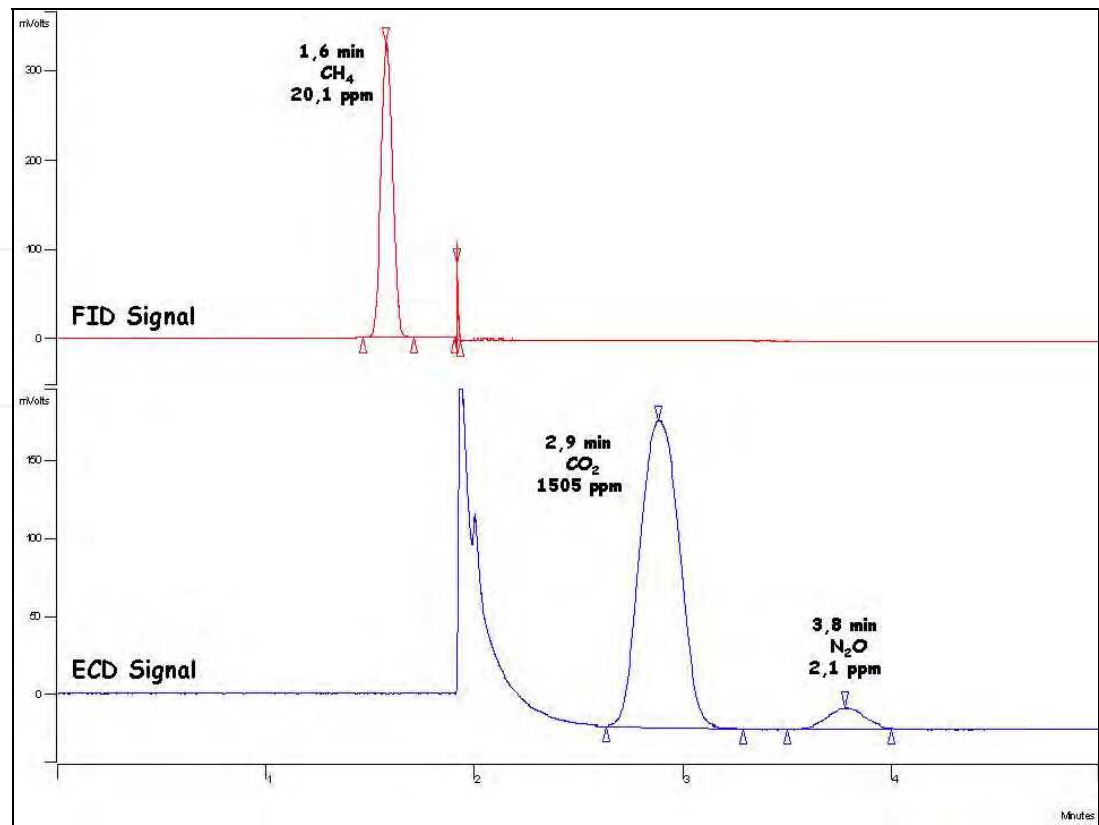Fig. 5. Standard gas chromatograph and oven

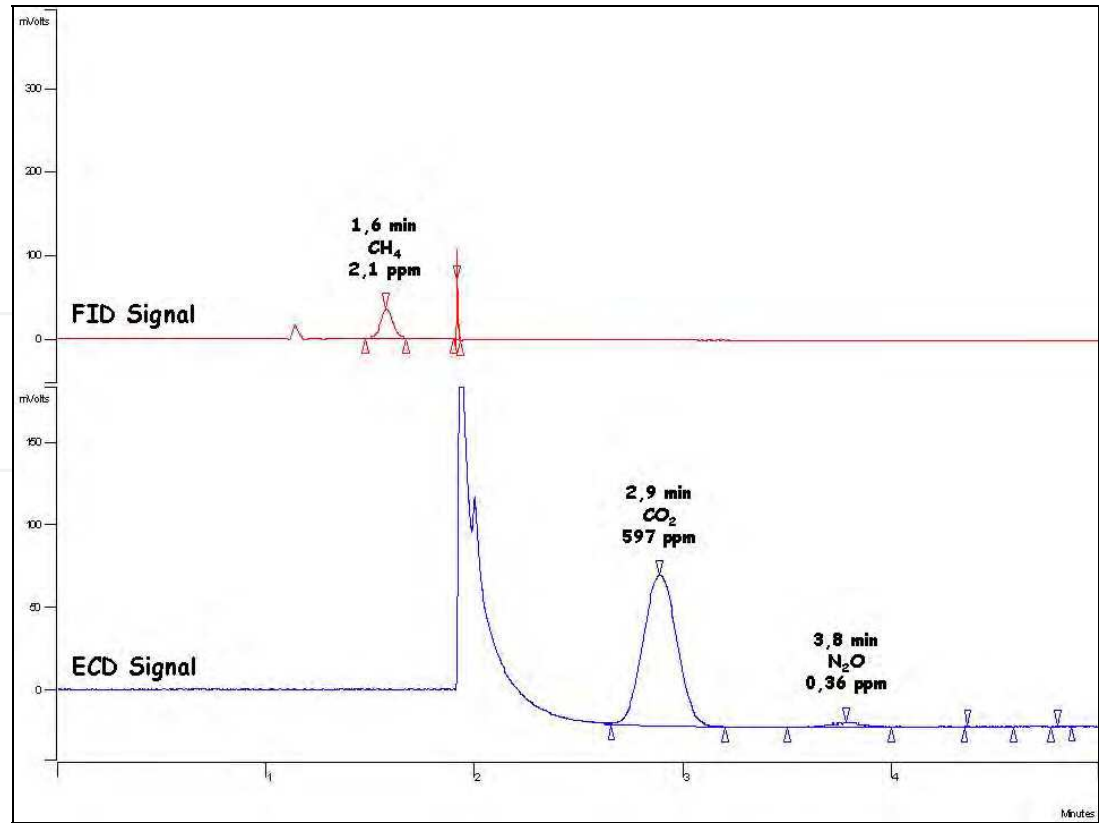Fig. 6. Chromatograms of the greenhouse standard calibration gases

Fig. 7. Chromatograms of an ambient air sample

3.4 Quality control of the analyses

Chromatographic instrumentation analysis is usually calibrated at the beginning of each period of analysis using standard calibration gases qualified as "Certified Standards". The three GHG are available mixed and diluted with N_2 in a single cylinder and at concentrations similar to those expected in real samples. The response factors of the chromatographic analysis are calculated with a single point calibration for each analyzed gas since the response of the detectors used are linear over the concentration ranges encountered.

To document the long-term performance of the overall system and to control the quality of the data obtained, standard analysis are performed automatically at a specified frequency. The samples used are the ambient air in the mobile laboratory and the standard gases from cylinders used for calibration of the GC. The curves showing the responses of the system over time are used to observe and confirm the periods of normal operation of the system and other statistical calculations on the results are used to estimate the overall accuracy of analysis including management and quantification of the sample. Table 1 shows typical examples of results for standard analysis.

	Ambient air			Standard calibration gases		
	CH_4	CO_2	N_2O	CH_4	CO_2	N_2O
Mean value (ppmv)	2,0	595	0,32	20,5	1 510	2,1
Precision (%)	5,8	4,6	16,0	1,0	3,8	5,8
Maximum value (ppmv)	2,4	638	0,41	20,7	1 589	2,3
Minimum value (ppmv)	1,9	541	0,21	20,1	1 403	1,9

Table 1. Typical concentrations measured for standard analysis

4. Ventilation rate measurement

4.1 Basic principle

To determine the gas emission rates of an animal housing facility, the air exchange rate of the facility must be measured accurately. In northern climates, HV buildings have become more common since buildings relying on NV during cold weather conditions develop numerous problems. These problems include poor inlet air distribution into the building, poor control of the exchange air within the building, uneven temperature and air velocity distribution throughout the building. Therefore, HV buildings rely on MV during cold weather conditions and on NV during spring, summer and fall weather conditions.

4.2 Mechanically ventilated barn

Many methods have been developed to measure ventilation rates from animal housing facilities. These have included airborne tracer techniques (Leonard et al., 1984), diffusion of animal-produced CO_2 (Feddes et al., 1984) or heat (Barber et al., 1994), vane anemometers (Heber et al., 2000), orifice plates (Godbout et al., 2005), multi-port averaging pitot tubes (Clark et al., 2008) and thermal (e.g., hot-wire) anemometers (Feddes & McQuitty, 1980). Each of these methods, however, has limitations.

Fan airflow rates can be evaluated using a standardized ventilation conduit developed using the standard ANSI/ASHRAE 41.2-1987 (RA 92) (ASHRAE, 1992). The static pressure

difference between the interior of the room and the outside of the building as well as the fan rotational speed of each ventilation stage should be continuously measured during the trials. During measurements within the duct, conditions occurring during each trial are recreated (static pressure and rotation speeds of each stage of ventilation). Collected data make it possible to calculate regression equations for each fan predicting air flow rate based on room static pressure and fan rotation speed. Regression equations are calculated from the supplier information (Belzile et al., 2006).

For MV buildings, the ventilation related data collected are: daily number of animals and their mass, hourly mean exhaust fan rotational speeds, building static pressures and hourly temperatures inside and outside the building.

Ventilation rates can be predicted using a CO_2 balance. Using data monitored in that barn, the animal CO_2 production values can be calculated from published data like, e.g., values suggested by CIGR (2002).

4.3 Natural and hybrid ventilated barn

Determining the ventilation rate of NV or HV buildings remains challenging. With ventilation controls becoming more sophisticated, side curtain and ridge vent openings can be controlled more precisely based on anticipatory logic used to determine upcoming temperatures and wind conditions. Traditionally, NV buildings have only been used for larger animals where changes in the thermal environment are not as critical. With improved controller logic, NV buildings will soon be used more extensively for housing smaller animals. Consequently, the ability to predict airflow in these facilities is very important in controlling the thermal and non-thermal well-being of the confined animals.

A number of researchers have proposed methods to calculate the air exchange rates in NV buildings. These airflow rates are dependent on wind speed at the opening and effectiveness of the opening. Morsing et al. (2002) and Choinière et al. (1988) reported coefficients to be used for agricultural buildings to calculate the wind speed at the opening. Nääs et al. (1998) and Choinière et al. (1988) described an algorithm to determine an opening effectiveness relative to the wind direction. This methodology is described as the ventilation rate due to wind and thermal buoyancy.

For HV buildings, the ventilation related data collected included: daily number of animals and their mass, hourly wind speed and direction, curtain opening areas, operating status of the exhaust fans and hourly temperatures inside and outside the building. As for MV buildings, ventilation rates from NV and HV barns can be predicted by establishing a CO_2 balance. In order to be representative, the CO_2 concentrations should be measured at least at three locations: on each side of the barn close to the curtains and in the center of the barn at the animal level. For HV barns, the CO_2 concentrations should also be measured close to the fans.

5. Emission factors from swine and poultry confined buildings

5.1 Swine production

The literature identifies emission factors from the three types of swine confinement buildings (Table 2). The swine production system begins with the maternity stage

comprising both of gestating sows and farrowing sows with their piglets. Gestating sows are usually reared either in individual stalls or in group pens. Farrowing sows and their piglets are mainly kept in farrowing crates. The swine nursery or post-weaning building rears the weaning piglets brought from the maternity. Piglets remain there until they reach a certain weight, generally between 20 and 25 kg. Feed and ambient conditions are adjusted with pig growth. Then, pigs are transferred to grower/finisher facilities until they leave for slaughter.

Growing phase	Gas	Units	Mean emissions[**]	Minimum value	Maximum value	Standard deviation
Maternity	CO_2	kg d^{-1} sow^{-1}	5,29	1,83	9,35	2,26
	CH_4	g d^{-1} sow^{-1}	30,1	13,3	119,7	25,3
	N_2O	g d^{-1} sow^{-1}	0,00	0,00	0,00	0,00
	GHG [*]	g CO_2-eq. d^{-1} sow^{-1}	632	-	-	-
Nursery	CO_2	kg d^{-1} $piglet^{-1}$	0,55	0,49	0,59	0,04
	CH_4	g d^{-1} $piglet^{-1}$	2,77	0,32	10,7	4,11
	N_2O	g d^{-1} $piglet^{-1}$	0,007	0,000	0,010	0,005
	GHG [*]	g CO_2-eq. d^{-1} $piglet^{-1}$	60,3	-	-	-
Grower/ finisher	CO_2	kg d^{-1} pig^{-1}	1,92	0,30	5,00	1,05
	CH_4	g d^{-1} pig^{-1}	5,54	1,16	17,5	4,72
	N_2O	g d^{-1} pig^{-1}	0,66	0,00	3,50	1,39
	GHG [*]	g CO_2-eq. d^{-1} pig^{-1}	321	-	-	-

[*] Total greenhouse gas emissions calculated on a CO_2-equivalent basis considering the mean emissions and the global warming potential of CH_4 (21) and N_2O (310).
[**] References: Gallman et al., 2003; Gallmann & Hartung, 2000; Godbout et al., 2003, 2006; Groot Koerkamp & Uenk, 1997; Guarino et al., 2003; Guimont et al., 2007; Hinz & Linke, 1998; Lemay et al., 2007; Sharpe et al., 2001; Zhang et al., 2007.

Table 2. GHG emission factors for swine confined buildings (adapted from Hamelin et al., 2009)

Overall, sows produce more CO_2 on an animal basis (5,29 kg d^{-1} $animal^{-1}$) than weanling piglets (0,55 kg d^{-1} $animal^{-1}$) or grower/finisher pigs (1,92 kg d^{-1} $animal^{-1}$) since the CO_2 production increases as the animal weight grows. In fact, the emission ratios between two growing stages correspond approximately to the animal unit ratios.

In the same way, the greater amount of urine and feces excreted by sows favours the establishment of anaerobic conditions and the CH_4 emission (30,1 g d^{-1} $animal^{-1}$) in comparison with the offspring (2,77 and 5,54 g d^{-1} $animal^{-1}$, respectively for weanling piglets and grower/finisher pigs).

N_2O emissions from maternity and nursery were relatively close to zero as found in several studies. Grower/finisher pigs emit 0,66 g N_2O d^{-1} $animal^{-1}$. The non frequent change in protein requirements during the growth stage leads to more N being excreted.

5.2 Poultry production

Broilers are mainly reared on a floor surface covered with bedding. Laying hens can be reared in multiple-deck battery cages, aviary systems, high-rise systems or percheries. In the first case, there is a possibility to dry manure directly under the cages with different manure drying systems. Table 3 presents emission factors from these two types of poultry production confinement buildings.

Production type	Gas	Units	Mean emissions **	Minimum value	Maximum value	Standard deviation
Broiler	CO_2	kg yr^{-1} $bird^{-1}$	31,5	31,5	31,5	-
	CH_4	g yr^{-1} $bird^{-1}$	12,3	8,3	20,0	6,7
	N_2O	g yr^{-1} $bird^{-1}$	17,6	4,0	34,2	12,6
	GHG *	kg CO_2-eq. yr^{-1} $bird^{-1}$	5,71	-	-	-
Layer	CO_2	kg yr^{-1} hen^{-1}	28,2	12,6	37,8	2,87
	CH_4	g yr^{-1} hen^{-1}	44,7	4,0	80,0	18,7
	N_2O	g yr^{-1} hen^{-1}	10,9	0,63	30,0	11,3
	GHG *	kg CO_2-eq. yr^{-1} hen^{-1}	4,32	-	-	-

* Total greenhouse gas emissions calculated on a CO_2-equivalent basis considering the mean emissions and the global warming potential of CH_4 (21) and N_2O (310).
** References: Chadwick et al., 1999; EPA, 2001; Fabbri et al., 2007; Fournel, 2011; Groot Koerkamp & Uenk, 1997; Hörnig et al., 2001; Monteny et al., 2001; Neser et al., 1997, as cited in Jungbluth et al., 2001; Sneath et al., 1996, as cited in Jungbluth et al., 2001; Wathes et al., 1997; Wu-Haan et al., 2007.

Table 3. GHG emission factors for broiler and layer confinement buildings

Broiler and layer productions emit similar quantities of CO_2 to the atmosphere (31,5 and 28,2 kg yr^{-1} $head^{-1}$, respectively). However, the different layer systems using liquid manure management generate a greater emission factor for CH_4 (44,7 g yr^{-1} $head^{-1}$) comparatively to broiler systems with litter (12,3 g yr^{-1} $head^{-1}$). On the other hand, litter increases the succession of nitrification and denitrification phases which result in greater N_2O emissions (17,6 g yr^{-1} $head^{-1}$ vs. 10,9 g yr^{-1} $head^{-1}$).

6. Mitigation techniques

6.1 In animal production

Several technologies have been developed to reduce gas and odour emissions from livestock housing. Several of these techniques, including reduction efficiencies for each technology, were inventoried by Godbout et al. (2010) from an exhaustive literature review. The inventory revealed that progress has been made in reducing odour and ammonia emissions, while less concern has been placed on GHG emissions. Three distinct techniques have been recognized, namely under slat separation, air cleaning and nutrient management.

6.2 In-barn manure management: under-slat separation

Separating urine and feces beneath the slats and removing both the solid and liquid fractions frequently is a reliable manure management technique to reduce gas and odour

emissions from buildings (Andersson, 1995; Arogo et al., 2001; Bernard et al., 2003; Jongebreur, 1981). The aim of this technique is to separate solid and liquid phases of the manure immediately after it falls through the slats to reduce the contact time between both phases. Three major under-slat manure separation systems have been studied over the years: the conveyor net, the V-shape scraper and the conveyor belt.

The conveyor net is composed of a mesh, tensioned under the slats, through which urine can flow while feces are collected. When this separation system is mechanized, the conveyor scrapes the feces to the end of the building while the urine stays in a gutter that is sloped toward a conventional storage pit (Fig. 8a).

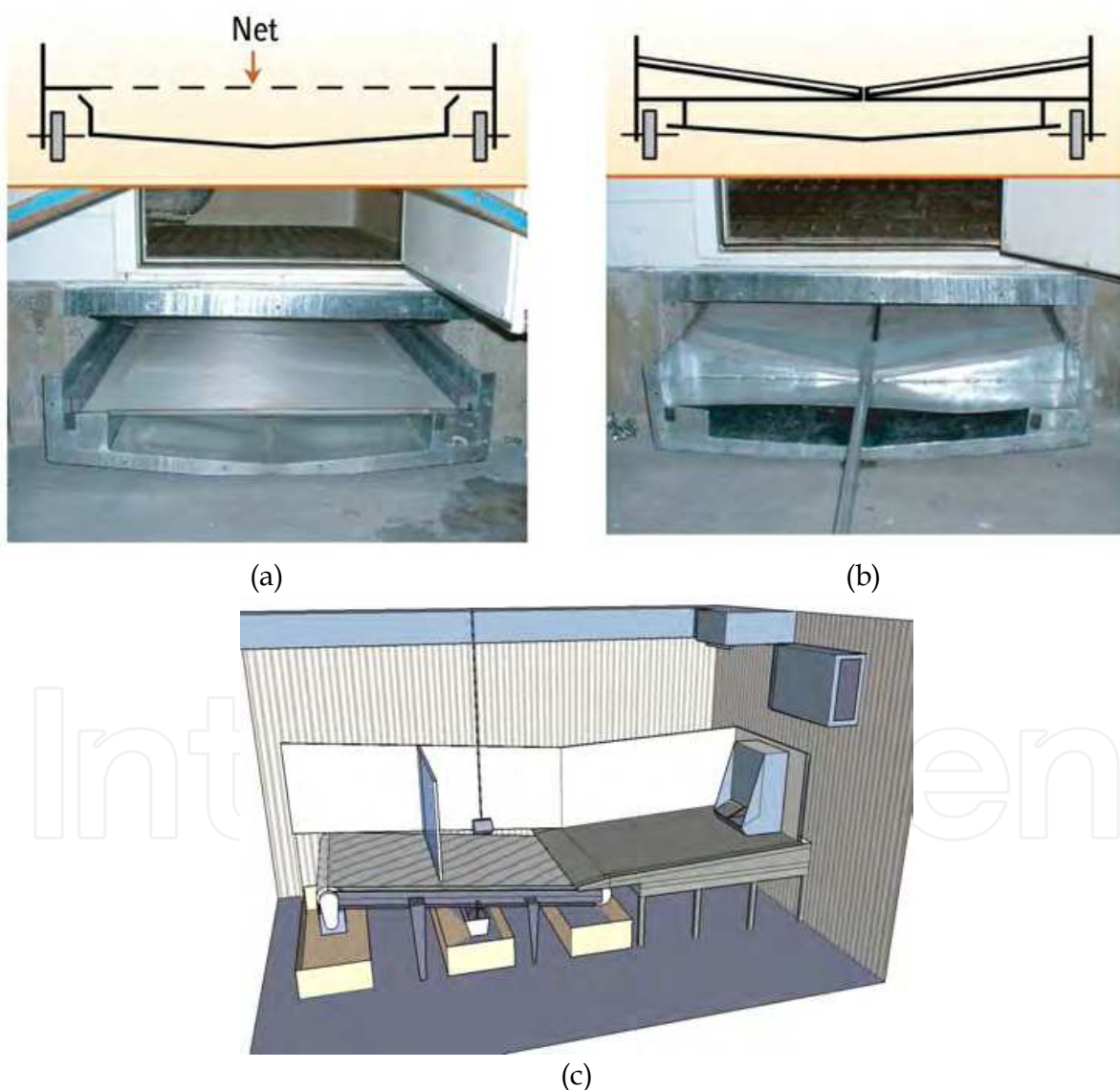(a)   (b)

(c)

Fig. 8. a) Conveyor net (Lemay et al., 2007); b) V-shape scraper (Lemay et al., 2007); c) Diagram of the conveyor belt (adapted from Lemay et al., 2007)

In V-shaped scrapers (Fig. 8b), the feces stay on inclined gutter walls while urine is gathered into the bottom of the gutter and continuously drains out of the room by gravity. The solid fraction remaining on the inclined walls is scraped at a certain frequency using mechanically driven scrapers. Godbout et al. (2010) measured CO_2 and CH_4 emissions from a V-shaped scraper and compared these to a pull-plug system (emptied every week). However, even if emission reductions were observed, there were no statistical differences.

Conveyor belts (Fig. 8c) were adapted from poultry to swine production, placing the belt at an angle under the slatted portion of the pens. Its lower edge feeds into a pipe that collects the urine and transports it to the end of the building, thus allowing the separate collection of urine and feces within the hog house (van Kempen et al., 2003). Koger et al. (2003) founded that CH_4 emission from a belt-based housing were reduced between 52 and 83% throughout the grower period studied comparatively to conventional pig houses.

Most of studies evaluating these techniques have been mainly conducted in order to measure the reduction of NH_3 emissions (Voermans and van Asseldonk, 1990; Voermans and van Poppel, 1993; Hendriks and van de Weerdhof, 1999). The study carried out by Belzile et al. (2006) found 13% and 19% CO_2 and CH_4 emission reduction, respectively, from a conveyor net compared to a drainage system without separation (emptied once a week). The same gas reduction values could be expected from the other separation techniques since they use the same principle.

6.3 Air cleaning

Air cleaning techniques for livestock buildings have the potential to improve air quality. However, efforts have been focused for improving performances on the reduction of dust and the abatement of NH_3 and H_2S. The air cleaning techniques are classified into two broad categories, physicochemical treatment and biological treatment (Godbout et al., 2010).

The physical - chemical absorption (scrubbing) is the physicochemical method most widely used for the treatment of air. This is a technology developed for many industrial applications. Gases are absorbed when the air from the barn is in contact with a liquid in which gas become soluble within the solution. The mass transfer from gas to the liquid is achieved by using a filter material within the filter unit (Devinny et al., 1999). The filter material usually has a large porosity, or void volume, and a large specific area (Melse & Ogink, 2005). Water is often used as the liquid solvent and its pH can be adjusted (basic or acid) depending on the pollutant to increase the solubility of gases. Contaminated air is introduced, either horizontally (crosscurrent) or upwards (counter-current), resulting in good contact between air and water, and enabling mass transfer from gas to liquid phase. A fraction of the trickling water is continuously recirculated; another fraction is discharged and replaced by fresh water (Fig. 9) (Melse & Ogink, 2005).

On the other hand, a biological treatment of air is based on the capacity of microorganisms to transform organic and inorganic pollutants into non-toxic compounds and odour free (Devinny et al., 1999; Hartung et al., 2001; Revah & Morgan-Segastume, 2005). Three main types of bioreactors are currently used: biofilters, biotrickling filters and bioscrubbers (Fig. 10). The basic mechanism is the same for all biological treatment systems; the difference is

due to the equipment configuration to carry out the transfer between the gas and the liquid, and on the pollutant biodegradation process (Table 4) (Devinny et al. 1999; Revah & Morgan-Segastume, 2005). Removal efficiency for NH$_3$ and H$_2$S emissions with a biological treatment can range from 6 to 100% and 3 to 99%, respectively (Nicolai & Janni 2001; Armeen, 2008; Iranpour et al., 2005). The reduction of odour emission is also widely variable, going from 29 to 100% depending of the operation conditions (Luo, 2001). A first bioreactor prototype developed by Belzile et al. (2010) found that NH$_3$ emissions from small-scale swine chambers were reduced by 62 to 91% and H$_2$S emissions were decreased by 24 to 66% by the biological treatment compared to a drainage system without separation (emptied once a week). However no significant reduction was obtained for CO$_2$ and CH$_4$ emissions at this first stage.
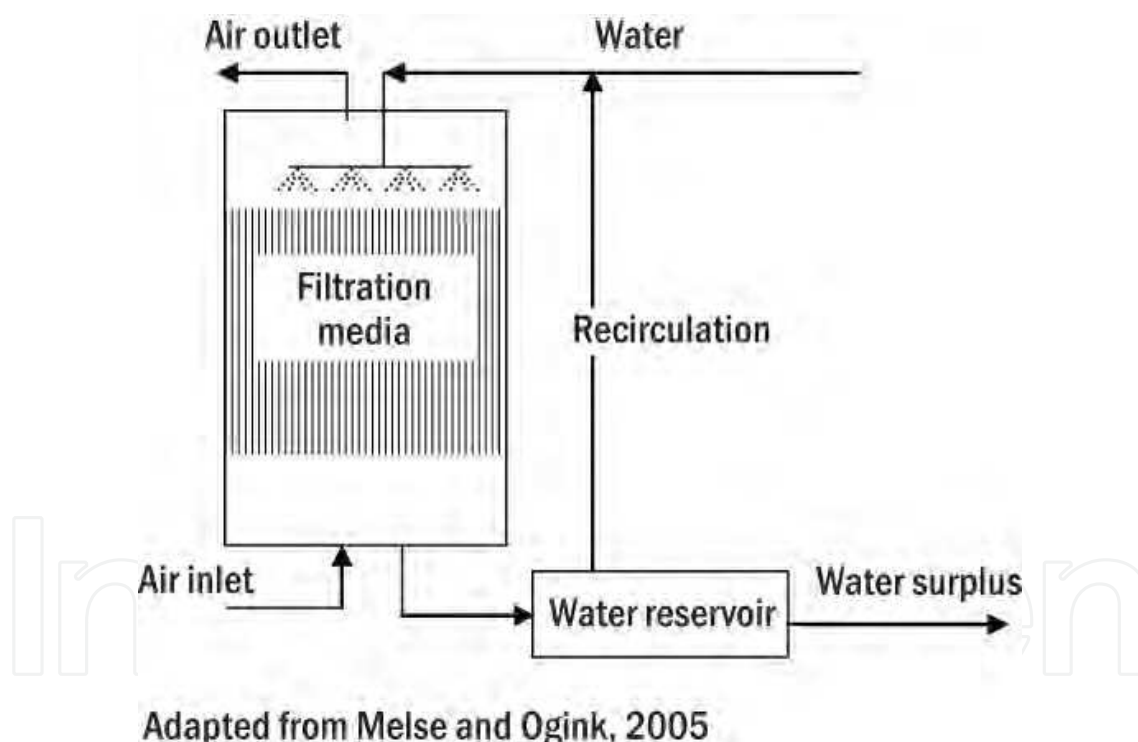

Fig. 9. A counter-current air scrubber (adapted from Melse & Ogink, 2005)

The discharged water from a scrubber might be used as nitrogen fertilizer for crops; sometimes the water is added to the liquid manure storage (Melse et al., 2009). The discharge water from a biotrickling filter might be treated in a denitrification process in order to decrease the nitrogen content (Melse et al., 2009; Sakuma et al., 2008).

Reactor	Microorganisms	Liquid phase
Biofilter	Fixed	Stationary
Biotrickling filter	Fixed	Flowing
Bioscrubber	Suspended	Flowing

Table 4. Classification of biological reactors for air treatment

(a)

(b)

(c)
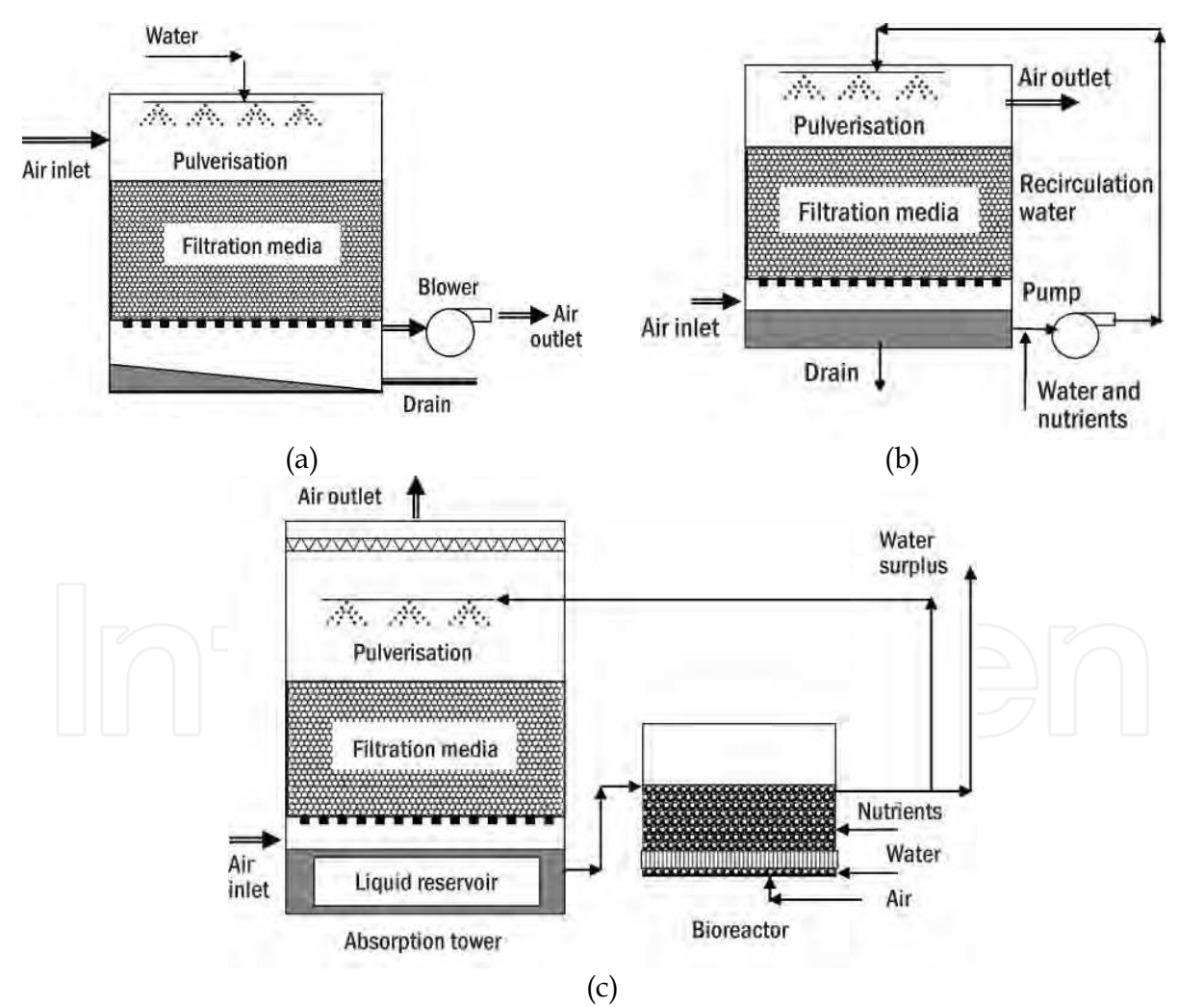
Fig. 10. a) Diagram of a closed biofilter system (adapted from Devinny et al., 1999);
b) Diagram of a biotrickling filter (adapted from Revah & Morgan-Segastume, 2005);
c) Diagram of a bioscrubber (adapted from Revah & Morgan-Segastume, 2005).

6.4 Nutrient management

An additional method to reduce emissions caused by excess nitrogen is the alteration of the ratio of nitrogen excretion in urine versus feces by nutrient management (Mroz et al., 1993). Reduction of dietary protein combined with supplementation of synthetic amino acids in pig diets might reduce total nitrogen excretion by 25 to 40% (Hartung & Phillips, 1994; Kay & Lee, 1997). Additionally, the inclusion of fermentable carbohydrates or non-starch polysaccharides into diets stimulates bacterial fermentation in the hindgut and reduced urinary versus fecal nitrogen ratio by 68% (Canh et al., 1997a).

However, GHG emission reduction is generally not measured or documented when using nutrient management. Principally, studies target reducing NH_3 and other odorant compound emissions (Garry et al., 2007; Le et al., 2006; Lyngbye et al., 2006). GHG emissions measurements (CO_2, CH_4 and N_2O) were carried out by Godbout et al. (2010) when protein content is reduced and lysine is increased in the diet. As a result, such diet treatment presented no impact on CO_2 and N_2O emissions while CH_4 emissions increased by 58% compared to a commercial diet. Therefore, a more thorough analysis should be carried out for a better understanding of dietary management in GHG emission reduction.

7. Summary and conclusions

Contaminants exhausted from confined animal buildings include various gases, dust particles, micro-organisms and odours. The most important gases are CO_2, NH_3, H_2S, CH_4, N_2O and some trace gases (aldehydes, amines, aromatics, organic acids, sulphur compounds, etc.). The main GHG emitted from livestock building are CH_4, N_2O (from manure decomposition) and CO_2 (from animal metabolism). Generally, CH_4 emissions are more present in liquid manure management while N_2O is produced under solid manure management.

The emission is the product of the gas concentration and the air exchange rate. An accurate measurement of these values is very important and is still a challenge today for emissions from agricultural sources. Since the agricultural emissions are very low, the concentration measurement requires equipment having great sensitivity and selectivity like those utilizing optical properties of gas such as FTIR, PAS and NDIR or separation techniques like chromatography with selective detectors. Most of the gases in air which are mainly composed of N_2, O_2 and Ar with several others gases in trace concentrations like CO_2, CH_4 and N_2O can be separated by chromatography and detected by different detectors more or less specific to the target gas. The technique is simple, proven and allows the simultaneous quantification of CO_2, CH_4 and N_2O. Compared to other techniques having the required sensitivity, like modern spectroscopic techniques, gas chromatography is known to produce reliable results and can be envisaged as moderate to low cost techniques with easy apparatus implementation.

The air flow measurement is very important and often, a lot of uncertainty is related to this value bringing an error in the emission determination. The measurement techniques are function of the ventilation system. Three main systems exist: MV, NV and HV buildings. Various methods have been developed to measure ventilation rate from animal housing facilities including airborne tracer techniques, diffusion of animal-produced CO_2 or heat, vane anemometers and orifice plates. Each of these methods, however, has limitations.

In the case where is not possible to measure emissions, values from literature can be used for swine, broiler and layer productions. The typical CO_2 emissions for sows, weanling piglets and grower/finisher pigs are 5,29, 0,55 and 1,92 kg d^{-1} animal^{-1}, respectively. The greater amount of urine and faeces excreted by sows favours the establishment of anaerobic conditions and the CH_4 emissions (30,1 g d^{-1} animal^{-1}) in comparison with the offspring (2,77 and 5,54 g d^{-1} animal^{-1}, respectively for weanling piglets and grower/finisher pigs). N_2O emissions from maternity and nursery were relatively close to zero as found in several studies. Grower / finisher pigs emit 0,66 g N_2O d^{-1} animal^{-1}. Broiler and layer productions emit similar quantities of CO_2 to the atmosphere (31,5 and 28,2 kg yr^{-1} animal^{-1}, respectively). However, the different layer systems using liquid manure management generate a greater emission factor for CH_4 (44,7 g yr^{-1} animal^{-1}) comparatively to broiler systems with litter (12,3 g yr^{-1} animal^{-1}). The N_2O emissions range from 10,9 to 17,6 g yr^{-1} head^{-1}. However, since the gas emissions are influenced by many factors, on-site measurement should be privileged instead of typical values from literature to determine the typical emissions from building.

Several technologies have been developed to reduce odour and gas emissions from swine housing. Two in-barn approaches are encouraging: the under slat separation system and diet manipulation while air cleaning systems have been developed for the exhaust air outlet. In agreement with the literature, the under slat separation system can reduce around 13% and 19% of CO_2 and CH_4 emissions, respectively. No studies have reported GHG emission reductions using diet manipulation. Many types of air cleaning systems already exist and they have been developed mainly for odour and ammonia emission reductions and the effect on GHG is not clearly shown.

8. Acknowledgments

9. References

Andersson, M. (1995). *The Effect of Different Manuring Systems on Ammonia Emissions in Pig Buildings. A Comparing Study between Scrapers Under Slatted Floors and Rubber Mats Under Slatted Floors*, Report 100, Lund, Swedish University of Agricultural Sciences, Department of Agricultural Biosystems and technology

Armeen, A.; Feddes, J. J. R.; Leonard, J. J., & Coleman, R. N. (2008). Biofilters to Treat Swine Facility Air: Part 1. Nitrogen Mass Balance. *Canadian Biosystems Engineering*, Vol.50, No.6, pp. 21-28

Arnold, S. L.; Parkin, T. B.; Doran, J. W.; Eghball, B. & Mosier, A. R. (2001). Automated Gas Sampling System for Laboratory Analysis of CH_4 and N_2O. *Communications in Soil Science and Plant Analysis*, Vol.32, No.17&18, pp. 2795–2807

Arogo, J.; Westerman, P.W.; Heber, A.J.; Robarge, W.P. & Classen, J.J. (2001). Ammonia in Animal Production –A Review, *ASAE Annual International Meeting*, Paper No 01-4089, Sacramento, California, USA, July 30-August 1, 2001

ASABE. (2010). *Psychrometric Data*, American Society of Agricultural and Biological Engineers,ASAE Standard D271.2 APR1976 (R2010)

ASHRAE. (1992). *Standard Methods for Laboratory Airflow Measurement*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, inc., ANSI/ASHRAE 41.2-1987 (RA 92), ISSN 1041-2336, Atlanta, Georgia, USA

Barrington, S. (1999). Comment se fait-il que les gaz des fumiers liquides soient tellement nauséabonds? [Why Do Gases from Liquid Manure Stink So Much?]. *Le producteur de lait québécois*, Vol.20, No.3, pp. 41-45

Barber, E.M. ; Strom, J.S.; Bantle, M.R.L.; Morsing, S. & Feddes, J.J.R. (1994). Ventilation Performance Standards – Applying Danish Experience in Canada. *Applied Engineering in Agriculture*, Vol.10, No.3, pp. 395-401

Belzile, M.; Lemay, S.P.; Zegan, D.; Feddes, J.J.R.; Godbout, S.; Larouche, J.-P.; & Martel, M. (2010). Reduction of Gas and Odour Emissions from a Swine Building Using a Biotrickling Filter, *XVIIth World Congress of the International Commission of Agricultural Engineering*, Québec City, Québec, Canada, June 13-17, 2010

Belzile, M.; Godbout, S. ; Lemay, S.P. ; Lavoie, J. ; Lachance, I. & Pouliot, F. (2006). Impact de la séparation fèces-urine sous caillebotis sur la qualité de l'air ambiant en porcherie [Impact of the Separation of Feces and Urine Under the Slats on the Quality of Ambient Air in Swine Buildings]. *Journées Recherche Porcine*, Vol.38, pp. 21-26.

Belzile, M.; Lemay, S.P.; Godbout, S.; Côté, C. & Lavoie, J. (2006). Gas Concentrations and Emissions in Milk-Fed Calf Buildings, *CSBE/SCGAB 2006 Annual Conference*, July 16-19, 2006

Bernard, C. ; Côté, D. ; Giroux, M. ; Grégoire, R. ; Joncas, R. & Martin, D.-Y. (2003). Mémoire de l'Institut de recherche et de développement en agroenvironnement inc. [Report of the Research and Development Institute for the Agri-Environment inc.]. In: *Commission sur le développement durable de la production porcine au Québec*, April 16, 2003

Blackmer, A.M. & Bremner, J.M. (1977). Gas Chromatographic Analysis of Soil Atmospheres. *Soil Science Society of American Journal*, Vol.41, pp. 908-912

Blanes-Vidal, V.; Hansen, M.N.; Pedersen, S. & Rom, H.B. (2008). Emissions of Ammonia, Methane and Nitrous Oxide from Pig Houses and Slurry: Effects of Rooting Material, Animal Activity and Ventilation Flow. *Agriculture, Ecosystems and Environment*, Vol.124, pp. 237-244

Brasseur, G.P.; Orlando, J.J. & Tyndall, G.S., (Ed.). (1999). *Atmospheric Chemistry and Global Change*. Oxford University Press, New York. In: Cabaraux, J.F.; Philippe, F.X.; Laitat, M.; Canart, B.; Vandenheede, M. & Nicks, B. (2008). Gaseous Emissions from Weaned Pigs Raised on Different Floor Systems. *Agriculture, Ecosystems and Environment*, Vol.130, pp. 86-92

Canh, T.T.; Verstegen, M.W.A.; Aarnink, A.J.A. & Schrama, J.W. (1997). Influence of Dietary Factors on Nitrogen Partitioning and Compositions of Urine and Feces of Fattening Pigs. *Journal of Animal Science*, Vol.75, pp. 700-706

Chadwick, D.R.; Sneath, R.W., Phillips, V.R. & Pain, B.F. (1999). A UK Inventory of Nitrous Oxide Emissions from Farmed Livestock. *Atmospheric Environment*, Vol.33, No.20, pp. 3345-3354

Choiniere, Y.; Blais, F. & Munroe, J.A. (1988). A Wind Tunnel Study of Airflow Patterns in a Naturally Ventilated Building. *Canadian Agricultural Engineering*, Vol.30, No.2, pp. 293-297

CIGR. (2002). *4th Report of Working Group on Climatization of Animal Houses – Heat and Moisture Production at Animal and House Levels*, International Commission of Agricultural Engineering, Section II, Horsens, Denmark

Clark, O.G.; Segura, J.C.; Feddes, J.J.R. & Ouellette, C. (2008). Multiport Averaging Pitot Tube to Measure Airflow Rates from Exhaust Fans. *Canadian Biosystems Engineering*, Vol.50, pp. 5.1-5.7

Cowper, C.J. & DeRose, A.J. (1983). The Analysis of Gases by Chromatography. Pergamon Series in Analytical Chemistry, Volume 7, Pergamon Press Ltd., United Kingdom

de la Farge, B. (1978). Les déchets de l'élevage porcin : traitement – valorisation [Swine Production Wastes: Treatment – Valorization]. Ph.D thesis, Université Paul Sabatier, Toulouse, France

Devinny, J. S.; Deshusses, M. A. & Webster, T. S. (1999). *Biofiltration for Air Pollution Control*, Lewis Publishers, Washington, DC, USA

EPA. (2001). *Emissions from Animal Feeding Operations*. Environmental Protection Agency, Draft Report No. 68-D6-0011. Research Triangle Park, North Carolina: Emission Standards Division, Office of air quality planning and standards

Fabbri, C.; Valli, L., Guarino, M., Costa, A. & Mazzotta, V. (2007). Ammonia, Methane, Nitrous Oxide and Particulate Matter Emissions from Two Different Buildings for Laying Hens. *Biosystems Engineering*, Vol.97, pp. 441-455

Feddes, J.J.R. & J.B. McQuitty. (1980). Design of an Air-Speed Sensor System. *Canadian Agricultural Engineering*, Vol.22, No.1, pp. 97-99

Feddes, J.J.R.; Leonard, J.J. & McQuitty, J.B. (1984). Carbon Dioxide Concentration As a Measure of Air Exchange in Animal Housing. *Canadian Agricultural Engineering*, Vol.26, No.1, p. 53-56

Fournel, S. (2011). *Étude comparative des émissions de gaz et d'odeurs issues de différents systèmes de gestion des déjections en production d'œufs de consommation* [Comparative Study of Gas and Odour Emissions from Different Manure Management Systems in Egg Production], M.Sc. thesis, Université Laval, Québec City, Québec, Canada

Gallmann, E. & Hartung, E. (2000). Evaluation of the Emission Rates of Ammonia and Greenhouse Gases from Swine Housings, *Proceedings of the 2nd International Conference on Air Pollution from Agricultural Operations*, pp. 92-99, Des Moines, Iowa, USA

Gallmann, E.; Hartung, E. & Jungbluth, T. (2003). Long-Term Study Regarding the Emission Rates of Ammonia and Greenhouse Gases from Different Housing Systems for Fattening Pigs – Final Results, *Proceedings of the International Symposium on Gaseous and odour emissions from animal production facilities*, pp. 122-130, Horsens, Denmark, June 1-4, 2003

Garry, B.P.; Fogarty, M.; Curran, T.P. & O'Doherty, J.V. (2007). The Effect of Cereal Type and Exogenous Enzyme Supplementation in Pig Diets on Performance, Odour and Ammonia Emissions from Finisher Pigs. *Livestock Science*, Vol.109, pp. 212–215

Guarino, M.; Fabbri, C., Navarotto, P., Valli, L., Moscatelli, G., Rossetti, M. & Mazotta, V. (2003). Ammonia, Methane and Nitrous Oxide Emissions and Particulate Matter Concentrations in Two Different Buildings for Fattening Pigs, *Proceedings of the International Symposium on Gaseous and odour emissions from animal production facilities*, pp. 140-149, Horsens, Denmark, June 1-4, 2003

Godbout, S.; Lemay, S.P.; Pelletier, F.; Belzile, M.; Larouche, J.P.; Tamini, L.D.; Palacios, J. H. & Zegan, D. (2010). *Réduction des émissions gazeuses et odorantes aux bâtiments porcins : techniques simples et efficaces applicables à la ferme* [Gas and Odour Emission Reductions in Swine Barns: Simple and Effective Techniques Applicable at the Farm], Final Report, Québec City, Québec, Canada: Research and Development Institute for the Agri-Environment inc.

Godbout, S.; Belzile, M., Lachance, I., Lemay, S.P., Turgeon, M.J., Dufour, V., Pouliot, F. & Marquis, A. (2006). *Évaluation technico-économique d'un système de séparation solide/liquide des déjections à la source dans un bâtiment porcin et les impacts sur l'environnement – Volet II* [Technico-Economical Assessment of an In-Barn Solid/Liquid Separation System for Pig Slurry and Impacts on the Environment – Phase II], Final Report, Québec City, Québec, Canada: Research and Development Institute for the Agri-Environment inc.

Godbout, S.; Lavoie, J.; Lemay, S.P.; Lachance, I.; Pouliot, F. & Belzile, M. (2005). Impact of In-Barn Manure Separation on the Biological Air Quality of Swine Buildings, *ASAE Annual International Meeting*, Paper No. 055018, Tampa, Florida, USA

Godbout, S.; Laguë, C., Lemay, S.P., Marquis, A. & Fonstad, T.A. (2003). Greenhouse Gas and Odour from Swine Operations Under Liquid Manure Management in Canada, *Proceedings of the International Symposium on Gaseous and odour emissions from animal production facilities*, pp. 426-443, Horsens, Denmark, June 1-4, 2003

Groot Koerkamp, P.W.G. & Uenk, G.H. (1997). Climatic Conditions and Aerial Pollutants in and Emissions from Commercial Animal Production Systems in the Netherlands, *Proceedings of the International Symposium of Ammonia and Odour Control from Animal Production Facilities*, pp. 139-144, AB Rosmalen : Netherlands

Guimont, H.; Dufour, V. ; Pelletier, F. ; Coulibaly, A. ; Giguère, C. ; Godbout, S. ; Lemay, S.P. ; Massé, D.I. ; Pouliot, F. & Fortin, N. (2007). Évaluation technique et économique d'un système d'isolement des fèces avec grattes en « V » dans un engraissement commercial. [Technical and Economical Assessment of a « V » Scraper System for Isolation of Feaces in a Commercial Fattening Barn], Rapport final [Final Report], Québec City, Québec, Canada : CDPQ, IRDA, La Coop fédérée & AAC

Hamelin, L.; Pelletier, F. & Godbout, S. (2007). Impacts environnementaux, économiques et sociaux des différentes chaînes de gestion des déjections des poules pondeuses [Environmental, Economical and Social Impacts of Different Manure Management Systems in Layer Production], Final Report, Québec City, Québec, Canada: Research and Development Institute for the Agri-Environment inc.

Hartung, J. & Phillips, V.R. (1994). Control of Gaseous Emissions from Livestock Buildings and Manure Stores. *Journal of Agricultural Engineering Research*, Vol.57, No.3, pp. 173-189

Heber, A.; Lim, T.; Ni, J.; Grant, R. & Sutton, A. (2000). *Development of a Site-Specific Odor Impact Distance Guideline for Swine Production Systems*, Report No. 98-131. Washington, DC: National Pork Producers Council

Heinemeyer, O. & Kaiser, E.A. (1996). Automated Gas Injector System for Gas Chromatography: Atmospheric Nitrous Oxide Analysis. *Soil Science Society of American Journal*, Vol.60, pp. 808-811

Hendriks, H.J.M & van de Weerdhof, A.M. (1999). *Dutch Notes on Bat for Pig- and Poultry Intensive Livestock Farming*. Draft published by Ministry of Housing, Spatial Planning and the Environment et Ministery of Agriculture, Nature Management and Fisheries, The Netherlands

Hinz, T. & Linke, S. (1998). A Comprehensive Experimental Study of Aerial Pollutants in and Emissions from Livestock Buildings – Part 2: Results. *Journal of Agricultural Engineering Research*, Vol.70, pp. 119-129

Hörnig, G.; Brunsch, R., Stollberg, U., Jelínek, A., Plíva, P. & Češpiva, M. (2001). Ammonia, Methane and Carbon Dioxide Emissions from Laying Hens Kept in Battery Cages and Aviary Systems, *Proceedings of the 2nd Agricultural Engineering Conference of Central and East European Countries*, pp. 37-43, Prague, Czech Republic, 23-24 October, 2001

Houghton, J.T.; Meira Filho, L.G.; Callander, B.A.; Harris, N.; Kattenberg, A. & Maskel, K., (Ed). (1995). *IPCC Second Assessment Report: Climate Change 1995*, 572 pp., Cambridge University Press

Iranpour, R.; Cox, H.H.J.; Deshusses M.A. & Schroeder, E.D. (2005). Literature Review of Air Pollution Control Biofilters and Biotrickling Filters for Odor and Volatile Organic Compound Removal. *Environmental Progress*, Vol.24, No.3, pp. 254-267

ITP. (1998). Odeurs et environnement – Cas de la production porcine [Odours and Environment – Swine Production Case]. Institut technique du porc, Paris, France

Jiang, X.; Ku, W.L.; Shia, R.L.; Li, Q.; Elkins, J.W.; Prinn, R.G. & Yung, Y.L. (2007). Seasonal Cycle of N_2O: Analysis of Data. *Global Biogeochemical Cycles*, Vol.21, doi:10.1029/2006GB002691

Jongebreur, A.A. (1981). *Housing System and Their Influence on the Environment. Environmental Aspects of Housing for Animal Production*, pp. 431-436, Butterworths, London, UK

Jungbluth, T.; Hartung, E. & Brose, G. (2001). Greenhouse Gas Emissions from Animal Houses and Manure Stores. *Nutrient Cycling in Agroecosystems*, Vol.60, pp. 133-145

Kay, R.M. & Lee, P.A. (1997). Ammonia Emission from Pig Buildings and Characteristics of Slurry Produced by Pigs Offered Low Crude Protein Diets, *Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities*, pp. 253-260, CIGR and EurAgEng publication, Rosmalen, The Netherlands

Koger, J.B.; Kaspers, B.A.; Burnette, R.P.; van Kempen, M.H.J.G. & van Kempen, T.A.T.G. (2003). *Manure Belts for Harvesting Urine and Feces Separately and Improving Air Quality in Swine Facilities*. Report to the Smithfield Panel, Raleigh, North Carolina, USA, 21 May, 2003

Le, P.D.; Aarnink, A.J.A.; Jongbloed, A.W.; van der Peet Schwering, C.M.C.; Ogink, N.W.M. & Verstegen, M.W.A. (2006). Effects of Crystalline Amino Acid Supplementation to the Diet on Odor from Pig Manure. *Journal Animal Science*, Vol.85, pp. 791–801

Lemay, S.P.; Godbout, S., Bergeron, R., Belzile, M., Predicala, B., Laguë,C., Marquis, A., Pouliot, F. & Rondeau, F. (2007). *Développement d'un nouveau concept d'enclos pour élevages porcins "sans lattes" permettant de séparer les déjections et de réduire les émissions gazeuses et odorants* [Development of a New Pen Concept Without Slats Allowing to Separate Slurry Phases and Reduce Gaseous and Odorant Emissions for Pig Production], Final Report, Québec City, Québec, Canada: Research and Development Institute for the Agri-Environment inc.

Leonard, J.J.; Feddes, J.J.R. & McQuitty, J.B. (1984). Measurement of VR Using a Tracer Gas. *Canadian Agricultural Engineering*, Vol.26, No.1, pp. 49-51

Loftfield, N.; Flessa, H.; Augustin, J. & Beese, F. (1997). Automated Gas Chromatographic System for Rapid Analysis of the Atmospheric Trace Gases Methane, Carbon Dioxide, and Nitrous Oxide. *Journal of Environmental Quality*, Vol.26 pp. 560-564

Luo, J. (2001). A Pilot-Scale Study on Biofilters for Controlling Animal Rendering Process Odours. *Water Science and Technology*, Vol.44, No.9, pp. 277-285

Lyngbye, M.; Hansen, M.J.; Riis, A.L.; Jensen, T.L. & Sørensen, G. (2006). 1000 Olfactometry Analyses and 100 TD-GC/MS Analyses to Evaluate Methods for Reducing Odour from Finishing Units in Denmark, *Workshop on Agricultural Air Quality*, Washington, D.C., USA

Melse, R.W.; Ogink, N.W.M. & Rulkens, W.H. (2009). Air Treatment Techniques for Abatement of Emissions from Intensive Livestock Production. *The Open Agriculture Journal*, Vol.3, pp. 6-12

Monteny, G.J.; Groenestein, C.M. & Hilhorst, M.A. (2001). Interactions and Coupling between Emissions of Methane and Nitrous Oxide from Animal Husbandry. *Nutrient Cycling in Agroecosystems*, Vol.60, pp. 123–132

Morsing, S.; Ikeguchi, A.; Bennetsen, J.C.;. Strøm, J.S; Ravn, P. & Okushima, L. (2002). Wind Induced Isothermal Airflow Patterns in a Scale Model of a Naturally Ventilated Swine Barn with Cathedral Ceiling. *Applied Engineering in Agriculture*, Vol.18, No.1, pp. 97-101

Mosier, A. R. & Mack, L. (1980). Gas Chromatographic System for Precise, Rapid Analysis of Nitrous Oxide. *Soil Science Society of American Journal*, Vol.44, pp. 1121-1123

Mroz, Z.; Jongbloed, A.W.; Beers, S.; Kemme, P.A.; de Jonge, L.; van Berkum, A.K. & van der Lee, R.A. (1993). Preliminary Studies on Excretory Patterns of Nitrogen and Anaerobic Deterioration of Faecal Protein from Pigs Fed Various Carbohydrates. In: *Nitrogen Flow in Pig Production and Environmental Consequences*, Verstegen, M.W.A.; den Hartog, L.A.; van Kempen, G.J.M. & Metz, J.H.M., (Ed.), 247-252, Pudoc Scientific Publishers, Wageningen, The Netherlands

Nääs, I.A.; Moura, D.J.; Bucklin, R.A. & Fialho, F.B. (1998). An Algortithm for Determining Opening Effectiveness in Natural Ventilation by Wind. *Transactions of the ASAE*, Vol.41, No.3, pp. 767-771

Neftel, A.; Fischer, C. & Flechard, C. (2006). Measurements of Greenhouse Gas Fluxes from Agriculture. *International Congress Series*, vol.1293, pp. 3-12

Nicolai, R.E. & Janni, K.A. (2001). Biofilter Media Mixture Ratio of Wood Chips and Compost Treating Swine Odors, Department of Biosystems and Agricultural Engineering, University of Minnesota, USA

Olsen, K.; Wellisch, M.; Boileau, P.; Blain, D.; Ha, C.; Henderson, L.; Liang, C.; McCarthy, J. & McKibbon, S. (2003). *Canada's Greenhouse Gas Inventory: 1999-2001*, Greenhouse Gas Division, Environment Canada, 205 pp.

O'Neill, D.H. & Phillips, V.R. (1992). A Review of the Control of Odour Nuisance from Livestock Buildings. Part 3. Properties of the Odorous Substances, Which Have Been Identified in Livestock Wastes or in the Air Around Them. *Journal of Agricultural Engineering Research*, Vol.53, No.1, pp. 23-50

Philippe, F.X.; Laitat, M.; Canart, B.; Vandenheede, M. & Nicks, B. (2007). Comparison of Ammonia and Greenhouse Gas Emissions Furing the Fattening of Pigs, Kept Either on Fully Slatted Floor or on Deep Litter. *Livestock Science*, Vol.111, pp. 144-152

Phillips, M.P.; Sievers, R.E.; Goldan, P.D.; Kuster, W.C. & Fehsenfeld, F.C. (1979). Enhancement of Electron Capture Detector Sensitivity to Nonelectron Attaching Compounds by Addition of Nitrous Oxide to the Carrier Gas. *Analytical Chemistry*, Vol.51, pp. 1819-1825

Revah, S. & Morgan-Sagastume, J.M. (2005). Methods of Odor and VOC Control. In: *Biotechnology for Odour and Air Pollution Control*, Shareefdeen, Z. & Singh, A., (Ed.), Springer, Verlag, Berlin, Heidelberg

Sakuma, T.; Jinsiriwanit, S.; Hattori, T. & Deshusses, M.A. (2008). Removal of Ammonia from Contaminated Air in a Biotrickling Flter – Denitrifying Bioreactor Combination System. *Water research*, Vol.42, pp. 4507–4513

Sharpe, R.R.; Harper, L.A. & Simmons, J.D. (2001). Methane Emissions from Swine Houses in North Carolina. *Chemosphere – Global change science*, Vol.3, pp. 1-6

Sitaula, B.K.; Luo, J. & Bakken, L.R. (1992). Rapid Analysis of Climate Gases by Wide Bore Capillary Gas Chromatography. *Journal of Environmental Quality*, Vol.21, pp. 493-496

Taiganides, E. P. (1987). Animal Waste Management and Wastewater Treatment. In: *World Animal Science B6, Animal Production and Environmental Health*, Strauch (Ed.), Elsevier, Amsterdam, 324 pp.

UGPVB. (1996). Les gaz en élevage porcin: une problématique à dominance ammoniac [Gases in Swine Production: Ammonia Is a Major Case], Union des groupements des producteurs de viande de Bretagne, 67 pp.

van Kempen, T.; Kaspers, B.; Burnette, P.; van Kempen, M. & Koger, J.B. (2003). Swine Housing With A Belt For Separating Urine And Feces; Key To Flexibility. *Swine Housings II Proceedings Conference*, pp. 159-165, Research Triangle Park, North Carolina, USA, 12-15 October, 2003. ASAE Publication Number 701P1303, ed. L.D. Jacobson.

Voermans, J.A.M. & van Asseldonk, M.M.L. (1990). Separation of Pig Manure Under a Slatted Floor. *Proefverslag-Proefstation-voor-de-Varkenshouderij*, No P1.151, 32 pp.

Voermans, J.A.M. & van Poppel, F. (1993). Scraper Systems in Pig Houses. *Proceedings of Livestock environment IV*, pp. 650-656, Coventry, UK, July 6-9, 1993

Wathes, C.M.; Holden, M.R., Sneath, R.W., White, R.P. & Phillips, V.R. (1997). Concentrations and Emissions Rates of Aerial Ammonia, Nitrous Oxide, Methane, Carbon Dioxide, Dust, and Endotoxin in U.K. Broiler and Layer Houses. *British Poultry Science*, Vol.38, No.1, pp. 14-28

Weiss, R.F. (1981). Determinations of Carbon Dioxide and Methane by Dual Catalyst Flame Ionization Chromatography and Nitrous Oxide by Electron Capture Chromatography. *Journal of Chromatographic Science*, Vol.19, p. 611-616

Wu-Haan, W.; Powers, W.J., Angel, C.R., Hale III, C.E. & Applegate, T.J. (2007). Effect of an Acidifying Diet Combined with Zeolite and Slight Protein Reduction on Air Emissions from Laying Hens of Different Ages. *Poultry Science*, Vol.86, pp. 182-190

Zhang, Q.; Zhou, X.J., Cicek, N. & Tenuta, M. (2007). Measurement of Odour and Greenhouse Gas Emissions in Two Swine Farrowing Operations. *Canadian Biosystems Engineering*, Vol.49, pp. 6.13-6.20
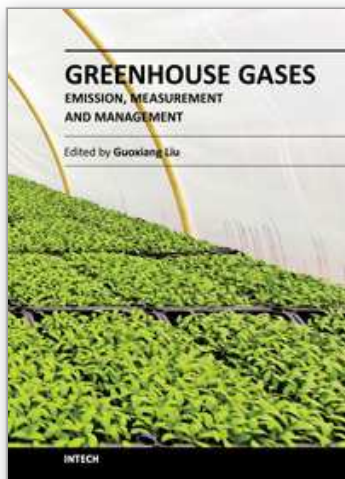
Greenhouse Gases - Emission, Measurement and Management

Edited by Dr Guoxiang Liu

ISBN 978-953-51-0323-3

Hard cover, 504 pages

Publisher InTech

Published online 14, March, 2012

Published in print edition March, 2012

Understanding greenhouse gas sources, emissions, measurements, and management is essential for capture, utilization, reduction, and storage of greenhouse gas, which plays a crucial role in issues such as global warming and climate change. Taking advantage of the authors' experience in greenhouse gases, this book discusses an overview of recently developed techniques, methods, and strategies: - A comprehensive source investigation of greenhouse gases that are emitted from hydrocarbon reservoirs, vehicle transportation, agricultural landscapes, farms, non-cattle confined buildings, and so on. - Recently developed detection and measurement techniques and methods such as photoacoustic spectroscopy, landfill-based carbon dioxide and methane measurement, and miniaturized mass spectrometer.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

S. Godbout, F. Pelletier, J.P. Larouche, M. Belzile, J.J.R. Feddes, S. Fournel, S.P. Lemay and J.H. Palacios (2012). Greenhouse Gas Emissions Non-Cattle Confinement Buildings: Monitoring, Emission Factors and Mitigation, Greenhouse Gases - Emission, Measurement and Management, Dr Guoxiang Liu (Ed.), ISBN: 978-953-51-0323-3, InTech, Available from: http://www.intechopen.com/books/greenhouse-gases-emission-measurement-and-management/greenhouse-gas-emissions-from-non-cattle-confined-buildings-monitoring-emission-factor-and-mitigatio

INTECH

open science | open minds