

Measurement of odour and greenhouse gas emissions in two swine farrowing operations

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Zhang, Q., Zhou, X.J., Cicek, N. and Tenuta, M. 2007. **Measurement of odour and greenhouse gas emissions in two swine farrowing operations.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 49: 6.13 - 6.20. Odour and greenhouse gas (GHG) emissions were measured on two 3000-sow swine farrowing farms, one with open earthen manure storage (EMS) and another with negative air pressure (NAP) covered EMS. Air samples were taken in Tedlar bags with a vacuum chamber from exhaust fans of barns and the NAP EMS. A wind tunnel was used to collect air samples from the manure surface in the open EMS. Collected samples were analyzed for odour concentrations with a dynamic dilution olfactometer and for GHG concentrations with gas chromatography. The average odour emission rate of the two farms was 316 OU s⁻¹ AU⁻¹ (AU – animal unit) from farrowing rooms and 113 OU s⁻¹ AU⁻¹ from gestation rooms. Odour emission from the NAP EMS was negligible in comparison with the open EMS. The open EMS contributed 57% to the total odour emission from the operation; whereas the NAP EMS contributed only 2% to the total emission. The total odour emission from the farm with NCP EMS was 58% of that from the farm with open EMS. The CO₂ emission rates from the building exhaust ranged from 4.8 to 16.6 kg d⁻¹ AU⁻¹ and the rate from farrowing rooms was significantly higher than that from gestation rooms. The CH₄ emission rates from the building exhaust ranged from 73 to 351 g d⁻¹ AU⁻¹. Both CO₂ and CH₄ emissions (CO₂ = 2 g d⁻¹ m⁻²; CH₄ = 0.3 g d⁻¹ m⁻²) from the secondary cell of the NAP EMS were negligible in comparison with the primary cell (CO₂ = 89 g d⁻¹ m⁻²; CH₄ = 30 g d⁻¹ m⁻²) or with the open EMS (CO₂ = 455 g d⁻¹ m⁻²; CH₄ = 44 g d⁻¹ m⁻²). The CO₂ emission rate from the primary cell of the NAP EMS was significantly lower than that from the open EMS. Although the CH₄ emission rate from primary cell of the NCP EMS was not significantly different from the open EMS, the total CH₄ emission from the NCP EMS was only 26% of that from the open EMS because the size of the primary cell of the EMS was small in comparison with the open EMS. **Keywords:** swine operation, odour, greenhouse gases.

Les émissions d'odeur et de gaz à effet de serre (GES) ont été mesurés pour deux maternités porcines de 3000 truies dont l'une était munie d'une structure d'entreposage de lisier en sol (SES) et l'autre d'une SES équipée d'une membrane à pression négative (MPN). Des échantillons d'air ont été prélevés à la sortie des ventilateurs des porcheries et de la SES MPN à l'aide d'une chambre à pression négative et ceux-ci ont été emmagasinés dans des sacs en Tedlar. Un tunnel à soufflerie a été utilisé pour recueillir des échantillons d'air provenant de la surface du lisier de la SES non couverte. Les échantillons recueillis ont été analysés à l'aide d'un olfactomètre à dilution dynamique pour déterminer les concentrations en odeur et d'un chromatographe en phase gazeuse pour évaluer les concentrations de GES. Les moyennes de taux d'émissions d'odeurs des deux porcheries étaient de 316 OU s⁻¹ UA⁻¹ (OU – unité d'odeur; UA – unité animale) pour les salles de mise bas et 113 OU s⁻¹ UA⁻¹ pour les salles

de gestation. Les émissions d'odeur provenant de la SES MPN étaient négligeables en comparaison avec celles de la SES non couverte. La SES non couverte contribuait à 57% du total des émissions d'odeurs provenant de la ferme; tandis que la SES MPN contribuait à seulement 2% du total des émissions d'odeurs. Le total des émissions d'odeurs de la ferme équipée d'une SES MPN représentait 58% de celles provenant de la ferme munie d'une SES non couverte. Les taux d'émissions de dioxyde de carbone (CO₂) provenant des ventilateurs d'évacuation des porcheries ont varié de 4,8 à 16,6 kg j⁻¹ UA⁻¹ et les taux provenant des salles de mise bas étaient significativement supérieurs à ceux des salles de gestation. Les taux d'émissions de méthane (CH₄) provenant des ventilateurs d'évacuation des porcheries ont varié de 73 à 351 g j⁻¹ UA⁻¹. Les émissions de CO₂ et CH₄ (CO₂ = 2 g j⁻¹ m⁻²; CH₄ = 0.3 g j⁻¹ m⁻²) provenant de la cellule secondaire de la SES MPN étaient négligeables en comparaison à celles de la cellule primaire (CO₂ = 89 g j⁻¹ m⁻²; CH₄ = 30 g j⁻¹ m⁻²) ou de celles de la SES non couverte (CO₂ = 455 g j⁻¹ m⁻²; CH₄ = 44 g j⁻¹ m⁻²). Les taux d'émissions de CO₂ provenant de la cellule primaire de la SES MPN étaient significativement plus faibles que ceux de la SES non couverte. Bien que les taux d'émissions de CH₄ provenant de la cellule primaire de la SES MPN n'étaient pas significativement différents de ceux de la SES non couverte, les émissions totales de CH₄ de la SES CNP représentaient seulement 26% de celles de la SES non couverte car la cellule primaire de la SES MPN était plus petite en comparaison à celle de la SES non couverte. **Mots clés:** ferme porcine, odeur, gaz à effet de serre.

INTRODUCTION

Odour is one of the major concerns to the general public when considering the siting of new or the expansion of existing swine operations. Odour associated with swine operations is from three main sources: (1) building exhaust, (2) manure storage, and (3) land application. A shift to injection-spreading of manure seems to result in more odour complaints traceable to animal production facilities and manure storage units than to the land application of manure (Jacobson et al. 1998). In other words, odour from land application is becoming less of a concern as more and more swine producers are adopting manure injection. Odour emission from swine buildings is influenced by a number of factors, such as the type of operation, management practice, manure handling and storage, and ventilation. Odour emission rates reported in the literature vary widely among different facilities and within the same type of facilities (Zhang et al. 2002). Odour emission from manure storage also varies widely with the type of storage facilities. To develop odour control strategies, it is important to quantify odour emissions from each of the two main sources (buildings and manure

MATERIALS and METHOD

Site description

Two farms (A and B) with 3000-sow farrowing operation, located in southern Manitoba, were selected for this study. The two farms were similar in layout, each with 17 production rooms, but Farm A had an additional quarantine room at the end of the building (Fig. 1). The barns on both farms were mechanically ventilated with wall mounted exhaust fans. Farm A had 90 exhaust fans, including six in the quarantine room and Farm B had 84. Since the quarantine room was normally empty, its contributions to odour and GHG emissions were negligible. Both farms were owned by the same company; therefore, the operation and management, including feed rations, were similar between the two farms. Manure on both farms was handled as liquid which was stored in under-floor shallow gutters and then removed to outdoor earthen manure storage (EMS) once every week from gestation/breeding rooms and once every three weeks from farrowing rooms. The major difference between the two farms was that Farm A had a two-cell EMS with negative air pressure covers (NAP); whereas Farm B had an open single cell EMS. The NAP technology was developed by DGH Engineering Inc. (DGH Engineering Inc., St. Andrews, MB). The cover was made of reinforced polyethylene plastic and anchored in a trench along the perimeter of the EMS. A system of perforated pipes and fans (Fig. 1) drew air from underneath the plastic cover to create a negative pressure under the cover. This negative pressure secured the plastic cover on the manure surface. Although odour emission from the two-cell EMS would be different from the single cell EMS, the NAP cover system virtually eliminated odour emission year round (Small and Danesh 1999). In other words, emissions from the EMS on Farm A would be negligible no matter if the EMS was two cells or a single cell.

Air sampling from barns

Because of the large number of exhaust fans (90 and 84 on the two farms, respectively) and the limit of the number of samples that could be handled in the olfactometry lab for odour analysis, taking samples from all exhaust fans was not feasible. Based on the production schedule, at least one room was sampled to represent other rooms at the same production stage. For each room, a composite sample was collected by sampling from two or three exhaust fans in the center of the room. Air samples were collected in 10-L Tedlar bags using a vacuum chamber (AC'SCENT Vacuum chamber, St. Croix Sensory Inc., Stillwater, MN). When sampling, a bag was placed in the chamber and the inlet of the bag was connected to a Teflon probe which was placed in the mid stream of the airflow from the exhaust fan. Each sample was taken in two steps: (i) fill the bag with 2 L of sample air and then evacuated to "coat" the bag, and (ii) draw odorous air into the bag at a rate of 1 to 2 L/min until the bag was 75% full. For each sampling session, one reference sample was taken upwind from the facility to represent the background odour level.

To determine the ventilation rate for each room, air velocity was measured at five points across the radius of each and every running fan in the room with a hot wire anemometer (FloRite 800, Bacharach, Pittsburgh, PA). The airflow rate for each fan was estimated from the average air velocity and fan (duct) diameter. This is a simplified method based on a standard

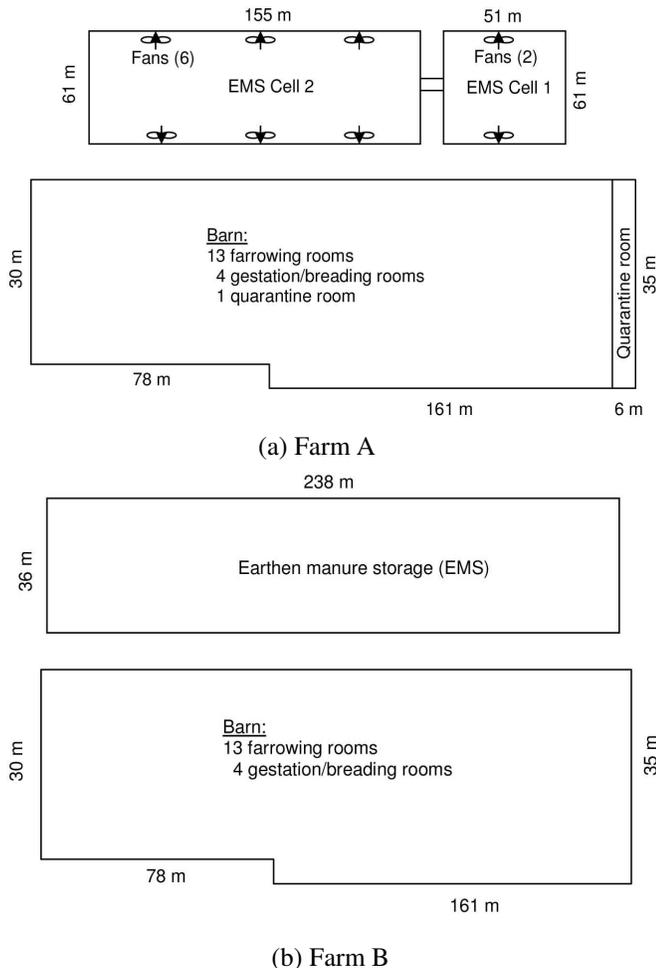


Fig. 1. Sketch of site plans of two swine farms on which odour and greenhouse gas measurements were taken (no drawn to scale).

storage). Producers and regulatory authorities often need the baseline data in accessing the effectiveness of odour control technologies. For example, some municipalities in Manitoba require the swine producers to cover their manure storage units. An often asked question is: *Would covering the manure storage unit be sufficient to alleviate the odour problem?* To answer this question, we need to know the relative contributions to odour from barns and the manure storage. The first objective of this study was to quantify these relative odour contributions by comparing odour emissions between two similar swine operations with different manure storage systems – open and covered manure storage. This information will assist producers and regulatory authorities in making decisions on what to focus on, barns or manure storage, when adopting and recommending odour control technologies.

It is estimated that agricultural operations contribute approximately 8% of the total greenhouse gas (GHG) emissions in 2002 in Canada, with about 49% of that originating from livestock production (Matin et al. 2004). However, little is known about the relative contributions to GHG emissions from barns and manure storage in swine production. The second objective of this study was to determine these relative contributions.

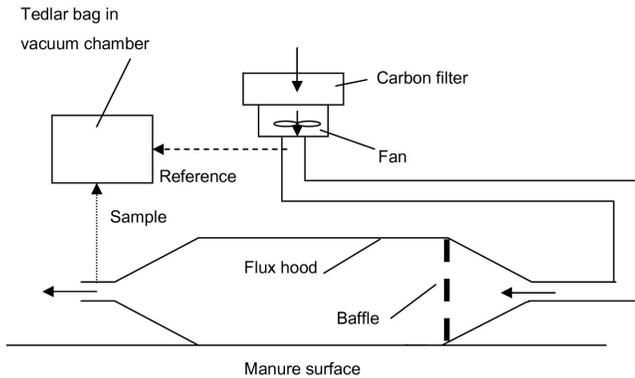


Fig. 2. Floating wind tunnel for sampling emissions from the manure surface in open earthen manure storage (EMS).

method of AMCA (1999) that recommends four measurement points across one radius for a total of six radii. Due to the large number of fans in the barns, it was unrealistic to measure 24 points for each fan; therefore, the air velocity profile across one radius was considered representative for the duct cross-section.

Air temperature was also recorded from the hot wire anemometer for each fan to estimate the room temperature. A portable weather station (WatchDog Model 550, Spectrum Technologies, Inc., Plainfield, IL) was set up near the barn to record outdoor temperature, relative humidity, and solar radiation.

Air sampling from manure storage

A floating wind tunnel was used to collect air samples from the manure surface in the open EMS (Fig. 2). There are no universally accepted standard devices for sampling odour from manure surfaces. Commonly used methods are wind tunnels and flux hoods. One of the earliest wind tunnels for odour emission measurement was introduced by Lindvall (Lindvall et al. 1974). A research team at University of New South Wales (UNSW) improved Lindvall's design and developed the UNSW wind tunnel. The team extensively studied the aerodynamic characteristics and performance of the UNSW wind tunnel (Jiang et al. 1995; Bliss et al. 1995; Jiang and Kaye 1997; Wang et al. 2001). After an extensive review of various odour sampling methods, Gostelow et al. (2003) concluded that the UNSW wind tunnel "would appear to be the choice of hood for emission measurement from liquid surfaces". The design and operation of the wind tunnel in this study followed the specifications of the UNSW wind tunnel. The standard dimensions of the UNSW wind tunnel are given by UNSW (2006). The wind tunnel covered a surface area of 0.32 m² (0.8 m x 0.4 m). Fresh air was drawn through a carbon filter and introduced into the sample collection hood through a 100-mm diameter PVC duct (Fig. 2). Airflow rates were measured inside the duct using a hot wire anemometer and were adjusted if necessary to maintain an air velocity of 0.3 m/s.

For each sampling session, two odour samples were collected at the outlet of the hood and one reference sample was collected after the carbon filter using a vacuum chamber and Tedlar bags (Fig. 2). Manure temperature was measured at 100 mm below the manure surface using a digital thermocouple indicator.

For the NAP EMS on Farm A, one composite sample was taken from the exhaust fans on each of the two cells, and airflow rate from the exhaust fans was measured in the same fashion as for building exhaust fans. It should be noted that manure temperature in the NAP EMS could not be measured because the manure under the cover was not accessible.

Sampling dates

Air samples were taken on 19 different dates in September and October 2003 and from June to September 2004. On each sampling date, eight samples were taken from the building exhaust and two from manure storage. Therefore, a total of 152 samples were taken from building exhaust and 38 from manure storage on the two farms. The majority (57%) of these samples were taken in the afternoon, 31% in the morning, and 22% in the evening. The outdoor temperature ranged from 8 to 32°C on these sampling dates.

Odour and greenhouse gas analysis

Collected samples (in Tedlar bags) were evaluated within 24 h for odour concentrations. A single-port olfactometer (AC'SCENT, St. Croix Sensory Inc., Stillwater, MN) with six trained assessors was used for odour concentration measurement. The triangular forced-choice method was used to present samples to the assessors, with a 3-s sniff time. Assessors were selected and re-evaluated periodically following the procedure of CEN (1999). For each olfactometry session, data were retrospectively screened by comparing assessors' individual threshold estimates with the panel average (CEN 1999). Odour concentration was expressed as odour units per unit volume (OU/m³) (CEN 1999).

Fifteen milliliters of gas were transferred from each sample collected in the Tedlar bag to Exetainer vials for analysis of GHG concentrations by gas chromatography (Varian CP-3800, Varian Inc., Walnut Creek, CA). The gas chromatograph was equipped with electron capture, flame ionization, and thermal conductivity detectors for determination of N₂O, CH₄, and CO₂ concentrations in sample gas, respectively. The CP-3800 was also automated to sample GHG gases from Exetainer vials using a Varian Combi PAL sampler. All gas analyses were done following the Good Laboratory Practices (Shugar and Ballinger 1996a, 1996b) with repeated standardization within sample runs and cross checking of calibration gases with several laboratories in Canada.

Calculation of odour and greenhouse gas emission rates

The odour emission rate from buildings was calculated from the measured odour concentration and ventilation rate (airflow rate of exhaust fans) using Eq. 1.

$$Q_{od-B} = (C_{odour} - C_{od-BK})V_B / AU \quad (1)$$

where:

- Q_{od-B} = odour emission rate from building exhaust (OU s⁻¹ AU⁻¹),
- C_{odour} = odour concentration of sample (OU/m³),
- C_{od-BK} = background odour concentration (OU/m³),
- V_B = ventilation rate (m³/s),
- AU = $(N_{pig} \times M_{pig})/500$ = animal units,
- N_{pig} = number of pigs, and
- M_{pig} = average mass of a pig (kg).

Table 1. Measured odour concentrations and emission rates from buildings.

	Farrowing		Gestation	
	Farm A	Farm B	Farm A	Farm B
Odour emission (OU s ⁻¹ m ⁻²)	22.7 (15.2)*	23.0 (14.4)	11.6 (6.0)	7.6 (3.4)
Odour emission (OU s ⁻¹ AU ⁻¹)	314 (214)	317 (198)	136 (71)	90 (40)

* Numbers in parentheses are standard deviations.

The GHG emission rate from building exhaust was calculated from Eq. 2.

$$Q_{GHG-B} = \frac{(C_{GHG} - C_{GHG-BK}) V_B \rho_{GHG}}{AU} \left(\frac{3600 \times 24}{1000} \right) \quad (2)$$

where:

Q_{GHG-B} = GHG emission rate from building exhaust (g d⁻¹ AU⁻¹),

C_{GHG} = GHG concentration of sample (ppm),

C_{GHG-BK} = background GHG concentration (ppm), and

ρ_{GHG} = GHG density (kg/m³) (CH₄ = 0.65; CO₂ = 1.72; N₂O = 1.72).

Odour and GHG emission rates from the open manure storage were determined from Eqs. 3 and 4.

$$Q_{od-S} = (C_{odour} - C_{od-Ref}) V_h / A_h \quad (3)$$

$$Q_{GHG-S} = \frac{(C_{GHG} - C_{GHG-Ref}) V_h \rho_{GHG}}{A_h} \left(\frac{3600 \times 24}{1000} \right) \quad (4)$$

where:

Q_{od-S} = odour emission rate from manure storage (OU s⁻¹ m⁻²),

C_{od-Ref} = odour concentration of reference sample (OU/m³),

V_h = airflow rate through wind tunnel (m³/s),

A_h = manure surface area covered by wind tunnel = 0.4 x 0.8 m²,

Q_{GHG-S} = GHG emission rate from manure storage (g d⁻¹ m⁻²),

C_{GHG-S} = GHG concentration of sample (ppm), and

$C_{GHG-Ref}$ = GHG concentration of reference sample (ppm).

Odour and GHG emission rates from the NAP EMS were determined in a similar fashion as for the building exhaust using Eqs. 5 and 6.

$$Q_{cd-S} = (C_{odour} - C_{od-BK}) V_c / A_s \quad (5)$$

$$Q_{GHG-S} = \frac{(C_{GHG} - C_{GHG-BK}) V_c \rho_{GHG}}{A_s} \left(\frac{3600 \times 24}{1000} \right) \quad (6)$$

where:

V_c = airflow rate through exhaust fans of NAP EMS (m³/s) and

A_s = total area of manure surface (m²).

RESULTS and DISCUSSION

Odour emission from buildings

Measured odour emission rates are summarized in Table 1 in two commonly used units: odour units per second per unit area of the building floor (OU s⁻¹ m⁻²) and odour units per second per

animal unit (OU s⁻¹ AU⁻¹). The average odour emission rates from farrowing and gestation rooms were, respectively, 22.7 and 11.6 OU s⁻¹ m⁻² on Farm A. Corresponding values were 23.0 and 7.6 OU s⁻¹ m⁻² on Farm B. There was no statistically significant (P<0.05) difference between the two facilities in emission rates from farrowing rooms; however, the emission rates

from gestation rooms on Farm A were significantly higher than that on Farm B (P<0.05). The emission rates from farrowing rooms was 2.0 times that from the gestation rooms on Farm A, and 3.0 times on Farm B. The differences in odour emission between the farrowing and gestation rooms were statistically significant (P>0.05) for both farms. The higher odour emission from the farrowing rooms was attributed to the fact that lactating pigs produce more manure with higher BOD than gestating pigs (ASAE 2005). Furthermore, manure was removed every three weeks in the farrowing rooms, but weekly in the gestation rooms. The longer manure removal cycle would also lead to more odour emission from the farrowing rooms. Measured emission rates in this study were within the range reported by other researchers. For example, Zhang et al. (2002) reviewed odour emission data published in the literature and summarized that odour emission from swine farrowing buildings varied from 0.4 to 62 OU s⁻¹ m⁻², and the published odour emission from gestation buildings ranged from 3 to 20 OU s⁻¹ m⁻².

Odour emission was significantly (P<0.05) lower in September than June, July, and August for farrowing rooms (Fig. 3). Odour emission from gestation rooms was significantly (P<0.05) higher in July than September. Low odour emission in September was attributed to the low outdoor temperature, which resulted in low ventilation. The average outdoor temperature in September was 12°C; whereas the average temperature was 22, 23, and 17°C in June, July, and August, respectively. As the outdoor temperature rose, the ventilation rate would increase to maintain desirable indoor temperature for the animals. Higher ventilation would result in higher odour emission, as per Eq. 1. It should also be noted that higher ventilation would remove more odour from the building and might lower the odour concentration in the building. The net increase in odour emission caused by the outdoor temperature rise attributed the combined effect of increasing ventilation rate and decreasing odour concentration.

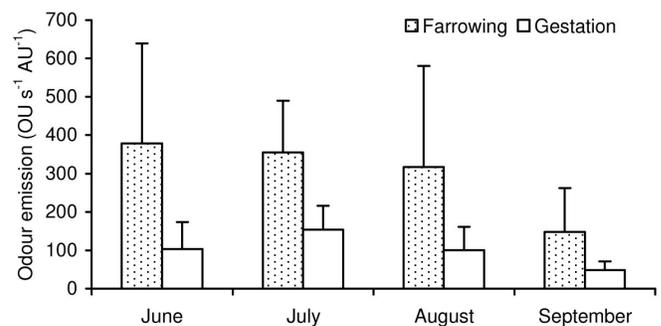


Fig. 3. Average odour emission rates from swine barns in four summer months (error bar indicates the standard deviation).

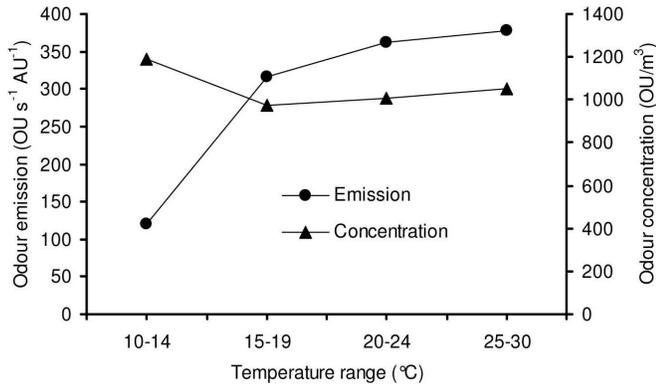


Fig. 4. Variation of odour concentration and emission from farrowing rooms with outdoor temperature.

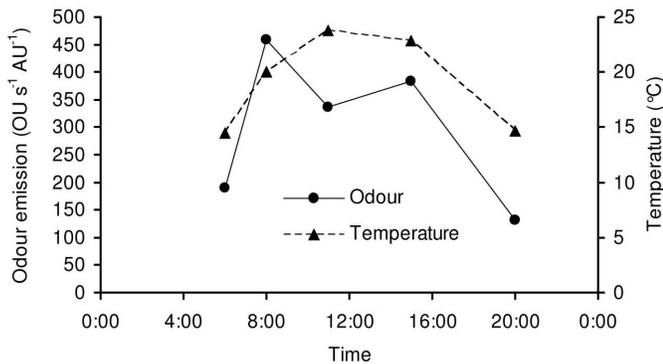


Fig. 5. Variation of odour emission from farrowing rooms and temperature during the day.

Figure 4 shows the effect of outdoor temperature on both odour level and emission rate for farrowing rooms. The odour concentration in the temperature range of 10-14°C was slightly higher than that in other temperature ranges and it remained fairly constant after 19°C. The odour emission rate at the 10-14°C range was significantly ($P < 0.05$) lower than that for other temperature ranges and there was no significant ($P > 0.05$) change in odour emission rate when outdoor temperatures were above 19°C (Fig. 4).

The variation in odour emission grossly followed that of outdoor temperature during the day (Fig. 5). It should be mentioned that each data point in Fig. 5 represents the average emission rate over a sampling session of about two hours. Odour emission was lower in the early morning (500 – 700h) and evening (1900 – 2100h) than other times of the day. Again these lower rates were attributed to lower ventilation at lower outdoor temperature. The relatively low ventilation during the night would also cause the odour to “accumulate” in the building. Rising outdoor temperature in the morning triggered the ventilation rate to step up. This combination of accumulated odour in the building and increasing ventilation resulted in the highest emission rate in the morning (700-900h).

Odour emission from manure storage

The odour concentration in the NAP EMS on Farm A was much higher than that in the open EMS on Farm B (Table 2). However, because only a small amount of air (0.6 m³/s) was exhausted from the NAP EMS, the odour emission rate from NAP EMS, determined as the product of the odour concentration and the airflow rate, was much lower than that from the open EMS. The average measured emission rate for the open EMS on Farm B was 20.3 OU s⁻¹ m⁻² (Table 2). This value seems to be high in comparison with data reported in the literature ranging from 3.1 to 17.6 OU s⁻¹ m⁻² (Zhang et al. 2002); but these reported data were not specifically for farrowing operations. The emission rate from the primary cell of the NAP EMS ranged from 0.2 to 2.0 OU s⁻¹ m⁻², with an average of 0.7 OU s⁻¹ m⁻², which is only 3% of that of the open EMS on Farm B (Table 2). The emission rate from the secondary cell of the NAP EMS (0.2 OU s⁻¹ m⁻²) was less than 1% of that from the open EMS. The total manure surface area in the primary cell was about 33% of that in the secondary cell (Fig. 1). Based on the area ratio between the primary and secondary cells, the weighted average emission rate from the entire NAP EMS was calculated to be 0.3 OU s⁻¹ m⁻², which is negligible in comparison with the open EMS (20.3 OU s⁻¹ m⁻²). This confirms that the NAP cover technology is extremely effective in reducing odour emission from EMS.

Total odour emission (building plus manure storage)

The total odour emission was determined as the sum of the building and EMS emissions and expressed in OU/s. The total odour emission from Farm A with NCP EMS was 58% of that from Farm B with open EMS (174,522 vs 303,120 OU/s) (Table 3). The open EMS contributed 57% to the total odour emission on Farm B; whereas the NAP EMS contributed only 2% to the total emission on Farm A. This indicates that covering the manure storage may reduce the odour emission from the swine operations by up to 57%. Apparently, something has to be done about the remaining 43% of emission from buildings in order to alleviate the odour problem in the swine operations.

GHG emission from buildings

The measured CO₂ concentrations in the building exhaust air ranged from 492 to 2787 ppm on Farm A and 413 to 1131 ppm on Farm B. The CO₂ concentration in farrowing rooms on Farm A were statistically ($P < 0.05$) higher than that on Farm B (792 vs 669 ppm); whereas there was no significant ($P > 0.05$) difference in CO₂ concentration between the two farms in gestation rooms (1012 vs 691 ppm) (Table 4). The measured CO₂ concentrations were within the range reported in the literature for swine production buildings (e.g., Ni et al. 1999).

Table 2. Measured odour concentrations and emission rates from manure storage.

	NAP EMS on Farm A		Open EMS on Farm B
	Primary cell	Secondary cell	
Odour concentration (OU/m ³)	4646 (3646)*	1991 (1568)	769 (356)
Odour emission (OU s ⁻¹ m ⁻²)	0.7 (0.60)	0.2 (0.14)	20.3 (25.4)

* Numbers in parentheses are standard deviations.

Table 3. Total odour emission and relative contributions of building and manure storage.

	Farm A (covered EMS)			Farm B (open EMS)		
	Total	Building	EMS	Total	Building	EMS
Emission (OU/s)	174,522	170,707	3815	303,120	129,267	173,853
Contribution (%)		98	2		43	57

Table 4. Greenhouse gas (GHG) concentrations and emission rates from buildings.

	Farrowing		Gestation	
	Farm A	Farm B	Farm A	Farm B
CO ₂ concentration (ppm)	792 (179)*	669 (131)	1012 (619)	691 (110)
CO ₂ emission (g d ⁻¹ AU ⁻¹)	16588 (10977)	11576 (7073)	11514 (7429)	4808 (2996)
CH ₄ concentration (ppm)	14 (8)	20 (10)	18 (13)	12 (6)
CH ₄ emission (g d ⁻¹ AU ⁻¹)	184 (170)	351 (204)	118 (119)	73 (51)
N ₂ O concentration (ppm)	0.4 (0.1)	0.4 (0.0)	0.4 (0.1)	0.4 (0.0)
N ₂ O emission (g d ⁻¹ AU ⁻¹)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

* Numbers in parentheses are standard deviations.

The CH₄ concentration in farrowing rooms on Farm A ranged from 2 to 42 ppm (average 14 ppm) and was significantly (P<0.05) lower than that on Farm B (ranged from 2 to 41 ppm and averaged 20 ppm). For gestation rooms, the CH₄ concentration on Farm A (ranged from 3 to 39 ppm and average 18 ppm) was not statistically (P>0.05) different from that on Farm B (ranged from 2 to 23 ppm and average 12 ppm). The CH₄ concentrations measured in this study were within the range reported in the literature. Laguë (2003) reviewed the literature data on greenhouse gas emission from swine barns and reported that CH₄ concentrations ranged from 2.8 to 99.8 ppm in farrowing operations. Measured N₂O concentrations were 0.4 ppm on both farms (Table 4). This concentration was about the same as the measured ambient (background) level 0.3 - 0.4 ppm; therefore, the N₂O emission from the building exhaust was considered to be zero.

Carbon dioxide emission from farrowing rooms was significantly (P<0.05) higher than that from gestation rooms for both farms (Table 4). Measured CO₂ emission rates for both farrowing and gestation rooms on Farm A were significantly (P<0.05) higher than the corresponding rates on Farm B (Table 4). When the rates were expressed as per kilogram of animal mass, the CO₂ emission was 33.2 and 23.2 g d⁻¹ kg⁻¹ from farrowing rooms for Farms A and B, respectively, and 23.0 and 9.6 g d⁻¹ kg⁻¹ from gestation rooms for the two farms, respectively. These rates were slightly lower than, but comparable to, those reported by Laguë et al. (2004) for two swine facilities in Saskatoon, Saskatchewan. Their values were 42.9 and 36.8 g d⁻¹ kg⁻¹ for farrowing rooms, and 21.0 and 26.9 g d⁻¹ kg⁻¹ for gestation rooms.

Methane emission from farrowing rooms on Farm A was significantly (P<0.05) lower than that on Farm B; whereas there was no significant (P>0.05) difference in CH₄ emission from gestation rooms between the two farms (Table 4). The difference in CH₄ emission between farrowing and gestation rooms on Farm A was not significant (P>0.05); whereas emission from farrowing rooms was significantly (P<0.05) higher than that from gestation rooms on Farm B (Table 4).

The measured CH₄ emission rates were in good agreement with the study conducted by Laguë et al. (2004) for two swine facilities in Saskatoon. They reported that the CH₄ emission rates in farrowing rooms were 0.63 and 0.10 g d⁻¹ kg⁻¹ in the two facilities, respectively. The rates measured in this study were 0.37 and 0.70 g d⁻¹ kg⁻¹ for the two farms, respectively. The CH₄ emission from gestation rooms in the Laguë et al. (2004) study was 0.27 and 0.07 g d⁻¹ kg⁻¹ for the two sites, respectively. Emission rates of 0.24 and 0.15 g d⁻¹ kg⁻¹ were measured in this study for gestation rooms on the two farms, respectively.

Greenhouse gas emissions from buildings varied with month from June to September (Figs. 6 and 7). The CO₂ emission rates in

July and August were significantly (P<0.05) higher than those in June and September, whereas, there was no significant (P>0.05) difference between July and August, or between June and September (Fig. 6). A similar trend was observed for CH₄ emission. There was not significant (P>0.05) difference in CH₄ emission in June, July, and August, and the emission rate in September was significantly (P<0.05) lower than for the other three months.

GHG emission from manure storage

The CO₂ concentration in the NAP EMS on Farm A varied from 1404 to 7955 ppm in the primary cell and from 505 to 866 ppm in the secondary cell. In contrast, the CO₂ level in the open EMS on Farm B ranged from 385 to 583 ppm. The average CO₂ concentration in the primary cell of the NAP EMS on Farm A was eight times that in the open EMS on Farm B (3943 ppm vs 452 ppm) (Table 5); whereas the CO₂ concentration in the secondary cell of the NAP EMS was in the same order of magnitude as that in the open EMS (Table 5).

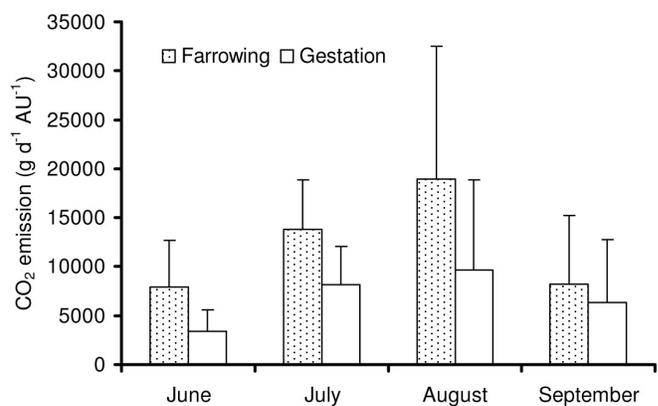


Fig. 6. Average carbon dioxide emission rates from swine barns in four summer months (error bar indicates the standard deviation).

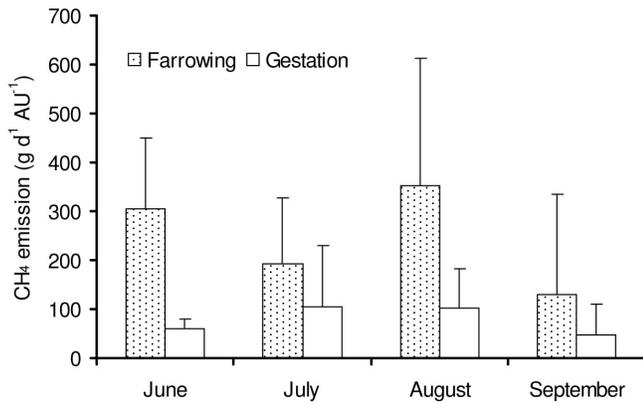


Fig. 7. Average methane emission rates from swine barns in four summer months (error bar indicates the standard deviation).

Table 5. Greenhouse gas (GHG) concentrations and emission rates from manure storage.

	NAP EMS on Farm A		Open EMS on Farm B
	Primary cell	Secondary cell	
CO ₂ concentration (ppm)	3943 (2149)	619 (119)	472 (44)
CO ₂ emission (g d ⁻¹ AU ⁻¹)	89 (65)	2 (0.7)	455 (329)
CH ₄ concentration (ppm)	3221 (2491)	108 (215)	20 (14)
CH ₄ emission (g d ⁻¹ AU ⁻¹)	30 (25)	0.3 (0.5)	44 (27)
N ₂ O concentration (ppm)	0.4 (0.1)	0.4 (0.1)	0.4 (0.0)
N ₂ O emission (g d ⁻¹ AU ⁻¹)	(0.0 (0.0))	0.0 (0.0)	0.0 (0.0)

* Numbers in parentheses are standard deviations.

Table 6. Total greenhouse gas (GHG) emissions and relative contributions of building and manure storage.

	Farm A (covered EMS)			Farm B (open EMS)		
	Total	Building	EMS	Total	Building	EMS
CO ₂ (kg/d)	12721	12426	295	9826	5928	3898
Contribution (%)		98	2		60	40
CH ₄ (kg/d)	225	129	96	492	118	374
Contribution (%)		57	43		24	76

Although the CO₂ concentration was high in the primary cell of the NAP EMS, the emission rate was low because only a small amount of air was exhausted from the NAP EMS. The CO₂ emission rate from the open EMS was significantly ($P < 0.05$) higher than that from both cells of the NAP EMS (Table 5). The CO₂ emission from the secondary cell was negligible in comparison with the primary cell or the open EMS.

The CH₄ concentration varied from 234 to 5556 ppm in the primary cell of the covered EMS and from 3 to 592 ppm in the secondary cell. Because of the anaerobic conditions in the covered EMS, the average CH₄ concentrations in the primary and secondary cells of the NAP EMS were 161 and 8 times that in the open EMS, respectively (Table 5).

Although only a small amount of air was drawn from under the negative pressure cover, the extremely high CH₄ concentration in the primary cell of the NAP EMS resulted in an emission rate comparable to that from the open EMS (30 vs 44 g d⁻¹ m⁻², and the difference was not statistically significant, $P > 0.05$) (Table 5). The CH₄ emission from the secondary cell (0.3 g d⁻¹ m⁻²) was negligible in comparison with the primary cell or the open EMS (Table 5).

Again, the N₂O concentrations measured in both open EMS and the NAP EMS were about the same as the measured ambient (background) level (Table 5). In other words, the N₂O emission from EMS was considered to be zero.

Total GHG emission (building plus manure storage)

The CO₂ emission from the open EMS accounted for 40% of the total CO₂ emission on Farm B; whereas CO₂ emission from the NAP EMS was only 2% of the total emission on Farm A (Table 6). Although the CH₄ emission rate from the primary cell of the NCP EMS on Farm A was not significantly different from the open EMS on Farm B, the total CH₄ emission from the NCP EMS was only 26% of that from the open EMS because the manure surface area in the primary cell of the EMS was relatively small (3111 m²) in comparison with the open EMS (8568 m²). The open EMS contributed 76% to the total CH₄ emission on Farm B and the NAP EMS contributed 43% on Farm A. The total CH₄ emission from Farm A with NAP EMS was 46% of that from Farm B (225 vs 492 kg/d).

CONCLUSIONS

1. Odour emission from farrowing rooms was two to three times that from gestation rooms. Outdoor temperature had the most influence on odour emission from buildings.
2. The average odour emission rate from the negative pressure covered earthen manure storage (NAP EMS) was negligible in comparison with the open EMS (0.3 vs 20.3 OU s⁻¹ m⁻²).
3. The total odour emission (combined building and manure storage) from Farm A with NAP EMS was 58% of that from Farm B with open EMS (174,522 vs 303,120 OU/s). The open EMS contributed 57% to the total odour emission on Farm B; whereas the NAP EMS contributed only 2% to the total emission on Farm A.
4. Carbon dioxide emission from farrowing rooms was significantly higher than that from gestation rooms.
5. Both CO₂ and CH₄ emissions from the secondary cell of the NAP EMS were negligible in comparison with the primary cell or with the open EMS.
6. The average CO₂ concentration in the primary cell of the NAP EMS was eight times that in the open EMS (3943 vs 472 ppm). However, the CO₂ emission rate from the primary cell of the NAP EMS was significantly lower than that from open EMS (89 vs 455 g d⁻¹ m⁻¹).

7. A large amount of CH₄ was produced in the NAP EMS under anaerobic conditions. The average CH₄ concentration in the primary cell of the NAP EMS was 160 times that in the open EMS (3221 vs 20 ppm). Consequently, the NAP did not result in any significant reduction in CH₄ emission rate in comparison with the open EMS. However, the total CH₄ emission from the NAP EMS was only 26% of that from the open EMS because the size of the primary cell of the EMS was relatively small in comparison with the open EMS.
8. Carbon dioxide emission from the open EMS accounted for 40% of the total CO₂ emission (combined building and EMS) on Farm B; whereas the CO₂ emission from the NAP EMS was only 2% of the total CO₂ emission on Farm A.
9. CH₄ emission from the open EMS contributed 76% to the total CH₄ emission on Farm B; whereas CH₄ emission from the NAP accounted for 43% of the total CH₄ emission on Farm A. The total CH₄ emission from Farm A with NAP EMS was 46% of that from Farm B with open EMS.
10. Nitrous oxide emissions from building exhaust and from EMS were negligible in the two swine farrowing operations.

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