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Odour and gas emissions from a commercial layer barn

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ABSTRACT This study is to acquire diurnal and seasonal concentration and emission profiles of odour, greenhouse gases (CH_4, CO_2 and N_2O) and toxic gases (NH_3 and H_2S) from a commercial layer barn on the Prairies in Canada. The monthly results from March to June 2015 suggested concentrations and emissions of odour and gases tended to present different trends. Diurnal results on the best-case day (when manure was removed) and worst-case day (when manure was accumulated to maximum) under mild climate showed there were significant differences ($P<0.05$) in concentrations and emissions of both odour and NH_3, suggesting removing manure was very effective in reducing odour and NH_3 production. When using 3-hourly data, diurnal odour and NH_3 concentrations and emissions vary significantly ($P<0.05$) on both the two days. As for CO_2, diurnal CO_2 concentrations change greatly while no such variations were observed in CO_2 emissions on both the two days. The concentrations and emissions of H_2S, CH_4 and N_2O were very low with only less than 3 ppm for CH_4, less than 350 ppb for N_2O and less than 100 ppb for H_2S. More data in the future is needed to generate complete concentration and emission profiles of odour and gases over the year and to investigate the correlations between odour and gases as well as to develop prediction models for odour and gas emissions.

Keywords: Layer barn, Odour, Gases, Diurnal, Seasonal, concentration, emission.

INTRODUCTION In the last several decades, intensive, confined housing and feeding practice around the world have been largely developed. Intensive livestock production is associated with various environmental effects including air emissions (e.g., odour, ammonia (NH_3), greenhouse gases and particulate matter) and discharges to soil and surface water (e.g., nitrogen, phosphorus and heavy metals) (Melse et al., 2009), all of which have become global concerns and could be obstacles to the development of animal industry in the future if the negative impacts on environment are not properly solved.

Odour and gas production are the result of complex bacterial degradation of organic matter affected by various factors. Animal barn, animal waste management, and manure land application are the three major sources of odour and gas emissions in livestock production. Concern has been raised by the public on potential environmental and health effects caused by odour and gas emissions (greenhouse gases, NH_3 and hydrogen sulfide (H_2S)) from animal operation in recent years (Wang, 2007; Blanes-Vidal et al., 2012; Amon et al., 1997). High levels of odours have been indicated to harm the health of workers and contribute to the friction between animal farms and residents living in the vicinity (Schiffman, 1998). The complaints of health symptoms from odours such as eye, nose and throat irritation, headache and drowsiness have been frequently reported (Schiffman, 1998). With the fact that now people would pay more attention to their health and environment protection, governments have to impose stricter regulations and guidelines to avoid odour nuisances from odour emission sources.

A more widely used approach to address odour issues is to establish appropriate setback distances to separate the livestock production facilities from residences or public facilities (Yu and Guo, 2011). Accurate source emission data is the primary input for odour dispersion modelling. Large diurnal and seasonal variations in odour concentrations and emission rates from swine rooms (Guo et al., 2007) and dairy manure storage (Zhao et al., 2007) have been observed, which suggests that the representative odour concentration and emission rates cannot be obtained by a snapshot measurement. Although there have been a few research on odour from swine production in Canada (Wang, 2007; Zhang et al., 2005), study on diurnal and seasonal odour concentration and emission from different poultry and dairy operations in Canada has not been conducted.

The objective of the study is to acquire diurnal and seasonal concentration and emission profiles of odour as well as greenhouse gases (CH_4, CO_2 and N_2O) and toxic gases (NH_3 and H_2S) from a commercial layer barn on the Prairies in Canada.

MATREIALS AND METHODS

Description of the layer barn Information of the layer barn is given in Table 1. The layer barn was a 4 tier stacked cage building. The operation cycle was one year including one-week break for cleaning and washing at the end of each cycle. The manure dropped on the belt and was cleaned up to outside for field application immediately every 3-4 days. On each measurement day, the detailed information of the birds including the accurate bird number, age and weight was surveyed. Other information such as worker and animal activity was also recorded.

Table 1. Basic information of the layer barn

Facility	Bird number	Floor area (W × L)	Air inlets	Ventilation	Fans
Layer	~35000	985.76 m^2 (12.2×80.8)	172, on the ceiling	Mechanical (negative pressure)	24 wall fans (4 variable speed fans and 20 single speed fans)

Instruments The sampling air was drawn from inside at a fixed sampling point with an approximate height of 1.5 m. The sampling point was located at area close to the exhaust fan which would be working all year around, where the air could represent the well mixed air that would be exhausted. The sampling station is shown in Figure 1. The air firstly went through a filter to remove dust and water before it was pumped to the gas sensors. A vacuum box was used to suck the air from the main sampling line and filled two Tedlar® air bags simultaneously for odour measurement. A small amount of air was drawn to the H_2S analyzer (JEROME 631-X, Arizona Instrument Corporation, Arizona Instrument LLC, USA) by an internal pump and the left air went through the head space of the CO_2 sensor (K30 CO_2 sensor, CO_2 Meter, USA) for CO_2 concentrations measurement and the head space of the NH_3 sensor (C21 NH_3 transmitter, GFG Instrumentation, USA) for NH_3 concentration measurement. The accuracies were ±0.003 ppm at 0.05 ppm, ±0.03 ppm at 0.50 ppm and ±0.3 ppm at 5.0 ppm for H_2S analyzer and ±30 ppm ±3% of measured value for CO_2 sensor, and ±5% for NH_3 sensor. The average gas concentrations were recorded by a data logger (CR10X, Campbell Scientific Corporation, Canada) every 5 minutes on site.

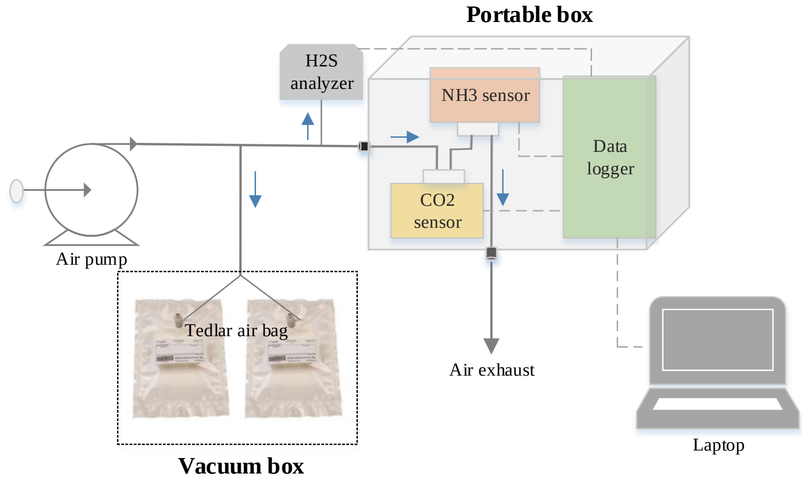

Figure 1. Sampling station.

The air samples from the air bags were analyzed for odour concentration in the Olfactory Laboratory at the University of Saskatchewan within 30 hours after collection. The screening of panelists and measurement for odour concentration was conducted in compliance with the standard of CEN (2003) by dynamic forced choice olfactometry. A small amount of air was extracted from the air bags to vacuumed tubes for CH_4 and N_2O concentration measurement using GC (Gas Chromatograph) method at Soil Laboratory of University of Saskatchewan. Besides odour and gases measurement, indoor temperature and relative humidity was also monitored continuously over the whole measurement period by wireless T/RH data logger (OM-EL-USB-2, Omega, Canada) with -35℃ to 80℃ and 0 to 100% RH measurement ranges, and 0.5℃ and 3.5% RH accuracies. The data of ambient temperature and humidity was acquired from the website of Environment Canada.

Sampling schedule The seasonal and diurnal measurements were conducted over a period of 12 months from Mar 2015 to Feb 2016.

<u>Diurnal sampling schedule</u> Odour sampling and quantification is time-consuming and high-costly, which makes it unpractical and maybe unnecessary to conduct diurnal measurement in every month. According to Saskatoon climate normals, the weather condition of Saskatoon can be categorized into three groups, which are cold climate (January, February, March, November and December), mild climate (April and October) and warm climate (May, June, July, August and September), respectively. To acquire the representative results as well as to reduce the cost, diurnal measurement was performed only in February, April and July (or August), which represented cold, mild and warm seasons, respectively. The level of air pollution was presumably

strongly related to manure accumulation and treatment inside the layer barn. To acquire replicates for statistical analysis while consider both the best and worst cases for layer barn in the three different seasons, diurnal sampling was performed on two days in each season, the day before manure-removing day (worst case) and the day after the same manure-removing day (best case). From 6 am to 9 pm on each measurement day, the gas station was working continuously on-site for NH_3, CO_2 and H_2S measurement and data recording, while every 3 hours at 6:00 am, 9:00 am, 12:00 pm, 3:00 pm, 6:00 pm and 9:00 pm, 4 identical air samples were collected for odour properties, CH_4 and N_2O measurement.

Seasonal sampling schedule The seasonal measurement was conducted in each of the 12 months except when the diurnal sampling and measurement was conducted for that month. Only worst case was considered for seasonal measurement when the manure was accumulated to maximum inside the barn. As already found by previous studies, diurnal odour and gas concentrations would show great variations (Guo et al, 2007). Considering possible diurnal variations in this study, seasonal measurement was conducted for 2 hours in both the morning from 10:00 am to 12:00 pm and the afternoon from 2:00 to 4:00 pm on each measurement day. Air sampling for odour, CH_4 and N_2O measurement was performed around 11:00 am during the morning measurement period and around 3:00 pm during the afternoon measurement period. The results of the average were used for data analysis. However, for the 3 selected months when diurnal measurements were conducted, the data acquired under the worst case was used to represent the monthly results. During each period, 4 identical air samples for odour measurement was collected. After the samples were transported back to the lab, 2 samples from each sampling period were analyzed for odour concentration, while the other 2 samples were used for odour intensity measurement.

Odour and gas emission rate calculation Ventilation rate was estimated by CO_2 mass balance method. The principle is that the CO_2 gain of a room from the incoming air and CO_2 produced by the animals is equal to the CO_2 loss through the exhaust air (Albright, 1990). The equation is:

$$V = (CO_2)_p / ((CO_2)_i - (CO_2)_o) \quad (1)$$

Where $(CO_2)_p$ is the volumetric rate of carbon dioxide production, $m^3\ s^{-1}$; $(CO_2)_i$ is the volumetric concentration of indoor carbon dioxide which will be measured by CO_2 sensor, $m^3\ m^{-3}$; and $(CO_2)_o$ is the volumetric concentration of outdoor carbon dioxide (345 ppm), $m^3\ m^{-3}$. Knowing the odour and gas concentrations and ventilation rates of the rooms, the odour and gas emission rates from animal buildings can be calculated as follows:

$$E = V \times \Delta C \quad (2)$$

Where E is emission rate of odour in unit of OU s^{-1} (odour unit per second) or OU s^{-1} $bird^{-1}$ (odour units per second per bird), and of gases in unit of mg s^{-1} (milligram per second) and g s^{-1} (gram per second) or mg s^{-1} $bird^{-1}$ (milligram per second per bird) and g s^{-1} $bird^{-1}$ (gram per second per bird); V is ventilation rate of the room, $m^3\ s^{-1}$, and ΔC is the difference of odour and gas concentrations between the room inlet air and exhaust air, in unit of OU m^{-3} (odour unit per cubic meter), ppm or mg m^{-3}.The odour, NH_3 and H_2S concentrations of room inlet air (ambient air) is assumed to be negligible. The ambient concentrations of CH_4 and N_2O are considered to be 1.7 ppm and 0.3 ppm, respectively (Arya, 1999).

Statistical data analysis The statistical evaluation of data was performed using the SPSS software 17.0 for only diurnal measured data in this paper. As discussed before, diurnal measurement was conducted on two days in each season for replication. For statistical analysis, each measurement day was treated as a block and two factors “manure condition” and “diurnal” were considered. Factor “manure condition” was categorized as “0” which was the best-case day after manure was removed and “1” was the worst-case day when manure was accumulated to the maximum. Factor “diurnal” was treated as the function of ambient T and RH, ventilation rate, management, etc. Six diurnal levels were determined on each measurement day which were 6:00-9:00 am, 9:00-12:00 am, 12:00-3:00 pm, 3:00-6:00 pm and 6:00-9:00 pm, respectively. Duncan test was selected in General Linear Model (GLM). Firstly the interaction between “manure condition” and “diurnal” factor was examined based a probability level of 0.05. If the P-value was great than 0.05, which meant the interaction of the two factors was not significant, then the main effect of each factor could be examined and the test results were used. If the P-value was less than 0.05, the results for each measurement day would be analyzed separately. The variances between the results of the two days were tested by paired t-test, and analysis of diurnal variances on each day was conducted by GLM.

RESULTS AND DISCUSSION This paper only shows the seasonal results that were acquired from March to June, and the diurnal results that were acquired under mild climate in April.

Seasonal odour and gases concentration and emission The results of the daily average indoor and outdoor temperature (T) and relative humidity (RH), ventilation rate (VR) and bird information on the measurements days are given in Table 2. The average results were calculated based on the 2-hour data in the morning and 2-hour data in the afternoon. From March to May when the climate turned from cold to warm, the outdoor T increased significantly from 3.4 to 22.5℃ which explained the obvious increasing of VR from 7.91 to 40.58 $m^3 s^{-1}$; and the indoor T increased from 21.9 to 26.6℃.

Table 2. Environmental parameters and bird information on the measurement days.

	Indoor T (℃)	Outdoor T (℃)	Indoor RH (%)	Outdoor RH (%)	VR ($m^3 s^{-1}$)	Bird information		
						number	Age (weeks)	Weight (kg)
17-Mar-2015	21.9	3.4	54.6	64.3	7.91	33922	70	1.975
28-Apr-2015	24.2	18.3	43	36.1	23.43	39760	22	1.564
21-May-2015	26.6	22.5	27.1	18.5	40.58	39747	25	1.606
23-Jun-2015	25.4	21.6	48.8	45.2	31.74	39710	30	1.672

As introduced before, in April when diurnal measurement was conducted, the data acquired from 10:00-12:00 am and from 2:00-4:00 pm on the worst-case day would be extracted to give the monthly results. Odour, CH_4 and N_2O sampling was only performed every 3 hours at 6:00 am, 9:00 am, 12:00 pm, 3:00 pm, 6:00 pm and 9:00 pm. To be consistent, the results acquired at 12:00 pm and 3:00 pm were used as the monthly results of odour, CH_4 and N_2O. Table 3 summarizes the seasonal odour and gas concentrations and emissions obtained from March to June. As can be seen, the average odour emission rate ranged from 0.21 to 0.38 OU s^{-1} $bird^{-1}$ which is in compliance with the results of Hayer et al. (2006) who reported odour emission rates at a range of 0.26-0.61 OU s^{-1} $bird^{-1}$ for a similar layer barn system in spring, while the average NH_3 emission rate was 0.09-0.38 OU s^{-1} $bird^{-1}$ which is a little higher than 0-0.2 g d^{-1} $bird^{-1}$ reported by the same study. Gay et al (2006) summarized H_2S flux rates from 66 farms in Minnesota, which varied from 0.03 to 0.35 g m^{-2} d^{-1} for poultry housing. Similar results were found in this study where H_2S emission rates were 0.04 to 0.41 g m^{-2} d^{-1}. Low concentrations and emissions were observed for H_2S, CH_4 and N_2O.

As can be seen in Table 3, the maximum odour and gas concentrations all occurred in March when it was still cold with low outdoor T and ventilation rate. However, it should be pointed out that at the end of March the previous birds were harvested and at the beginning of April a new batch of birds were placed after one-week cleaning and washing inside the barn. Thus significant differences in bird number, age and weight and room condition were caused from March to April. To avoid bias, the monthly results for March 2015 would be treated to represent the results for March 2016 when it would be the last month with minimum number and maximum weight for the new batch of birds. Therefore, the results of March was excluded in the following discussion in this paper. Based on the monthly results acquired from April to June, the maximum odour, CO_2 and NH_3 concentrations were observed in April when the ventilation rate was the lowest while the minimum concentrations were found in May when the ventilation rate was the highest. However, emission rate is a product of concentration and ventilation rate. The increased ventilation rates would compensate the decrease in concentrations. As a result, the maximum and minimum of odour, CO_2 and NH_3 emission rates were found in June and May, respectively. Besides, different from odour and NH_3 emissions, CO_2 emission rates were relative stable and would not vary greatly from April to May. The concentrations and emissions of H_2S, CH_4 and N_2O were all very low based on the current results.

Table 3. Seasonal odour and gas concentrations and emissions from March to June.

	17-Mar-15	28-Apr-15	21-May-15	23-Jun-15
Odour concentration (OU m^{-3})	887	604	216	466
Odour emission (OU s^{-1} or OU s^{-1} $bird^{-1}$)	7017 or 0.21	12901 or 0.32	8799 or 0.22	15026 or 0.38
CO_2 concentration (ppm)	2605	1157	781	927
CO_2 emission (g s^{-1} or g d^{-1} $bird^{-1}$)	35.1 or 89.3	34.4 or 74.8	34.8 or 75.7	36 or 78.3
NH_3 concentration (ppm)	20	10	1	7
NH_3 emission (g s^{-1} or g d^{-1} $bird^{-1}$)	0.12 or 0.30	0.16 or 0.36	0.04 or 0.09	0.17 or 0.38
H_2S concentration (ppb)	196	26	76	96
H_2S emission (mg s^{-1} or mg d^{-1} $bird^{-1}$)	2.35 or 5.98	0.90 or 1.96	4.66 or 10.13	4.58 or 9.97
CH_4 concentration (ppm)	4.36	2.12	2.22	
CH_4 emission (mg s^{-1} or mg d^{-1} $bird^{-1}$)	15.1 or 38.4	7.1 or 15.5	15.1 or 32.8	
N_2O concentration (ppb)	346	345	335	
N_2O emission (mg s^{-1} or mg d^{-1} $bird^{-1}$)	0.71 or 1.82	2.04 or 4.44	2.77 or 6.02	
Monthly GHG emission (of CO_2 equivalent, tons)	94	92.7	94.9	

Diurnal odour and gases concentration and emission During the following discussion about diurnal results under mild climate, April 28 was the day when the worst case happened and April 30 was the day when the best case occurred. The bird information for the two measurement days were recorded as the same which can be found from Table 2.

Figure 2 gives the indoor and outdoor T and VR on the two measurement days. The weather in mild climate changed greatly from early morning to the evening. The ambient T ranged from 4 to 22.4℃ on April 28, and from 7.2 to 18.6℃ on April 30, while the indoor T was controlled in a relatively narrow range which was from 21.3 to 26.2℃ on April 28 and 21.1 to 23.5℃ on April 30. The purpose of ventilation system is to provide optimal environment for animals. Usually ventilation rate will be designed based on three concerns, including temperature, relative humidity and gas concentration (Albright, 1990). During mild and warm climate, temperature will be the major concern. Therefore, the great change in ambient temperature during day time under mild climate accounted for the great change of ventilation rate. On both the two days, ventilation rate was low in the early morning and kept increasing gradually along with the ambient temperature and reached maximum in the afternoon. In late afternoon and early evening, when ambient T began to decrease, ventilation rate also started to decrease. The average ventilation rates on April 28 and 30 were 23.04 $m^3 s^{-1}$ and 22.67 $m^3 s^{-1}$, respectively.

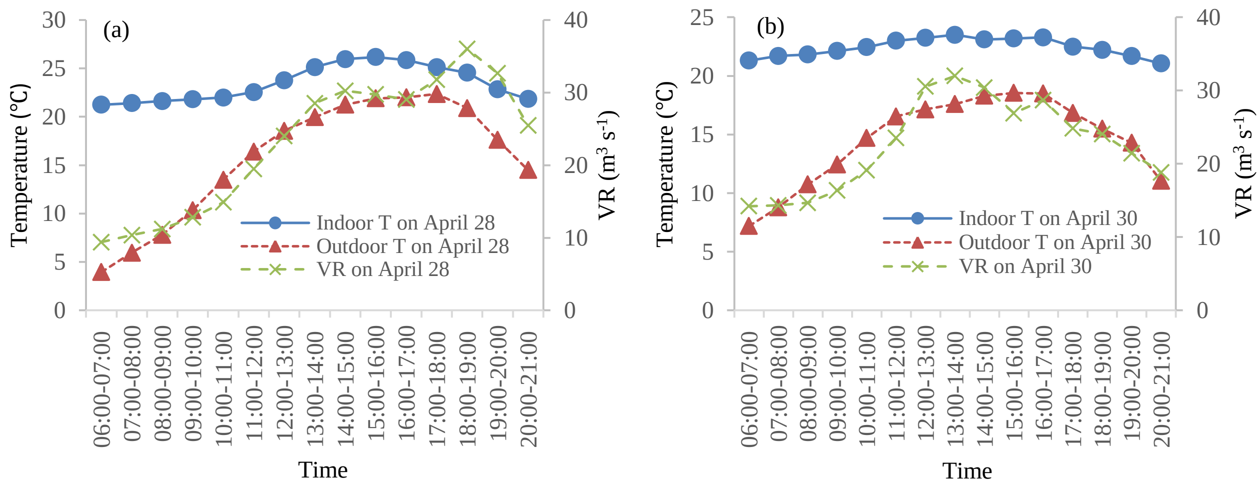

Figure 2. Diurnal outdoor and indoor temperature and relative humidity under mild climate; (a) is T and VR on April 28 and (b) is T and VR on April 30.

Figure 3 presents diurnal 3-hourly odour concentration and emission. As can be seen, diurnal odour concentration varied obviously with a sharp decrease from early morning to afternoon and then a slow recovering till the end of the measurement. Odour emission rates had different trends with relatively stable odour emissions for April 30 and apparently higher emission rate in early evening (6:00-9:00 pm) than that in early morning (6:00-9:00 am) for April 28. The average odour concentrations and emissions were 803 OU m^{-3} and 16436 OU s^{-1} for April 28, and 558 OU m^{-3} and 11147 OU s^{-1} for April 30, respectively.

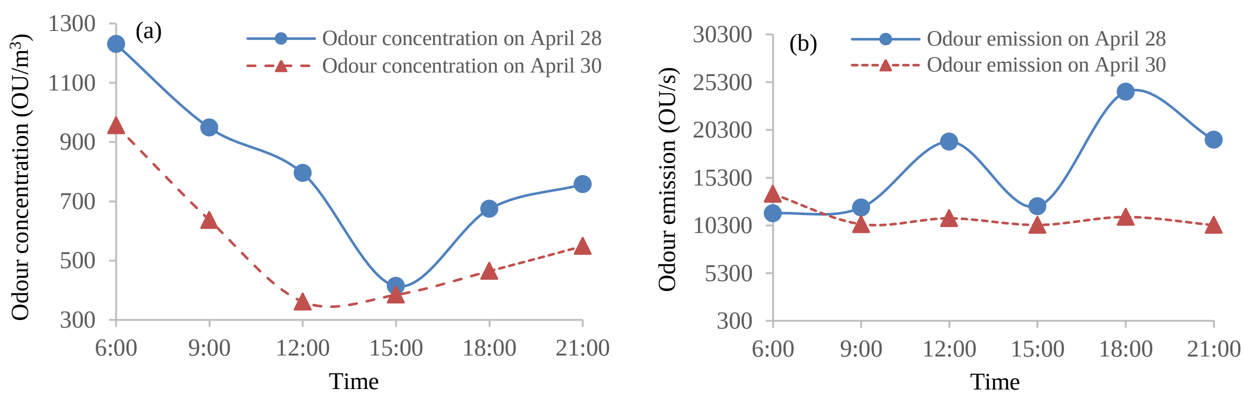

Figure 3. Diurnal odour concentrations and emissions under mild climate; (a) is odour concentration and (b) is odour emission.

According to SPSS results, both the “manure condition” factor and “diurnal” factor had significant effects on odour concentrations ($p<0.05$) while the interaction was not significant ($P>0.05$), which meant removing manure had significant effect on reducing odour concentrations and great diurnal variations in odour concentrations would exist under mild climate. Odour concentration in the early morning was significantly higher than that in the afternoon for both the two days ($P<0.05$). However, for odour emissions the two factors would interact each other significantly ($P<0.05$), thus the diurnal variances for the two days were analyzed separately. It turned out there was still significant difference in daily average odour emissions ($P<0.05$) while diurnal odour emission rates would not change significantly for both the two days ($P>0.05$).

Diurnal hourly CO_2 concentration and emission on the two measurement days can be found from Figure 4. The CO_2 concentration fluctuated significantly on both the two days, with the maximum value of 2227 ppm and minimum value of 831 ppm for April 28, and with the maximum value of 1588 ppm and the minimum value of 894 ppm for April 30. The average CO_2 concentrations were similar for April 28 and 30 which were 1278 ppm and 1186 ppm, respectively. When regarding the emission rate, no big apparent difference was observed in the diurnal hourly CO_2 emissions for both the two days and the hourly CO_2 emission fell within a narrow range, except when from 8:00 to 9:00 pm the CO_2 emissions obviously increased.

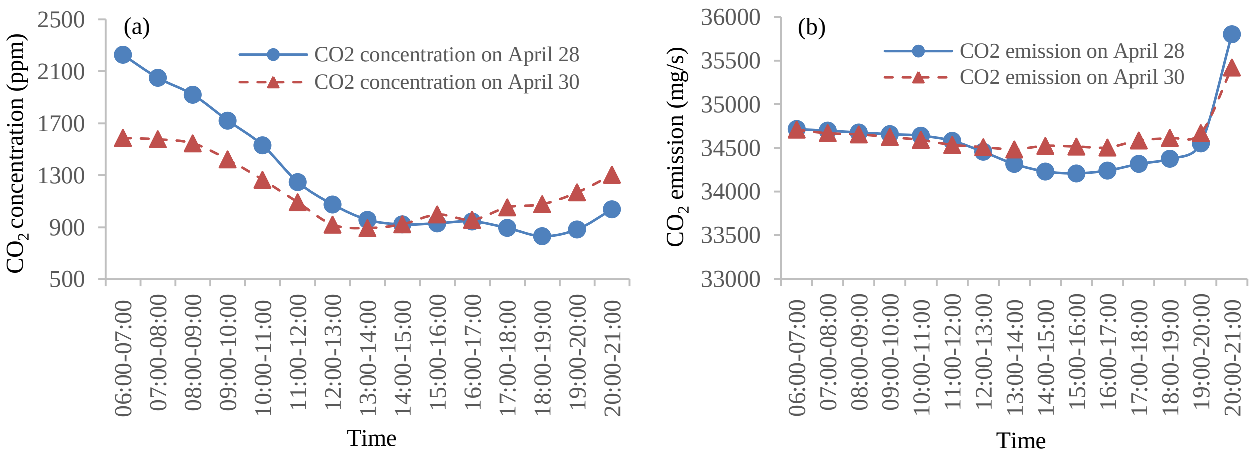

Figure 4. Diurnal CO_2 concentrations and emissions under mild climate; (a) is CO_2 concentration and (b) is CO_2 emission.

Significant interaction between "manure condition" factor and "diurnal" factor were found for CO_2 concentrations ($P<0.05$), therefore, diurnal variances in CO_2 concentrations were analyzed separately for the two days. Statistical results showed that average CO_2 concentrations and emissions would not change significantly after the manure was removed, which may suggested that under mild climate CO_2 production inside the barn was mainly due to birds respiration, and CO_2 production from manure decomposition could be ignored. On both the two days 3-hourly CO_2 concentrations would vary greatly ($P<0.05$) while no such results could be found for 3-hourly CO_2 emissions ($P>0.05$).

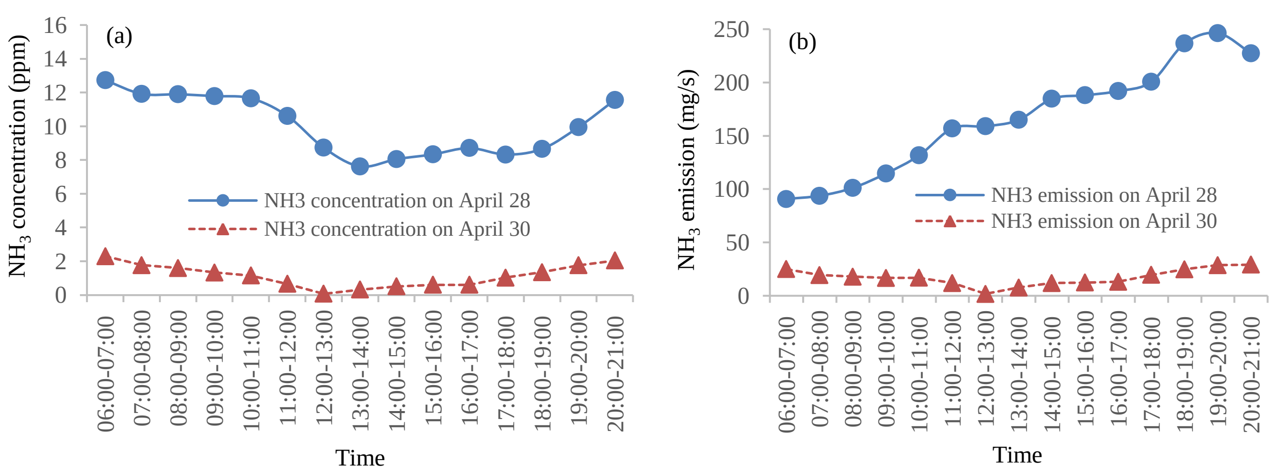

Figure 5. Diurnal NH_3 concentrations and emissions under mild climate; (a) is NH_3 concentration and (b) is NH_3 emission.

Compared to odour and other gases, the biggest difference was observed in the overall NH_3 concentration and emission for the two measurement days. As can be seen from Figure 5, average NH_3 concentration and emission were reduced greatly by 90% from 10 ppm to 1 ppm and by 90% from 165.96 mg s^{-1} to 17.03 mg s^{-1} respectively after the manure was removed. Similar to odour concentration, NH_3 concentration was higher in early morning and early evening than that in afternoon. However, NH_3 emission kept increasing all the time on April 28 with the highest emission rate occurred during 6:00-9:00 pm and lowest emission rate during 6:00-9:00 am. On April 30, NH_3 emission rate was dominated by the low NH_3 concentration thus showed a similar pattern to that of NH_3 concentration. From statistical analysis, NH_3 concentration on April 30 was significantly lower than that on April 28 ($P<0.05$). Analysis of Diurnal variances for the two days were conducted separately because of the significant interaction of the "manure condition" factor and the "diurnal" factor. Great variations were found in diurnal 3-hourly NH_3 concentration and emissions on both the two days ($P<0.05$).

Diurnal H_2S, CH_4 and N_2O concentrations and emissions were very low and stable on both the two days. The average H_2S, CH_4 and N_2O concentrations (emissions) were 28 ppb (0.92 mg s^{-1}), 2.18 ppm (7.51 mg s^{-1}) and 0.34 ppm (1.99 mg s^{-1}) respectively on April 28, and were 1 ppb (0.03 mg s^{-1}), 2.17 ppm (7.05 mg s^{-1}) and 0.34 ppm (1.85 mg s^{-1}) respectively on April 30. Removing manure showed great potential to reduce H_2S concentration and emission. After 11:00 am until the end of the measurement on April 30, no H_2S could be detected by the instrument.

CONCLUSION Monthly odour and gases concentrations and emissions tended to present different trends. Based on the results acquired from April to June, the maximum odour, CO_2 and NH_3 concentrations were observed in April when the ventilation rate was the lowest while the minimum concentrations were found in May when the ventilation rate was the highest. However, when discussing emission rate which was a product of concentration and ventilation, the maximum and minimum odour, CO_2 and NH_3 emissions were found in June and May, respectively. Compared with odour and NH_3 emissions, seasonal CO_2 emission was relatively stable and would not vary greatly. The concentrations of H_2S, CH_4 and N_2O were very low with only less than 100 ppb for H_2S, less than 3 ppm for CH_4 and less than 350 ppb for N_2O.

When comparing the diurnal results for the best-case and worst-case days, concentrations and emissions were significantly reduced by 30% and 32% for odour ($P<0.05$), and both by 90% for NH_3 ($P<0.05$), respectively when the manure was removed. Therefore, the manure condition such as removal frequency inside the layer barn should be considered when estimating odour and gas concentrations and emissions. No significant differences were found in daily CO_2 concentration and emission on the two days. The average CH_4, N_2O and H_2S concentrations were very low and no significant diurnal variances were found for both the two days. Removing manure more frequently shows a great potential to reduce H_2S concentration and emission. Diurnal odour and NH_3 concentrations and emissions changed significantly on both the two days. As for CO_2, 3-hourly CO_2 concentrations would vary greatly while no such variations were observed in CO_2 emissions on both the two days. As for odour and gas concentrations and emissions under mild climate when diurnal ventilation rate and outdoor temperature may vary greatly, it was found that either early morning from 6:00-9:00 am or early evening from 6:00-9:00 pm was the most interesting period when the highest concentrations or emissions seemed to occur. However, more results in the future are needed to prove or modify the above conclusions. With more data, the correlations of odour, different gases and environment parameters will be studied and prediction models for odour concentrations or emissions will be developed.

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