Air Quality in a Low Profile Cross Ventilated Dairy Barn

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TAKE HOME MESSAGES

During the evaluation of emissions from an 800-cow low profile cross ventilated dairy freestall barn in North Dakota, gaseous emissions were found to be dominated by nitrogen-based compounds. No concentrations of hydrogen sulfide were detected inside the barn using an open-path ultraviolet spectrometer at $R^2 \geq 0.75$ of library prediction. Indoor ammonia concentrations were found to be considerably less than those reported in naturally ventilated freestall barns during previous studies. Lastly, emission rates from the 800-cow barn were lower than 100 lb/day CERCLA/EPCRA reporting limits, but they would likely increase if more than 1100 cows were housed together.

INTRODUCTION

In addition to the many details that go into the design of a low profile cross ventilated facility, air quality is an extremely important consideration. A common term used when discussing air quality is the air exchange rate. An air exchange is equivalent to replacing all of the air inside the building with fresh air. For example, during warm weather, the air exchange rate is 60 to 90 seconds. This means that every 60-90 seconds the fans move enough air to completely exchange the air inside the building with outdoor air. The air exchange rate lessens during the winter months, however. An 800-cow LPCV building in North Dakota has a wintertime exchange rate of 180 to 240 seconds. Instead of managing airflow rates based on air temperatures, this facility relies on the ability to smell ammonia to document air flow.

STUDY METHODOLOGY

An air quality study was conducted on a 420’ x 210’ 800-head LPCV barn in Milnor, ND from March 2006 through August 31, 2006. Tests were conducted 3 times using 3 randomly assigned, pre-selected ventilation (low = 20 fans, medium = 40 fans; high 78 = fans) periods lasting 2 hours each. The herd was comprised of crossbred and Holstein cows milked 3 times per day and housed in freestalls with sand bedding. A skid steer loader mounted with a rubber tractor tire was used to scrape manure to a flush-flume collection pit on the north end of the barn. Collected manure was then processed with a McLanahan sand-manure separator before it was stored in an earthen manure collection basin, along with the parlor wastewater.

Five of the 84 fans (J&D, model# 84540) were selected for representative airflow measurements. The JD fans were 48 inches in diameter with 54 inch shutter openings. Each fan was tested using the Fan Assessment Numeration System (Casey et. al, 2002). This unit was placed on the intake side and sealed to the wall. Airflow through each of the tested fans was measured at 3 different static pressures (typically 0, 0.1 and 0.2 inches of water) in order to create a fan curve for each fan.

Three temperature and humidity data loggers (HOBO H8 RH/Temp Data Logger) were placed inside the building near the evaporative pads, and three other units were placed near the exhaust fans. Two loggers were used to record ambient conditions. Data was collected every 5 minutes.

Gas emission rates were estimated using an open-path ultraviolet (UV) spectrometer system. This non-invasive method is recognized by the US-EPA for its superior precision, accuracy, and versatility. It is able to quantify dozens of emitted gases simultaneously across source areas without inhibiting the flux of various compounds that have been identified with the use of small area chambers or flux hoods. During this study a UV Sentry (Cerex Environmental, Atlanta, GA) was placed inside the barn adjacent to the exhaust fans. The UV light transmitter was placed at one end of the barn while the receiver, computer, and 3-dimensional anemometer were placed at the opposite end. The UV light beam was placed 0.5 m from the rear of the fans at a height bisecting the fans on the east side of the LPCV. Data logging software and a portable computer were used to collect data from the UV Sentry. Sample UV spectra were recorded every minute during each of the eighteen sampling periods. Sampling software was programmed to estimate the concentration from the recorded spectra: Ammonia (NH_3), Nitric Oxide (NO), nitrogen dioxide (NO_2), Nitrogen Oxides (NO_x), Hydrogen Sulfide (H_2S), other reduced Sulfide (S_2) compounds, and various Volatile Organic Compounds (VOCs).

Gas concentrations with a library spectra prediction of $R^2 > 0.75$ were used in determining average concentrations or emission rates. Measurements with predictions below the 0.75 threshold were treated as non-detected concentrations. Emission rates were calculated from the product of the gas concentration, gas molecular weight, and air velocity. Data from this study was found to meet the assumption of normality without transformation. Differences between groups were tested for significance ($P < 0.05$) using the “Differences in Least Squared Means” test of the PROCMIXED procedure. Linear regressions were calculated using PROCREG of SAS (SAS 9.1)

STUDY RESULTS

Results of the FANS assessment are presented in Table 1.

Table 1: Fan Performance from an 800-head LPCV Facility

Parameter	**Ventilation Rate**		
Testing Rate	Low	Medium	High
Number of Fans	21	40	78
Static Pressure	0.025”	0.07”	0.15”
CFM[1] per fan	20,000	19,300	14,600
CFM total	420,000	772,000	1,138,800

[1] CFM = cubic feet per minute (ft^3/min)

Gases emitted from the LPCV were dominated by nitrogen-based gases (NH_3, NO_2, NO) during the spring and summer testing periods. During the study, concentrations of H_2S were not observed at any time to have a spectra prediction greater than the $R^2 > 0.75$ threshold established by the investigators. Periodic recordable concentrations were detected for S_2, but continuous detections did not last more than 5 minutes and, therefore, were not reported. The lack of H_2S detection is not surprising. Because of the twice daily scraping of manure from the LPCV barn, a large amount of stagnant manure was not allowed to accumulate and anaerobically degrade within the barn, thus limiting H_2S production.

Ammonia concentrations and emission rates were under the lowest ventilation rate tested (420,000 cfm), as shown in Table 1 above, and measured highest during the springtime. No statistical difference was found between NH_3 concentration and emission rates at the high ventilation rate during springtime, low ventilation rate during the summer, and high ventilation rate during the summer. No statistical difference in NH_3 concentrations was observed during the medium ventilation rates of both seasons. Average observed concentrations of NH_3 (spring = 1219 $^{+}$/-5 ppb; summer = 1117 $^{+}$/- 4 ppb) were lower than the 0.3 – 3.0 ppm and 36 – 51 ppm previously reported by Zhoa et al. (2005) and Mutula et al (2004), at naturally ventilated freestall barns in Ohio and Texas, respectively.

Springtime NH_3 emissions from the LPCV barn were found to be higher than those calculated during studies of naturally ventilated freestall barns in Minnesota and Texas. As shown in Table 2, during this study NH_3 emissions at the low ventilation rate were found to be 856 mg/h/500-kg live weight during the spring and 678 mg/h/500-kg live weight during the summer. This data can be compared to 224 mg/h/500-kg live weight during the winter and 481 mg/h/500-kg live weight during the summer in the Minnesota study (Schmidt et al., 2002). Comparatively, NH_3 emission rates in the current study were found to be 21.02 $\mu g/m^2/s$ during the spring and 16.65 $\mu g/m^2/s$ during the summer, compared to 11 $\mu g/m^2/s$ during the winter and 32 $\mu g/m^2/s$ during the summer in a Texas freestall barn (Mutula et al., 2004). These differences are likely due to variations in the gaseous measurement techniques and the methods used for quantifying the ventilation rate from each barn. Various barn configurations, manure management, and desired ventilation rate also cause differences in emission rates.

Table 2: Gaseous Concentration and Emissions from an 800-cow LPCV Dairy Barn

Concentration as ppb

Season	Ventilation Rate	NH_3		NO_2		NO	
		Mean	**Standard Error**	**Mean**	**Standard Error**	**Mean**	**Standard Error**
Spring	Low	1,370	10.3	445^{a}	35.9	8^{ab}	5.2
	Medium	$1,181^{b}$	8.2	296	28.6	27	4.1
	High	$1,108^{a}$	8.2	417^{a}	28.6	0^{a}	4.1
Summer	Low	$1,084^{a}$	7.0	176^{b}	24.4	0^{a}	3.5
	Medium	$1,157^{b}$	7.0	145^{b}	24.5	4^{b}	3.5
	High	$1,112^{a}$	7.1	155^{b}	24.5	0^{a}	3.5

Emission Rate as µg/s

Season	Ventilation Rate	NH_3		NO_2		NO	
		Mean	**Standard Error**	**Mean**	**Standard Error**	**Mean**	**Standard Error**
Spring	Low	172,248	2,464	$151,469^{b}$	24,117	$1,779^{ab}$	2,050
	Medium	$273,133^{a}$	1,962	$185,446^{b}$	19,202	11,074	1,632
	High	$377,874^{b}$	1,962	385,073	19,202	0^{a}	1,632
Summer	Low	136,426	1,676	$60,088^{a}$	16,407	0^{a}	1,394
	Medium	$268,596^{a}$	1,679	$91,455^{a}$	16,429	$1,572^{a}$	1,395

	High	379,190^b	1,681	142,958^b	14,452	0^a	1,398

^{abc} within a column, means without a common superscript differ ($P<0.05$) using Differences in Least Squares Means.

Schmidt et al. (2002) determined average ammonia concentrations using continuous chemiluminescence NO analyzer and a thermal NH_3 converter (Model No. 17C Thermal Environment Instrument). Ventilation rates were calculated using the "CO_2 Balance" method described by Albright (1990). Mutula et al. (2004) also determined ammonia concentrations using a Model 17C TEI while utilizing an isolation flux chamber to determine the emission rate per square meter. In order for engineers, scientists, regulators, and air quality professionals to make accurate comparisons between study results, further research is needed.

The indoor and outdoor temperature and indoor relative humidity were significant factors in the maximum NH_3 concentration within the LPCV dairy barn during the spring, as shown in Table 3. Other factors such as outdoor relative humidity and ventilation rate were not as significant. However, during the summer, all model variables were found to be statistically significant ($P< 0.05$ level) for the prediction of maximum ammonia concentrations. Further research should be conducted to investigate the predictive relationship between maximum NH_3 concentration within the barn, with or without the use of evaporative cooling pads during the summer.

Table 3: Seasonal Regression Analysis for Ammonia Concentration at LPCV Outlet

Variable	Estimate	Standard Error	t Value	Pr > t
Spring	*Root MSE = 92.55; Dependent Mean=1187.41; Coefficient Variable = 7.79; R^2 = 0.5920; Adjusted R^2 = 0.5886*			
Intercept	1174.26	165.22	7.11	< 0.0001
Temperature - Inside	117.31	16.36	7.17	< 0.0001
Relative Humidity - Inside	4.27	2.19	1.95	0.0514
Temperature - Outside	-131.88	13.67	-9.65	< 0.0001
Relative Humidity - Outside	-4.01	3.21	-1.26	0.2096
Ventilation Rate	-0.0000539	0.00003939	-1.37	0.1713
Summer	*Root MSE =34.48; Dependent Mean=1117.47; Coefficient Variable = 3.09; R^2 = 0.5022; Adjusted R^2 = 0.4998*			
Intercept	-73.76	40.27	-1.83	0.0673
Temperature - Inside	53.42	2.84	18.80	< 0.0001
Relative Humidity - Inside	4.55	0.35	12.86	< 0.0001
Temperature - Outside	-16.21	2.11	-7.68	< 0.0001
Relative Humidity - Outside	0.64	0.30	2.14	0.0327
Ventilation Rate	0.000140	0.00000573	24.45	< 0.0001

Temperature = 0C; Relative Humidity = %; Ventilation Rate = ft3/min; Inside = Inside Barn; Outside = Outside Barn

Table 4 shows that the current 800-cow LPCV barn would emit a maximum of 72 pounds/day (32.8 kg/day) of NH_3 and 73 pounds/day (33.3 kg/day) of NO_2. These values are less than the 100 pound/day reporting limit required for compliance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the emergency notification provisions of the Emergency Planning and Community Right-to-Know Act (EPCRA). However, based on these values, an LPCV barn with more than 1090 cows should report potential maximum emission for NO_2, and an LPCV barn with more than 1107 cows should report for NH_3.

Table 4: Emission Rates from an 800-cow LPCV Dairy Barn

Emission Rate as lb/cow/day				
		NH_3	**NO_2**	**NO**
Spring	Low	0.0410	0.0361	0.0004
	Medium	0.0650	0.0442	0.0026
	High	0.0900	0.0917	0.0000
Summer	Low	0.0325	0.0143	0.0000
	Medium	0.0640	0.0218	0.0004
	High	0.0903	0.0340	0.0000
Emission Rate as lb/day				
Spring	Low	32.81	28.85	0.34
	Medium	52.03	35.32	2.11
	High	71.98	73.35	0.00
Summer	Low	25.99	11.45	0.00
	Medium	51.16	17.42	0.30
	High	72.23	27.23	0.00
Emission Rate as g/day				
Spring	Low	14,882.2	13,086.9	153.7
	Medium	23,598.7	16,022.5	956.8
	High	32,648.3	33,270.3	0.0
Summer	Low	11,787.2	5,191.6	0.0
	Medium	23,206.7	7,901.7	135.8
	High	32,762.0	12,351.6	0.0
Emission Rate as g/cow/day				
Spring	Low	18.60	16.36	0.19
	Medium	29.50	20.03	1.20
	High	40.81	41.59	0.00
Summer	Low	14.73	6.49	0.00
	Medium	29.01	9.88	0.17
	High	40.95	15.44	0.00
Emission Rate as µg/m^2/s[a]				
Spring	Low	21.02	18.49	0.22
	Medium	33.33	22.63	1.35
	High	46.12	46.99	0.00
Summer	Low	16.65	7.33	0.00
	Medium	32.78	11.16	0.19
	High	46.28	17.45	0.00
Emission Rate as mg/h/500-kg live weight[b]				

Spring	Low	856	752	9
	Medium	1357	921	55
	High	1877	1913	0
Summer	Low	678	298	0
	Medium	1334	454	8
	High	1883	710	0

[a] based on barn interior dimensions of 64m x 128m (210ft x 420ft)

[b] based on an average weight per cow of 454 kg (1000 lb)

DUST EMISSIONS

In another study, dust measurements were taken inside a 200-foot wide LPCV that had sand bedded freestalls. Particulate emissions from the three samplers were 78.2 $\mu g/m^3$ near the east end of the barn, 74.8 $\mu g/m^3$ in the barn's center, and 94.8 $\mu g/m^3$ near the west end of the barn. These values are 10 to 100 times less than recorded dust concentrations from poultry and swine units (Jerez, et al., 2006). By comparison, the U.S. Environmental Protection Agency (USEPA, 1987) and the National Ambient Air Quality Standards (NAAQS) limit primary and secondary PM_{10} dust concentration for a 24-hour sampling period to 150 $\mu g/m^3$. The purpose of the primary standard is public health protection, and the purpose of the secondary standard is to shield the public from known or anticipated adverse effects. The values obtained from this site are below the current standard. Further research is needed to investigate if dust emissions are higher when organic bedding, such as dried manure solids or sawdust, are used.

SUMMARY

Low-profile cross-ventilated (LPCV) freestall buildings are another option for dairy cattle housing. These facilities allow producers to have greater control over the cow's environment during all seasons of the year. These buildings are placed closer to the parlor, reducing time cows are away from feed and water, resulting in a smaller overall site footprint compared to naturally ventilated freestall facilities. This study evaluated the gaseous emissions from an 800-head LPCV dairy barn located near Milnor, ND across three ventilation rates during the spring (May 8 - 12, 2006) and summer (August 28 - 31, 2006). Gaseous emissions were found to be dominated by nitrogen-based compounds. Hydrogen sulfide was not detected inside the barn using an open-path ultraviolet spectrometer at $R^2 \geq 0.75$ of library prediction. Indoor ammonia concentrations were found to be considerably less than those reported in naturally ventilated freestall barns during previous studies. Lastly, emission rates from the 800-cow barn were lower than 100 lb/day CERCLA/EPCRA reporting limits, but would likely be exceeded if more than 1100 cows were housed together.

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