**Effectiveness of a Manure Scraper System for Reducing Concentrations of Hydrogen Sulfide and Ammonia in a Swine Grower-Finisher Room**

**B. Z. Predicala, E. L. Cortus, S. P. Lemay, C. Laguë**

**ABSTRACT.** The effectiveness of a manure scraper system for reducing the risk of barn worker and animal exposure to hydrogen sulfide ($\text{H}_2\text{S}$) was evaluated by comparing gas levels in two swine production rooms, one with a manure scraper system installed (scraper) and the other with a conventional manure pit-plug system (control). Measurements were done over four production cycles; during each 12-week cycle, gas concentrations were measured 4 to 5 times during weeks that conventional manure removal activities were performed in the control room, while the scraper system was operated daily in the scraper room. Daily removal of manure from the scraper room resulted in measured maximum $\text{H}_2\text{S}$ concentrations that were significantly lower (by 90%) compared to the control room. The type of manure removal system had no significant effect on ammonia ($\text{NH}_3$) concentration and emission; during each trial, $\text{NH}_3$ emission increased in both rooms over the 4 to 5 monitored weeks. The scraper system was also operated in two different modes. These tests revealed that $\text{NH}_3$ production was reduced when all the manure was removed from the room compared to leaving the liquid portion on the pit floor surface, although the differences were not significant ($p > 0.10$). The estimated cost of including the scraper system in the construction and operation of a new barn is CDN$1.89 per pig sold, which is 35% less (on a per pig basis) than the cost of retrofitting an existing facility. The manure removal system tested was effective in reducing exposure of workers and animals to $\text{H}_2\text{S}$, without significant adverse impact on $\text{NH}_3$ production. However, given the highly variable nature of $\text{H}_2\text{S}$ production and dispersion within a room, care should always be taken when handling manure inside swine barns.

**Keywords.** Ammonia, Hydrogen sulfide, Manure, Scraper, Swine.

Hydrogen sulfide ($\text{H}_2\text{S}$) is a potentially hazardous gas that has been shown to reach elevated levels in swine barns, thus potentially posing a threat to the health and safety of workers and animals. Saskatchewan Labour (1996) stipulates that worker exposure to $\text{H}_2\text{S}$ should not exceed an 8 h time-weighted average (TWA) of 10 ppm (threshold limit value – TLV), or a 15 min TWA of 15 ppm (short-term exposure limit – STEL). The immediately dangerous to health (IDLH) level for $\text{H}_2\text{S}$ is 100 ppm; at this level, olfactory detection is generally desensitized; thus, an exposed individual may not be able to distinguish higher concentrations based on intensity of smell alone. Chénard et al. (2003) found that swine barn workers were at risk of $\text{H}_2\text{S}$ exposure while performing manure management tasks that result in manure agitation, such as pulling pit-drain plugs to clear manure out of under-floor manure channels in swine production rooms. Out of 119 plug-pulling events monitored in different sections of various barns, 29% generated values higher than 100 ppm, and 48% generated 15 min TWA values that were higher than the 15 ppm STEL value at the worker level. In the same study, spatial monitoring of concentrations over the manure pit during emptying showed that the highest $\text{H}_2\text{S}$ concentrations were not always measured in the vicinity of the pit drain but could occur anywhere over the manure channel.

Hydrogen sulfide gas is created by anaerobic degradation of manure (Arogo et al., 2000). Long storage times of manure inside barns can contribute to the anaerobic degradation process, and consequently, to increased risk of generating potentially hazardous levels of $\text{H}_2\text{S}$ when manure is agitated during clear-out. A potential method to reduce the production and eventual release of $\text{H}_2\text{S}$ and other manure gases is to remove the manure from the room on a more frequent basis. Manure scraper systems are commonly used in cattle barns and have been modified to work in swine barns as well. Voermans and van Poppel (1993) studied six scraper systems designed for swine barns, with and without separate discharge for urine, and found an overall reduction in ammonia ($\text{NH}_3$) emissions. Because of the potential severity of health effects from being exposed to $\text{H}_2\text{S}$, the main goal of this study was to evaluate the effectiveness of daily operation of a manure scraper system for reducing the risk of $\text{H}_2\text{S}$ exposure of swine barn workers and animals during in-barn manure handling activities. Specifically, a manure scraper system was evaluated under actual swine production conditions for its impact on $\text{H}_2\text{S}$ lev-
els; the effect on other air quality parameters, particularly $\text{NH}_3$, was also monitored. The economic feasibility of either retrofitting the system into existing barns or incorporating it into the design of new barns was also evaluated.

**MATERIALS AND METHOD**

**DESCRIPTION OF FACILITIES**

Two commercial grower-finisher rooms (each 5.3 m wide $\times$ 14.2 m long) at Prairie Swine Centre, Inc. (PSCI; Saskatoon, Saskatchewan, Canada) were used over four production cycles. Each room had six pens (4.2 m $\times$ 2.0 m each) with partially slatted floors over a 0.6 m deep manure channel (2 m wide $\times$ 12 m long) with a pit drain on each end. Each room held a total of 70 pigs; for this experiment, one end pen remained empty throughout the trial, while the other pens had 14 pigs each. The empty pen was necessary because the scraper system was operated in two modes (described in next section). Equal numbers of male and female pigs at an average weight of about 21.5 kg were brought into the rooms; the difference in total starting weight for the two rooms was within $\pm$ 1.0 kg. The rooms were mirror images of each other, and both used dry feeders with an automatic feeding system and nipple drinkers. Pigs were fed *ad libitum* with mash diets formulated according to National Research Council (NRC, 1998) requirements.

One room was operated normally (control), i.e., manure was allowed to accumulate in the under-floor pit for two to three weeks, and then cleared out of the room by pulling the pit-drain plugs and allowing the manure slurry to empty into the pit drain by gravity. In the other room (scraper), a manure scraper system was installed and operated daily to remove the manure from the room. Pulling the plug daily does not clear the manure channel completely because the manure slurry does not flow and drain properly due to inadequate accumulated volume; thus, a scraper system was needed.

**MANURE SCRAPER SETUP**

The manure scraper system was made from components of a commercially available scraper system used in some swine operations in Québec and in other livestock (dairy) industries (fig. 1). This typical scraper system consisted of a cable and pulley system used to pull a blade that scraped the manure channel bottom. Although the main focus of this study was to evaluate the impact of the scraper system on H$_2$S levels, previous studies reported the potential adverse impact of scraper systems on NH$_3$ levels, attributed to the film of excreta left on the scraped surface that may actively produce the gas. Recharging the manure pit with a relatively small amount of liquid after draining the manure from the pit has been found to reduce NH$_3$ emissions (Lim et al., 2004). Hence, to investigate possible means to mitigate this concern with NH$_3$ production, the experimental setup used in this study was designed to allow two modes of operation of the scraper system: (1) in a typical manner in which the manure slurry mixture was scraped and removed completely, or (2) in a “separator” mode in which the scraper blade removed about 80% of the solids while the liquids were retained to act roughly as “pit recharge.”

To achieve these two modes of scraper operation, a false floor was built on the manure pit floor with one end raised by 0.25 m, sloping down to a height of 0.2 m at the other end (fig. 2). As shown in figures 1 and 2, the resulting false flooring had a longitudinal slope of 0.5% and did not extend to either end of the manure channel. Instead, two manure tubs (figs. 1b and 2) were constructed out of mild steel, and one was placed at each end of the false floor. Both tubs were built with sloping floors to ensure complete drainage of the manure into the drain opening when the plug was pulled. The false floor and tubs were sealed around all edges and joints to prevent manure infiltration.

A removable retaining wall was installed across the low end of the false floor (fig. 2). When the wall was in place and the scraping direction was toward the top of the slope (upslope), the scraper blade moved mainly the manure solids into

![Figure 1. The scraper blade was pulled over the false floor (a) and deposited the manure in the accumulation tub, where the pit plug (b) was pulled to drain the manure to the sewer line. The scraper blade can be operated in two directions, and the manure pit has drains at both ends.](image)

![Figure 2. Schematic diagram of the sloped false floor in the manure pit with the removable retaining wall in place (not to scale).](image)
the accumulation tube while retaining the liquids above the false floor. With the wall removed and by running the scraper blade to the bottom of the slope (downslope), both solid and liquid manure components were scraped and moved to the tub for subsequent removal from the pit. Daily operation of the scraper system included operating the scraper blade in the designated direction (upslope or downslope), and then pulling the plug in the accumulation tub filled with the scraped manure to drain the slurry out of the channel. The plug was then replaced and the scraper blade returned to the initial position. When the scraper was operated in the downslope direction, the tub on the opposite end of the channel was not used and the end pen above this tub was kept empty of pigs. The corresponding pen in the control room was also left empty, and the same scraping direction was used throughout one monitored week. The scraping direction was alternated between successive monitored weeks; the pigs in the end pen were also moved between the two end pens of the room to coincide with the scraping direction.

The scraper pulley system was designed so that the worker would only need to enter the room to operate the scraper motor. A pit-plug pulling system (fig. 1b) allowed remote pulling of the pit plugs from outside the room (Lemay et al., 2004).

**DATA COLLECTION**

The room air quality and H2S concentrations in the two experimental rooms were compared over four production cycles; each cycle represented one trial, which lasted for 12 weeks. During trials 1 and 2, four 5-day periods (weeks) were monitored. An additional monitored week was added in trials 3 and 4.

The monitored weeks coincided with the typical plug-pulling schedule in the control room, which allowed for manure to accumulate initially over a 4-week period while the pigs were small, while subsequent plug-pulling events were done after every two to three weeks to account for an increase in manure production as the pigs grew larger. The pit plug in the control room was pulled on day 3 of each of the monitored weeks. In the scraper room, the scraper system was operated once a day, and the pit plug was pulled after each scraper operation. For each trial, the removable wall was not used (i.e., downslope scraping direction) during monitored weeks 1 and 3. The removable wall was installed (upslope direction) for weeks 2 and 4 (and week 5 for trials 3 and 4).

For each scraping and plug-pulling event during the monitored week, two H2S monitors (model Pac III, with XS EC 1000 ppm H2S sensor, Draeger, Lübeck, Germany) were installed in each room: one over the middle of the pit (middle pen) and another directly above the pit plug (of the tub in use), both at about 1 m above the floor. The manufacturer-specified repeatability of the H2S sensor readings was ±5% of measured value or better. Before each sampling day, both H2S monitors were calibrated using test gases at 100 and 500 ppm H2S, ensuring that the readings at these levels were within ±2 ppm of the test gas concentration. Additionally, the performance of the H2S monitoring devices was verified by comparing readings with a reference analytical method using a gas chromatograph. Out of 131 paired readings ranging from 2 to 985 ppm, the H2S monitor readings did not differ significantly (p > 0.05) from the reference method. Comparison of mean readings at various concentration ranges (intervals of 100 ppm) also showed that the H2S monitor yielded readings that were not significantly different (p > 0.05) from those obtained from the reference method at all H2S concentration ranges (Predicala et al., 2006).

Throughout the study, the same two H2S monitors were used in both rooms to eliminate errors due to variation in performance of specific H2S monitors. The H2S measurement procedure included the following steps: (1) the H2S monitors were turned on and put in position 5 min before pulling the plug, (2) the plug was pulled and manure slurry was allowed to drain to the sewer for approximately 10 min, (3) the plug was put back in place, and (4) monitoring continued for an additional 5 min, and then the H2S monitors were turned off. During the first monitored week of trial 1, the H2S concentrations were measured in both rooms (control and scraper) during the daily 15 min period that the scraper system was operated in the scraper room. However, initial results showed that no (zero) detectable H2S was measured in the control room during these days, and measurable H2S readings were detected only during day 3 (of the monitored week) on which the pit plug was actually pulled. Thus, in subsequent monitored weeks, the H2S levels were measured in the control room only during the day that the pit plug was pulled in that room, while H2S monitoring was done in the scraper room for the entire week during scraper operation.

The NH3 concentration and thermal environment parameters in both rooms were measured on a continuous basis during the monitored week. Ammonia concentrations were measured at the inlet and outlet of both rooms using a sampling manifold system attached to an NH3 analyzer (model Chillgard RT, MSA Canada, Edmonton, Alberta; ±2 ppm accuracy). Monitoring of NH3 concentrations was conducted primarily to ensure that use of the scraper system did not lead to generation of NH3 levels that exceeded the 25 ppm NH3 occupational exposure limit. Temperature (type-T thermocouples), relative humidity (model F22H-65, Rotronic Instrumentation Corp., Huntington, N.Y.; ±1.5% accuracy), fan speed (proximity sensor model SR3, Microswitch, Freeport, Ill.), and static pressure (model 264, Setra, Foxborough, Mass.) were measured every minute and averaged every 15 min.

The ventilation rate in each room was calculated as follows: the static pressure and fan speed were measured in each room; these values were used in fan equations developed for each type of fan to calculate the fan airflow rate. Each room had three types of fan, which operated depending on ambient conditions; the total ventilation rate for each room at any time was the sum of the airflow rates of the fans in operation. The fan equations were developed from fan performance data (airflow rate, static pressure, and fan speed) for each type of fan using the generalized mathematical model described by Barber et al. (1988). Fan performance data were obtained from actual fan test calibration of each type of fan, under different fan speeds and fan static pressures and in accordance with the Canadian Standard Association Ventilation Fan Test (Standard No. CANCSA C320-M86). This was conducted by a third-party testing institution for the fan manufacturer. Using this ventilation rate measurement approach and taking into consideration the errors associated with the static pressure transducer, fan speed sensor, and fan equations, the calculated error in the total room ventilation rate when all fans were operating at full capacity was estimated to be about 6%. 
The NH3 emission from each room was calculated using a steady-state mass balance approach. Taking into account the NH3 in the inlet air, the NH3 emission (E) produced in each room was calculated on an hourly basis using equation 1, with the appropriate conversion of units:

\[
E = \frac{(C_{NH3,exhaust} - C_{NH3,inlet}) \cdot 0.6894 \cdot V \cdot 3600}{10^6}
\]

where

- \( E \) = net NH3 emission rate from the room (g h\(^{-1}\))
- \( C \) = hourly average concentration of NH3 at the exhaust and inlet (ppm)
- \( V \) = hourly average room ventilation rate (L s\(^{-1}\))

The density of NH3 gas was assumed constant at 0.6894 kg m\(^{-3}\), equivalent to NH3 gas density at standard pressure and at a temperature of 27°C.

**DATA ANALYSIS**

Given that high levels of H2S can pose immediate danger to the health and safety of workers and animals, the effect of the scraper system on both the daily maximum H2S concentration and the 15 min time-weighted average (TWA) H2S concentration was examined. The time-weighted average values were calculated by:

\[
TWA = \frac{\sum_{i=1}^{k} C_{H2S,i} \cdot I_{s,i}}{I_T}
\]

where

- \( TWA \) = time-weighted average (ppm)
- \( i \) = sampling interval
- \( k \) = total number of intervals
- \( C_{H2S,i} \) = concentration of H2S during the \( i \)th interval (ppm)
- \( I_{s,i} \) = sampling duration of the \( i \)th interval (s)
- \( I_T \) = total sampling duration (s).

The sampling interval of the H2S monitors was 10 s, and the total sampling duration considered was 15 min, which covered the pit-plug pulling event that generated the H2S gas.

The maximum concentration and TWA data were analyzed using a split-split plot approach, with room (scraper vs. control) as the main plot, location of measurement (over plug vs. middle of pit) as the subplot, and week (1 to 4 in trials 1 and 2, and 1 to 5 in trials 3 and 4) as the sub-subplot measured over time. The experiment was repeated four times (trials 1 to 4) over the course of a year, thus covering one complete seasonal variation in environmental conditions. Room, location, and week were treated as fixed variables, and trial was considered a random variable. Interactions between fixed variables were included in the statistical model. Analysis was performed using the PROC MIXED procedure in SAS (SAS Institute, Cary, N.C.). The data set was unbalanced because of the addition of a fifth monitoring week in trials 3 and 4. The impact of the direction of scraping was evaluated by comparing the least-square means between weeks within the scraper room.

To evaluate the effect of the scraper system on NH3 concentration, a second analysis was completed to determine the effect of the main plot (room: scraper vs. control), subplot (week: 1 to 4 in trials 1 and 2, and 1 to 5 in trials 3 and 4), and interactions of these effects over the four trials using the PROC MIXED procedure in SAS. Again, room and week were considered fixed variables, and trial was considered a random variable. Again, the impact of the direction of scraping was evaluated by comparing the least-square means between weeks within the scraper room.

**RESULTS**

Throughout the trials, standard environmental control settings recommended for growing-finishing pigs were maintained in both rooms, depending on the age of the pigs and the season. The average difference in temperature and relative humidity between the control and scraper rooms was less than the indicated accuracy of the instruments used. Similarly, the average ventilation rates for the two rooms differed by less than 1%, which was less than estimated accuracy of the ventilation rate measurement approach used. These indicated that while using a ventilation control system typically used in commercial swine barns, the thermal environment and ventilation rates were maintained as close as possible in the two rooms throughout the duration of the study.

**HYDROGEN SULFIDE CONCENTRATIONS**

Table 1 summarizes the raw maximum H2S concentration and TWA H2S concentration values, respectively, measured in the two rooms during the day that the pit plug was pulled in the control room. An initial statistical analysis using the raw H2S concentration values showed that the variances between treatments were heterogeneous and the model residuals were not normally distributed, thus requiring data transformation to satisfy normality and variance homogeneity requirements for analysis of variance. After exploring various data transformation schemes (Zar, 1984), the maximum and TWA concentration data sets were transformed by taking the fourth root of the concentration values. The transformed data set satisfied Bartlett’s test for homogeneity of variance (Zar, 1984) when comparing the control and scraper rooms (\( \lambda^2 = 1.14 \) with 1 degree of freedom). The transformation also increased the Shapiro-Wilk statistic for the maximum and TWA concentration model residuals to 0.971 (\( n = 70; \ p = 0.099 \)) and 0.947 (\( n = 70; \ p = 0.005 \)), respectively, indicating that the model residuals tended towards normal distribution. In the subsequent discussion, the mean and standard error (SE) H2S values presented were calculated from raw maximum and TWA concentration values, while the results of the analysis of variance were based on the transformed data.

The room with the scraper system had significantly lower maximum H2S concentration levels (1.4 ppm) than the room with conventional pull-plug system (14.5 ppm) (SE 3.9 ppm; \( F_{1,3} = 20.5; \ p < 0.05 \)), equivalent to an average reduction of 90%. Comparison of the average maximum H2S concentrations measured from the two locations in both rooms showed that H2S levels over the plug (12.7 ppm, SE 3.2 ppm) tended to be higher (\( F_{1,6} = 4.18; \ p < 0.10 \)) than over the middle of the pit (3.2 ppm, SE 3.2 ppm). The week variable and interactions between fixed variables had no significant effect (\( p > 0.1 \)). There were several occasions in both rooms when no H2S was detected by the H2S monitors. This could be attributed to the highly variable composition of manure slurry, which when considered together with the shallow slurry depth and short storage durations, may have prevented sufficient H2S accumulation within the manure before agitation. Another likely possibility was that, because the airspace in
Table 1. Summary of raw maximum H₂S concentrations and time-weighted average (TWA)
H₂S concentrations measured in the control and scraper rooms at two locations in each room.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Date</th>
<th>Maximum H₂S Concentration (ppm)</th>
<th>TWA H₂S Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control Room</td>
<td>Scraper Room</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over Plug</td>
<td>Middle Pen</td>
</tr>
<tr>
<td>1</td>
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<td>4</td>
<td>2</td>
</tr>
<tr>
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<td>24 Mar. 04</td>
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<td>0</td>
</tr>
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<td>21 Apr. 04</td>
<td>12</td>
<td>4</td>
</tr>
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<td>2</td>
<td>30 June 04</td>
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<td>2</td>
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</tr>
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</tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td>23 Mar. 05</td>
<td>52</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>06 Apr. 05</td>
<td>23</td>
<td>5</td>
</tr>
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</table>

LSM[b] 23.4 a 5.6 b 2.0 c b 0.8 c 4.23 d 1.24 d 0.17 e 0.06 e
SE[b] 4.5 4.6 4.5 4.6 0.83 0.84 0.83 0.84

[a] n/a = data not available, instrument malfunction.
[b] LSM = least square mean; SE = standard error of the mean; degrees of freedom = 6.

Different letters (a, b, c) accompanying LSM values indicate significant differences (α = 0.05) between room × location combinations for maximum concentration values, determined using transformed data.

Different letters (d, e) accompanying LSM values indicate significant differences (α = 0.05) between room × location combinations for TWA concentration values, determined using transformed data.

the rooms was typically not very well mixed, the H₂S may have been released in a plume that did not pass through the two fixed sampling locations. This was supported by observations from spatial H₂S measurements in swine rooms conducted by Chénard et al (2003).

Similarly, the combined average TWA H₂S concentration from both locations in the scraper room was significantly lower compared to the control room (0.11 ppm vs. 2.74 ppm, SE 0.71 ppm; F1,3 = 19.10; p < 0.05), showing a reduction of about 96%. The location of measurement did not have a significant effect; however, the week tended to influence the TWA concentration (F4,38 = 2.25; p < 0.10) and the room × week interaction was significant (F 4,38 = 3.19; p < 0.05), as shown in figure 3. The week × location × room, and week × location interactions were not significant in the analysis of variance (p > 0.10). There was no significant difference between weeks within the scraper room (p > 0.1), indicating that the direction of scraping had no significant impact on the TWA H₂S concentration levels.

AMMONIA CONCENTRATION AND EMISSION

Table 2 shows the average NH₃ concentration values at the inlet and exhaust of the scraper and control rooms for every monitored week. Only the average inlet concentration for both rooms was reported because the values from the two rooms were very similar, which was expected because the two rooms were adjacent and were drawing inlet air from the same airspace (barn attic). The room had no significant effect on NH₃ concentrations measured at the outlet of these rooms (F1,3 = 4.89, p > 0.10), indicating that more frequent manure removal from the room using a scraper system did not significantly affect NH₃ concentration levels. However, an average of 35.6% more NH₃ was emitted from the scraper room compared to the control room, indicating that the manure removal system tended to increase room emission (F1,3 = 4.19, p < 0.10). There was no significant effect of week (p > 0.10) or room × week interaction on the average exhaust concentration (fig. 4), which indicated that there was no significant effect of the scraping direction on the exhaust NH₃ concentration in the scraper room.

Table 3 summarizes the weekly average NH₃ emissions from the scraper room for the two scraping directions. Although the mean value for upslope direction was higher compared to the downslope direction, statistical comparison of the emission values showed no significant difference (p > 0.1), indicating that the direction of scraping had no significant impact on the TWA NH₃ concentration levels.

[Figure 3: Least square mean time-weighted average (TWA) H₂S concentration for the five sampling weeks during the production cycles. Bars indicate standard error. Significant differences between rooms for each week are signified by * (p < 0.10), ** (p < 0.05) and *** (p < 0.001).]
HYDROGEN SULFIDE CONCENTRATIONS

The scraper system significantly reduced maximum H$_2$S concentrations by 90% and TW A values by 96%. As expected, the daily removal of manure prevented a build-up of manure in the pit and reduced the time available for anaerobic decomposition of manure, thus generating less H$_2$S during agitation. The maximum H$_2$S concentration measured differed by location, which was expected because the airspace in swine production rooms is generally not well mixed, especially during the cold season when ventilation rates are low.

DISCUSSION

0.10) between the two scraping directions, indicating that removal of solids and retaining the liquids in the manure pit had no significant impact on NH$_3$ emissions from the room.

Under this condition, the sudden release of H$_2$S during manure agitation could create plumes that would generally move with the prevailing airflow pattern in the room (Chénard et al., 2003), potentially resulting in air pockets with elevated H$_2$S concentrations. While this can be dissipated by ventilation in due course, the risk to workers and animals of being exposed to such plumes can be better mitigated by measures that eliminate conditions for creating H$_2$S in the first place, such as daily removal of manure using a scraper system. The TW A concentration was less sensitive to sudden increases and decreases in concentration.

The H$_2$S concentration was significantly higher during sampling weeks 2, 4, and 5, which corresponded to scraping in the upslope direction. During these weeks, the manure liquids were continuously retained in the pits, thus possibly causing the increased H$_2$S levels observed. Additionally, each pit drain on the opposite ends of the manure pit was connected to a separate drainage line. Typical of drainage systems in a large proportion of swine barns, no air trap was installed in the drainage line. Gas build-up can occur in these lines and it was possible that the line used during these weeks had worse build-up compared to the other line; during plug-pulling, the gas in the drainage line could escape into the room, thus possibly contributing to higher levels of H$_2$S. Despite these elevated H$_2$S values associated with the scraping direction, the observed levels were still significantly lower compared to the control room. Although measurements were taken only at two specific locations within the room, it appeared that the scraper system could effectively reduce the overall levels of H$_2$S in the room.

Safety Emphasis

The maximum H$_2$S concentration measured in the control room during the study period was 95 ppm, which was very close to the IDLH value. The maximum concentration measured in the scraper room was 19 ppm; however, this may be an isolated observation because at about the same time that this particular measurement was taken, it was documented that there was manure pit plug-pulling taking place in an adjacent room, thus possibly resulting in backflow of gases from the drainage lines into the scraper room. The TW A H$_2$S
values in the control room exceeded the 15 min average contamination limit value of 15 ppm H$_2$S (Saskatchewan Labour, 1996) once, and there were other instances when the TWA was above 10 ppm. In contrast, the scraper system helped maintain TWA levels below 2 ppm for all trials, demonstrating the effectiveness of the system in preventing H$_2$S build-up inside the rooms and protecting workers and animals against potential exposure to elevated H$_2$S levels. However, regardless of the type of manure removal system, barn workers still need to exercise caution and observe established safety protocols when performing manure handling activities inside swine production rooms.

**AMMONIA CONCENTRATION AND EMISSION**

The overall average NH$_3$ concentration at the inlets to the scraper and control rooms was about 5.5 ppm, but weekly average values as high as 7.7 ppm were also measured. These relatively significant inlet concentration levels were attributed to possible recirculation of air exhausted from the fans into the supply air coming into the barn, as well as from backdraft of NH$_3$ from adjacent rooms into the barn attic where ventilation air passed into the experimental rooms.

The maximum average NH$_3$ concentrations at the exhaust of the scraper and control rooms were 16.5 ppm and 14.1 ppm, respectively, both of which were below the TLV for NH$_3$ of 25 ppm (Saskatchewan Labour, 1996). The observed NH$_3$ levels tended to be higher in the scraper room than in the control room, but the difference in average NH$_3$ concentrations at the exhausts of the control and scraper rooms was less than the rated accuracy of the NH$_3$ analyzer used ($\pm$ 2 ppm). Ammonia production is dependent on many factors, including diet, temperature, and floor type. Although the scraper room had slightly higher NH$_3$ levels compared to the control room in this experiment, the magnitude of increase that could be attributed to the type of manure handling system used was not large enough to result in NH$_3$ levels that would place the health and safety of workers and animals at risk. Instead, the more immediate concern revealed in this experiment, which must be addressed first to avoid generating potentially harmful NH$_3$ levels, is the cause of the elevated background NH$_3$ levels measured at the inlet of these rooms.

While there was no significant increase in room NH$_3$ concentrations and in ventilation rates from week to week, there was a slight increase in both parameters between weeks 1 and 5. This can be attributed to the increase in NH$_3$ production as larger amounts of manure were produced as the pigs grew larger, and the need to increase ventilation rates to account for increased heat and moisture production by the larger animals. The combined effect of the slightly higher concentration and ventilation rates resulted in a significant increase in NH$_3$ emission over the course of a production cycle.

With the scraper system operated in the upslope direction, the NH$_3$ emission was expected to be lower because of the “pit recharge” effect of retaining the liquid portion of the slurry in the pit, compared to operating the scraper in the downslope direction. However, the results from this experiment showed a slight increase in NH$_3$ emission when this liquid layer was present. The liquid portion left in the room may have been more concentrated than anticipated and continued to actively generate gases (including H$_2$S); in comparison, it appeared that scraping in the downslope direction left less active residue in the manure pit from which less NH$_3$ was generated.

**SYSTEM DESIGN, INSTALLATION, OPERATION, AND COST**

The experimental system was retrofitted into an existing barn with a shallow pit. A significant component of the cost for this setup was the labor required for the installation of the false floor over the existing concrete floor. This false floor was important for this experiment to test the two different scraping modes; it may not be required for a typical scraper installation, although a smooth floor surface is important to ensure complete removal of the manure (Voermans and van Poppel, 1993). Operating the scraper was relatively simple and only required approximately 5 min per day. For this experiment, extra labor was required to clean the false floor and accumulation tubs every two weeks to prevent a build-up of dry manure on the false floor surface, but in an actual commercial installation, this may be achieved with the standard practice of pressure-washing production rooms regularly. It was also useful to have a removable section of slatted floor over the plugs for periodic maintenance tasks such as cleaning and fixing the pulley system and for rare occasions when some components moved out of place (e.g., cable stops).

The estimated cost to install the scraper system in an existing facility or to include the scraper system in the construction of a new barn was analyzed (table 4) using a financial model of a swine enterprise (Engele et al., 2005). The largest difference between the two scenarios is the cost associated with retrofit work to lay a smooth flat floor on the manure channel bottom, which may not be necessary for some retrofit situations if the existing channel floor surface is sufficiently flat and smooth already. The annual construction and operating costs to include the scraper system in the manure management system is an extra CDN$2.51 and $0.39 per pig sold, respectively, in an existing facility, assuming a floor retrofit is required. In a new facility, the construction and operating costs are CDN$1.49 and $0.39 per pig sold, respectively. The total annual cost on a per pig basis is 35% lower for a new facility versus retrofitting an existing barn. This analysis did not take into account the potential health and safety benefits

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost (CDNS)</th>
<th>Retrofitting an Existing Barn</th>
<th>Installation in a New Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction costs (per room)</td>
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<tr>
<td>Scraper</td>
<td>2,823</td>
<td>2,823</td>
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<tr>
<td>Retrofitting supplies</td>
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<tr>
<td>Labor to install scraper</td>
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<td>Labor to retrofit</td>
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<td>Total annual construction costs (for entire barn, including interest and depreciation, management, insurance, and taxes)</td>
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<td>20,757</td>
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<td>Annual operating costs (for entire barn)</td>
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<td>Repair supplies</td>
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<td>Operating labor</td>
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<tr>
<td>Total annual operating costs</td>
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<td>(0.39 per pig sold)</td>
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<tr>
<td>Total annual cost (for entire barn)</td>
<td></td>
<td>40,600</td>
<td>26,316</td>
</tr>
</tbody>
</table>

Table 4. Cost estimation using the Enterprise Returns Model (Engele et al., 2005) to install the scraper system in the grower-finisher component of a 600-sow farrow-to-finish operation. Assumptions include two scrapers installed in 14 rooms, and that the equipment will depreciate over 10 years with a salvage value of 10%. All amounts in Canadian dollars.
from installing this system; a more detailed analysis for a given barn and commercial scraper system may show the cost is warranted given the increased worker safety.

**CONCLUSIONS**

A manure scraper system was installed in a full-scale grower-finisher room at PSCI and evaluated by comparing the H$_2$S and NH$_3$ levels in the experimental (scraper) room with another grower-finisher room operated under normal production conditions (control). Four trials were completed, corresponding to four production cycles for the rooms. The maximum H$_2$S concentrations measured in the scraper room were significantly lower (p < 0.05) by an average of 90% compared to the control room, and TWA concentrations were significantly lower (p < 0.05) by 96%. Maximum concentration levels tended to be higher over the plug area, compared to the middle of the manure pit channel (p < 0.10). Ammonia concentrations at the exhausts of the scraper and control rooms were not significantly different, but the NH$_3$ emission from the scraper room tended to be higher than from the control room (p < 0.10) by 36%. Retaining the liquid portion of the slurry in the manure pits did not decrease NH$_3$ emissions, indicating no effect of scraping direction.

Overall, the results obtained in this study demonstrated the effectiveness of the scraper system in reducing H$_2$S exposure of swine barn workers, with marginal impact on NH$_3$ production. Based on the costs associated with this study, the estimated cost to construct and operate the scraper system in a new or existing facility was approximately CDN$2 to $3 per pig sold, respectively. This cost estimate includes components that may not be required for an actual installation, and does not take into account improved worker safety and potential health benefits of having reduced risk of exposure to elevated H$_2$S levels.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


