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HYDROGEN SULPHIDE EMISSIONS FROM GROWER PIG EXCRETA PRODUCED BY A BELT CONVEYOR SYSTEM

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Abstract: Hydrogen sulphide (H_2S) gas remains an occupational health and safety issue in Canada because exposure to this toxic gas can represent a threat to both human and animal health. A new housing concept featuring a belt conveyor (BC) system to separate feces from the urine at the pen level has been successfully developed. The pen concept utilizes an inclined BC as the pen dunging area. The feces are removed by a wiper underneath the top of the belt incline as the belt moves upslope periodically whereas the urine continuously drains to the bottom of the incline into respective containers. A water soaked brush is located beneath the belt to periodically clean the belt. The objective of the study was to measure the effectiveness of the BC at reducing H_2S and ammonia (NH_3) emissions from separated excreta compared to conventional liquid manure. Approximately 50 kg of 2-wk excreta collections from the control (manure) and BC (solids, urine, washwater) rooms were placed in ventilated (0.19 L/s) 0.9 m x 0.9 m x 0.7 m chambers over a 4-wk period (three replicates) to measure H_2S and NH_3 emission rates. Undisturbed stored manure slurry and separated manure components showed no significant difference in H_2S emissions. However, the removal of urine from the pig space immediately after excretion can reduce the room H_2S emission rate by 50%. When agitated, stored manure slurry released about 3 times more H_2S compared to the BC excreta. Isolation of the urine and washwater would result in the BC room generating H_2S emission which is only 12% of that in the control treatment. Production of NH_3 was similar between the BC and control rooms. When undisturbed the BC room excreta generated 725, 134 and 89 mL/h of NH_3 for the urine, solids and washwater, respectively, and the manure slurry in the control room produced 857 mL/h for six pigs. An optimized BC pen design can be potentially incorporated in a deep-pit barn construction with separate long-term in-barn storage for the separated solid and liquid manure components, without the typical hazards from high H_2S levels associated with conventional deep-pit barns.
Keywords: hydrogen sulphide emissions, manure separation, ammonia emissions, belt conveyor system.

INTRODUCTION

Two challenges that the Canadian pork industry face are land application of manure and the exposure of barn workers and animals in confined swine facilities to hydrogen sulphide (H_2S). Hydrogen sulphide gas remains an occupational health and safety issue in Canada because exposure to this toxic gas can represent a threat to both human and animal health (ACGIH 2001; Chénard et al. 2003; Wenger 2004). Within the swine facilities, H_2S as well as many other odorous gases, are produced through the anaerobic decomposition of stored animal manure. Outside the facilities, phosphorus buildup in soils receiving swine manure is becoming an environmental concern. The nitrogen/phosphorus ratio of manure should be similar to that of the crop nutrient requirements. In this way, manure nitrogen or phosphorus buildups would not occur.

A new housing concept featuring a belt conveyor (BC) system to separate feces from the urine at the pen level has been successfully developed (Lemay et al., 2006). The pen concept utilizes an inclined BC as the pen dunging area. There was no indication of any detrimental effect of the BC system on animal performance or comfort. Both growth and feed efficiency were similar between the control and the BC system. The BC system has been very effective at isolating most of the phosphorus in the solid fraction. A range of 52 to 90% of the phosphorus excreted by the pigs in the BC room has been isolated within the solid phase of excreta representing 20 to 38% of the total manure mass. This will enable proper handling and management of the isolated solid mass containing most of the phosphorus. The wash water used to clean the belt increased water storage requirements by 34% and further investigations are necessary to decrease the amount of water required for cleaning.

Predicala et al. (2007) measured gas and odour emissions from an experimental room installed with a BC conveyor system at the Prairie Swine Centre Inc. (PSCI). No significant impact of the system was observed for ammonia and odour emissions. However, to assess the full potential of that barn concept, an accurate evaluation of H_2S and NH_3 emissions from the solids, urine, washwater in the BC system and from manure in the typical pen system is required.

The overall goal of this project is to develop a new housing system capable of reducing odour and H_2S emissions while facilitating the management and handling of phosphorus and nitrogen and allowing safe storage of the excreta phases underneath the building (Lemay et al., 2008). The specific objectives were:

a) To evaluate the BC system performance in terms of separation efficiency, and the mass of belt liquid drainage, urine, and solids compared to manure collection in the control treatment;

b) Part 1: to measure the effectiveness of the BC at reducing continuous H_2S emissions from undisturbed stored excreta compared to undisturbed stored liquid manure; and

c) Part 2: to measure the effectiveness of the BC at reducing H_2S emissions from agitated stored excreta compared to agitated stored liquid manure.

MATERIALS AND METHODS

PART 1. UNDISTURBED EXCRETA TRIALS

Laboratory Facilities and Experimental Protocol

Two independent experimental and environmentally controlled rooms were available at the IRDA facility. In each room (3.66 m wide by 5.49 m long), a pen was constructed on a raised platform. Each pen is 1.45 m wide by 3.58 m long and capable of housing eight growing pigs from 25 to 50 kg. In the control room, conventional concrete slats provided typical barn flooring with a plastic container placed underneath the slats to collect the manure produced by the pigs. The solid floor area represents 2/3 of the total pen area in each room.

The sloped BC system replacing the slats is illustrated in Fig. 1 and installed in one room. A custom-made belt conveyor and washing unit, designed by a Québec supplier of agricultural equipment (Valmétal, St-Germain de Grantham, QC) became the rear of the pen (Fig. 1). The belting profile was carefully selected to facilitate urine drainage, while being sufficiently non-slippery for the pigs. Pigs are trained to step on the sloped BC to urinate and defecate and to use the solid concrete floor area for resting and eating. Urine continuously drains out through a small gap underneath the end portion of the solid floor in the middle portion of the pen, while solid feces stay on the non-perforated belt. When the BC is activated and the belt moves toward the upper end of the BC, fecal material moves through the gap underneath the end pen partition and drops into a container under the end of the BC by a belt wiper. The washing unit installed underneath the BC cleans the belt before it moves back to the top of the BC. The BC pen has the same dimensions as the control pen. The exposed belting surface of the BC is slightly larger (1.52 m) than the pen itself to allow pen partitions to overlap on top of the belting edges. Three rectangular plastic containers are positioned underneath the BC to separately collect the urine, the feces and the wash water, respectively.

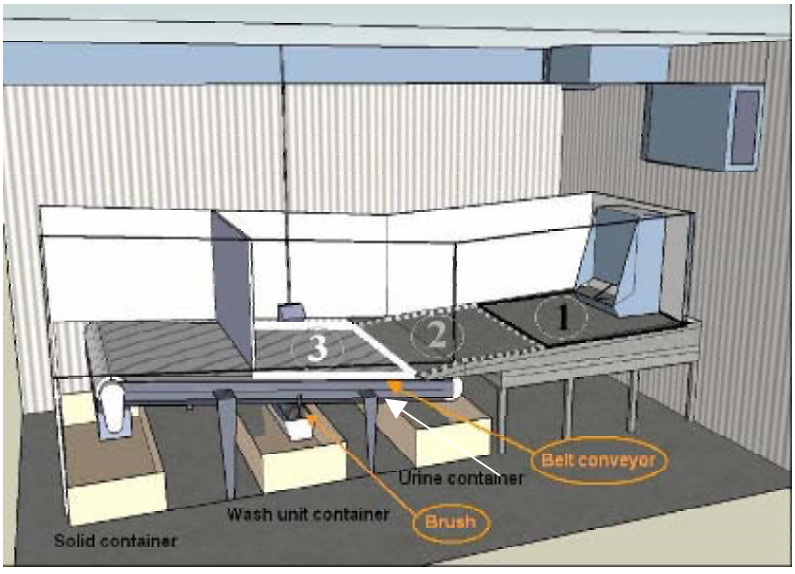

Figure 1. Pen enclosure showing the belt conveyor system.

To ensure pig safety in the BC pen, the linear speed of the belting was limited to 0.83 m/min. The pen end partition was equipped with a counterweight mechanism to allow the bottom of the partition to pivot out to prevent the pig's legs from being trapped during the belt operation. Figure 2 shows the pigs using the belted area to defecate and urinate with the fecal material left on the belt.

Figure 2. Pigs occupying the belt conveyor pen.

The pigs were female F1 cross (YY x NN) x Duroc (Y: Yorkshire and N: Landrace) with a 25 kg initial weight. Both feed and water were provided ad-libitum by a double-space dry feeder and a bowl drinker, respectively. The diet met published requirements (NRC, 1998). This experiment was conducted in accordance with the Canadian Guide to the Care and Use of Experimental Animals (CCAC, 1993) and was authorized by the Deschambault Research Centre in Animal Science (CRSAD) Animal Policy and Welfare Committee. The feed consumption and drinking water disappearance were determined every two weeks to coincide with the 2-wk excreta collections. Lighting was provided from 7:00 to 19:00.

The pigs occupied the Control and BC rooms over a 9-wk period in which the pig mass ranged from 30 to 90 kg to produce excreta for the H_2S emission trials. All of the liquid manure was collected from the control room and the urine, solids and the washwater were collected from BC room at end of week 5, 7 and 9. To meet the floor space requirements, two pigs from each room were removed at week 7. These collections were moved to the IRDA BABE Laboratory (French acronym for Environmental Balance of Agricultural Buildings) to obtain H_2S and NH_3 emission rates. All the excreta plastic containers were thoroughly cleaned and returned to the rooms for another 2-wk collection. For each 2-wk period, the feed and drinking water usage, the mass of liquid manure, solids, urine, and washwater and the water used by the washing apparatus were measured.

Excreta Measurements

Approximately 60 kg of 2-wk collections were transported to the IRDA BABE Laboratory. This BABE laboratory consists of 12 identical and totally independent environmentally controlled bench-scale chambers. A total of eight chambers were used in this study. Each chamber, maintained at 20°C, housed a 0.9 m x 0.9 m x 0.7 m stainless steel collection box which contained a sample from either the control or the BC rooms. These small collection boxes were ventilated at a rate of 0.19 L/s. This rate was determined from cited H_2S emission rates (Clark et al., 2005) and the operating range of the H_2S monitoring equipment. Each sample was placed in

the collection box over a 4-wk period. A total of eight collection boxes were used to facilitate the 2-wk collections.

The total mass of the liquid manure, solids, urine, and washwater collections were weighed at the start and the end of the 4-wk period. The temperature within each collection box was monitored every 15 min. Since the solids were observed to heat during the 4-wk period, a temperature sensor was installed to measure the floor-surface temperature. The temperatures were recorded by a data acquisition system (Model CR-21X, Campbell Scientific, Edmonton, AB).

Temperature data consisted of collection box air temperatures and collection box floor surface temperatures. During trial 1, floor surface temperatures were not measured since the experimental design assumed that no heating of the materials would take place.

Hydrogen Sulphide Concentrations

An M101E analyzer from Teledyne API (USA) measured the H_2S concentration of the air sampled from each collection box. This instrument measures, by ultraviolet fluorescence, the sulfur dioxide (SO_2) produced by the selective oxidation of H_2S with a catalytic converter at 315°C. A dilution unit (M700, Teledyne API, USA) connected to a certified H_2S tank (1.01 ppm of H_2S) was automatically operated every three days (every second day at the beginning of the experiment) to verify the analyzer response at 200 ppb H_2S. The H_2S monitor can precisely measure H_2S gas concentrations within the 15 to 2,000 ppb range. Dry air required for the mixing was coming from a separate tank (Zero 2.0, BOC, Canada).

With the sampling of eight collection boxes along with a background source, each box was sampled every 135 min (2-h period and 15 min). Sample air was drawn from each collection box over a 15-min period. The H_2S concentration was recorded every 10 s. The average box concentration was calculated as the average of the 10-s readings collected over the time period elapsed between the 9^{th} and the 12^{th} minutes of the 15-min interval. The H_2S concentration data were obtained from the internal data acquisition system of the M101E analyzer while the room selection and sampling were controlled by a separate data acquisition system (Model CR-21X, Campbell Scientific, Edmonton, AB). This logger was also dictating the analyser accuracy checks against the 200 ppb reference gas.

Ammonia Concentrations

Ammonia concentrations were measured by bubbling sample air serially through two 150-ml 0.1 N sulphuric acid solutions (OSHA, 2008). The acid solutions were contained in Erlenmeyer flasks. The sample air was introduced at the bottom of the flask solution by a sparger and exhausted from the top of the flask (Fig. 3). The flow of the sample air was adjusted to 1 L/min over a 2-h period. The NH_3 emission rate (mL/h) was calculated from the laboratory analysis (mg/L of N) and multiplied by 17/14 to reflect the NH_3 content. The volume of acid (300 mL), the sampling time (min), the sample flow rate (L/h) and the density of NH_3 (mg of NH_3/L of NH_3) were other factors included in the calculations. Ammonia emission rates were measured over a 2-h period on day 4, 7, 11 and 21 of each 4-wk trial.

Figure 3. Ammonia trap containing sulphuric acid.

Gas Emission Rates

The equation used to calculate the H_2S emission rate is as follows:

$$E_{H2S} = \left(\frac{C_{Out} - C_{In}}{10^6}\right) \times Q_{Collection\ chamber} \times 86{,}400 \times \left(\frac{34.0}{22.4}\right) \times \left(\frac{273+18}{273}\right) \times \frac{1}{M_{Excreta}} \quad (1)$$

Where: E_{H2S}= H_2S emissions per kg of excreta (g d^{-1} kg^{-1}); C_{Out} = gas concentration in the collection chamber exhaust air (ppm); C_{In} = gas concentration in the collection chamber inlet air (ppm); $Q_{Collection\ chamber}$ = ventilation rate through collection box (L/s); 86,400 s/d = 24h/d * 3,600 s/h; 34.0 g of H_2S per g equivalent; 22.4 L/g equivalent; (273+18)/273 temperature adjustment; and $M_{Excreta}$ = mass of excreta within the collection chamber (kg).

The equation used to calculate the NH_3 emission rate is as follows:

$$E_{NH3} = C_{Trap} \times 24 \times 3{,}600 \times \frac{Q_{Collection\ chamber}}{Q_{Trap}} \times \frac{1}{M_{Excreta}} \quad (2)$$

Where: E_{NH3} = NH_3 emission rate per kg of excreta (g d^{-1} kg^{-1}); C_{Trap} = NH_3 trapped in 0.3 L of acid solution after a two-h period (g/h); 24 h/d; 3,600 s/h; and Q_{Trap} = ventilation rate through NH_3 trap (L/h).

PART 2. AGITATED EXCRETA TRIALS

Laboratory Facilities and Experimental Protocol

Two environmental chambers at PSCI Floral facility were used for this phase of the study (Fig. 4). Each of the two identical chambers had inside dimensions of 4.3 m x 3.7 m x 2.7 m, and had internal walls and ceiling covered with stainless steel sheets. To ventilate the two chambers, pre-conditioned room air was passed through a filtration unit (Circul-Aire USA-H204-B, Dectron International, Roswell, GA, USA) to remove particulates in the air. The filtered air was split through a T-connection in the supply duct to deliver the air to the two chambers through an actuated air inlet located at the ceiling of each chamber. Each chamber had a negative-pressure exhaust fan (H18, Del-Air Systems Inc., Humboldt, SK, Canada) to draw the air out of the chamber into an exhaust duct leading to outside the building. The ventilation rate in each chamber was monitored using an iris damper (Continental Fan Manufacturing, Buffalo, N.Y., USA, accuracy ±5%) in the exhaust duct from each chamber, which was calibrated to measure

the airflow through the duct based on the pressure difference across the iris damper. A Rapid controller system (Del-Air Systems Inc., Humboldt, SK, Canada) controlled the in-duct heaters, and the chamber inlets and exhaust fans.

Figure 4a shows the BC pen design with the belt conveyor system in place of the concrete slats. The total pen area is 4.9 m^2, equivalent to an area of 0.61 m^2 per pig for 8 pigs, which was above the minimum 0.5 m^2 per grower pig under 45 kg recommended in Canadian Farm Buildings (CFBH, 1988; PPRG, 2000). The solid floor portion of the pen was 1.5 m x 2.1 m in size, corresponding to about 66% of the total pen area, and had a slope of 8% towards the belt. The belt conveyor had a slope of 10% towards the solid floor area. It was operated at a speed of 1.2 m/min for 3 min at 30-min intervals to move the manure solids to a collection tub under the higher end of the belt. Figure 4b shows the lay-out of the other chamber with a slatted floor and manure handling system. A collection tub placed under the slatted area was used to collect the mixture of feces and urine deposited on the slats. In both chambers, a commercial feeder was installed along the penning of the solid floor area, and a cup-type water drinker was installed on one side of the dunging area to encourage the pigs to use the area for defecation and urination. The overall principle of operation of the BC pen and the control pen was similar to that at IRDA.

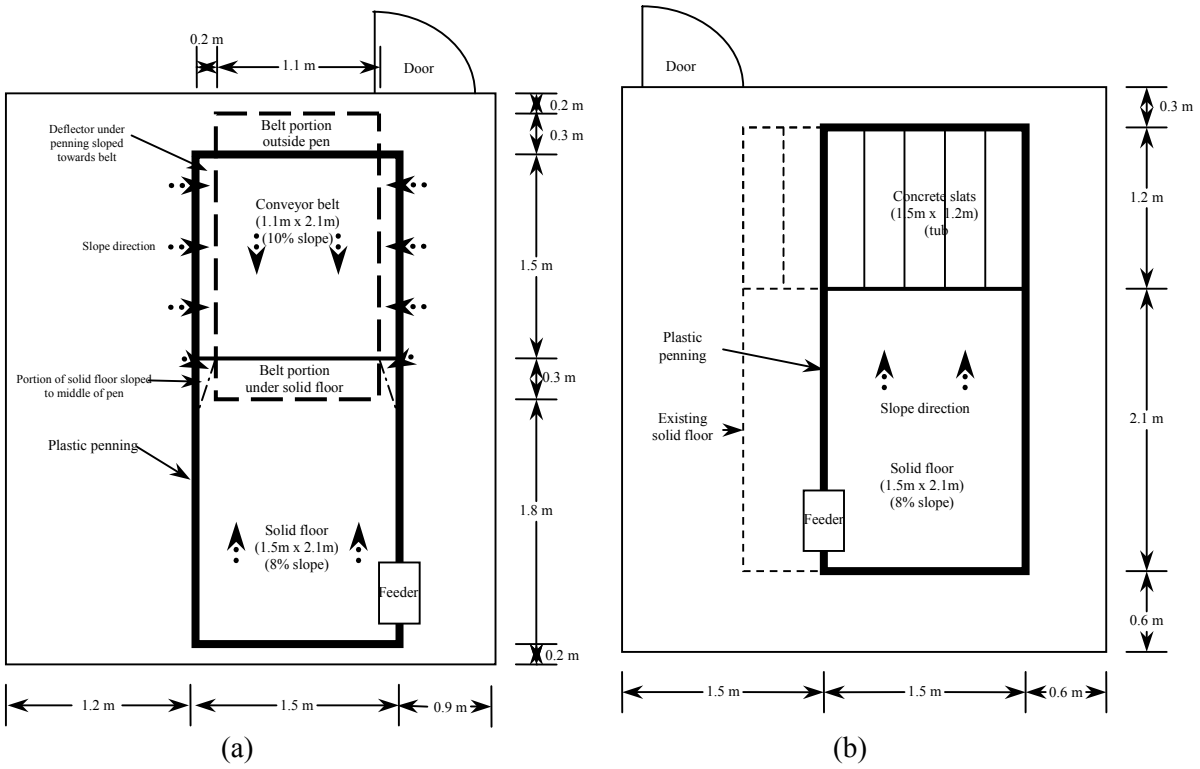

Figure 4. Lay-out of the pens in the experimental chambers configured (a) with a belt conveyor to replace the slatted area, and (b) as a conventional partially-slatted pen concrete slats as dunging area.

Two batches of pigs were used in this experiment. A total of eight female grower pigs (27 to 31 kg) were introduced to the chambers three days before collecting data with a total pen mass within ±2 kg. This period was sufficient time to train the pigs to use the designated dunging area (conveyor or slats) for urination and defecation and the solid floor area of the pen as laying area. After wk 8, a second batch of pigs with an average weight of 30 kg was brought in to complete

the trial. The room experiment was originally designed for eight weeks, during which manure samples were collected every two weeks (at the end of wk 4, 6, 8 and 10).

Since the focus of this phase of the study was on H_2S emissions from the excreta, the batches of samples collected during the room experiment were considered as replicate samples from which H_2S emissions were measured. A total of four batches of samples were used for the H_2S emission monitoring part of the study.

The air temperatures in the chamber were maintained at a set-point of 21ºC initially, then gradually decreased to 19ºC at wk 6. It was kept constant thereafter. Standard grow-finish diets were provided to the pigs during the trial; the amount of feed delivered to the feeder in each pen was weighed. Daily health checks were also conducted to monitor the health status of the animals. In addition, the solid portion of the pen floor was scraped daily or as necessary, and all systems were checked to ensure proper operation.

During the room experiment, the following parameters were monitored in both chambers: a) gas (NH_3, H_2S, CO_2) concentrations, b) air quality parameters (room air temperature, relative humidity, ventilation rates), c) manure production, d) water use, e) feed intake and f) average daily gain.

Manure Sample Collection

Every two weeks, the contents of the collection tubs (slurry tub in Control room; solids, urine and washwater in BC room) were taken out using a ShopVac and weighed. After weighing, 15 kg of the slurry (from control chamber), solids, urine, and wash water (from BC room) were collected and transferred to a 75-L container. Each container was labelled and stored without cover in a separate room at ambient conditions. These containers were left undisturbed until H_2S measurements were taken from each container.

After sample collection, each collection tub in both chambers was thoroughly washed and cleaned and put back in place. The washing unit tub and the trough holding the brush were cleared and flushed; clean water was used to re-fill the washing unit tub.

Measurement of H_2S Levels from Stored Manure Samples

After collection, the samples were stored in the 75-L containers without cover in a separate room under ambient conditions. Each batch of samples was stored for a period of six weeks, during which measurement of H_2S levels in each container was conducted every week using the set-up shown in Fig. 5. An H_2S monitor (Model PacIII, Draeger Safety) was used to take H_2S readings from each container, both with the samples undisturbed and after agitation for 1 min. A vacuum pump system was used to draw gas out of the container at a flowrate of 0.5 L/min and passed through the H_2S monitor. The H_2S readings were monitored and logged until a steady-state value was attained (about 5 min). Then the sample was agitated for 1 min using a portable electric hand drill attached to a mixing blade through a port in the lid. No gas was extracted from the container during agitation and for another 1 min after agitation to avoid drawing out any suspended droplets or particles into the sampling lines. Then, the level of H_2S generated from the sample was monitored by drawing gas out of the container at 0.5 L/min and passing this through the H_2S monitor. The peak H_2S readings were recorded until the levels diminished and a steady-state value was attained (about 10 min).

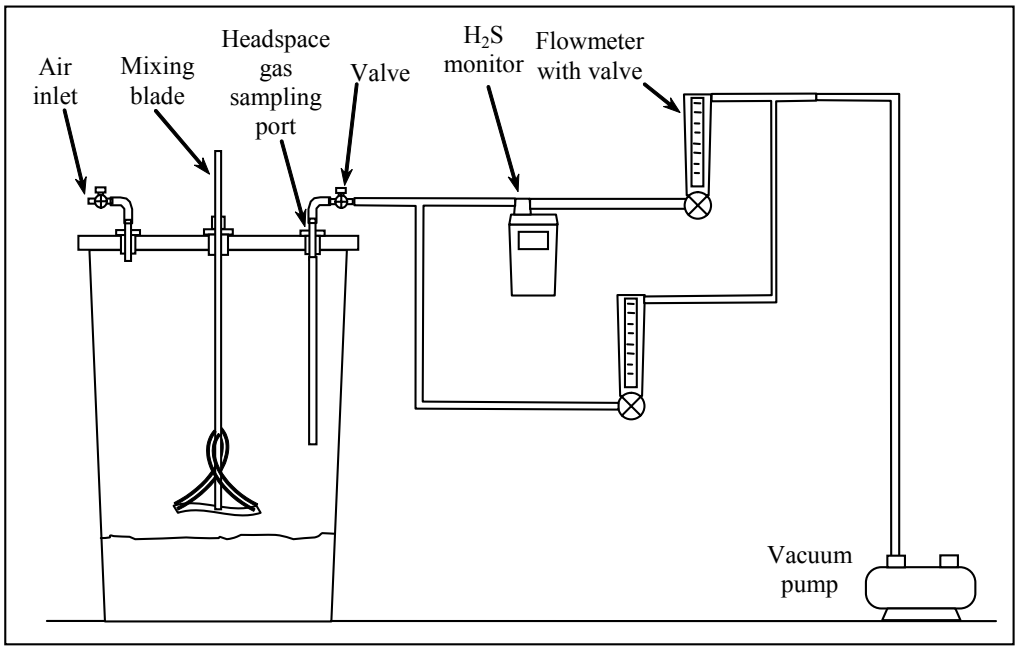

Figure 5. Schematic diagram of gas sampling set-up for determining H_2S levels in each sample container.

Statistical Analysis

For the data analysis, the experimental design was completely randomized with repeated measures. This was applied to the gas levels measured from the manure samples. The statistical tests to compare room conditions were Proc MIXED and LSMEANS in SAS (SAS, 2000). These procedures determined if there were significant differences ($P<0.05$) between the hourly temperature, RH, and ventilation rates in the two chambers.

RESULTS

PART 1. UNDISTURBED EXCRETA TRIALS

Environmental Conditions

As previously indicated, temperature data initially consisted of collection box air temperatures and collection box floor surface temperatures. The solids began to heat immediately upon introduction from the BC room whereas the solids in the BC room were cool (15°C). As shown in Table 1, the temperatures in the collection boxes containing the urine, washwater and manure remained at the temperatures of the environmental chambers (18.0 to 18.7°C). The solids collection box gained an average temperature of 1.2 to 2.0°C over the other collection box material over the 4-wk period (Table 1). The solids collection box floor gained an average temperature of 5 to 6°C relative to the other collection box material over the 4-wk period (Table 1).

Table 1. Mean 4-wk box air and floor surface temperatures for collection boxes.

Trial (n. u.)	Collection box temperatures (°C)			
	Excreta			
	Manure	Urine	Solids	Washwater
Air				
1	18.5	18.2	19.4	18.3
2	18.7	18.5	19.9	18.5
3	18.6	18.0	20.1	18.4
Floor surface				
2	18.0	17.9	22.4	17.8
3	18.2	17.3	23.5	18.2

Pig Performance

The pigs occupying the Control and the BC rooms were found to perform similarly to those reared under commercial conditions. However, it is interesting to note the BC pigs performed slightly better. This was also confirmed in a previous study (Lemay et al., 2006). Table 2 shows the performance data. The BC pigs gained 82 g per day more than the Control pigs, however, the feed conversion was 0.2 kg of feed per kg of gain less (Table 2). Also, the BC pigs used or spilled less water than the Control pigs. These results suggest that the animal enrichment and comfort may have been added by the provision of the conveyor belt. This requires further research.

Table 2. Pig performance in the belt conveyor and control rooms.

Parameter description	Parameter value	
	Experimental room	
	Belt conveyor	Control
Number of pig time days (Pig-day)	442	442
Initial pig mass (kg)	240	236
Final pig mass (kg)	686	671
Feed consumption (kg)	1,020	938
Water disappearance (L)	2,432	2,569
Feed conversion(kg_{feed}/kg_{gain})	2.3	2.1
Water/feed ratio (n. u.)	2.4	2.7
Average daily gain (g/day)	1,009	984
Feed disappearance (g/d)	2,309	2,069

Belt Conveyor Performance

The excreta production data for the BC and Control rooms are presented in Table 3. The production values between the trials appeared to be similar. Of particular interest are the relative quantities of the urine, solids, washwater and the manure collected every two wks. The urine plus solids to drinking water ratios were similar. The overall mean value is 0.62. This also confirms that the quantities of urine plus solids and manure were similar. In the BC room the amount of

washwater used is of interest since it is an added cost. The washwater to drinking water ratio ranged from 0.46 to 0.55.

Table 3. Daily excreta production from the Control and the Belt Conveyor Rooms.

Parameter description	Parameter Value					
	Trial 1 - 8 pigs		Trial 2 – 6 pigs		Trial 3- 6 pigs	
	Control	BC	Control	BC	Control	BC
Collected Wash Water, kg/(pig.d)		1.98		2.17		2.20
Collected Manure, kg/(pig.d)	3.54		3.93		4.53	
Collected Urine, kg/(pig.d)		2.65		3.28		4.42
Collected Solids, kg/(pig.d)		0.52		0.58		0.59
Drinking water, L/(pig.d)	6.81	5.91	6.52	6.70	7.25	7.32
Metered Wash Water, L/(pig.d)		2.90		2.76		3.40
(Urine+Solids)/Drinking Water	0.68	0.54	0.59	0.58	0.64	0.68
Wash Water/Drinking Water		0.49		0.55		0.46
Col. Wash Water/Metered Wash Water		0.68		0.59		0.64
Collected Wash Water/Manure		0.55		0.55		0.48

The collected washwater to metered washwater used ranged from 0.59 to 0.68. This loss is reflected by the evaporation losses. The collected washwater to manure ratio indicated the additional storage required when incorporating the BC technology. This ratio ranged from 0.48 to 0.55. The storage requirements would almost have to be increased by 50%.

Excreta Collection Box Samples

The mass of the excreta samples are presented in Table 4. The loss in mass over a 28-d period ranged between 14.2 and 17.4 %, whereas the loss in mass of the solid excreta ranged between 23 and 29% due to the high composting temperatures. When the evaporative loss was expressed on an area basis (g/(m^2-d), the mean solids loss was 576 g/(m^2-d) whereas the manure, urine and washwater evaporated at a mean rate of 412 g/(m^2-d) (Table 4).

Table 4. Excreta samples in the collection boxes.

Trial	Parameter description	Parameter Value			
		Excreta			
		Manure	Urine	Solids	Washwater
1	Initial mass (kg)	60.6	61.6	53.8	63.3
	Final mass (kg)	52.0	52.6	41.4	54.4
	Loss (%)	14.2	14.6	22.9	14.6
	Loss (g/m^2-d)	379	396	544	409
2	Initial mass (kg)	60.8	60.3	46.1	59.0
	Final mass (kg)	50.2	50.9	32.7	49.2
	Loss (%)	17.4	15.6	29.1	16.6
	Loss (g/m^2-d)	467	414	591	432
3	Initial mass (kg)	63.0	61.4	48.9	61.9
	Final mass (kg)	53.8	52.9	35.4	52.2
	Loss (%)	14.6	13.8	27.6	15.7
	Loss (g/m^2-d)	406	375	595	428

H_2S Emissions

Typical H_2S concentrations from the excreta samples are presented in Fig. 6. It shows that the solids emitted relatively high amounts of H_2S which coincided with high solids temperatures (Table 1). This also agreed with the higher rate of moisture loss (23 to 29%; Table 4). Emission rates were expressed on a kg of excreta basis and on the mass of excreta collected after 14 d from the Control and BC rooms.

On a kg basis, the mean excreta emission rates ranged from 58 to 149 ug/d-kg for the urine and solids, respectively (Table 5). Both the urine and the washwater values were expected to be relatively lower than the manure and solids values. Large deviations occurred between trials except for the urine emission values.

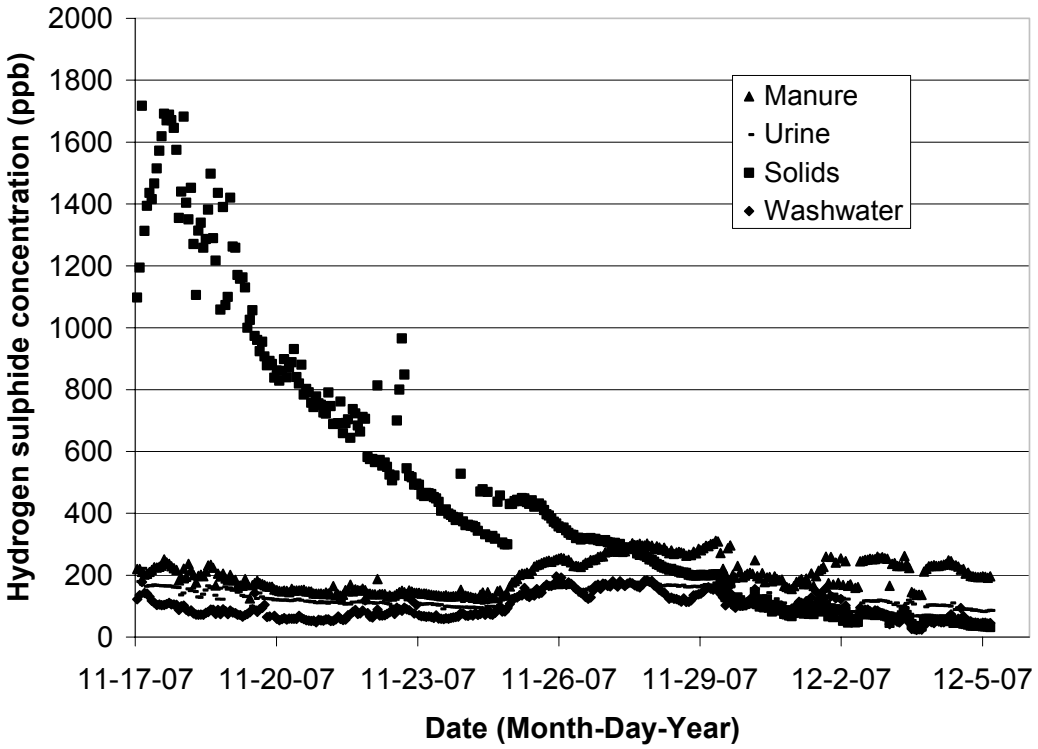

Figure 6. H_2S concentrations for Trial 1 for the four types of excreta over a 28-d period.

Table 5. Hydrogen sulphide emission rates from collection boxes.

Trial	Hydrogen sulphide emission rate (ug/day-kg)			
	Excreta			
	Manure	Urine	Solids	Washwater
1	89	55	232	41
2	128	62	139	129
3	95	58	76	46
Mean	104	58	149	72

When the emission rates were based on the amount of excreta collected after 14 d, it is interesting to note that the emission rates for both rooms were similar. The Control room emitted a mean of 37.8 mg/d while the BC room emitted 40.0 mg/d (Table 6). Also, of interest was that the urine emitted 46% of the H_2S while the solids and washwater emitted 20 and 34%, respectively (Table 6). A sulphur analysis carried out on the excreta before and after the 28-d sampling period indicated that no differences were detectable. This was confirmed by estimating the sulphur (S) emitted during each 28-d period in the collection boxes (Table 5). Over a 28-d period, the mass of sulphur emission from each collection box ranged between 0.094 and 0.198 g for the urine and solids, respectively. From Table 7, each collection box contained from 16 to 84 g of sulphur. Therefore, sulphur losses over a 28-d period represented a minuscule fraction (< 0.3 %) of sample sulphur content.

Table 6. Hydrogen sulphide emission rates after a 14-d collection period in the rooms.

Trial	No. of pigs[1]	Excreta production rate (kg/pig-d)				Hydrogen sulphide emission rate (mg/d)			
		Excreta				Excreta			
		Manure	Urine	Solids	W. water*	Manure	Urine	Solids	W. water*
1	8	3.54	2.65	0.52	1.97	35.2	16.4	13.4	9.1
2	6	3.93	3.27	0.58	2.17	42.1	17.0	6.8	23.5
3	6	4.54	4.42	0.60	2.19	36.2	21.7	3.8	8.5
Mean		4.00	3.45	0.56	2.11	37.8	18.3	8.0	13.7
Percentage							46	20	34

[1] – pig mass range: 30 to 90 kg.; *: washwater.

Table 7. Average sulphur content of excreta within the collection boxes.

Excreta	Sulphur content	
	(mg/kg)	(g)
Manure	1,162	65
Urine	746	42
Solids	1,878	84
Washwater	303	16

Both the solids and the manure had a high S content relative to the urine and washwater, however, because of the relative amounts of excreta from the pigs, the urine and manure contributed to the major fraction of the room S.

NH_3 Emissions

Ammonia emission rates are presented in Table 8. These means are based on NH_3 samples collected on days 4, 7, 11 and 21 in the three replicated trials. On a mass basis, NH_3 emissions ranged from 0.45 for washwater to 2.54 mL/h-kg for the solids. The relative amounts for urine, solids and manure were found to be similar (2.28 to 2.54 mL/h-kg; Table 8). When emissions were based on the 14-d excreta collection, NH_3 emission rates were highest for the urine and the manure excreta. Again, the total NH_3 for the BC room (948 mL/h) was similar to that of the Control room (857 mL/h). Table 8 shows the mean NH_3 emission rates over the trials. No consistent trends in emission rates were found for the excreta over the 21-d period. Perhaps there was a marked decrease in NH_3 in the solids excreta from 2.92 to 1.85 mL/h-kg.

Table 8. Ammonia emission rates for day 4, 7, 11 and 21 and after a 14-d collection period from collection boxes and from the control and conveyor belt rooms.

Excreta phase	Box ammonia emissions (mL/h-kg)					Room ammonia emissions (mL/h)
	Day 4	Day 7	Day 11	Day 21	Average	Average - 14-day collection
Manure	2.42	2.62	2.36	2.85	2.33	857
Urine	2.33	2.05	2.52	2.32	2.28	725
Solids	2.92	2.09	2.23	1.85	2.54	134
Washwater	0.35	0.47	0.48	0.53	0.45	89

Relative Gas Emission Rates

The relative emission rates of H_2S, NH_3 and S from the excreta are shown in Table 10. It is interesting to note that the emission rate from the solids excreta is the highest for each gas emission rate. The S content and the H_2S emission rate from the urine is relatively low, however, because of its larger mass it is the major contributor. Washwater had low values for the three parameters. Perhaps a lower water usage rate for washing can be considered. The metered washwater to drinking water usage ratio was almost 50%.

Table 10. Emission rates of H_2S and NH_3 from collection boxes.

Excreta	**Emission rates**	
	H_2S (mg/d-kg)	**NH_3 (mL/h-kg)**
Manure	**104**	**2.33**
Urine	**58**	**2.28**
Solids	**149**	**2.54**
Washwater	**72**	**0.45**

PART 2. AGITATED EXCRETA TRIALS

Animal Performance

The performance indicators for the pigs in both chambers are shown in Table 11. Two pigs from the first batch of pigs were taken out from the BC room due to injury; both pigs were replaced with a similar sized pig to retain equal numbers in both chambers. Overall, the pigs in both chambers showed average performance. Although the pigs in the BC room had consistently higher average daily gain compared to the pigs in the conventional room, the difference was not significant for both batches of pigs. These indicate that the use of the BC pen concept does not adversely affect the performance of the pigs and may in fact lead to enhanced growth.

Table 11. Pig performance parameters for the two chambers.

Parameter description	Parameter value			
	1st batch (Oct 12 – Dec 6)		2nd batch (Dec 7 –Jan 3)	
	Conventional	Belt Conveyor	Conventional	Belt Conveyor
Average initial weight, kg	27.3	28.3	30.8	30.3
Average final weight, kg	76.1	79.9	54.3	54.2
No. of pigs	8	8	8	8
ADG ± SD, kg/day	0.871 ± 0.12	0.922 ± 0.11*	0.900 ± 0.10	0.920 ± 0.15
Total feed consumption, kg	1058.3	970.5	418.0	418.0
ADFI, kg/day-pig	2.36	2.17	2.01	2.01

*Data for the two replacement pigs not included in calculating the mean.

Manure Production and Water Use

Manure production and water use in both chambers were monitored and shown in Tables 12 and 13. The average volume of drinking water used in each pen per day was 32.5 and 31.6 L/day for the Control and BC pigs, respectively. This was as expected (PPRG, 2000). The volume of water used throughout the trial did not differ significantly between the two chambers.

Table 12. Average weekly water use in the two chambers during the room trial.

Room	Water use (L/day)	
	Average	SD
Conventional	32.5	7.1
Belt conveyor	31.6	8.5

The entire contents of the various collection tubs in both chambers were weighed during manure sample collection day (every two weeks). The manure production from the two chambers measured during sampling days for collecting replicates 1 to 4 manure samples (from which subsequent H_2S measurements were taken) are shown in Table 13. As expected, as pig mass increased, more manure was produced. Comparing the amount of manure slurry from the conventional room with the combined amount of solids and urine from the BC room showed no definite trend; with larger pigs (from 1st batch), more slurry was produced from the conventional room than the combined solids and urine in the BC room, while the reverse was observed for the smaller pigs (from 2nd batch). The overall total and the average from the four replicates were comparatively close to each other. However, if the volume of washwater was considered, then the total volume collected from the BC room (solids, urine, and washwater) was about 65% higher than in the conventional room.

Table 13. Excreta production in the two chambers.

Pig batch	Sample collection date	Sample replicate #	Excreta production rate (kg/pig-day)[1]				
			Conventional	Belt Conveyor			
			Slurry	Solid	Urine	Washwater	Total
1st	22-Nov	1	2.33	0.64	1.25	1.14	3.03
1st	06-Dec	2	2.44	0.67	1.73	1.17	3.57
2nd	20-Dec	3	1.11	0.45	0.81	1.12	2.38
2nd	03-Jan	4	1.45	0.64	1.27	1.16	3.08
Mean			1.83	0.60	1.27	1.15	3.02
SD			0.65	0.10	0.38	0.02	0.49

[1] – pig mass range (30-60 kg).

From the temperature and pH data of the stored samples, urine had a higher pH compared to the other samples (Table 14). The mean temperature of the stored samples was 8.7°C.

Table 14. Sample means for manure temperature and pH values.

Manure Sample	Temperature (°C)	pH
Manure slurry	**8.7**	**7.12**
Solids	**9.1**	**6.88**
Urine	**8.6**	**9.08**
Washwater	**8.4**	**7.76**

Concentrations of H_2S from Stored Manure Samples

The mean peak H_2S levels from the different manure samples for the four replicate batches are shown in Table 15. Initial readings taken when the samples were undisturbed showed very minimal H_2S levels, even after the samples were stored for six weeks. However, after agitating the sample for 1 min, significant levels of H_2S were recorded. The peak H_2S levels recorded from the slurry samples (from control room) were significantly higher ($P<0.05$) than those from solids, urine, and washwater collected from the BC room (Table 15), with the urine samples generating the least amount of H_2S.

Table 15. Average peak hydrogen sulphide concentrations from different agitated manure samples (n = 4 replicates).

Week	Peak H_2S concentration from agitated samples (ppm)*							
	Manure slurry		Solids		Urine		Washwater	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	178.5	85.0	40.5	3.9	4.0	0.7	58.3	42.5
2	104.8	42.8	42.5	24.4	5.5	2.2	16.3	6.0
3	122.8	49.6	68.3	38.1	6.3	3.3	42.5	29.7
4	71.8	17.5	31.5	8.2	5.0	0.7	29.5	17.2
5	64.5	22.5	20.0	10.7	5.3	0.6	17.3	7.6
6	53.3	11.9	23.5	11.1	5.0	1.2	20.5	11.6
Average	**99.3a**	38.2	**37.7b**	16.1	**5.2c**	1.4	**30.7b**	19.1

*Means with the same letter are not significantly different (P>0.05).

Excreta H_2S Emissions

Based on the measured peak H_2S concentrations, sampling flow rate of 0.5 L/min, and manure samples of 15 kg, the peak H_2S emission rate from the agitated excreta samples ranged from 0.3 to 5.3 μg/min per kg of sample, with the highest emissions generated from the manure slurry. However, these emission values are based on peak H_2S concentrations during the sampling period; since the H_2S levels rapidly diminished during the sampling period, actual H_2S emission rates could be substantially less than the above calculated values if time-weighted average H_2S concentrations over the sampling period are used in the emission calculations. When expressed on a room basis to reflect the different quantities of excreta, the peak H_2S emission rate from the agitated excreta samples ranged from 40 to 1,097 μg/min from a 14-d of excreta accumulation, with the highest emissions generated from the manure slurry from the control room (Table 16). Again the emission rates from the rooms are relative amounts to reflect the different quantities of excreta produced. The H_2S emission rate for agitated excreta was a lot higher than in the control room (1,097 μg/min) compared to the BC room (390 μg/min) (Table 16).

Table 16. Emission rates of H_2S for agitated excreta.

Excreta	Excreta production rate (kg/pig-day)	Peak H_2S concentration (ppm)	H_2S emission rate (μg/min-kg)	H_2S emission rate[1] (μg/min)
Manure slurry	1.83	99.2	5.3	1,097
Urine	1.27	5.2	0.3	40
Solids	0.60	37.7	2.0	136
Washwater	1.15	30.7	1.7	214

[1] – Emission rate from 14-d excreta collection.

DISCUSSION

The project hypothesis was that the BC room would have lower emission rates of H_2S and NH_3 relative to the control room. The undisturbed manure results show that the emission rates for both gases were similar for both rooms. From a mass balance point of view, this is not surprising since the fecal matter and urine excreted by the pigs should be similar due to diet and environmental conditions. The H_2S emissions for the solids, urine, and wash water in the BC room (40.0 mg/d) were similar to the manure in the Control room (37.8 mg/d). However, the urine fraction can be conveniently removed from the animal space since it contains few solids. By removing the collected urine, the H_2S and NH_3 emission rates could be lowered by approximately 50 and 80%, respectively.

The H_2S emission rate from the agitated manure slurry in the control room was almost 3 times that of the BC room. This 66% reduction in H_2S during excreta agitation will greatly reduce the H_2S short term exposure to barn workers. A further reduction of 22% is possible, since the urine and washwater can be isolated from the pig space without agitation due to the absence of solids.

CONCLUSIONS

In this study, an innovative manure handling system using a pen concept with a belt conveyor was investigated for its impact on H_2S and NH_3 emissions from the separated manure components. Based on the results of the trials, the following conclusions can be drawn from this study:

1. Comparison of a conventional pen and a pen with BC system in terms of animal performance, water use, manure production, room gas concentrations, showed trends that were consistent with results from previous phases of this project.
2. Stored manure slurry and separated manure components showed no significant difference in total emission of H_2S when left undisturbed. However, the removal of urine from the pig space immediately after excretion can reduce the room H_2S emission rate by 50%. This has implications for improved worker health environment.
3. When agitated, stored manure slurry released about 3 times more H_2S compared to the stored separated solid feces and urine/liquids. The removal of non-disturbed urine and washwater would result in the BC room generating H_2S emissions which is only 12% of that in the confinement facilities with stored liquid manure. This would significantly reduce the short term exposure of barn workers to H_2S during manure removal activities.
4. Ammonia production was similar between the BC and Control room. The BC room generated 725, 134 and 89 mL/h of a 14-day excreta collection for the urine, solids and washwater, respectively. The manure in the control room produced 857 mL/h of the corresponding excreta collection.

These experiments demonstrated the potential of the BC system in helping mitigate the hazard from H_2S generation from agitating stored manure inside swine barns. An optimized BC pen design can be potentially incorporated in a deep-pit barn construction with separate long-term in-barn storage for the separated solid and liquid manure components, without the typical hazards

from high H_2S levels associated with conventional deep-pit barns. With urine removal from the pig space the emission rates from the room can be reduced by 50%.

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