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REDUCTION OF GAS AND ODOUR EMISSIONS FROM A SWINE BUILDING USING A BIOTRICKLING FILTER

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ABSTRACT Animal housing can emit substantial amounts of aerial contaminants such as odorous compounds and gases. Since total ammonia and odour removal is not possible within the confined animal space, the remaining option is to remove these contaminants from the exhaust air. The air treatment at the exhaust of the building could thus play an important role in the reduction of atmospheric pollution due to swine production. Three laboratory-scale air treatment units (ATU) were developed and used to treat the air from three bench-scale pig chambers over two 4-wk trials. Methane, carbon dioxide and nitrous oxide emissions were evaluated using a gas-chromatograph while non-dispersive infrared spectroscopy and UV fluorescence techniques were used to measure ammonia and hydrogen sulphide emissions. Dynamic olfactometry was also used to predict odour emissions and the hedonic tone before and after air treatment. Gases were monitored on a continuous basis while odour emissions and hedonic tone were determined once a week. NH_3 emissions were reduced by 62 to 91% and H_2S emissions were decreased by 24 to 66% whereas CO_2 and CH_4 emissions were practically unchanged by the ATU treatment. N_2O emissions were increased by 100 to 700% after the air treatment. As for odour emissions, after 4 wks of operation, a 54 to 92% reduction was observed. The N_2O production as well as water consumption of the equipment are two of the elements which will be optimised during the next development stages of the system.

Keywords: Air treatment, biotrickling filter, odour abatement, gas removal, emission.

INTRODUCTION Recent studies show that the environmental issues caused by the global expansion and the intensification of agricultural operations in the last 50 years have become extremely important (Martinez et al. 2008, Godbout and Lemay 2007). The contaminants expelled from pig barns include a number of gases, dust particles (inhalable and respirable), bioaerosols (bacteria, viruses, endotoxins, fungi) and several other volatile compounds such as ammonia (NH_3) and hydrogen sulphide (H_2S). In addition, an increasing importance is given to the odour nuisance associated with swine production. Thus, research in this area has become more important in recent years. Air treatment systems for pig barns may represent a part of the solution to reduce odours and airborne contaminants. A study on the research and development status of concepts used to reduce swine odours (Joncas et al. 2002) identified, among about thirty technologies, the air treatment at the outlet of swine buildings as a promising technology.

The air treatment methods for odour control are classified into two broad categories, the non-biological treatment (physicochemical) and the biological treatment (Manuzon et al. 2007, Sheridan et al. 2002, Kim et al. 2000, Revah and Morgan-Segastume 2005). Industries use either one of these methods or a combination of both (Devinny et al. 1999, Revah and Morgan-Segastume 2005). The range of contaminants is large, the airflow to deal with reached extremely high values and the temperature and pressure conditions for the treated gas are often very different from ambient conditions. Agricultural applications, such as livestock buildings, require different solutions for the treatment of the air emitted. The air volume is high and the concentrations of pollutants are lower as compared from industrial applications. In addition, the systems must be simple and easy to operate and maintain (Devinny et al. 1999). In those applications, the main objectives of the air treatments are the reduction of odours, NH_3, H_2S and dust. The temperature and pressure of the air to be treated are similar to those of the ambient air. However, the climatic factor is sometimes an important element to consider.

According to Deshusses and Gabriel (2005), biotrickling filters involve biological techniques that are more promising for controlling odour and VOCs. Unlike biofilters that use mostly organic materials for the filter bed and operate with a minimum water flow rate, biotrickling filters use only inorganic materials and the water flow is achieved by continuous percolation. In biotrickling filters, the air passes through an inert filter in which the liquid is continuously recirculated. The filter material is similar to that used in chemical scrubbers and must have high porosity and specific surface area.

The purpose of this research project was thus to develop an air treatment equipment capable of treating the air coming from a swine building and to reduce the gas and odour emitted. The specific objectives of the project were the following:

- To develop three air treatment units capable of treating the air coming from small-scale swine chambers;
- To measure the effectiveness of those units in reducing the odour and gas emissions from small-scale swine chambers.

MATERIAL AND METHODS

Gas and odour production Three environmentally controlled chambers housing growing pigs were used in this experiment to produce gases and odour. Those chambers are located in the BABE laboratory, at IRDA, Deschambault, Québec, Canada. The chambers have width, length, and height dimensions of 1.14 m, 2.44 m and 2.44 m, respectively. The flooring is fully slotted with the manure being stored in a shallow pit located under the floor. The manure was removed by a vacuum pump once a week.

Air treatment units Using the information available in the literature, three air treatment units (ATU 1, 2 and 3) were thus designed to meet the air treatment required for the three small-scale swine chambers. Each unit has a treatment volume of approximately 0,80 m^3

fabricated from synthetic material and a continuous recirculation of liquid was used to moisten them (Figure 1).

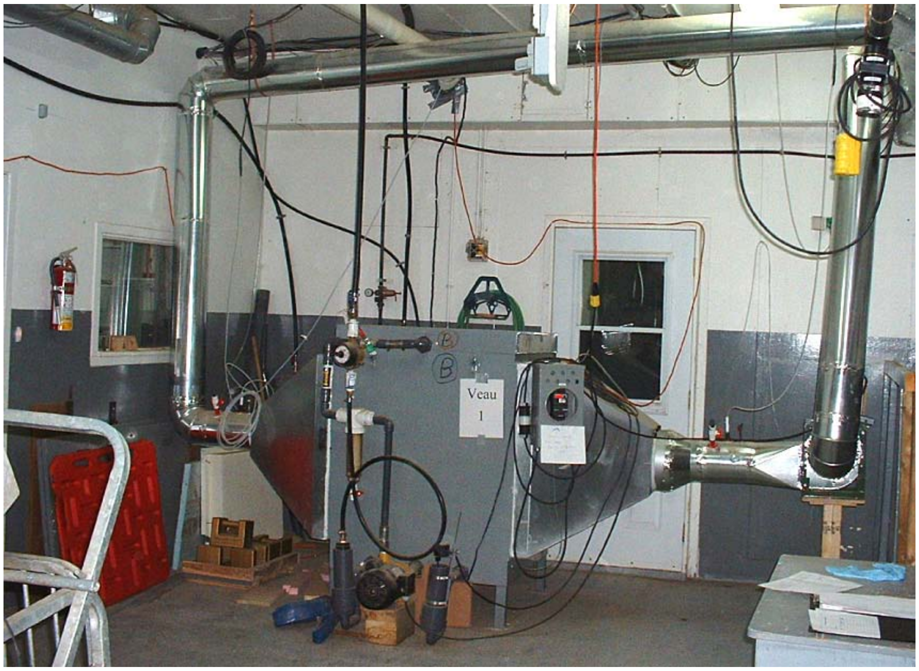

Figure 1. One of the three air treatment units used in the trials.

Experimental trials The experiment was achieved over two trials. Each trial lasted four weeks beginning on November 19th, 2008 and May 13th, 2009, respectively in which three UTA were operated per trial. The experimental unit (E.U.) was one system (including the chamber and the ventilation system). For each trial, each chamber housed 4 grower-finisher castrated males. Animals were distributed to obtain a similar average weight in every room. The pigs were raised from 65 kg to 90 kg.

Gas concentration measurements Gas concentrations (CO_2, CH_4, N_2O, H_2S and NH_3) were measured before and after each ATU on a 4-hour basis throughout the trials. The sample air was pumped to a mobile laboratory through Teflon tubing.

The concentration of methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) were measured with a gas chromatograph (Varian 3600, USA) equipped with a flame ionization detector (FID) for detection and quantification of CH_4 and an electron capture detector (ECD) for detection and quantification of CO_2 and N_2O. Ammonia (NH_3) was measured with a non-dispersive infrared (NDIR) analyzer (Ultramat 6E, Siemens, Germany) and the semi-quantitative evaluation of hydrogen sulphide (H_2S) was done with a UV fluorescence analyzer (M101E, Teledyne API, USA). Every two days, the analyzers would monitor ambient air and certified calibration gases.

Odour concentration measurements Two different methods were used to measure odour concentrations along the trials. The first technique is the dynamic olfactometry

(Odile olfactometrer, Odotech inc., Montréal, Québec, Canada). Sampling lung was used to fill up 50-L bags of air entering and exhausting from the biotrickling filter. The samples were then analysed within 24 h of sampling in a mobile olfactometer (CEN, 2003).

The second technique used four assessors who evaluated the odour level in nasal sampling ports installed before and after the filter. The assessors sniffed the odour in the port and then rested before the next measurement. The ambient odour intensity was evaluated with a 9 points n-butanol scale as described in the Standard Practices for Referencing Suprathreshold Odor Intensity Standard (ASTM 544-99, ASTM 1999). The scale was made of nine different solutions where n-butanol was mixed with water at various concentrations (0, 60, 120, 240, 480, 960, 1920, 3840 and 7680 ppm).

Airflow rates and emission calculation The ventilation system of the laboratory chambers consisted of an inlet and exhaust fan mounted in the ceiling of each chamber. The exhaust fan was able to vary its capacity from 14 to 75 L/s. In order to compensate for the pressure loss forces by the use of the biotrickling filter, auxiliary ventilators (Model 415, Delhi-industries, Delhi, ON) were used.

The air exhausted from the filters was then directed through a 204-mm iris orifice damper (Model 200; Continental fan manufacturer inc., Buffalo, NY). Its accuracy was rated at ± 5%. A differential pressure transducer measured the pressure across the orifice plate. The relationship between pressure and airflow was:

$$Q=A\,[P]^{\,0.5} \qquad (1)$$

where Q is the exhaust air flow (L/s), A is the orifice coefficient (n.u.) and P is the differential pressure (Pa).

Using measurements of gas and odour concentrations as well as airflow rates, the corresponding emissions can be calculated. The gas emissions were calculated as follows:

$$E_{gas} = \frac{C_{gas\,exit} - C_{gas\,in}}{10^6}\,X\left(\frac{\beta_{gaz}\,X\,Q}{M_{pig}}\right)x\,10^6 \qquad (2)$$

Where E_{gas} represents the gas emission (mg_{gas}/min-kg_{porc}), $C_{gas\ exit}$ is the gas concentration at the outlet of the filter (ppm), $C_{gas\ in}$ is the gas concentration at the inlet of the filter (ppm), β_{gas} is the gas mass per volume of air (kg_{gaz}/m^3_{air}), Q represents the airflow rate in the filter (m^3_{air}/min) and M_{pig} is the total mass of the pigs in the room (kg).

Equation 3 represents the parameters used for the calculation of odour emissions:

$$E_{odour} = \frac{C_{odour}\,Q}{M_{pig}} \qquad (3)$$

Where E_{odour} represents the odour emission (OU/h-kg_{pig}), C_{odour} is the concentration of odours of the sampled air (OU /m^3_{air}), Q is the airflow rate in the room (m^3_{air}/h) and M_{pig} is the total mass of the pigs in the room (kg).

Statistical analysis A mixed linear model was initially adjusted using procedure PROC MIXED from SAS to analyze the effects of the treatments on the gas and odour emissions. The fixed effects of the model are the treatment (T, B), the week (1, 2, 3, 4) and the interaction treatment×week. Random effects are the breeding, the interaction trial×treatment×rep due to the variation between the rooms for each trial and the residual error. The treatment comprises only two techniques, that is to say with and without the ATU. Moreover, an assumption has to be made that measurements before and after the passage in the ATU are correlated.

RESULTS AND DISCUSSION

Gas emission results During the first trial, the results show that the three ATU had the same effectiveness to reduce the gas emissions (Table 1). Indeed, the results are similar among the ATU treatments. Whereas the emissions of CO_2 and CH_4 are practically unchanged after the passage of the air in ATU, a reduction of the emissions of NH_3 and H_2S has been observed. Indeed, the NH_3 emissions along trial 1 were reduced by 90 to 91% and those of H_2S were reduced by 46 to 54%. Only the N_2O emissions were not reduced but rather increased after the biotrickling treatment. These emissions were approximately 700% higher at the outlet of ATU than at the inlet.

Table 1. Gas emissions prior and after the air treatment for trial 1.

Gas	Gas emissions[1]								
	ATU 1			ATU 2			ATU 3		
	Inlet	Outlet	Red. (%)	Inlet	Outlet	Red. (%)	Inlet	Outlet	Red. (%)
CO_2	9.5	9.1	5	9.1	8.8	3	11.6	11.4	2
CH_4	11.1	10.4	6	24.8	24.2	2	19.0	18.7	1
NH_3	57.3	5.2	91	33.3	3.0	91	40.7	4.1	90
N_2O	0.5	4.4	-790	0.4	3.2	-760	0.5	4.0	-762
H_2S	219	117	46	323	173	47	356	165	54

[1] Gas emissions presented in mg/min-kg for the CO_2 and in μg/min-kg for the other gases.

The results of the second trial are similar to the first one (Table 2). These results are once again very similar from one ATU to another. The reductions of the CO_2 emissions of and CH_4 are more variable (- 7 to 13% for the CO_2 and -15 to 34% for the CH_4), but the average of the obtained reductions is practically zero.

Table 2. Gas emissions prior and after the air treatment for trial 2.

Gas	Gas emissions[1]								
	ATU 1			ATU 2			ATU 3		
	Inlet	Outlet	Red. (%)	Inlet	Outlet	Red. (%)	Inlet	Outlet	Red. (%)
CO_2	13.3	14.2	-7	13.1	12.4	5	14.1	12.2	13
CH_4	18.4	21.2	-15	26.5	20.9	21	29.3	19.3	34
NH_3	58.0	21.6	63	88.6	29.6	67	50.6	19.3	62
N_2O	1.9	8.0	-324	1.5	7.2	-383	1.9	4.5	-132
H_2S	470	325	31	255	193	24	524	177	66

[1] Gas emissions presented in mg/min-kg for the CO_2 and in µg/min-kg for the other gases.

The NH_3 and H_2S emissions were reduced in a range of 62 to 67% for NH_3 and 24 to 66% for the H_2S. Whereas the reductions of the H_2S emissions are appreciably the same as during the first trial, the NH_3 ones are slightly lower than that of the first test (90 to 91%). This result may be due to the nitrification-denitrification processes.

As in the first trial, only the N_2O emissions were not reduced but rather increased by the circulation of the air in the filter. These emissions were 132 to 385% higher in the outlet of the ATU than in their inlet. This N_2O production was however much lower than during the first trial (approximately 700%) and seems to be associated with the lower effectiveness to reduce the NH_3. Once again, those results are closely related to the nitrification-denitrification processes and more samples will have to be taken to well understand all the reactions found inside the biotrickling filter. When those reactions are fully understood, then the N_2O production could be reduced in the next optimization stages of the system.

Odour emission results The results obtained for the measurement of the odour reduction (Table 3) are similar to those obtained for the gas emissions. The first odour samplings of the first trial were carried out only two days after the ATU start-up. Consequently, the odour concentration reductions measured at that time with the olfactometer varied between only 18 and 67%. Indeed, the highest odour emission at the outlet of the ATU was 352 OU/h-kg_{pig} while the lowest inlet emission was 236 OU/h-kg_{pig}. Thereafter, the measurements taken by olfactometry improve constantly until last measurements were collected on December 17th. The inlet emission was comparable to the beginning of the trial (348 to 357 OU/h-kg_{pig}) while the outlet emission was much lower that in the beginning (29 to 87 OU/h-kg_{pig}). The measured reductions increased from 76 to 92%.

Table 3. Odour emissions and hedonic tone prior and after the air treatment in trial 1.

ATU	Position	Odour emissions and hedonic tone											
		Week 1			Week 2			Week 3			Week 4		
		Nasal[1]	Olf[2]	HT[3]	Nasal	Olf	HT	Nasal	Olf	HT	Nasal	Olf	HT
1	Inlet	-	116	-2.5	-	268	-3.0	2880	43	-2.5	4800	82	-2.2
	Outlet	-	38	-1.0	-	19	-0.5	120	4	-0.3	60	7	-0.3
	Red (%)	-	67		-	80	-	96	90	-	99	92	-
2	Inlet	-	144	-2.3	-	118	-2.7	2400	161	-2.3	2880	92	-3.2
	Outlet	-	118	-2.2	-	59	-0.3	150	23	0.2	600	22	-0.5
	Red (%)	-	18		-	50	-	94	86	-	79	76	-
3	Inlet	-	71	-1.7	-	-	-2.7	3840	59	-2.8	4800	148	-2.2
	Outlet	-	47	-1.3	-	59	-0.5	120	11	-0.5	540	18	-0.5
	Red (%)	-	34		-	-	-	97	82	-	89	88	-

[1] Nasal ranger (n-butanol ppb),
[2] Olfactomety (OU/h-kg_{pig}),
[3] Hedonic tone

Odour concentration measurements done by the "nasal rangers" in the first trial were carried out only for the last two weeks. During these two periods of measurements, the odour reductions were always higher than 79%, reaching 99% with ATU 1 on the last day of the trial. Those results are similar to the one done with the olfactometer.

Measurements of hedonic tone (on a scale from -5 to +5, -5 being very unpleasant and +5 being very pleasant) show that "the taste" of the odour improved with time. Whereas the hedonic tone was of -1.0 to -2.2 at the outlet of the ATU in the first week, it was rather from -0.3 to -0.5 at the same place at the time of the last week. This result show that the air is decreasing in odour concentration but is also increasing in pleasantness.

In the beginning of trial 2, the odour emissions measured with the olfactometer were slightly higher than in trial 1 (181 to 223 OU/h-kg_{pig}) but the odour reduction associated with the ATU was higher than in trial 1 (75 to 88%). Then, along the trial, no increase of the performance was observed (Table 4). Moreover, instability in the performance of the units was observed. For example, ATU 3 obtained 75% in odour reduction measured with the olfactometer for the first week. That result decreased to 68% in the second week and then after re-increased to 89% in the third one before re-decreased to 77% in the last week. At the end of the second trial, ATU 1 and ATU 2 got 55% and 54% of odour reduction measured with the olfactometer. That result is much lower than trial 1.

Table 4 Odour emissions and hedonic tone prior and after the air treatment in trial 2

ATU	Position	Odour emissions and hedonic tone											
		Week 1			Week 2			Week 3			Week 4		
		Nasal[1]	Olf[2]	HT[3]	Nasal	Olf	HT	Nasal	Olf	HT	Nasal	Olf	HT
1	Inlet	4567	181	-2.5	3229	152	-2.0	2715	229	-3.2	2715	281	-2.4
	Outlet	240	21	-0.3	679	70	-1.2	240	-	-2.0	240	126	-2.4
	Red (%)	95	88		79	54	-	91	-		91	55	
2	Inlet	3229	201	-2.5	4567	150	-2.7	5431	167	-2.3	5431	152	-2.5
	Outlet	480	29	0	240	27	-0.2	480	26	0	480	70	0
	Red (%)	85	86		95	82	-	91	68		91	54	
3	Inlet	1920	223	-0.2	2715	115	-0.8	1920	174	-3.0	1920	151	-2.2
	Outlet	480	55	0	339	36	-0.3	240	20	0.3	240	34	-0.7
	Red (%)	75	75		88	68	-	88	89		88	77	

[1] Nasal ranger (n-butanol ppb),
[2] Olfactomety (OU/h-kg_{pig}),
[3] Hedonic tone

All values measured with the "nasal ranger" technique indicated good performance of the units. During the four weeks of the trial, the lowest measured value was 75% while the highest reached 95%. Those results are quite higher than the one measured with the olfactometer. As mentioned, the measurement with the "nasal ranger" technique was done directly in the lab. The fact that the olfactometry required bag sampling, some manipulation before the analysis may partially explain the difference between those two techniques.

The hedonic tone measurement indicates also that the air coming from the outlet of the ATU is more pleasant than the one coming in. In the majority of the measurements, the outlet hedonic tone is much higher than at the inlet. In many cases, the outlet value is 0, meaning that the air at this point is neutral. On the other hand, ATU 1 had the worst result relative to the others. While ATU 2 and 3 got 0 and -0.7 at their outlet in the last week, ATU 1 had no improvement in hedonic tone between the inlet and the outlet. The phenomenon was also present during week 3 where there was only a slight amelioration of the hedonic tone.

CONCLUSION The ATUs developed at IRDA were found to be effective in reducing gas and odour emissions. Indeed, the ammonia and hydrogen sulphide were reduced by 62 to 91% and by 24 to 66%, respectively, after a treatment length of four weeks. While it decreases those gases, the use of ATU unfortunately produces large amounts of N_2O. This process will have to include denitrification-nitrification to deal with the N_2O.

The odour emissions were also decreased by the use of those units. After 4 weeks of measurement, the reduction reaches more than 90% for some ATU during the first trial. Unfortunately, the results for trial 2 were not as promising and lower values (54 to 77%) were measured.

Those trials conclude the first portion of the research program on air treatment systems. The next steps will involve the optimisation of those units to improve their technical performance.

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REFERENCES

ASTM. 1999. E 544-99: Standard practices for referencing suprathreshold odor intensity. In Annual Book of ASTM Standards. Philadelphia, PA: American Society for Testing and Materials.

Communauté Européen de Normalisation (CEN) 2003. Air quality – Determination of odour concentration by dynamic olfactometry. Standard No.EN 13725:2003 F, April. European Committee for Standardization, 65 pages.

Deshusses, M. A., D. Gabriel. 2005. Biotrickling filter technology. Biotechnology for odour and air pollution control. ed. Z. Shareefdeen and A. Singh. Springer. Verlag, Berlin, Heidelberg.

Devinny, J. S., M. A. Deshusses, T. S. Webster. 1999. Biofiltration for air pollution control. Lewis Publishers. Washington, DC, USA.

Godbout, S., S. P. Lemay. 2007. Les activités de recherche sur les odeurs et la cohabitation à l’IRDA. Journée sur la gestion des gaz et des odeurs en production porcine. IRDA, FPPQ, CDPQ.

Joncas, R., S. Godbout, F. Pouliot, A. Marquis. 2002. État de la recherche et du développement sur les concepts de bâtiments porcins réduisant les odeurs. IRDA.

Kim, N. J., Y. Sugano, M. Hirai, M. Shoda. 2000. Removal of a high load of ammonia gas by a marine bacterium, Vibrio Alginolyticus. Journal of Bioscience and Bioengineering. 90 (4): 410-415.

Manuzon, R. B., L. Y. Zhao, H. M. Keener, M. J. Darr. 2007. A prototype acid spray scrubber for absorbing ammonia emissions from exhaust fans of animal buildings. Transactions of the ASABE. 50 (4): 1395-1407.

Martinez, J., A-M. Pourcher. 2008. Cohabiter avec la production porcine : mythes et réalités. Forum sur la cohabitation en production porcine. CRAAQ.

Revah, S., J. M. Morgan-Sagastume. 2005. Methods of odor and VOC control. Biotechnology for odour and air pollution control. ed. Z. Shareefdeen and A. Singh. Springer. Verlag, Berlin, Heidelberg.

Sheridan, B. A., T. P. Curran, V. A. Dodd. 2002. Assessment of the influence of media particle size on the biofiltration of odorous exhaust ventilation air from a piggery facility. Bioresource Technology. 84: 129-143.