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Innovative Air Treatment Unit for Swine Exhaust Air – Commercial-Scale Tests

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ABSTRACT Swine housing facilities can emit substantial amounts of aerial contaminants, such as ammonia, dust and odour. These emissions can have a significant impact on both the environment and human health. It is also known that by reducing odour emissions, producers can improve their relationship with their neighbors. In this study, a commercial-scale swine exhaust air treatment unit (ATU) was developed and tested under real barn conditions for its effectiveness to reduce the emissions of ammonia, dust and odour.

Results from laboratory-scale tests carried out at the IRDA facilities in Québec were used to design the commercial-scale ATUs. Three of these units were then built using recycled shipping containers and retrofitted to three grower-finisher rooms at the barn facility of the Prairie Swine Centre Inc. in Saskatoon, SK. Each room was filled with 60 pigs and the exhaust air was ducted to an ATU. During the 12-week trial, samples were taken on a regular basis to monitor concentrations of ammonia, dust and odour before and after each ATU.

After a short start-up period, the commercial-scale ATUs provided robust and consistent performance under real barn conditions. The maximum removal efficiencies obtained during these tests were 77%, 92% and 75% for ammonia, dust and odour, respectively. However, the results for odour removal were variable with the replicates and with time. The water consumption, used to maintain performance over the duration of the trials, tended to increase as the ATU removed more contaminants from the air.

Keywords: air treatment; swine odour; ammonia; biotrickling filter

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). Animal housing can emit substantial amounts of aerial contaminants such as odorous compounds, ammonia (NH_3), hydrogen sulphide and airborne particulate. Downwind odours from confined feeding operations are considered to be a nuisance by nearby residents that may lead to a reduced quality of life. Canada is one of the world's leading pork producing nations and is known for its high quality pork products and excellent standards of food safety. The swine industry must therefore be very proactive in managing contaminated air that is exhausted from these pig rearing facilities.

Since the source of these contaminants can only be reduced, additional treatment of the exhaust air may be necessary where residents are impacted. A literature review has identified biofilters as the most common mode of treatment. However, maintaining good biofilter operating conditions for commercial-scale applications can be difficult. Consequently, biotrickling filters are considered to be an improvement since they are easier to manage and are smaller in size. According to Deshusses and Gabriel (2005), biotrickling filters involve biological techniques that are more promising for controlling odour. By reducing odour emissions, producers can improve the relationship with their neighbours and as well as the social acceptability of the swine industry.

Based on extensive laboratory-scale tests, a commercial-scale air treatment unit (ATU) was developed to treat swine exhaust air. The main objective of this project was to test the ATU under real barn conditions for its effectiveness to reduce the emissions of ammonia, dust and odour.

Material and Methods

Design of the commercial-scale ATUs

Since 2008, the Research and Development Institute for the Agri-Environment (IRDA) has been developing an air treatment unit based on biotrickling filters. In a biotrickling filter, the polluted air passes through a porous filter bed which is continuously wetted by a nutrient solution. The pollutants are first absorbed in the liquid solution before being degraded by microorganisms. Extensive tests conducted at the laboratory scale have wielded promising results (Lemay et al. 2012; Girard et al. 2012). Using the conclusions from these experiments, a commercial-scale ATU was designed and tested at the Prairie Swine Center inc. (PSCI) in Saskatoon.

From the different operating parameters tested in the laboratory, it was concluded that the most restrictive parameters were able to provide an adequate removal of contaminants. The design of the commercial-scale ATU was therefore based on the following criteria: an empty bed residence time (EBRT) of 3 seconds and a filtering solution recirculation rate of 2.35 $m^3/m^3/h$ (m^3 of solution per m^3 of filter bed per hour). In order to reduce costs and to obtain a fully contained mobile unit, the ATUs were designed to fit inside 20 foot shipping containers.

The maximum air flow rate at the PSCI was estimated using the animal capacity of the experimental rooms (60 pigs) and the highest theoretical air flow requirements in summer (50 L/s) (CPVQ 1998). However, the maximum air flow rate is only used on the hottest summer days; the actual flow rate fluctuates below this value the rest of the time. The size of the required ATU was therefore calculated based on 75% of this value to accommodate the fluctuating flow rate and to reduce building costs. A final volume of 238 ft^3 of filter media was determined using the following equation:

$$60\, pigs * 50\, {}^{L}/_{s} = 3000\, {}^{L}/_{s} * 75\% * EBRT\ of\ 3s = 6750\ L = 238 ft^3$$

Using 2 walls of filter material in each container with a height of 7 feet and a thickness of 1 foot, the required wall length was 17 feet. The swine exhaust air was supplied at one end of the container, it flowed through the filter walls and exited each side of the container. The conceptual diagram of the ATUs is presented in figure 1.

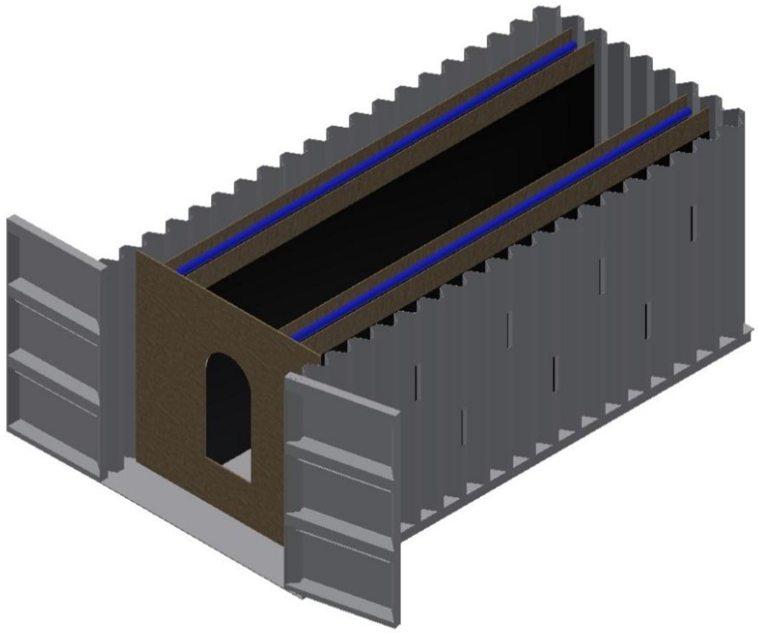

Figure 1: Conceptual diagram of the interior of each ATU.

The filter media used in the laboratory-scale tests was too expensive to be used in the commercial-scale ATU; a new filter media was therefore required. A structured plastic media from Jaeger Environmental (DURA-PAC XF68 PVC modular cross-flow media) with a surface area of 223 m^2/m^3 was selected, as shown in Figure 2.

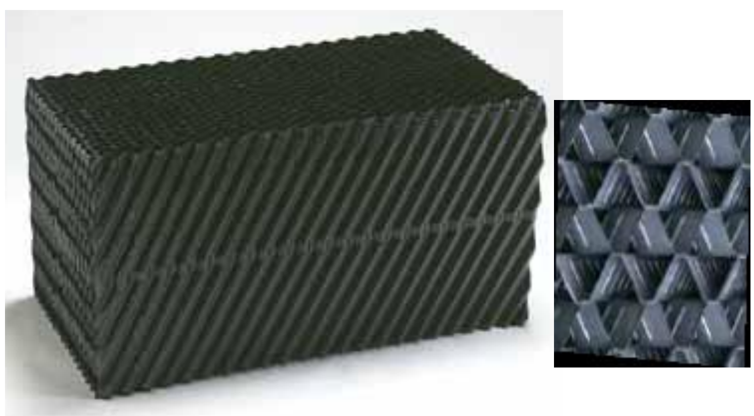

Figure 2: Picture of the filter media used in the commercial-scale ATU.

With the recirculation rate of 2.35 $m^3/m^3/h$, the total liquid flow rate for the commercial-scale ATU was calculated as follows:

$$Liquid\ flow\ rate = 2.35\frac{m^3}{m^3h} * 238ft^3 * 0.0283\frac{m^3}{ft^3} = 15.8\frac{m^3}{h} = 70gpm$$

The nutrient solution was supplied to the top of both walls with a recirculation pump and then trickled down the filter material.

Experimental site and analytical methods

Three rooms housing 60 grower-finisher pigs at the PSCI barn facility were used for this project. The pigs had a starting weight of about 20-25 kg and were raised to market weight. Each room had six 1.98 × 4.11 m pens with partially slatted floors and an underfloor shallow manure pit under the slats. The rooms were mechanically-ventilated with 3 exhaust fans at one end of the room.

During the trial, conventional management of ventilation settings, manure pits, and basic husbandry and veterinary services were applied to all three rooms. All pigs were given standard PSCI grow-finish diets and water ad libitum during the trial. The exhaust air from each room was supplied to three ATUs installed outside of the rooms. The rooms and ATUs were all controlled identically to provide three replicates.

The trial ran for 12 weeks during which NH_3, dust, odour, ATU water consumption, pig performance and environmental parameters were monitored. Most parameters were continuously monitored during weeks 3, 5, 7, 8, 9, 10, 11 and 12 of the trial. On day 7 of each sampling week (except on week 8), air samples were collected into 50-L Tedlar bags before and after each ATU and sent to an olfactometry laboratory for odour analysis. Two total dust samplers were also installed in each ATU to assess the removal of dust by the ATU.

An ammonia analyzer (Model Chillgard RT, MSA Canada, Edmonton, AB; accuracy of ±2 ppmv) was used to monitor levels of ammonia. Sampling lines were installed to extract air samples before and after the treatment unit and passed through the ammonia analyzer; a PLC system was used to cycle through the different sampling locations, allowing for semi-continuous monitoring of NH_3 levels.

A water meter was installed on the water supply line to each ATU. Total dust sampling was conducted according to the NIOSH 0500 method (Particulates NOR, Total). Dust sampling cassettes were used to collect air samples before and after the air treatment unit. A pump system was installed to extract the required air volume at the required flow rate from each sampling location over 24 hours to meet the requirements of the standard method. The sampling filters were weighed (after conditioning) to determine the mass of dust collected and the dust concentration was then calculated.

Results

Effect on ammonia concentration

The average NH_3 concentration before (room exhaust air) and after the ATU for each sampling week is provided in Table 1. The concentration of NH_3 in the room exhaust air ranged from 5 to 70 ppmv while the concentration at the outlet of the ATUs varied from 4 to 11 ppmv. The difference in NH_3 levels before and after the units were statistically significant (p<0.0001) demonstrating that the ATUs were able to significantly reduce levels of NH_3 in the exhaust airstream before being released to the environment. Furthermore, it was shown that the NH_3 concentration in the exhaust air (before treatment) increased significantly ($p<0.0001$) as the trial progressed, but the NH_3 concentration after the air passed through the ATUs did not fluctuate significantly ($p=0.059$). This observation implies that the ATU provided a relatively constant outlet NH_3 concentration regardless of the inlet concentration. The resulting removal efficiency therefore fluctuated according to the inlet concentration: from 22% reduction on week 1 to 77% on week 12.

Table 1: Weekly concentration of NH_3 (in ppmv) before and after each ATU and the corresponding removal efficiency (RE).

Trial week #	ATU 1			ATU 2			ATU 3			Average		
	Before	After	RE (%)	Before	After	RE (%)	Before	After	RE (%)	Before	After	RE (%)
3	9.9	6.8	29.7	10.2	8.0	18.6	5.2	4.0	17.7	8.4	6.3	22.0
5	27.9	6.9	72.2	28.9	8.7	67.3	9.0	4.9	43.3	21.9	6.8	60.9
7	24.3	8.6	65.3	20.0	6.4	67.2	9.6	6.2	39.5	18.0	7.1	57.3
8	29.1	7.3	74.5	24.2	7.2	70.2	11.8	6.5	44.1	21.7	7.0	62.9
9	45.5	6.4	85.4	31.6	8.2	73.4	19.6	7.2	62.8	32.2	7.3	73.9
10	52.8	8.5	83.8	34.9	9.8	70.9	19.4	7.2	61.9	35.7	8.5	72.2
11	48.8	7.9	83.5	33.6	8.7	73.4	21.4	8.4	59.4	34.6	8.4	72.1
12	69.1	11.0	83.5	48.8	9.1	79.1	26.0	8.7	67.7	48.0	9.6	76.8
Ave	38.4	7.9	72.2	29.0	8.3	65.0	15.3	6.6	49.6	-	-	-

As shown in Table 1, ATU 3 achieved a slightly lower NH_3 removal efficiency compared to the other 2 ATUs, which could be due to the lower concentrations of NH_3 inside the room. However, ATU 3 also provided the lowest NH_3 concentration in the air released to the environment at 6.6 ppmv on average over the 12 weeks. The removal efficiency is therefore not necessarily the best indicator to describe the impact of the air treatment unit on swine emissions.

Effect on dust and odour concentration

Table 2 shows the concentrations of total dust before and after each ATU as well as the removal efficiency obtained. Dust concentrations varied from 0.25 mg/m^3 to 1.3 mg/m^3 in the room exhaust air and from 0.09 mg/m^3 to 0.27 mg/m^3 after the ATUs. The biotrickling filters had a significant effect ($p<0.0001$) on dust levels after the room exhaust air had passed through the treatment units. As with NH_3, dust levels after the treatment units were not significantly different ($p=0.183$) over the trial, but dust levels in the room exhaust air increased significantly ($p<0.0001$) with time. This resulted in higher dust removal efficiencies at the end of the trial when pigs were nearing market weights. Maximum dust reduction was about 92%, which was achieved on week 12 while the least reduction was about 65% during week 3.

The observed dust reduction is very promising for the swine industry since airborne viruses are generally closely associated with dust particles. However, the capacity of the ATUs to remove airborne pathogens has yet to be demonstrated. Further research is ongoing in this regard.

Table 2: Levels of total dust (in mg/m^3) measured inside the room (prior) and after each ATU and the corresponding removal efficiency (RE).

Trial week #	ATU 1			ATU 2			ATU 3			Average		
	Before	After	RE (%)	Before	After	RE (%)	Before	After	RE (%)	Before	After	RE (%)
3	0.039	0.034	12.8	0.115	0.060	47.4	0.612	0.172	71.9	0.255	0.089	65.2
5	0.341	0.046	86.4	0.314	0.119	62.1	0.764	0.260	66.0	0.473	0.142	70.0
7	0.504	0.052	89.7	0.681	0.181	73.4	1.160	0.175	84.9	0.781	0.136	82.6
9	0.568	0.320	43.7	0.909	0.157	82.7	1.572	0.322	79.5	1.016	0.266	73.8
10	1.067	0.245	77.1	1.086	0.298	72.6	1.477	0.234	84.2	1.210	0.259	78.6
11	1.075	0.018	98.3	1.222	0.222	81.8	1.605	0.491	69.4	1.301	0.244	81.2
12	1.005	0.092	90.9	1.039	0.173	83.3	1.729	0.039	97.7	1.258	0.101	91.9
Ave	0.657	0.115	71.3	0.767	0.173	71.9	1.274	0.242	79.1	-	-	-

The efficiency of the ATUs to reduce odour emissions from the pig rooms was not as readily obvious compared to NH_3 and dust. The results for odour concentration before and after the ATUs in Table 3 show that the units did provide statistically significant reduction ($p=0.017$) in overall odour levels. On average, odour concentration in the exhaust air (before treatment) was about 815 ± 419 OU/m^3 and was reduced to about 553 ± 208 OU/m^3 after the ATUs. Variations in odour levels after the treatment units were not significant ($p=0.119$) while odour variations inside the room were significant ($p=0.006$). The 7th week of the trial had the highest odour concentration inside the room (1443 ± 361 OU/m^3) while week 5 (241 ± 105 OU/m^3) had the lowest, which resulted in a reduction of 75% and an increase of 27%, respectively.

This variability in odour removal efficiency was also observed during laboratory-scale tests where the results varied with time and with the measurement method. The removal efficiencies obtained varied from 11 to 51% for dynamic olfactometry and from 64 to 82% for a method involving qualified panelists (Girard et al. 2013).

Table 3: Odour concentration (in OU/m^3) measured inside the room (prior) and after each ATU and the corresponding removal efficiency (RE).

Trial week #	ATU 1			ATU 2			ATU 3			Average		
	Before	After	RE (%)	Before	After	RE (%)	Before	After	RE (%)	Before	After	RE (%)
3	181	430	-137.6	152	1116	-634.2	724	1261	-74.2	352	936	-165.6
5	362	128	64.6	181	609	-236.5	181	181	0.0	241	306	-26.8
7	1217	152	87.5	1448	724	50.0	1663	208	87.5	1443	361	75.0
9	1448	362	75.0	362	430	-18.8	1448	861	40.5	1086	551	49.3
10	724	575	20.6	645	575	10.9	955	575	39.8	775	575	25.8
11	724	724	0.0	861	724	15.9	1448	512	64.6	1011	653	35.4
12	538	441	18.0	656	441	32.8	1188	594	50.0	794	492	38.0
Ave	742	402	18.3	615	660	-111.4	1087	599	29.8			

The nutrient solution in the ATUs had to be continuously supplied with fresh water to compensate evaporation and to maintain a low concentration of inorganic nitrogen salts. During the laboratory-scale tests, high concentrations of nitrogen salts such as ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-), were found to inhibit the microorganisms and significantly reduce the NH_3 removal efficiency (Girard et al. 2013). During the commercial-scale tests, the salt concentration was monitored with the electrical conductivity and a certain fraction of the nutrient solution was removed periodically to maintain the conductivity below 7.5 µS. As shown in Table 4, the water consumption associated with the ATUs was on average about 537.5 ± 113.3 liters of water per day. Wide variations in water consumption between the ATUs were observed; ATU 1 had the highest water consumption (663.0 L day^{-1}) while ATU 3 had the lowest (442.9 L day^{-1}). Water consumption for evaporation should have been relatively constant between the ATUs since each pig room was operated identically. The observed variations were therefore probably due to the control of the concentration of inorganic nitrogen salts. Since the nitrogen salts all come from the NH_3 in the air, the water consumption can be related to the NH_3 removal efficiency. As shown in Table 4, ATU 1 had the highest NH_3 removal efficiency while ATU 3 had the least which corresponds to the water consumption.

Table 4: Water consumption associated with each ATU.

Replicate	Average NH_3 removal efficiency (%)	Water consumed (L day^{-1})
ATU 1	72.2	663.0 ± 498.2
ATU 2	65.0	506.6 ± 427.3
ATU 3	49.6	442.9 ± 419.1
Average		537.5 ± 113.3

Discussion and Conclusion

In this project, the air treatment unit developed at the IRDA was used to design commercial-scale units that were tested under real barn conditions at the PSCI. The biotrickling air treatment units installed at the exhaust of swine grow-finish rooms were effective in reducing the levels of NH_3, dust, and odour by up to 77%, 92% and 75%, respectively. In order to maintain performance over the duration of the trials, part of the nutrient solution was replaced with fresh water when the concentration of inorganic nitrogen salts (evaluated with the conductivity) was too high as was recommended following the laboratory-scale tests. The ATUs were also able to reduce the levels of NH_3 even at the initial stage of the trial and the NH_3 levels at the outlet of the system remained almost the same throughout the trial. The removal efficiency of NH_3 therefore increased as the NH_3 concentration in the pig rooms before the filter increased. The water consumption tended to increase as the ATU removed more contaminants from the air. As observed with the laboratory-scale trials, the results for odour removal were variable with the replicates and with time.

By limiting emissions of gases and odours from swine barns, the innovative air treatment unit developed in this project will help reduce the environmental impact and improve the acceptability of swine farming in Canada.

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