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Protecting Swine Worker Health: Determining the Best Combination of Airborne Contaminant Reduction Technologies to Reduce Odours, Dust and Gases

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ABSTRACT The swine industry is important both worldwide and across Canada, but production sites can emit substantial amounts of airborne contaminants such as odorous compounds, gases, dust and bioaerosols. Workers and nearby communities are exposed to these airborne contaminants which represent a risk to their health. Over the years, different strategies have successfully reduced some of these contaminants, but no study has yet characterized the combined effect of several technologies on emissions from pig buildings.

In this study, the reduction of odour, dust and ammonia emissions were evaluated from the use of three different technologies for pig buildings: manure separation with a v-shaped scraper, oil sprinkling and air treatment unit (ATU). These technologies were used alone or combined in order to determine the best combination to be implemented in a commercial-scale pig building. Thus, 8 environmentally controlled chambers housing 4-5 grower/finisher pigs were used to produce the airborne contaminants. The air temperature, humidity and flow rate were monitored continuously over each 7 week trial. Samples for gas measurement were collected at 4 hour intervals while dust and odours were sampled at weekly and biweekly intervals respectively.

This paper presents the results for one on the four replicates of the study. For ammonia, the ATU shows a higher performance than the v-shaped scraper (about 60% and 30% respectively). The ATU is also the only technology able to reduce considerably odour (about 70%) in terms of intensity perception. For dust emissions, it seems that both the oil sprinkling and the ATU provide similar reductions (above 90%) and their combination does not seem to substantially decrease the emissions.

Keywords: Worker Health; Swine Emission Reduction; Air Biofiltration; Oil Sprinkling; Manure Separation.

INTRODUCTION

There are more than 7 100 swine farms in Canada. Only in Quebec, this industry employs 10 000 workers in a total of 1 890 livestock buildings (Conseil canadien du porc, 2014). These workers are exposed on a daily basis to significant concentrations of gases, dusts, odours and bioaerosols (Cormier et al., 2000; Donham et al., 1986; Duchaine et al., 2000; Létourneau et al., 2010). These contaminants come from the animals, litter, food, water, building materials and manure.

By their exposure to these airborne contaminants, pork producers can contract infections (Keessen et al., 2013; Poggenborg et al., 2008) and are at risk for many other respiratory problems such as chronic bronchitis and asthma (Cormier et al., 1991; Donham et al., 1984; Iversen et al., 2000). Also, the risk of catching these diseases increases with the amount of time spent inside animal buildings (Radon et al., 2000) and is related to the concentration of dusts (total and respirable), endotoxins and ammonia (Von Essen et al., 2005). These contaminants can also be released in the environment by the exhaust system of pig buildings and put at risk health of pork producers, their families and nearby communities (Thorne, 2007; Ko et al., 2008; Sigurdarson et al. 2006; Von Essen et al., 2005).

Many research teams have worked on ways to reduce gases, odours and dust emitted from pig farms. However, the impact of some good practices or technologies was not always interesting. For example, it was observed that reducing pig density in buildings can reduce dust emissions, but it also increases the ammonia concentration (Guingand, 2007). Within the existing technologies to protect the health of workers and nearby communities, three systems are particularly promising.

The solid-liquid separation of the manure under the slatted floor enables a more efficient management of the nutrients (nitrogen and phosphorus) and also reduces ammonia emissions (Godbout et al. 2006). In a review on dust control strategies, Maghirang et al. (1995) concluded that oil or water sprinkling was a promising technique for livestock buildings. Those two techniques can reduce gases, odours and dust, but not sufficiently to ensure that the air from pig buildings doesn't put nearby communities at risk. Therefore, treating the air emitted by pigs building has to be considered in order to reduce health risks and limit the dispersion of contaminants at the entrance of other buildings. For these reasons, an air treatment unit (ATU) based on the biotrickling filtration concept was developed by the IRDA during the past few years (2008-2013). The results obtained at the laboratory and pre-commercial scales were quite promising with reduction efficiencies up to 77%, 92% and 75% for ammonia, total dusts and odours respectively (Lemay et al. 2012; Lemay 2013).

These technologies used alone can remove part of the airborne contaminants, but few studies have looked at the combination of several technologies to provide a greater effect and to evaluate any synergistic effects. The main objective of this project is to determine the best combination of technologies to be implemented in a commercial-scale pig building. Therefore, the reduction of odorous compounds, dust and ammonia was evaluated from the use of 3 studied airborne contaminant reduction strategies for pig buildings: manure separation, oil sprinkling and air treatment unit (ATU), used alone or in combination with each other.

MATERIAL AND METHODS

Laboratory-scale Pig Chambers

Eight environmentally controlled bench-scale chambers housing 4-5 grower-finisher pigs from 25 to 85 kg were used to supply the contaminated air in this experiment. The chambers, which are 1.14 m wide, 2.44 m long and 2.44 m high, are located in the BABE laboratory, at IRDA, Deschambault, Québec, Canada. Each group of grower-finisher pigs was kept in the experimental pig chambers for a period of 7 weeks during which the following parameters were monitored: air flow rate, gas and dust concentrations as well as animal performance data (weight gain, feed and water consumption). Different combinations of three airborne contaminant reduction strategies were applied to each of the eight chambers used in this project. The technologies used are described below.

Airborne Contaminant Reduction Strategies

Four pig chambers were equipped with V-shaped scrapers (see figure 1a) to provide manure separation in the temporary manure storage located under the slatted floor. While the liquid phase is drained by a small canal at its center, the solid phase is held on the inclined concrete surface and then removed periodically with a scraper. There was no separation device in the four other pig chambers. For these chambers, the manure was stored in shallow pits underneath the slatted floors and was removed periodically.

For dust removal, canola oil was sprinkled (see figure 1b) as a light drizzle inside four pig chambers on a daily basis at a rate of 6ml/s during 5 sec. This application rate provided a daily oil dose of 10 ml/m^2. The sprinkling device was automated with an electric solenoid valve and a timer to ensure precision and repeatability.

Six cross-flow ATUs (see figure 1c), were designed to treat the exhaust air from six independent pig chambers. Each ATU was filled with 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. The air flow rate was maintained at 68 L/s through a volume of 0,34m^3 (12 ft^3) of packing material which provided an empty bed residence time (EBRT) of 5 sec. A diluted nutrient solution was continuously recirculated over the media at a rate of 20L/min to ensure proper filter bed moisture. It is not possible to reveal the exact nature of the nutrient solution due to a confidentiality agreement. All the operating conditions were identical from one ATU to another and were kept constant throughout each trial. To maintain the performance of the system, part of the nutrient solution was removed periodically in order to control quality and bacteria growth.

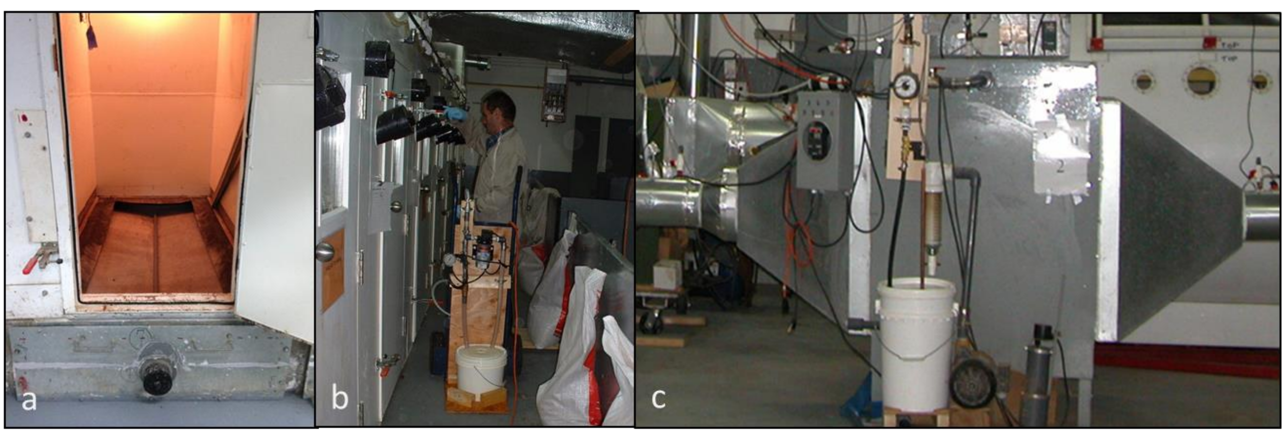

Figure 1. Technologies used in this study: a) v-shaped scraper installed in the temporary manure storage, b) oil sprinkling device in use, and c) one of the air treatment units.

Analytical Method

Air samples from the pig chambers and from the outlet of the ATUs were taken every 4 hours and the following compounds were analysed: ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). The sample air was pumped to a mobile laboratory through Teflon tubing. The concentrations of CH_4, CO_2 and N_2O were measured with a gas chromatograph (Agilent 6890N) equipped with a flame ionization detector (FID) for detection and quantification of CH_4 and CO_2 and an electron capture detector (ECD) for detection and quantification of N_2O. Ammonia was measured with a non-dispersive infrared (NDIR) analyzer (Ultramat 6E, Siemens, Germany). Every two days, certified calibration gases were supplied to the analysers for quality control purposes. Other physical parameters were measured every 15 minutes: air flow rate, air and water temperature, relative humidity and pressure drop across the filter bed.

Dust samples were collected inside the pig chambers and at the outlet of the ATUs using membrane filters at an air flow rate of 2 L/min. Filters are composed of a MF-Millipore™ (type AAWP, 37 mm, 0,8 µm) membrane made of a mixture of cellulose acetate and nitrate and placed on a cellulose support inside a polystyrene filter holder (as used in NIOSH industrial air sampling methods). The filters were changed on a weekly basis.

Measurements of odour concentration were performed using qualified panelists who evaluated the intensity of the ambient odour with a nine point scale of n-butanol as described in standardized techniques for measuring suprathreshold intensity of odour (ASTM 544-99, ASTM 1999).

RESULTS

In order to obtain sufficient data for a statistical analysis, four replicates are planned for this project. However, the trials have not all been completed yet and the results presented in this paper are from one trial only. Nevertheless, the impact of the different technologies on ammonia, odour and dust emissions can be clearly observed after just one trial.

Ammonia Emissions

Figure 2 shows the amount of ammonia emitted from the pig chambers and their related ATU for each combination of the technologies studied. The daily emissions are reported on the basis of the total mass of pigs raised inside each chamber.

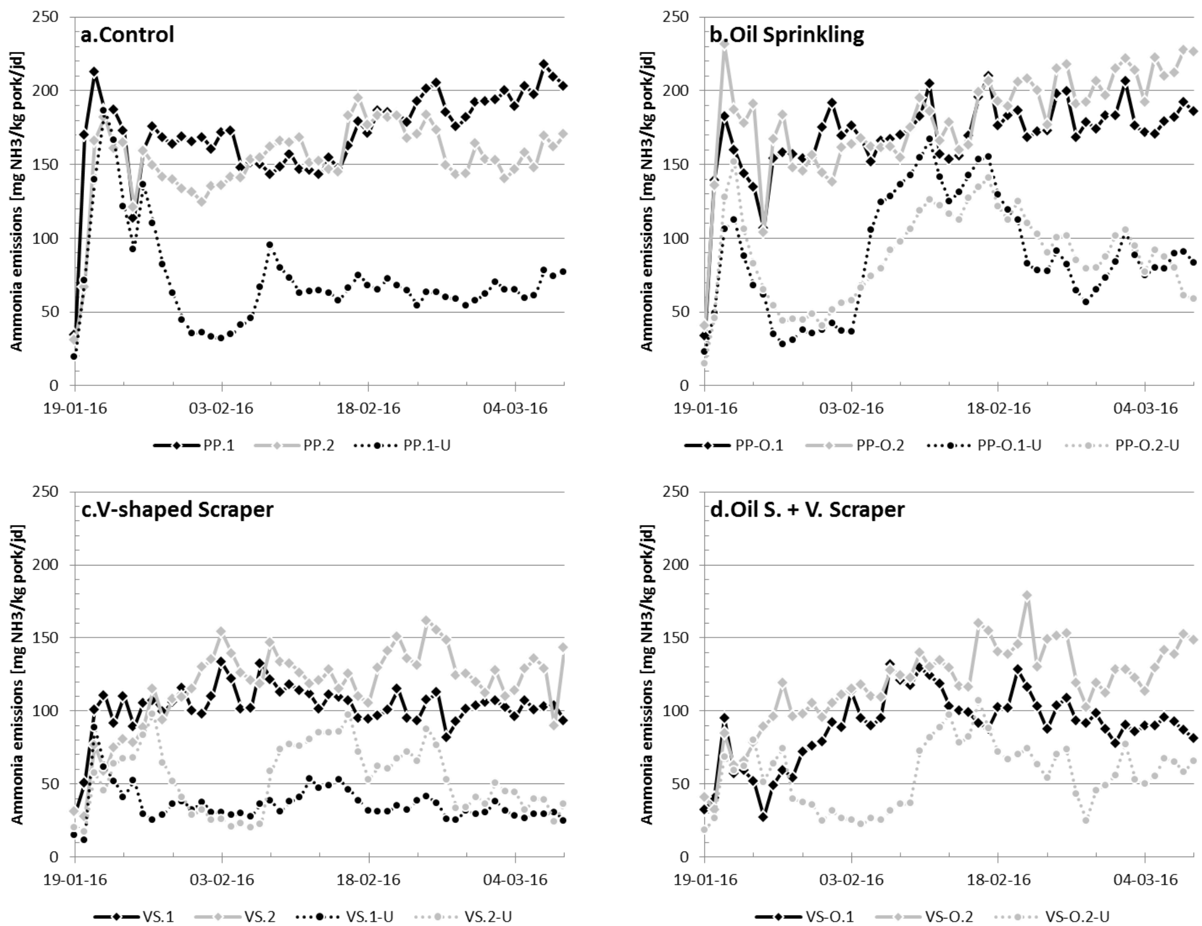

Figure 2. Ammonia emitted from the pig chambers and the outlet of each ATU related to each combination of technologies used: a) control chambers with pull-plug (PP) manure management only, b) chambers with pull-plug and oil sprinkling (O), c) chambers with v-shaped scraper (VS) only, and d) chambers with oil sprinkling and v-shaped scraper.

All replicated treatments have similar curves, as shown in figure 2. An upcoming statistical evaluation using all four trials will determine if these similarities are significant and if the observed effects of the treatments are repeatable.

Both curves of the control pig chambers are relatively similar and their mean ammonia emission (PP.1 & PP.2, figure 2a) was 162 ± 14 mg NH_3/kg pork/d during the trial. The ATU related to one of these control chambers (PP.1-U, figure 2a) took about three weeks of operation before stabilizing, but then provided a substantial impact on ammonia emissions with an average of 67 ± 9 mg NH_3/kg pork/d. The long period required for the process to stabilize can be explained by the biological nature of the air treatment unit. During this time, the microflora must adapt following the inoculation and develop specialised bacteria. According to figure 2, all the ATUs have a stabilisation period of about three weeks. Also, regardless of which technology the ATU is combined with, it seems to have an additional impact on ammonia reduction.

As expected, the oil sprinkling has little or no impact on ammonia reduction in the pig chambers (PP-O.1 & PP-O.2, figure 2b) with an average emission comparable to that of the control chambers of 175 ± 9 mg NH_3/kg pork/d. Furthermore, the oil seems to have a negative impact on ATU performance. Indeed, all curves where those technologies are combined (PP-O.1 & PP-O.2, figure 2b; VS-O.2-U, figure 2d) demonstrate some difficulties of stabilization during all the trial period. No oil was observed at the entrance of the ATUs nor inside the units which suggests that the impact on the microflora was indirect.

The v-shaped scraper, compared to control chambers, demonstrated a small reduction of the ammonia emitted from pig chambers (VS.1 & VS.2, figure 2c) with an average of 110 ± 10 mg NH_3/kg pork/d. Ammonia is a by-product of the decomposition of urea in the urine, but this reaction is accelerated by an enzyme found in feces. Therefore, by using the v-shaped scraper to limit the contact between the urine and the feces it is possible to reduce the ammonia emissions. Combining an ATU with a v-shaped scraper (VS.1-U & VS.2-U, figure 2c) doesn’t seem to have an additional impact on ammonia emission reduction compare to the use of an ATU alone (PP.1-U) with a comparable average emission of 47 ± 17 mg NH_3/kg pork/d.

Odour Emissions

Figure 3 shows odour emissions as analyzed with the n-butanol scale for each combination of technologies studied. These results can be interpreted as an intensity perception.

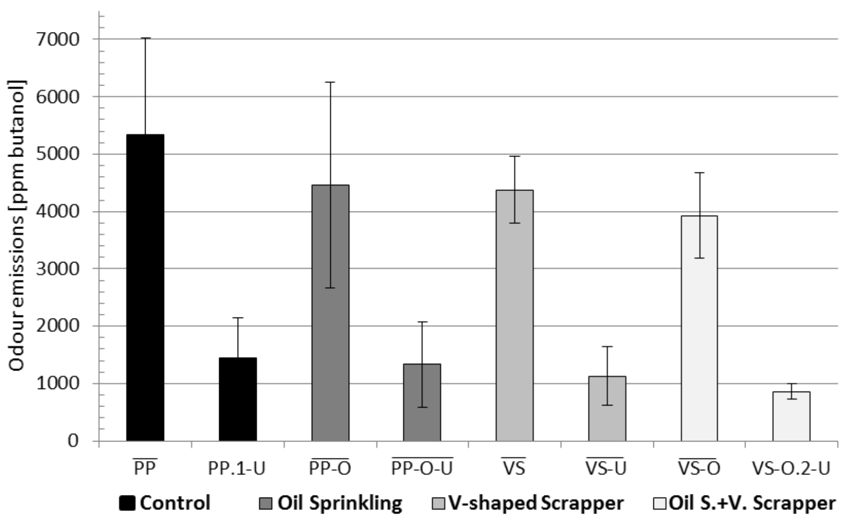

Figure 3. Odour intensity perception as emitted from the pig chambers and the outlet of each ATU related to each combination of technologies used: pull-plug (PP), oil sprinkling (O), v-shaped scraper (VS) and air treatment unit (U).

It is clearly observed on figure 3 that the ATU is the only technology used that has a clear impact on odour reduction. Furthermore, regardless of which technology the ATU is combined, the impact on odour emissions seems to be similar. With the addition of the results from the three other trials, it will be possible to better interpret the odour reduction obtained by using the v-shaped scraper and the oil sprinkling. With only one trial, it is only possible to distinguish the intensity perception between all the pig chambers (about 4500 ± 600 ppm butanol) and all the ATU (about 1200 ± 300 ppm butanol).

Dust Emissions

Figure 4 shows the amount of dust emitted daily from the pig chambers and their related ATU for each combination of technologies studied.

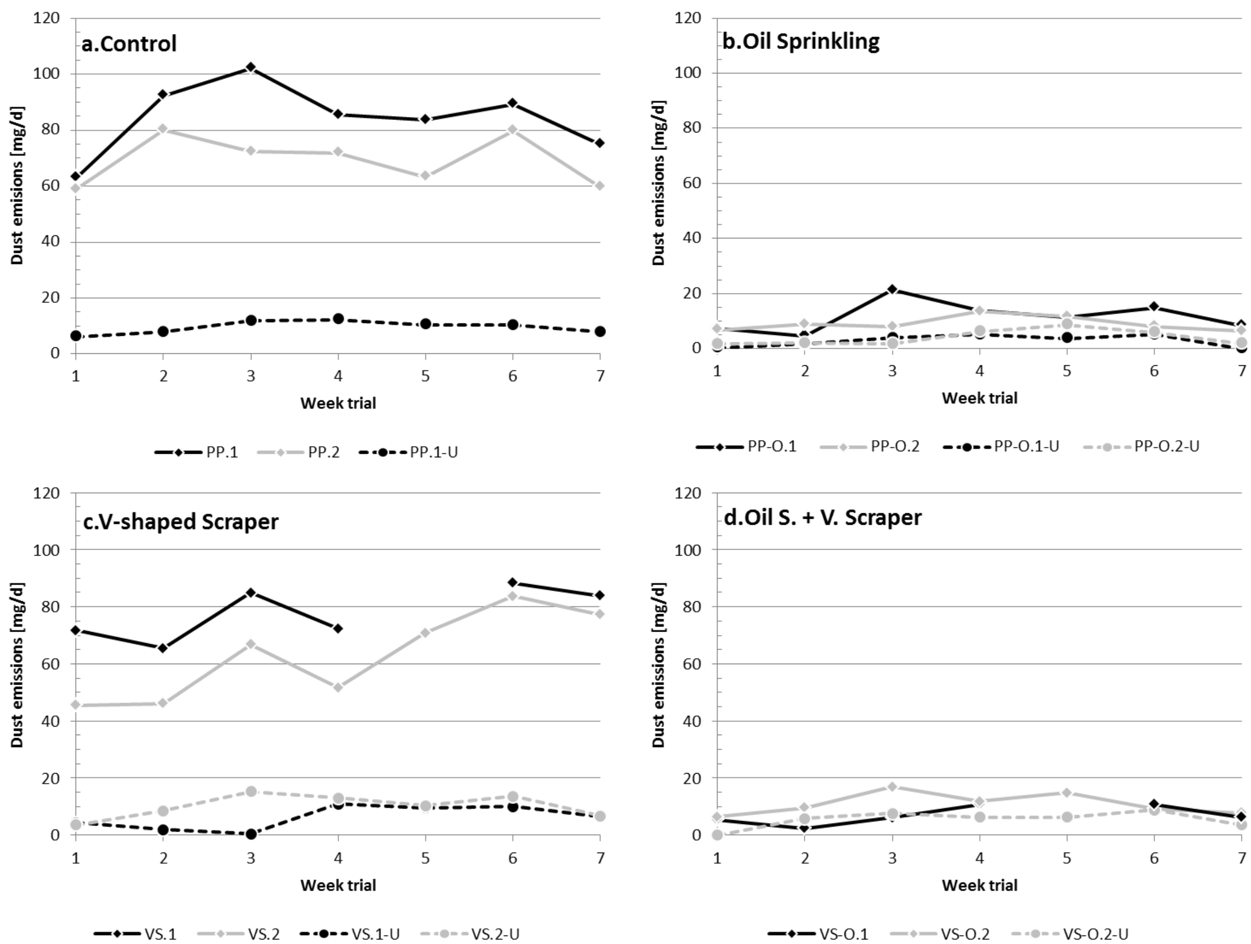

Figure 4. Dust emitted from the pig chambers and the outlet of each ATU related to each combination of technologies used: a) control chambers with pull-plug (PP) manure management only, b) chambers with pull-plug and oil sprinkling (O), c) chambers with v-shaped scraper (VS) only, and d) chambers with oil sprinkling and v-shaped scraper.

The results for dust emissions are not reported on the basis of the total mass of pigs, but rather on total mass of dust per day. This relative stability of all the curves shown on figure 4 seems to show that there is no relation between these two variables. So, while the pigs gain a lot of weight over the course of one trial, the same amount of dust is produced. Furthermore, it appears on figure 4 that all replicated treatments have similar curves. An upcoming statistical evaluation including all the trials will determine if these similarities are significant and if the impact of the treatments observed are repeatable.

The control pig chambers (PP.1 & PP.2, figure 4a) have a mean dust emission of 77 ± 11 mg dust/d. The ATU related to one of these control chambers (PP.1-U, figure 4a) shows an important impact on dust emissions with an average value of 10 ± 2 mg dust/d. According to figure 4, regardless of which technology the ATU is combined, it seems to have a similar impact on dust reduction. The ATU acts as a physical barrier to the dust and is quite effective with an average of 6 ± 3 mg dust/d of residual dust at the outlet.

As expected, the v-shaped scraper seems to have no impact on dust emissions in the pig chambers (VS.1 & VS.2, figure 4c) with an emission average of 66 ± 3 mg dust/d which is comparable to the results of the control chambers. Comparatively, the oil sprinkling shows a great reduction on dust emission with an average emission of 6 ± 3 mg dust/d, which is similar to the ATU. By making the surface sticky with the oil sprinkling, the dust is trapped on the different surfaces which reduces both the ambient concentration and the environmental emissions.

DUSCUSSION AND CONCLUSION

As previously mentioned, the data presented in this paper are the result of one of the four trials to be carried out in this project. Nevertheless, the results provide an indication of the potential reduction in airborne contaminants from the combination of the three technologies tested.

In order to reduce ammonia emissions from pig chambers, ATU shows higher performance than the v-shaped scraper (about 60% and 30% respectively), but the gain obtained by their combination is unclear. The ATU is also the only technology able to reduce considerably odour (about 70%) in terms of intensity perception. For dust emissions, it seems that both the oil sprinkling and the ATU provide similar reductions (above 90%) and their combination does not seem to substantially decrease the emissions.

The ATU is a quite promising technology to reduce considerably many airborne contaminants emitted from pig buildings. In this way, it has a greater impact on protecting public health. However, by recirculating part of the treated air back in the barn, the ATU could potentially be used to protect worker health as well.

Compared to other studies, the values reported here for each individual technology are similar to published data (Godbout et al. 2006; Lemay 2013; Lemay and Godbout 2004). Godbout et al. (2009) also studied the combined effect of the v-shaped scraper and a change in diet on some airborne contaminants. They observed a reduction of only 12% on ammonia emissions which is a few less than what we observed in this study. Once combined with the diet, a considerable gain was observed on ammonia reduction, from 46% with the diet alone up to 59% with both methods combined. For dust, a study by Pedersen et al. (2000) concluded that oil sprinkling was the technology that provided the best performance for reducing dust in pig buildings as compared to the type of feed (wet or dry), electrostatic filters, water application and ionization. The expected decrease in airborne dust suggest by these authors is typically between 50 and 90%. For biotrickling filters, relatively few studies have looked at their application to treatment of waste air from pig buildings. Melse et Mol (2004) studied a biotrickling filter treating air from 650 pigs and found ammonia reductions between 41 à 94 %, which is similar to the ATU used in this project.

Once the four repetitions will be completed, the data will be subjected to a statistical analysis to determine whether there are significant differences between the different technologies used in the laboratory-scale pig chambers. Following this statistical analysis, the best combination of technologies will be selected by a panel of experts. The experts will evaluate not only the performance of the technologies used alone and in combination with each other, but also the technical feasibility and the cost of each technology. The selected combination of technologies will have to provide a substantial improvement in air quality while respecting the financial and technical realities of modern swine producers.

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