Ozone treatment of air in pig sheds

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Treatment of airborne pollutants in livestock buildings with ozone as potential abatement option*

T Banhazi†
National Centre for Engineering in Agriculture,
University of Southern Queensland, Toowoomba, Queensland

ABSTRACT: *Previous research has demonstrated the negative effects of sub-optimal air quality on profitability, production efficiency, occupational health and safety, environmental sustainability and animal welfare. Ozone application has been used in North America to reduce internal air pollutant concentrations in livestock buildings and as a result potentially reduce airborne pollution emission. The main objective of this research was to evaluate the potential of using low concentration ozone (0.03 ppm) in Australian piggery buildings to reduce airborne pollution levels within piggery buildings and thus reduce pollution emission potentially. The data collected during the experiments demonstrated that ozone could be used effectively to reduce airborne bacteria (on average by 30% within this study) and reduce the concentration of inhalable particles (by 21% on average within this study). However, it appeared that ozone treatment did increase the concentration of respirable particles in the airspace of piggery buildings (within this study by approximately 26% on average).*

1 INTRODUCTION

Previous studies have identified several key management and housing factors that contribute to high concentrations of airborne pollutants within piggery buildings and to very high emission rates from those buildings (Banhazi et al, 2008a; 2008b; 2008c; 2008d). It has also been demonstrated that some airborne pollutants are associated with a reduced production efficiency in pigs (Banhazi & Cargill, 1998; Lee et al, 2005) and increased occupational health and safety risk for humans (Donham et al, 1989; Banhazi et al, 2009). Airborne pollutants appear to enhance both the prevalence and severity of respiratory diseases in pigs and it may also aid the spread of other infections (Donaldson, 1977). European data also suggests (Takai et al, 1998; Seedorf et al, 1998; Groot Koerkamp et al, 1998) that as a result of high indoor airborne pollution concentrations in piggery buildings, an average enterprise of 500 sows on a single site would release significant amounts of dust, bacteria, ammonia and endotoxins (the fine component of this mixture is often referred to as "bioaerosol") into the surrounding environment via emissions from buildings. For example 500 kg of pigs (standard livestock unit (SLU)) would generate 762 and 85 mg/h of dust (Takai et al, 1998). This would translate to above 100 kg of inhalable dust and around 15 kg of respirable dust released in the surrounding environment per year per 20 SLU produced on such a farm. It has been demonstrated also by a previous study that dust emission could travel significant distances, carrying other organic compounds, including bacteria and endotoxins (Banhazi et al, 2007). The potential health effects of airborne pollution emission on the health of people living in the vicinity of livestock buildings have been documented in the literature (Seedorf et al, 1998; Hartung & Seedorf, 1999; Radon et al, 1999; 2000).

Therefore, simple and practical techniques, which will have the potential to deliver a significant reduction of odour, ammonia and other pollutant concentrations inside the buildings and therefore reduced emissions from those buildings cost effectively, need to be investigated, developed and evaluated (Banhazi et al, 2008d; 2009). A number of emission reduction methods exist including the more precise balancing of diets to reduce excess protein intake, the lowering the pH of manure, oil-sprinkling of building floors and the use of air cleaning systems (Aarnink & Verstegen, 2007; Godbout et al, 2001; Seedorf et al, 2005). However, in recent years, in the USA, interest in using ozone in animal buildings for air quality improvements has increased (Elenbaas-Thomas et al, 2005; Kim-Yang et al, 2005; Watkins et al, 1997).

* Reviewed and revised version of a paper originally presented at the 2009 Society for Engineering in Agriculture (SEAg) National Conference, Brisbane, Queensland, 13-16 September 2009.

† Corresponding author A/Prof Thomas Banhazi can be contacted at thomas.banhazi@usq.edu.au.

Ozonisation is recognised as an environmentally safe and effective process for the treatment of industrial effluent, drinking water and sewage (Xu et al, 2002; Rice, 1997; Priem, 1977; Pan et al, 1995; Klingman & Christy, 2000; Hunt & Mariñas, 1999; Camel & Bermond, 1998; Boeniger, 1995). However, it is also generally accepted that high levels of ozone can cause respiratory problems (Brauer et al, 1996; Kinney & Lippmann, 2000; Paz, 1997). The current Occupational Safety and Health Association of the United States standard has a permissible exposure limit for ozone of 0.1 ppm for an 8-hour, time-weighted average exposure (NOHSC, 1995; Zhou & Smith, 1997).

In a study by Priem (1997), who evaluated the potential of using ozone as a deodorising agent, it was found that the ozone treated piggery buildings had a reduced the ammonia level of 18 ppm from the original concentration of 37 ppm over a 16-month period. During spring and autumn, the ammonia reduction was greater (from 21 to 15 ppm) than summer. During summer, the high ventilation rate reduced the retention and reaction time of ozone in the treated buildings, so the mean ammonia concentration was reduced by 2 ppm (from 14 to 12 ppm). During the study researchers also assessed the respiratory tract of 37 pigs, and no significant differences were observed, despite the fact that ozone levels of up to 0.2 ppm were recorded during the trial. There was a small improvement in daily gain (549 g/day in control and 564 g/day in ozone treated grower pigs) and feed efficiency improved slightly. However, another study reported a decrease in daily gain in pigs as a results of treatment of building air with ozone (Elenbaas-Thomas et al, 2005). The same study also reported an increase in ammonia concentrations as the result of ozone treatment on piggery buildings.

In summary, ozonisation might offer a relatively simple method of deodorisation and might also aide the reduction of airborne pollutants. This technique has been used extensively in other industries, such as the food industry (Segovia Bravo et al, 2007; Ricel et al, 1982; Guzel-Seydim et al, 2004), and can be applied successfully in the livestock industry as well. There are some occupational health and safety aspects of ozone use, (such as reliable and continuous monitoring) which need to be overcome, before the use of ozone can be more widely applied in livestock buildings. However, very little research data are available internationally on the effects of use of ozone in piggery buildings specifically and certainly no Australian research has been undertaken before. Thus, the main aim of this research was to evaluate the potential of using a low concentration of ozone in Australian piggery buildings to reduce airborne pollution levels within pig buildings and therefore reduce pollution emission from these buildings.

2 METHODOLOGY

Four weaner and two grower/finisher rooms (three times two paired identical rooms) were used to study the effects of ozonisation on air quality in pig production facilities at the University of Adelaide, Roseworthy campus, research piggery. The weaner rooms were negatively ventilated and partially slatted rooms with dry feeding system. The grower rooms were very similar in design, except they were naturally ventilated. All experimental facilities were built using sandwich panels. The control rooms were managed according to normal farm pig husbandry procedures (without ozone) while the experimental rooms were treated with ozone. All the three paired rooms were tested at the same time and were managed in an identical manner. Given the same age of livestock, ventilation rates were kept similar. The experiment was designed to determine the effect of ozonisation on air quality parameters and, to some limited extent on animal performance. It was a simple paired comparative design with each treatment facility having an identical control facility. The facilities were located and designed in such a way that the ventilation air was discharged at the opposite side of the building where the intake air was drawn into the buildings using negative-pressure ventilation principles. The study was undertaken during the summer season and relevant environmental information including temperature as well as humidity values are presented in table 1.

Table 1: CO_2 concentrations measured in the control and experimental facilities.

Room	CO_2 concentrations (ppm) Mean/max/min	Air temperature (°C) Mean/max/min	Relative humidity (%) Mean/max/min
Weaner 1	510/731/430	24.8/31.1/20.6	59.9/95.7/36.1
Weaner 2	509/750/413	24.9/32.2/18.6	57.7/91.9/35.2
Weaner 3	542/881/431	23.5/29.6/16.0	62.4/89.2/45.2
Weaner 4	538/862/419	23.4/30.8/15.3	57.4/85.6/33.2
Grower 1	633/844/506	22.8/36.5/12.4	57.2/94.8/25.7
Grower 2	642/859/511	22.2/37.3/13.1	59.6/96.1/23.9

Ozone were distributed in the rooms using equipment supplied by Ozone Solution Inc. (IA, USA) and following the protocol given by the company to achieve the desired ozone concentrations. The possible adverse effect of high levels of ozone was identified as an experimental risk. Therefore, to ensure that neither the pigs nor the piggery staff were exposed to risk, Ozone Solutions provided the research team with an ozone monitoring device (Ozone Hunter, NCEC Ltd. Osaka, Japan) which was used to record the levels of ozone in the experimental rooms four times daily.

The ozone system consisted of:

- ozone generator – located outside the weaner building
- distribution flow-meters – allowing the system to be balanced and adjusted
- 5/16" ozone compatible Teflon tubing
- distribution fans – used to mix confinement air with high concentration ozone and distribute it through PVC pipes
- PVC pipe – transports the ozonised air throughout the room (one pipe per room).

The ozone distribution system was comprised of PVC tubing and circulation fans designed by Ozone Solutions Inc. (figure 1). The PVC pipe was connected to the ozone generator and a simple mixing fan was mounted on one end of the mixing tubes, while the other end was capped. Holes were drilled along the PVC pipe to allow the ozone/air mixture to be evenly distributed throughout the weaner/grower rooms. Environmental parameters were recorded for 30 days in weaner rooms (1 and 2) and grower rooms, and 12 days in the weaner rooms (3 and 4), as described below.

The selection of airborne pollutants to be measured was based on the international scientific literature (Donham, 1995) and the results of previous Australian studies (Banhazi et al, 2008a).

2.1 Airborne particles

Total inhalable (< 100 μm) and respirable particle (< 5 μm) concentrations were measured using air pumps connected to cyclone filter heads (for respirable particles) and seven hole sampler filter heads (for inhalable dust) and operated at 1.9 and 2.0 L/minute flow rate, respectively. The pumps were operated over a 6-hour period. The selection of the monitoring period (9 am to 3 pm) was based on previous studies (Banhazi et al, 2008a). After sampling, the filter heads were taken back to the laboratory and weighed to the nearest 0.001 mg using certified microbalances and then the inhalable and respirable dust levels were calculated. Filter papers were conditioned, following standard operational procedures for gravimetric air sampling (Banhazi et al, 2008a).

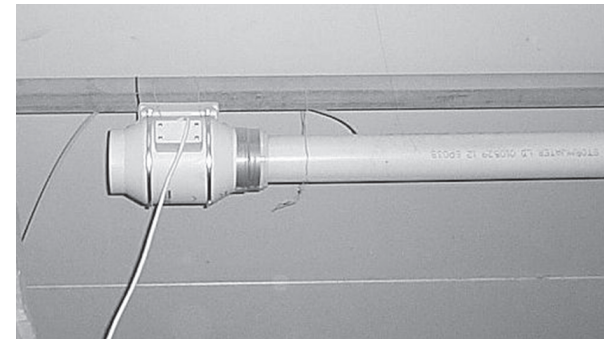

Figure 1: Distribution fan at the end of delivery pipe.

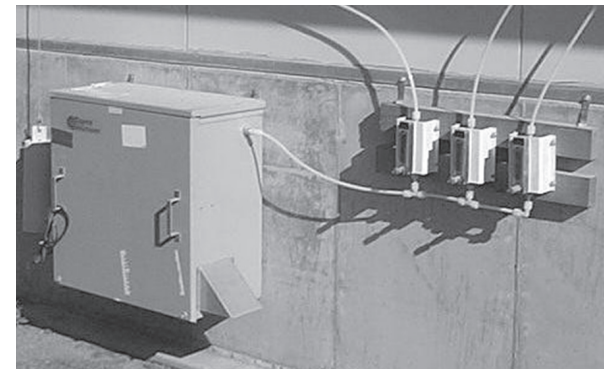

Figure 2: Ozone generator mounted on the wall of the weaner unit.

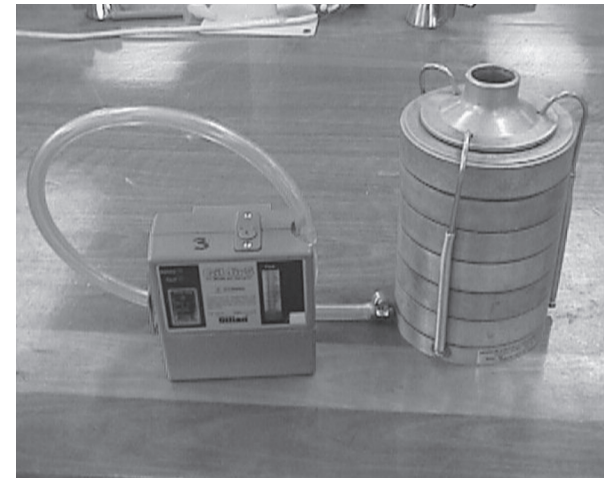

Figure 3: Anderson sampler.

2.2 Bacteria

Total viable airborne bacteria were measured using an Anderson viable six-stage bacterial impactor (Clarke & Madelin, 1987) filled with horse blood agar plates. The airspace was sampled for five minutes at a flow rate of 1.9 L/minute. The bacteria plates were incubated for 48 hours at 37 °C and the numbers of colonies were counted manually, entered into a database and the concentration of airborne microorganisms was calculated and expressed as colony forming units per m^3 (cfu/m^3). Mixed cellulose filter papers were used (Millipore Co., Billerica, MA, USA) and the filter papers were

treated according to standard laboratory procedures to ensure than neither electrostatic build-up or humidity could interfere with the measurement accuracy (Banhazi et al, 2008b).

2.3 Ammonia and carbon dioxide

Ammonia and carbon dioxide were planned to be monitored continuously using a gas monitoring machine (Banhazi et al, 2008a). The equipment was designed to take air samples from two different sampling locations (control and experimental buildings), using a sampling pump, which draws air from two different locations via two quarter-inch tubes. The airflow was directed by two solenoid valves to the actual sensor heads. Carbon dioxide was measured using a GMM12 infrared (Vaisala Oy, Finland) sensor head and ammonia was measured using a GS-DX (TX-FM/TX-FN) electrochemical (Bionics Instruments Co. Ltd, Japan) ammonia sensor. However, due to equipment failure (likely to be caused by the presence of ozone), no useable ammonia data were collected during this trial.

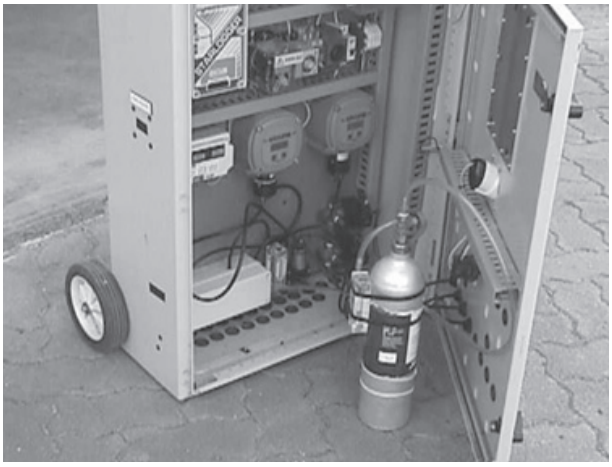

Figure 4: Gas monitoring machine in operation.

2.4 Temperature and humidity measurements

Temperatures were monitored continuously in all buildings for the duration of the experiment using Tinytalk temperature loggers (Hasting Dataloggers, Tinytalk-2). Sensors were placed as close to pig level as practicable, without allowing the pigs to interfere with the instruments. A Microsoft Excel-based software (developed "in-house") was used for temperature data analysis and presentation. The software included the relevant mathematical equations to compute the daily maximum and minimum and average values for the monitoring period.

2.5 Data analysis

Window based STATISTICA 6.1 (StatSoft Inc., 1996) were used to conduct statistical analyses of the data. Statistical models were developed using analysis of variance (ANOVA) procedures to test treatment effects. The dependent variables of interest were airborne particles and bacteria concentrations while the independent variables were the treatment and building effects. The results from these analyses presented graphically and are based on means and ± standard error (SE) values.

3 RESULTS AND DISCUSSION

3.1 Bacteria

Bacteria concentrations were recorded in all experimental sheds daily. There was a clear tendency of reduced bacteria concentrations in the ozone treated rooms. The difference was statistically significant ($p < 0.01$) in weaner rooms (1 and 2) and in the grower rooms (figures 5 and 6). The difference was not statistically significant in weaner rooms (3 and 4), but this might be related to the fact that the experimental period was reduced in these rooms

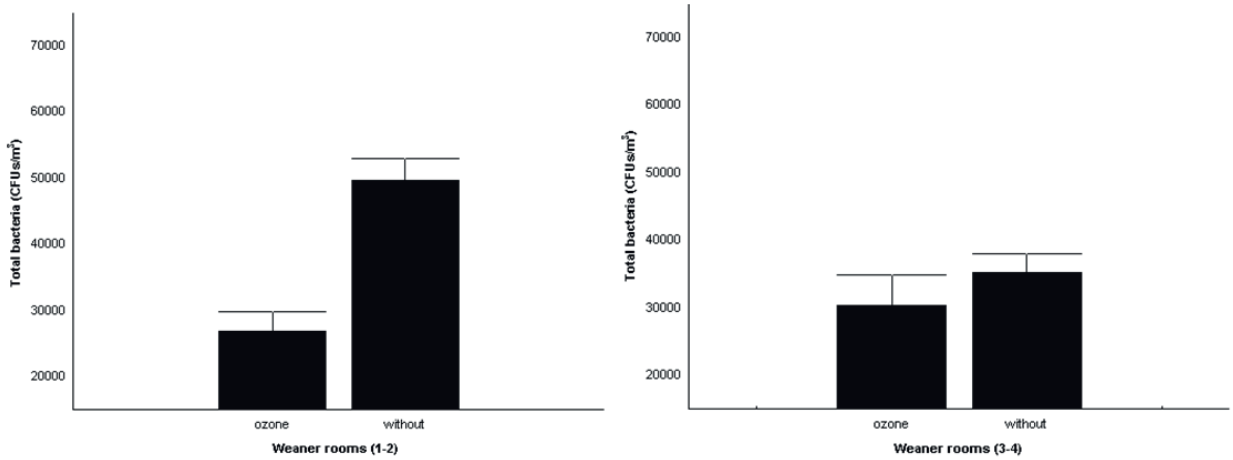

Figure 5: Mean total bacteria concentrations in the control and experimental weaner rooms (means ± SE). Difference was significant between weaner rooms 1 and 2 ($p < 0.01$), but not significant between weaner rooms 3 and 4 ($p > 0.05$). Reduction achieved in weaner room 1 was 46% and 14% in weaner room 3.

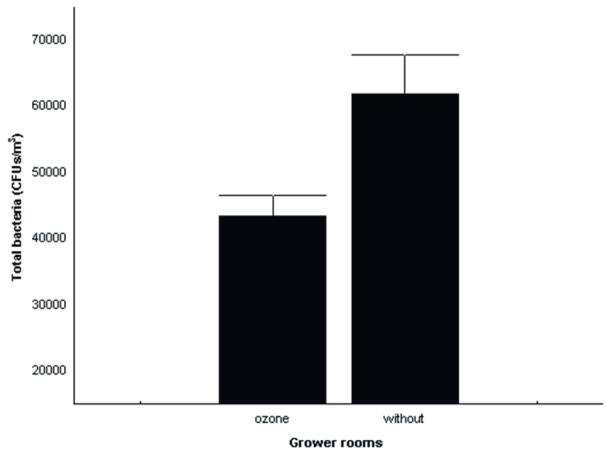

Figure 6: Mean total bacteria concentrations in the control and experimental grower rooms (means ± SE). Difference was significant ($p < 0.01$) and reduction achieved in the experimental grower room was 30%.

due to logistical problems (figure 5). For example, the concentration of airborne bacteria was reduced from approximately 49,600 cfu/m^3 to approximately 26,800 cfu/m^3 in the experimental grower building.

3.2 Inhalable particles

Inhalable particle concentrations were recorded in all experimental buildings daily. There were reduced inhalable particle concentrations in all ozone treated rooms; however, the difference was only statistically significant in the grower/finisher rooms (figure 8) where a 49% reduction was achieved, reducing the concentration of inhalable particles from 1.56 to 0.80 mg/m^3. However, the same tendency and arithmetic reduction was observed in all of the weaner rooms as well. The observed reduction in inhalable dust particle concentration is difficult to explain, although this finding was in agreement with previous anecdotal information obtained from researchers in the USA (Bottcher, 2001; personal communication). One possible explanation was suggested, that as a result of ozone treatment the coagulation and therefore the precipitation of large dust particles are enhanced possibly by unintentional ionisation effect of the ozone generator. However, this theory cannot be confirmed at this stage.

3.3 Respirable particles

Respirable particle concentrations were recorded in all experimental buildings daily. There was a clear tendency of increased respirable particle concentrations in all trial rooms, although none of the differences were statistically significant (figures 9 and 10). These findings cannot be explained at this stage, and it is especially interesting in the light of the previous findings on inhalable particles. One possible

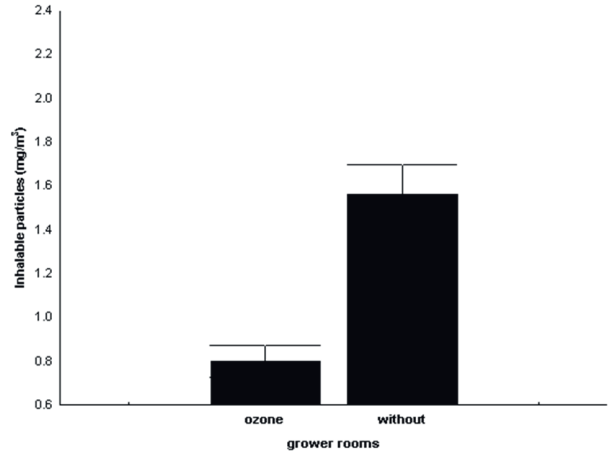

Figure 8: Mean inhalable particle concentrations in the control and experimental grower rooms (means ± SE). Difference was significant ($p < 0.01$) and 49% reduction was achieved in the experimental room.

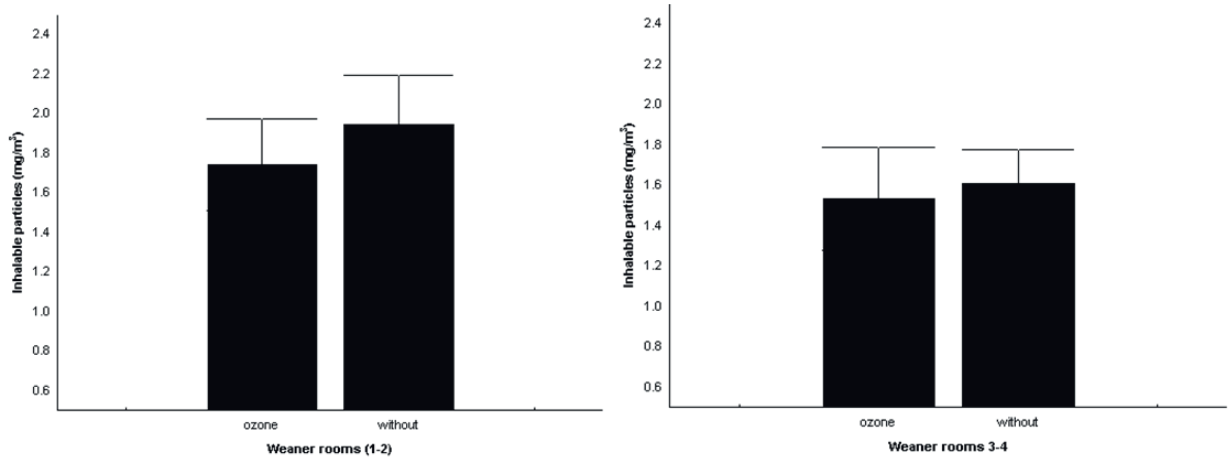

Figure 7: Mean inhalable particle concentrations in the control and experimental weaner (1 and 2) rooms (means ± SE). Difference was not significant between the paired experimental and control rooms ($p > 0.05$). Reduction achieved in weaner rooms 1 and 3 was 10% and 5%, respectively.

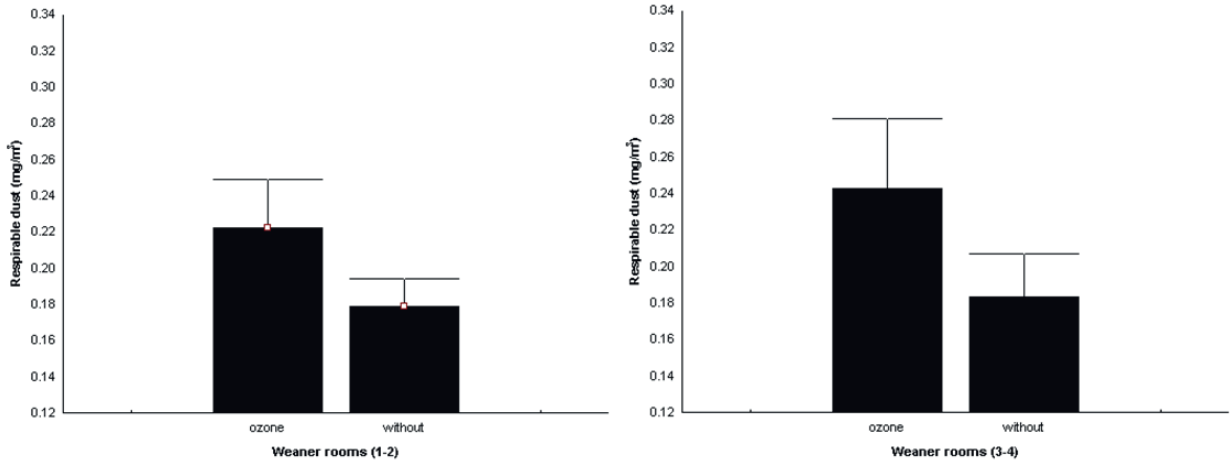

Figure 9: Mean respirable particle concentrations in the control and experimental weaner rooms (means ± SE). Difference was not significant ($p > 0.05$) between the paired experimental and control rooms, and 24% and 32% increase was detected in the experimental rooms 1 and 3, respectively.

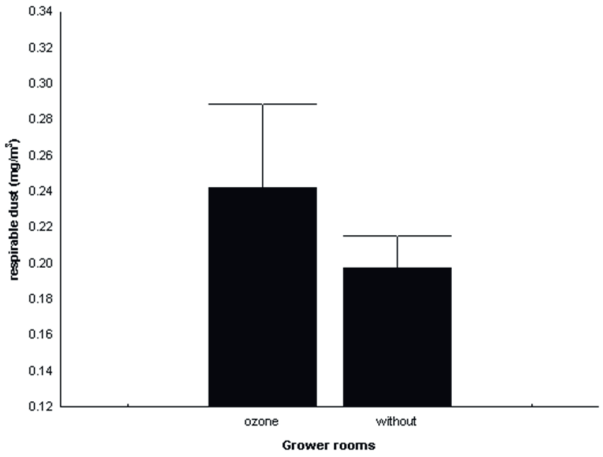

Figure 10: Mean respirable particle concentrations in the control and experimental grower rooms (means ± SE). Difference was not significant ($p > 0.05$) and a 23% increase was detected in concentration of respirable airborne particle concentrations in the experimental grower room.

explanation is that the smaller (respirable) particles are actually kept in suspension by the air turbulence caused by the ozone distribution system. As the ozone distribution system comprised tubes and fans that distributed the ozonised air in the building; this might have acted as a localised air-stirring system keeping the smaller particles in suspension. Ozone might also have an effect on the smaller particles, which enhances their ability to remain in suspension. However, the question still remains, as to why the two portions of airborne particles (respirable and inhalable) react to the presence of ozone so differently. At this stage no further explanation can be given, but this phenomenon certainly warrants further investigation.

In summary it does appear that the injection of low concentration of ozone into the airspace of piggery buildings can be effectively used to reduce the concentration of airborne bacteria. However, practically, ozone did not have any noticeable effect on the concentrations of airborne particles.

3.4 Other results

3.4.1 Gas data

Unfortunately, no useable ammonia data were collected, due to equipment failure. After talking to the supplier of the ammonia sensors used, it was concluded that most probably the ozone itself was likely to have affected the sensor heads, rendering them useless after a short period of time. In agreement with the US supplier of the ozone equipment, further experiments might be conducted. However, in the light of the current problems encountered with the equipment, it is planned that short-term tubes will be used for ammonia monitoring. However, usable carbon dioxide concentration data was collected during the experiment that proved that the paired experimental and control rooms had similar level of ventilation (table 1). In addition, temperatures and humidity values were similar in the paired experimental rooms.

3.4.2 Ozone levels

Throughout the trial, an average concentration of 0.03 ppm ozone was maintained in the experimental rooms. Despite the low levels measured, the staff at the piggery appeared to be concerned with the working environment and uncomfortable with spending too much time in the ozone treated rooms. In order to ease staff concerns, the research team organised a pre-trial information session as well as developed and distributed copies of an information brochure to all piggery staff. It appeared that the provision of detailed information about this technology have to be an essential component of any future marketing campaign by commercial companies.

3.4.3 Pen hygiene

Dunging patterns and pen hygiene was also documented throughout the trial using documented methodology (Banhazi et al, 2008a), as previous research demonstrated that these factors have a major influence on the resulting air quality (Banhazi et al, 2008b; 2008d). It has to be noted that the improved bacteria and inhalable particle concentrations were achieved in the experimental rooms, despite the fact that the experimental weaner (3 and 4) and grower rooms generally had a reduced level of pen hygiene compared to the control rooms.

3.4.4 Production results

No significant growth rate improvement was observed in the experimental rooms.

4 CONCLUSIONS

Overall the experiment confirmed the results of a preliminary study (Banhazi et al, 2002) and demonstrated the positive effect of ozone on airborne bacteria levels. This result was expected, as ozone is a strong oxidising agent, often used for sterilisation purposes in the food industry (Klingman & Christy, 2000; Julson et al, 1999).

The experiment also delivered consistent results in relation to the concentrations of inhalable particles, indicating a positive effect of ozone on the concentration of these particles. However, results also consistently indicated that ozone might have the opposite effect on very small (respirable) airborne particles. At this stage no plausible explanation was found for that phenomenon. In summary, ozone application during this study did not deliver large enough improvements in air quality to justify the potential occupational health and safety risks associated with piggery workers spending potentially long hours in ozone treated rooms and the investment needed in establishing the systems in pig production facilities.

ACKNOWLEDGEMENTS

This project was a collaborative effort between a number of organisations and was part of a larger Australian Pork Limited (APL) funded project. Thus the financial support of APL and the assistance of the staff of the Roseworthy research piggery and the technical assistance of K. Hillyard and T. Murphy are gratefully acknowledged.

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THOMAS BANHAZI

A/Prof Thomas Banhazi is a Principal Research Scientist at the National Centre for Engineering in Agriculture, University of Southern Queensland, and his research interests are related to livestock production. He has undertaken studies to investigate the relationship between environmental conditions and management factors in livestock buildings, and has also investigated methods for reducing the impact of poor environmental conditions on the health of both humans and animals. His recent research interest is related to the development of data acquisition and data management systems for the livestock industries to improve the precision of production management. He is the President of the International Commission for Agricultural Engineering (CIGR) – Section II group and the Chair of the Australian Society for Engineering in Agriculture.