Size-selective assessment of airborne particles in swine confinement building with the UVAPS

Victoria Agranovski[a], Zoran Ristovski[a*], Patrick J. Blackall[b], and Lidia Morawska[a]

[a] International Laboratory for Air Quality and Health, Queensland University of Technology, Brisbane, QLD, Australia;
[b] Agency for Food and Fibre Sciences, Queensland Department of Primary Industries, Animal Research Institute, QLD, Australia;

Agranovski, Victoria and Ristovski, Zoran and Blackall, Patrick and Morawska, Lidia (2004) Size-selective assessment of airborne particles in swine confinement building with the UVAPS. *Atmospheric Environment* 38(23):3893-3901.

Abstract

The Ultraviolet Aerodynamic Particle Sizer (UVAPS) is a novel aerosol counter for real-time monitoring of viable bioaerosols. The previous validation studies on the UVAPS were either laboratory based or were conducted outdoor with the artificially generated aerosols. In this study, the spectrometer was applied to investigate particulate pollution inside a swine confinement building (SCB). Real-time capabilities of the instrument were used to investigate the effect of on-farm-activities, such as an effluent flushing with recycled water, on aerosols load inside the SCB. In addition to the UVAPS, monitoring of viable bioaerosols (bacteria and fungi) was simultaneously conducted with the six-stage Andersen microbial impactor and the AGI-30 impingers. The UVAPS measurements showed that the concentrations of both viable (fluorescent) and total (fluorescent and non-fluorescent) particles inside the SCB were in order of 10^6 -10^7 particles/ m^3. These concentrations were approximately seven times the outside concentrations for total particles and up to 12 times for viable particles. Approximately 95 % of both total and viable particles were respirable (< 7 μm) and approximately 60 % of total and 50 % of viable particles accounted for the fine particle fraction (<2.5 μm). The concentration of culturable bacteria and fungi ranged from 1.12 x 10^5 to 5.17 x 10^5 CFU/m^3 and from 1.12 x 10^3 to 2.79 x 10^3 CFU/ m^3, respectively. Approximately 50-80 % of airborne particles which carried culturable fungi were within the respirable size range. The concentration of viable particles measured with the UVAPS was at least one order of magnitude higher than the concentration of the culturable microorganisms measured with the AGI-30 impingers. Nevertheless, the trends in the concentration changes of viable bioaerosols measured with the UVAPS followed the trends in the concentration changes of the culturable airborne microorganisms quite adequately. Thus, it was concluded that the UVAPS is an appropriate method for investigating the dynamic of viable bioaerosols in the SCBs. The results obtained in this study assist in advancing an understanding of the UVAPS performance in the real-life agricultural settings. In addition, the data provide a new insight on the particles size distribution inside the SCB, depending on their nature.

* Corresponding author.

E-mail addresses: v.agranovski@qut.edu.au (V. Agranovski), z.ristovski@qut.edu.au (Z. Ristovski), pat.blackall@dpi.qld.gov.au (P. J. Blackall), l.morawska@qut.edu.au (L. Morawska).

Keywords: The UVAPS; Swine confinement buildings; Viable bioaerosols; Particle size; Bacteria; Fungi

1. Introduction

Airborne particulate matter, or airborne particles, is considered to be a major air pollutant in a swine confinement building (SCB) (Hartung, 1994; Riskowski et al., 1998) and consequently a major risk factor for both farm workers and animals (Choudat et al., 1995; Riskowski et al., 1998). In addition, airborne particles from agriculture are an environmental concern due to the impacts on atmospheric chemistry and sensitive ecosystems. With the trend toward larger, more concentrated production operations, particles and other airborne emissions are rapidly becoming an important issue for agricultural producers. Besides manure storage facilities and land application of manure, animal housing is one of the primary sources of particle emissions originated from animal production systems.

An evaluation of air quality inside animal buildings, related environmental and health risk and subsequently development of effective air quality control strategies require thorough characterisation of airborne particles.

All effects of airborne particles depend on their composition, size and concentration, and the duration of exposure. Among other parameters, size of airborne particles is the most critical one as it determines the dispersion in atmosphere and the site at which they deposit within the respiratory system and, consequently, a dose of inhalable particles (ACGIH, 1989).

The size of airborne particles can be monitored most readily by using size-selective aerosol monitors such as optical particle counters or cascade impactors. Alternatively, particles can be collected on filters and then analysed by means of electron microscopy (ACGIH, 1989).

In addition to the size, the toxicity of the aerosol particles is largely defined by their composition. Airborne particles inside a SCB originate primary from feed, dried manure, bedding materials, and the swine themselves (Pedersen et al., 2000). They may contain grain and other plant-derived materials, antibiotics, animal-derived dander, excreta, and urine (Pedersen et al., 2000). Thus, such aerosols may contain viable and non-viable particles which may affect the health of humans and animals in various ways. Inert aerosol particles can irritate the respiratory tract and lessen local resistance to respiratory disease. Biological particles, also known as bioaerosols, may cause a whole spectrum of biological responses depending on the “viability, infectivity, allergenicity, toxicity, or pharmacological activity” (Cox and Wathes, 1995) of its constituents. In order to assess risk of exposure to aerosols inside a SCB accurately, the aerosols should be investigated for both biological and non-biological components.

Due to desiccation of collected particles by the airflow through the filter, filtration is not an adequate method for counting viable microogranisms (Cox and Wathes, 1995). Until recently, the six-stage Andersen microbial impactor (AMI) was the only appropriate size discriminating sampler for evaluating viable bioaerosols. However, in highly contaminated environments such as SCB the Andersen sampler becomes easily overloaded (Thorne et al., 1992; Chang et al., 2001). To avoid overloading, the sampler cannot be used longer than a few minutes, typically up to one minute (Thorne et al., 1992; Predicala et al., 2002). Such a short sampling time will inevitably diminish accuracy and the representative nature of such sampling practices.

The recently developed Ultraviolet Aerodynamic Particle Sizer (UVAPS, model 3312, TSI Inc., St. Paul, MN) eliminates the constraints of conventional bioaerosol

sampling for viable organisms and allows comprehensive investigations of aerosols in real-time. The spectrometer monitors aerosols within a size range of 0.5-15 μm. In addition to the size and the concentration of the airborne particles, the spectrometer measures the characteristic fluorescence associated with the metabolic activity of viable microorganisms attached to the particles (Hairston et al, 1997; Brosseau et al, 2000; Agranovski et al., 2003a, b). A detailed description of the UVAPS was published previously (Hairston et al, 1997; Brosseau et al, 2000; Agranovski et al., 2003a, b). Although the UVAPS cannot be used to differentiate airborne microorganisms, it can be applied to investigate various aspects of bioaerosols, including the dispersion in atmosphere, to evaluate source strength, and to inspect the spread of microbes. As the UVAPS is a novel and a unique technique for monitoring viable bioaerosols, it requires a thorough validation before it can be reliably applied to various bioaerosol studies. The previous validation studies on the UVAPS were either laboratory based (Hairston et al, 1997; Brosseau et al, 2000; Agranovski et al., 2003a, b) or were conducted outdoor with the artificially generated aerosols (feasibility studies) (Ho et al., 1999). Suitability of this method for investigation of viable aerosols in the specific research settings, however, remains to be evaluated.

In light of the above, the present study had the following objectives:

i. To investigate applicability of the UVAPS to study bioaerosols inside a SCB.
ii. To determine the concentration and the size distribution of both total (suspended) particles and bioaerosols in a SCB.
iii. To use real-time measurement capability of the UVAPS to investigate the effect of effluent flushing on aerosol load in the air inside a SCB.
iv. To investigate association of fluorescent particles measured by the UVAPS with the concentration of airborne viable microorganisms determined with the conventional biosamplers.

The results obtained in this study assist in advancing an understanding of the UVAPS performance in the real-life agricultural settings. In addition, the data provide a new insight on the particles size distribution inside a SCB, depending on their composition. The conclusions from the study can be used for developing strategies of future investigations of bioaerosols in agricultural settings.

2. Materials and methods

2.1 *Experimental site*

The study was conducted in a typical enclosed swine grower building in Queensland, Australia. The building was naturally ventilated and had automatic self-feeders and nipple waterers. The pens were concrete floored with the rear area covered with slats. Beneath the slats was a gutter for the collection of urine and manure. Once daily, the gutter was flushed with water from the main piggery effluent pond.

The building was 50 m long, 10 m wide and 2.5 m high. The groups of 220 weaned pigs were housed and grown in 22 fattening pens for 60 days (from age 24 days to age 84 days). The farm had an "all-in" "all-out" system, where all pigs in the buildings were marketed at the same time. Before loading a new group of pigs, the buildings were washed to remove dirt, manure, and dust. No cleaning was performed inside the building during each growing period.

2.2 *Aerosol monitoring*

Three sampling methods were used to measure aerosols: the UVAPS, a six-stage Andersen microbial impactor (Andersen Instruments Inc, Smyrna, USA) and the AGI-30 impinger (Ace Glass Inc., Vineland, USA). The last two methods were used to monitor airborne viable bacteria and fungi. Both the Andersen impactor (AMI) and the AGI-30 impinger are broadly used in bioaerosol research, including studies in

SCBs (Thorne et al., 1992; Chang et al., 2001), thus a description of these samplers can readily be found elsewhere. The biosamplers were prepared and used in accordance with standard guidelines (AIHA, 1997).

The particle size distributions of viable, non-viable and total aerosols were measured in real-time with the UVAPS spectrometer. Viable aerosols in the context of this study are referred to those airborne particles which carried fluorescent material detectable by the UVAPS. Under operating conditions of the UVAPS, the measured fluorescence was expected to have a microbiological origin (Hairston et al., 1997; Ho et al., 1999; Agranovski et al., 2003a, b). In other words, the fluorescent particles measured by the UVAPS were associated with viable bacteria or fungi, or mixture of both. The particles which did not produce a detectable fluorescence are, consequently, referred to as non-viable aerosols. Total aerosols are defined as all detected particles, regardless of their fluorescent properties.

Sampling of viable bioaerosols was performed simultaneously by the three techniques. In the case of the AGI-30 sampling, two impingers were run concurrently to collect duplicate samples. Due to limited number of agar plates, the sampling with the AMI was performed only once at each location/ event, during tests conducted on the same day.

The AMI was used at the standard air sampling rate of 28.3 L/ min. The agar media used to fill the plates varied depending on the microorganisms of interest. R2A agar (Oxoid) was used to enumerate heterotrophic bacteria. Dichloran Rose Bengal Chloramphenicol agar (DRBC, Difco) was used to enumerate fungi, as it was shown to be superior medium than commonly used for sampling airborne fungi Malt Extract Agar (Forbes-Smith and Paton, 2002). The sampling times ranged from 0.5 min to 5 min, depending on the type of microorganisms.

The AGI-30 impingers were filled with 25 ml of 0.1% peptone water and 0.005% antifoam A (Sigma Chemicals, St. Louis, MO, USA). The AGI-30s were run for a sampling time of 15-20 minutes. After sampling, the impinger necks were flushed with 2 ml of 0.1% peptone water, the final volume of the collection liquid was measured and corrected for the evaporation. To enumerate microorganisms, samples were serially diluted using sterile 0.1% peptone water. The aliquots of 0.1 ml were subsequently plated onto R2A agar (for bacteria) and DRBC agar (for fungi) in duplicates.

Regardless of sampling method, all agar plates were incubated at 25^{o}C for 5 days and inspected daily. Colonies were enumerated with a Quebec colony counter. When appropriate, the AMI counts were corrected by using the positive-hole method (Andersen, 1958).

2.3 *Experimental procedure*

To address the specific objectives of the study, the measurements were performed in four series.

The first series of measurements was conducted to determine the concentration and the size distribution of particles along the length of the nursery building. In these experiments, the aerosols were monitored with the UVAPS only.

The second series of measurements was conducted to investigate a correlation between the concentration of viable particles detected by the UVAPS and the concentration of viable airborne microorganisms measured with the reference biosamplers. Aerosols were sampled at the centre of the SCB, 1.5 m above the floor during normal activities inside the building (no flushing, feeding, etc). All three samplers were positioned side by side and operated simultaneously.

The third series of measurements attempted to determine the effect of effluent flushing on aerosol load in the air inside the SCB. Aerosols were sampled with the

UVAPS in the middle of the SCB, 1.5 m above the floor, from directly over the concrete area of the central pen before, during, and after flushing of pig manure with recycled piggery effluent. The UVAPS measurements were performed by taking 5 second samples continuously over the sampling periods. At the same time and from the same location, total bacterial counts using AGI-30s and methods similar to those described above were being determined in a parallel study (Chinivasagam and Blackall 2004). The flushing was conducted for the normal period of time, 15 minutes.

In fourth series, the samples were taken outside, approximately 0.5 m away from the nursery building. The aerosols were measured simultaneously with the UVAPS and the AGI-30 impingers.

The measurements were conducted over four visits to the farm. During the first visit, the measurements were conducted to investigate the aerosol profiles along the building (the first series), outside the building (as in the fourth series; the UVAPS measurements only), and to evaluate the effect of flushing (the third series). During other visits, the measurements were conducted to compare the UVAPS with the reference biosamplers (the second and the fourth series).

2.4 *Measurements of environmental parameters*

Air temperature and relative humidity (RH) data were concurrently collected at sampling sites with a hand-held hygrometer (Testo 610, Testo Pty. Ltd., Australia). The temperature inside the building ranged from 23 to 25^{o}C. The RH ranged from 37.1 to 39.2 %. The outdoor air temperature varied within 20 - 27 ^{o}C and RH varied within 37 - 45 %.

3. Results and discussion

3.1 Concentration profiles and particle size distribution.

The UVAPS measurements showed that there were very high levels of both viable and non-viable particles inside the SCB, in the order of 10^6 - 10^7 particles/ m^3. The particle concentrations varied along the length of the building, with the far end of the building having markedly lower levels. The highest levels of aerosols were detected in the middle of the building. Table 1 shows the mean values, standard deviations, and the range of particle concentrations in the middle of the SCB. The data presented in Table 1 were collected continuously during two-hour sampling session over 1 min sampling periods.

There was a strong linear relationship between the concentration of total aerosols and both viable and non-viable aerosols measured with the UVAPS (Fig. 1). The correlation factors (R^2) ranged from 0.9954 to 0.9991 and from 0.9601 to 0.9884 for viable and non-viable aerosols, respectively. These results indicate that the majority of particles carried the fluorescent/ microbial material and that the total particle concentrations may be used to draw the trends for the bioaerosol concentration.

Another interesting observation was a very strong fluctuation in the particle concentrations at the same location over the short periods of time. Fig. 2 demonstrates a typical variation of the particle concentrations in the middle of the building over 20 min sampling period. As can be seen, there were up to four fold differences in the particle concentrations within only two minutes. This concerns all the three categories of particles being studied, namely, total, viable and non-viable particles. These results demonstrate inadequacy of short-term air monitoring (in order of a few minutes, as

typically applied for sampling with the AMS) for producing a representative data for evaluating the aerosol levels within SCBs.

Unlike the concentrations, the particle size distributions were comparable along the building during all sampling events (Table 1, Fig 3a-b). Approximately 95 % of both total and viable (fluorescent) particles were respirable (< 7 μm) and approximately 60 % of total particles and 50 % of viable particles were smaller than 2.5 μm (fine particles). Analysis of the cumulative size distribution of the aerosols inside the building indicated that all particles larger than 6 μm carried fluorescent material.

3.2 Association of viable (fluorescent) particles with the airborne viable (culturable) microorganisms.

To determine the association of the fluorescent particles with airborne viable microorganisms, the UVAPS data for viable aerosols were compared with the results of side-by-side measurements for airborne viable bacteria and fungi with the AMI and the AGI-30.

Due to a heavy overloading of the plates while measuring the bacteria inside the building, all Andersen samples were neglected from the analysis. Only one sample had a countable amount of colony forming units (30-300 CFU per plate, for bacteria) on the plates from the last four stages, which collected particles with the aerodynamic diameters from 0.65 to 4.7 μm. During other sampling events, all bacterial plates had a number of colonies much greater than 300 (a maximal number which is considered appropriate for providing meaningful data on bacterial counts (AIHA, 1997). Although the Andersen sampling was successful in terms of providing the information on the concentration and the size distribution of viable fungal aerosols, these results were not sufficient for the comparison with the UVAPS data. The concentration of airborne viable fungi in the middle of the building ranged from 1.12×10^3 to 2.79×10^3 CFU/ m^3 (mean = 1.82×10^3 CFU/ m^3; std = 6.18×10^2). Approximately 50-80 % (mean = 71 %; std = 12) of viable fungal aerosols, or airborne particles which carried viable fungi, were within the respirable size range (< 7 μm).

The airborne concentration of viable bacteria measured with the AGI-30 impingers ranged from 1.12×10^5 to 5.17×10^5 CFU/m^3 (mean = 2.89×10^5 CFU/m^3; std = 1.69×10^5). The concentrations of viable fungi were considerably lower, ranging from 9.83×10^2 to 1.85×10^3 CFU/m^3 (mean = 1.49×10^3 CFU/m^3; std = 3.45×10^5). Comparison of the AGI-30 and the AMI data for viable fungi showed, that the AGI-30 samples underestimated the level of airborne fungi and that the AMI is, therefore, a more appropriate sampler for measuring viable fungal aerosols in SCBs.

The total (bacteria and fungi) microbial concentrations determined with the AGI-30 are plotted against the concentrations of the viable particles determined with the UVAPS in Fig. 4. The concentration of fluorescent particles was at least one order of magnitude higher than the concentration of the viable microorganisms. Assuming a linear relationship between the fluorescent and culturable particles, the correlation factor (R^2) value was 0.5398.

3.3 The effect of effluent flushing on bioaerosol load.

Using recycle water from the effluent ponds back into the SCBs as flushing liquid is a common practice in intensive piggeries in Australia. This practice raises the possibility that microorganisms present in the effluent may have the opportunity to affect microbial load inside the SCBs. Thus, the information on the effect of effluent flushing on aerosol loading is important for controlling the air quality in the pig buildings.

The results of the UVAPS measurements have demonstrated that the effect of flushing on air quality was primarily in the non-viable particle count (Fig.5a). There was a marked increase of the order of five to seven folds in the number of non-viable particles counted during the flushing event (performed between 9:40 and 9:55 am, Fig. 5a). In contrast, while a rise in bioaerosol number concentration did occur, this rise was not as marked as for the non-viable particles. The concentration of viable particles during flushing was approximately 1.6 times the concentration before flushing. Interestingly, the particle concentrations dropped to the background levels almost immediately after the flushing was completed. Thus, although this practice increased aerosol load in the already highly polluted nursery building, the effect was a short-term.

It has to be noted, that in addition to the aerosols generated by the effluent flushing, an increase in the particle loads can be caused by re-suspension of a dust due to the temporarily increased pig activities at the beginning of the exercise (during approximately the first 5-7 minutes after the flushing was started). If the movement of the pigs had significantly contributed to the aerosol load, it had to be accompanied by an increase of the particle concentrations only at the beginning of the flushing period. However analysis of the UVAPS data (Fig. 5a) shows that the particle increase corresponded to the whole flushing period. Furthermore, the size of the re-suspended dust particles would be rather large which would result in an increase of the particle median diameters measured with the UVAPS. However, this was not the case: the count median diameters of the aerosols decreased during the flushing (Fig. 5b). These data may be explained by considering the effect of the droplets size generated during flushing on the size of the particle residue after water evaporates. It appears that only the smallest droplets produced the aerosols which reached the area of the SCB under investigation. Thus, it is reasonable to expect that the aerosols generated by effluent flushing were primary source contributing to the rise of particle loads during the exercise.

In relation to the airborne viable bacteria, the AGI-30 sampling showed that the bacterial load was 4.3 x 10^5 CFU/ m^3 (before flushing) and increased to approximately 6.0 x 10^5 CFU/ m^3 (during flushing) (Chinivasagam and Blackall 2004), a rise of approximately 1.4 times. Thus, in terms of the ratio of the bioaerosol concentrations before and during flushing, the results of the AGI-30 sampling were in a reasonable agreement with the results obtained with the UVAPS, within the experimental error. No fungi were measured during these experiments.

3.4 Outdoor measurements.

A considerable decrease in aerosol concentrations occurred from inside the building to areas immediately outside. At a distance of only one meter outside the nursery, the particle counts had dropped approximately up to one order of magnitude (Table 1). Unlike the aerosols inside the building, the outdoor concentrations were more stable over the sampling periods (Fig. 6). In addition, the majority of the particles did not contain viable (fluorescent) material and were generally smaller than the particles inside the building (Table 1). In regards to the association of total particles with the viable particles measured with the UVAPS, the correlation was not as high as inside the building (R^2= 0.798, figure is not shown). At such correlation, the usefulness of the total particle counts as a tracer for viable particles is doubtful.

4. Summary and conclusions

The results of the present study can be summarised as follows:

- *Concentration levels.* There were very high levels of both viable (fluorescent) and non-viable (non-fluorescent) particles inside the SCB, in the order of 10^6 -

10^7 particles/ m^3. The total (fluorescent and non-fluorescent) particle concentrations inside the SCB were approximately seven times the outside concentrations, while the inside values for viable particles were up to 12 times higher than the outside values. The concentration of total particles inside the building strongly correlated ($R^2 > 0.99$) with the concentration of viable particles, indicating that the total particles may be used to trace the viable bioaerosol particles. This finding is important for developing sampling strategies for bioaerosol investigations within SCBs with the aerosol counters which are not capable of distinguishing between the viable and non-viable aerosols (e.g., the APS or the Aerosizer).

- *Concentration variation over the time.* The concentration of both total and viable particles inside the SCB fluctuated markedly within a very short periods of time, in order of a few minutes. These results demonstrate inadequacy of short-term air monitoring for producing a representative data for evaluating the aerosol levels within SCBs. This issue concerns, for instance, the use of the Andersen microbial impactors for evaluation of microbial air burdens in highly polluted environments such as animal buildings. While the AMI is appropriate method for identifying specific microorganisms, it may significantly underestimate the concentration level of bioaerosols when used in highly polluted environments.
- *Particle size distribution.* Approximately 95 % of both total and viable particles inside the SCB were respirable (< 7 μm) and approximately 60 % of total and 50 % of viable particles were within the fine particles size range (< 2.5 μm). It was also found that all indoor particles larger than 6 μm carried fluorescent material.
- *Bacterial concentration*. The airborne concentration of viable bacteria measured with the AGI-30 impingers ranged from 1.12×10^5 to 5.17×10^5 CFU/m^3 (mean = 2.89×10^5 CFU/m^3; std = 1.69×10^5). These concentrations were too high to allow the Andersen sampling of the bacteria.
- *Fungal concentration*. Based on the AMI results, the concentration of airborne viable fungi in the middle of the building ranged from 1.12×10^3 to 2.79×10^3 CFU/ m^3 (mean = 1.82×10^3 CFU/ m^3; std = 6.18×10^2). Approximately 50-80 % (mean = 71 %; std = 12) of airborne particles which carried viable fungi were within the respirable size range. Five minutes sampling period was found to be the upper limit at which the AMI sampling results in countable (25-250 CFU/m^3, for fungi) amount of the colonies. Compared to the AMI data, the AGI-30 samples underestimated the level of airborne fungi. It indicates that the AMI is a more appropriate sampler for measuring viable fungal aerosols inside the SCBs.
- *Correlation between viable (fluorescent) and culturable particles.* The concentration of viable particles measured with the UVAPS was at least one order of magnitude higher than the concentration of the culturable microorganisms measured with the AGI-30 impingers. Although the correlation between the viable (fluorescent) and culturable particles was not high (R^2 = 0.54), the trend in the concentration changes of fluorescent particles followed the trends in the concentration changes of the airborne microorganisms quite adequately.
- *Effect of effluent flushing on bioaerosol load.* The UVAPS measurements have demonstrated during effluent flushing with recycled water there was a temporary increase of aerosol loading inside the SCB. The concentration of viable particles was 1.6 times higher during flushing than before flushing. The AGI-30 sampling detected a 1.4 times increase of airborne bacteria in the middle of the SCB. In addition to the increase of particle concentration, the size of generated by

flushing particles was significantly smaller than the airborne particles typically observed inside the building. These data indicate that using recycle water for effluent flushing did increase the aerosol load in the shed. Further studies are required to evaluate the specific health risks, if any, of this practice, such as the spread of pathogens or an increased exposure to toxins (e.g. endotoxins).

As a conclusion, this study has demonstrated the capability of the UVAPS to measure viable aerosols inside a SCB. Although a part of the fluorescent signal may originate from non-microbial materials (Agranovski et al, 2003a) such as pig dander, grain, and other plant-derived materials, the fluorescent particles traced the amount of airborne microbial particles quite reasonably. Considering limitation of the UVAPS in terms of its selectivity (Agranovski et al, 2003a), a sole application of the instrument would likely overestimate the airborne concentration of viable microorganisms inside SCBs. Thus, a complementary use of the conventional biosamplers such as the AGI-30 impingers is highly advisable. Nevertheless, in the cases when investigation of the dynamics of bioaerosols or an assessment of the source strength is the aim of the research project, the UVAPS has been shown to be capable of providing the adequate results.

Acknowledgements

This research was supported by Australian Pork Limited (grant STU 136/1456). The authors are very grateful to Dr Megan Hargreaves (School of Life Sciences, QUT) for her valuable advices on the microbiological analysis of the fungal samples. The assistance of Ms Nalini Chinivasagam in providing access to her AGI-30 data during flushing experiments is acknowledged.

References

ACGIH (American Conference of Governmental Industrial Hygienists), 1989a. Air sampling instruments for evaluation of atmospheric contaminants. S. V. Hering (ed). Cincinnati, Ohio.

Agranovski, V., Ristovski, Z., Hargreaves, M., Blackall, P.J., Morawska, L., 2003a. Real-time measurement of bacterial aerosols with the UVAPS: performance evaluation. Journal of Aerosol Science 34, 301-317.

Agranovski, V., Ristovski, Z., Hargreaves, M., Blackall, P.J., Morawska, L., 2003b. Performance evaluation of the UVAPS: influence of physiological age of airborne bacteria and bacterial stress. Journal of Aerosol Science 34, 1711-1727.

AIHA (American Industrial Hygiene Association), 1997. Field guide for the determination of biological contaminants in environmental samples. H.K. Dillon, P.A. Heinsohn, J.D. Miller (Ed). Fairfax, Virginia.

Andersen, A.A., 1958. New sampler for collection, sizing, and enumeration of viable airborne particles. Journal of Bacteriology 76, 471-484.

Brosseau, L.M., Vesley, D., Rice, N., Goodell, M.N., Hairston, P., 2000. Differences in detected fluorescence among several bacterial species measured with a direct-reading particle sizer and fluorescence detector. Aerosol Science and Technology 32, 545-558.

Chang, C.W., Chung, H., Huang, C. F., Su, H. J., 2001. Exposure of workers to airborne microorganisms in open-air swine houses. Applied and Environmental Microbiology 67(1), 155-161.

Chinivasagam, H.N. and Blackall, P.J., 2004. Airborne bacteria in piggeries: evaluation of optimum recovery and levels of heterotrophs and E. coli within a shed environment. Journal of Applied Microbiology **(manuscript in preparation)**

Choudat, M., Goehen, D., Korobaeff, M., Boulet, A., Dewitte, J.D., Martin, M.H., 1995. Respiratory symptoms and bronchial reactivity among pig and dairy farmers. Journal of Safety Research 26, 199-200.

Cox, C.S., Wathes, C.M., 1995. Bioaerosol Handbook. Lewis Publishers, New York.

Forbes-Smith M., Paton J.E., 2002. Innovative product from Australian native foods. RIRDC publication 02/109, RIRDC Project CFO-1A.

Hairston, P.P., Ho, J., Quant, F.R., 1997. Design of an instrument for real-time detection of bioaerosols using simultaneous measurement of particle aerodynamic size and intrinsic fluorescence. Journal of Aerosol Science 28, 471-482.

Hartung, J., 1994. The effect of airborne particulates on livestock health and production. Pollution in Livestock Production System, I. Ap. Dewi, R.F. E. Axford, I. Fayez M. Marai and H Omed (eds). Wallingford: CAB International.

Ho, J., Spence, M., Hairston, P., 1999. Measurement of biological aerosol with a fluorescent aerodynamic particle sizer (FLAPS): correlation of optical data with biological data. Aerobiologia 15, 281- 291.

Pedersen, S., Nonnenmann, M., Rautiainen, R., Demmers, T.G.M., Banhazi, T., Lyngbye, M., 2000. Dust in pig buildings. Journal of Agricultural Safety and Health 6, 261-274.

Predicala, B.Z., Urban, J.E., Maghirang, R.G., Jerez, S.B., Goodband, R.D., 2002. Assessment of bioaerosols in swine barns by filtration and impaction. Current Microbiology 44, 136-140.

Riskowski, G. L., Maghirang, R. G., Funk, T. L., Christianson, L. L., Priest, J. B., 1998. Environmental quality in animal production housing facilities: a review and evaluation of alternative ventilation strategies. ASHRAE Transactions 104, 104-114.

Thorne, P.S., Kiekhaefer, M.S., Whitten, P., Donham, K.J., 1992. Comparison of bioaerosol sampling methods in barns housing swine. Applied and Environmental Microbiology 58, 2543-2551.

Venkataraman, C., Kao, A.S., 1999. Comparison of particle lung doses from the fine and coarse fractions of urban PM-10 aerosols. Inhalation Toxicology 11, 151–169.

FIGURE CAPTIONS

Table 1. Statistics of the aerosols measured with the UVAPS.

Fig. 1. Correlation between the total, viable, and non-viable particle concentrations (n=80) measured with the UVAPS inside the nursery building.

Fig.2. Variation of the particle concentrations inside the nursery building. The UVAPS data collected over 20 min sampling period in the middle of the building.

Fig. 3. Particle size distribution measured with UVAPS in the middle of building: A) total (both fluorescent and non-fluorescent) particles; B) viable (fluorescent) particles. Average spectrum of the data (n = 20) collected over 20 min sampling period.

Fig. 4. Correlation of the UVAPS measurements for viable aerosols with the concentration of the airborne viable microorganisms (bacteria and fungi) measured with the AGI-30 impingers.

Fig. 5. Effect of effluent flushing on the aerosol loading in the middle of the building: A) Number concentrations of the aerosols; B) Count Median Diameters of the airborne particles. The flushing was performed between 9:40 and 9:55 am.

Fig. 6. Variation of the particle concentrations outside the nursery building. The UVAPS data collected over 20 min sampling period 0.5 m away from the building.

Table 1. Statistics of the aerosols measured with the UVAPS in the middle of the building.

Aerosol [a]	Concentration, 10^6 particles/m^3				Count Median Diameter, μm			
	Mean	STD	Min	Max	Mean	STD	Min	Max
Inside the SCB [b]:								
Total	14.11	5.53	1.54	30.04	2.23	0.06	1.70	2.41
Viable	10.71	4.41	1.18	23.80	2.79	0.07	2.67	3.06
Non-viable	3.41	1.16	0.36	6.64	1.15	0.04	1.06	1.41
Outside the SCB [c]:								
Total	1.72	0.71	1.33	4.12	1.19	0.22	1.04	1.81
Viable	0.45	0.38	0.22	1.48	2.09	0.39	1.63	3.18
Non-viable	1.27	0.41	1.02	2.93	0.98	0.12	0.94	1.51

[a] The data were collected continuously over 1 min sampling periods.
[b] These data were collected over two-hour sampling session.
[c] These data were collected continuously for 20 min, on the same day as the inside data.

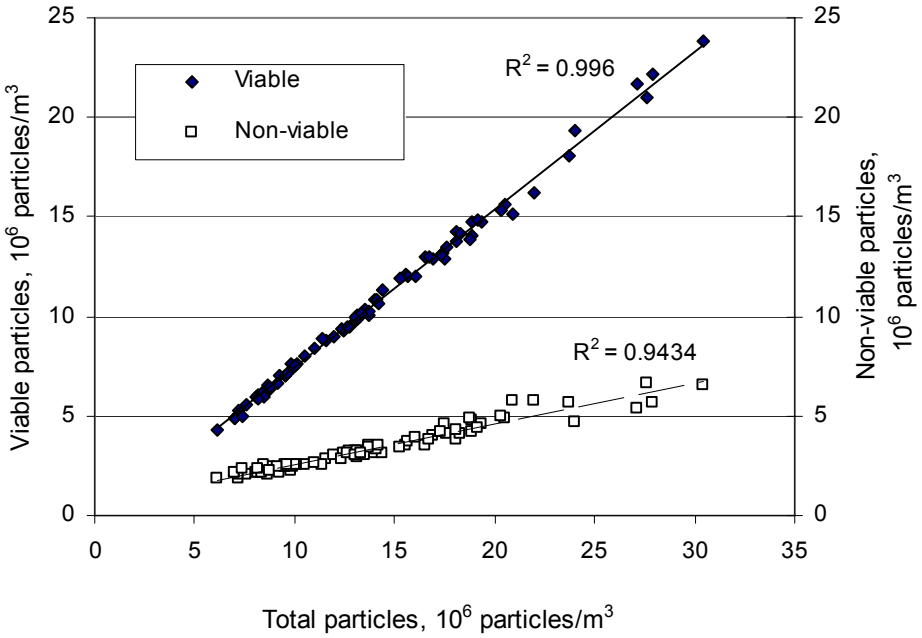


Fig. 1. Correlation between the total, viable, and non-viable particle concentrations (n= 80) measured with the UVAPS inside the shed.

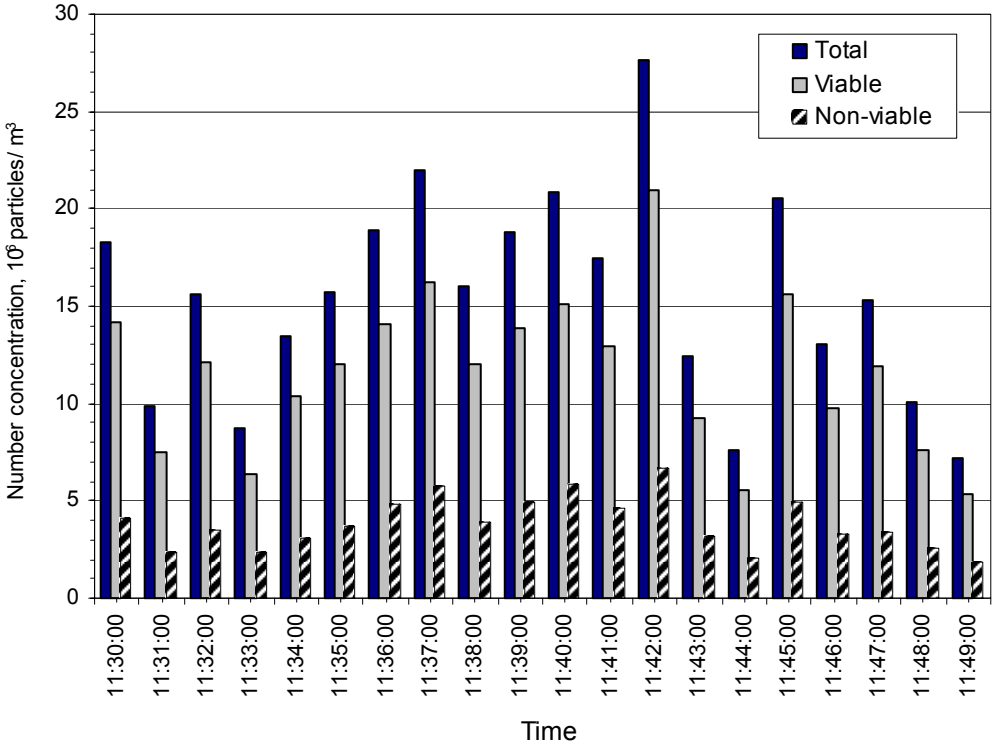
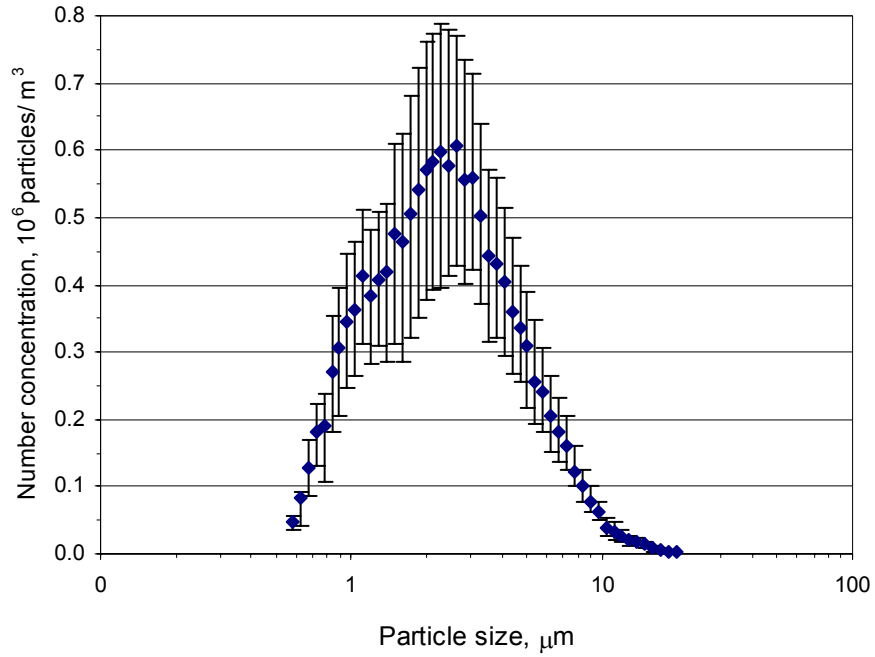


Fig.2 Variation of the particle concentrations in the middle of the building over 20 min sampling period.

A)



B)

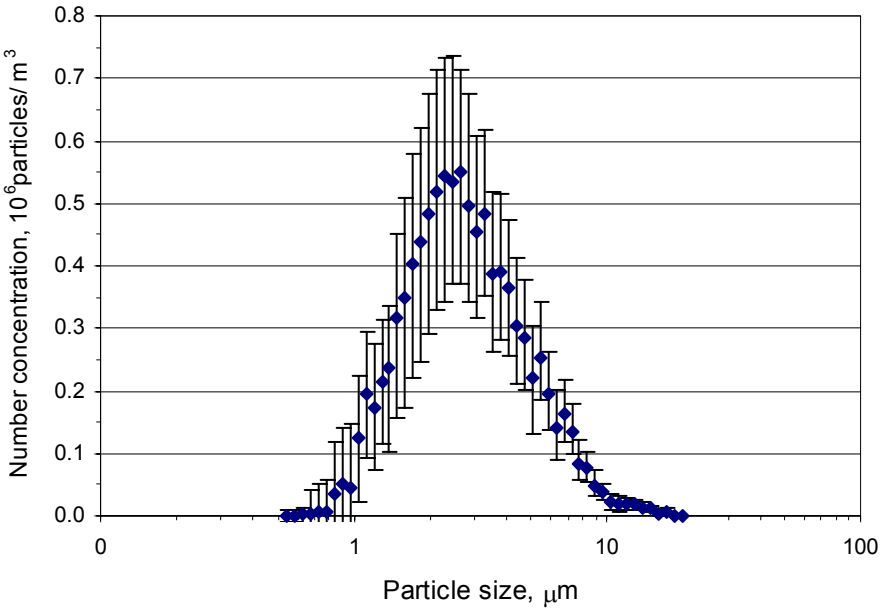


Fig. 3 Particle size distribution measured with UVAPS in the middle of shed: A) total (both fluorescent and non-fluorescent) particles; B) viable (fluorescent) particles. Average spectrum of the data (n = 20) collected over 20 min sampling period.

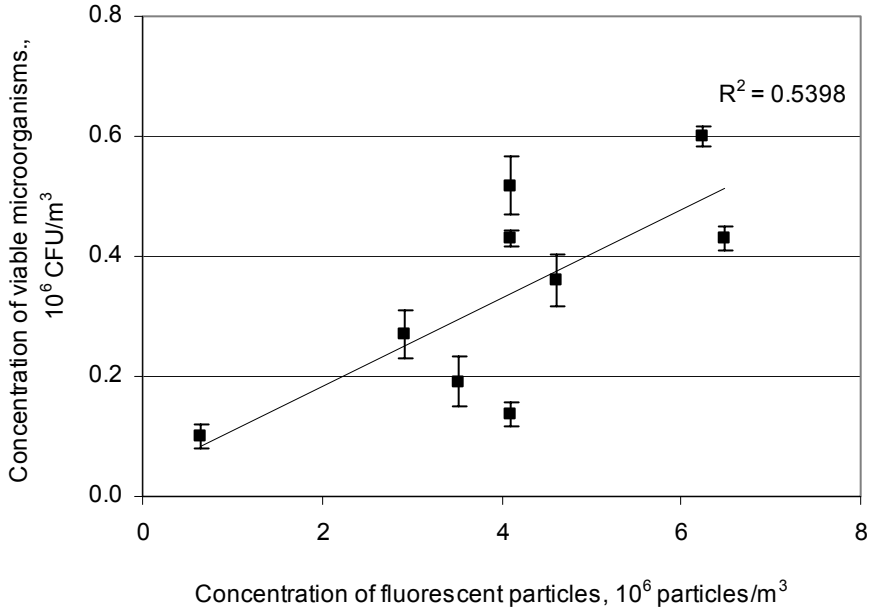
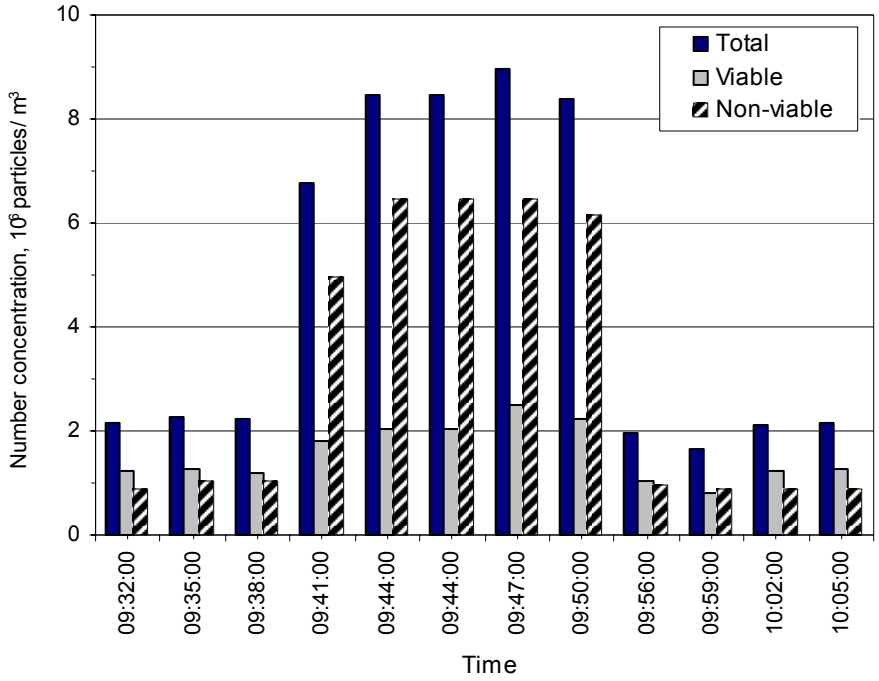


Fig. 4. Correlation of the UVAPS measurements for viable aerosols with the concentration of the airborne culturable microorganisms (bacteria and fungi) measured with the AGI-30 impingers.

A)



B)

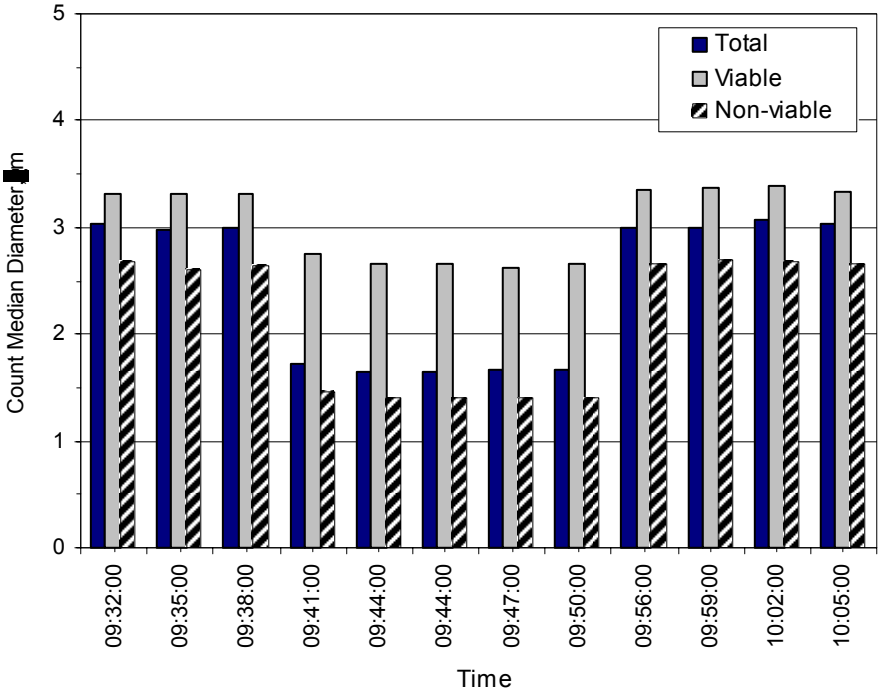


Fig. 5. Effect of effluent flushing on the aerosol loading in the middle of the building: A) Number concentrations of the aerosols; B) Count Median Diameters of the airborne particles.

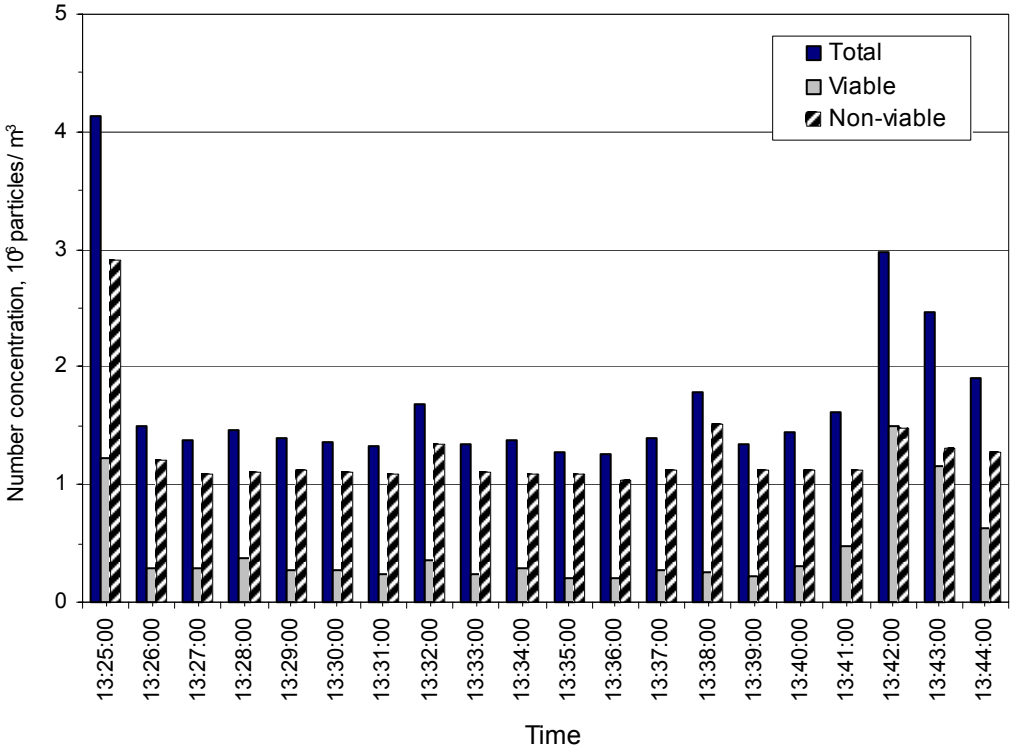


Fig. 6. Variation of the particle concentrations outside the nursery building. The UVAPS data collected over 20 min sampling period 0.5 m away from the building.