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AIR POLLUTION AND LIVESTOCK PRODUCTION

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ABSTRACT The air in a livestock farming environment contains high concentrations of dust particles and gaseous pollutants. The total inhalable dust can enter the nose and mouth during normal breathing and the thoracic dust can reach into the lungs. However, it is the respirable dust particles that can penetrate further into the gas-exchange region, making it the most hazardous dust component. Prolonged exposure to high concentrations of dust particles can lead to respiratory health issues for both livestock and farming staff. Ammonia, an example of a gaseous pollutant, is derived from the decomposition of nitrous compounds. Increased exposure to ammonia may also have an effect on the health of humans and livestock. There are a number of technologies available to ensure exposure to these pollutants is minimised. Through proactive means, (the optimal design and management of livestock buildings) air quality can be improved to reduce the likelihood of risks associated with sub-optimal air quality. Once air problems have taken hold, other reduction methods need to be applied utilising a more reactive approach. A key requirement for the control of concentration and exposure of airborne pollutants to an acceptable level is to be able to conduct real-time measurements of these pollutants. This paper provides a review of airborne pollution including methods to both measure and control the concentration of pollutants in livestock buildings.

Keywords: Agriculture, Control methods, Dust particles, Gaseous pollutants, Livestock farming, Measurements.

INTRODUCTION Dust particles within a livestock farming environment consist of up to 90% organic matter (Aarnink et al., 1999; Heber et al., 1988), which provides opportunities for bacteria and odorous components to adhere themselves to these particles. The contaminated air is dissipated into the external environment via ventilation (Arogo et al. 2006); however, the concentration of airborne contaminants can be still high within livestock building.

Dust particles that can potentially harm livestock and farm staff can be grouped as follows:

- Inhalable dust particles – contains particulate matter up to 100 microns in diameter. These particles can enter the nose and mouth during normal breathing.
- Thoracic dust particles – are up to 10 microns in diameter (PM10). These particles can enter the trachea and bronchi tubes and reach into the lungs.
- Respirable dust particles – are up to 4 microns in diameter and in the past often were referred as PM5. These particles can enter the smallest cavities of the lung, the Alveoli. They penetrate into the gas-exchange region (air, blood and tissue) of the lungs, thus making them the most hazardous.

Exposure to high concentration of dust particles can lead to respiratory problems, such as shortness of breath, chronic bronchitis, asthma and other lung diseases (Choiniere 1993; Banhazi 2009).

IMPACT ON HUMAN HEALTH The quality of air within livestock buildings can adversely impact on the health of farm workers, particularly if the farmer is exposed to the environment for many hours. When compared to non-agricultural workers, farmers who work inside a livestock buildings are likely to have an increase in the number of health issues associated with the respiratory system (Donham 2000; Dutkiewicz 1997; Von Essen & Donham 1999; Zejda et al., 1994).

The type of gases which present a concern to the workers' health include hydrogen sulphide (H_2S), carbon dioxide (CO_2), ammonia (NH_3) and methane (CH_4). Of these gases, it is NH_3 that has been in the focus of research for a number of years, particularly in Europe (Nimmermark 2004).

NH_3 is derived from the decomposition of nitrous compounds, such as uric acid and manure and the odour is detectable when it reaches concentrations of 5 to 10 ppm. Increased exposure to NH_3 will have a damaging effect on livestock health (Guy et al., 2002). The Time Weighted Average Exposure Value (TWAEV) for NH_3 is 25ppm (8 hours) and the Short Term Exposure Value (STEV) is 35ppm (15 minutes). Increasing exposure levels beyond that of TWAEV and STEV can generate symptoms such as coughing, wheezing and shortness of breath. Further exposure, combined with dust, can affect the upper airway (larynx and bronchi) resulting in edema, chemical pneumonitis and carcinoma of the oesophagus. If it enters the deep lung, diseases such as pulmonary edema might result (Choiniere 1993; CSBP Limited 2009; Seedorf & Hartung 1999).

The current recommended exposure standards for air pollution are summarised in Table 1.

Table 1. Recommended maximum exposure standards (ASCC 2009).

Contaminant	Maximum Exposure
Ammonia (NH_3), ppm	25
Hydrogen sulphide (H_2S), ppm	10
Carbon monoxide (CO), ppm	30
Carbon dioxide (CO_2), ppm	5,000
Inhalable/total dust, mg/m^3	10
Respirable dust, mg/m^3	None

MEASUREMENT METHODS There are a number of instruments available to collect and measure dust concentrations, including the gravimetric and the IOM Sampler (named after the Institute of Occupational Medicine). The gaseous pollutants generated in livestock buildings are normally measured either by utilising continuous measuring devices or by detector tubes for spot measurements (Banhazi et al., 2008b; Banhazi 2009).

A high volume dust sampler can be utilised to determine the average dust concentrations over a 24 hour period. This is accomplished by drawing a constant flow rate of ambient air through an inlet. A selective inlet is then fitted to a high volume sampler to restrict the particle size being sampled, e.g. PM2.5, PM5, PM10 filters. Utilising this type of dust sampler can mean additional cost for the farmer resulting from laboratory work in analysing the collected samples. The cost can be abated with the introduction of a continuous particle monitor, which provides real-time (continuous) dust concentrations.

The type of equipment utilised to detect and measure can be categorised pending on the targeted size of the airborne particles; summarised in Table 2 are a number of methods of measuring different airborne particle fractions.

Table 2. Methods of Measuring Different Airborne Particle Fractions (Banhazi et al., 2009)

	Total dust fraction	Inhalable fraction	Thoracal fraction	Respirable fraction	Very fine fraction
Cut-off size (µm)	>100	100	10	4	2.5
Detection method	Open face filter connected to a sampling pump or real-time dust monitor	IOM samplers connected to sampling pump	Rea-time dust monitor connected with PM10 inlet; gravimetric or cyclonic pre-separator	Gravimetric sampling or real-time dust monitor, with cyclone pre-separator	Real time dust monitor with PM2.5 inlet; gravimetric sampling with impaction or cyclone pre-separator

Data acquisition systems have been available for a number of years that can provide the means for data collection and monitoring. Software tools are also available to graph tabulated real-time results as they are transferred to the remote user. These results can be transferred back to livestock farmers to control peripherals such as feed, ventilation, heating and lighting systems. Utilising these technologies within the livestock environment is relatively new and offers many opportunities for expansion into technologies associated with precision livestock farming (Banhazi & Black 2009).

CONTROL METHODS The main purpose for implementing control methods for airborne pollutants in the livestock building is to ensure production efficiency is maximised without compromising the health of the staff (Banhazi et al., 2009). To control the dust we need to understand what takes effect within the livestock environment.

In the confines of a building, the air quality depends directly on building management, feeding and manure handling, ventilation system and on the overall cleanliness (Choiniere 1993).

There are a number of technologies available to ensure exposure is kept minimal. Through proactive means, the optimal design and management of livestock buildings used can improve the quality of air and reduce the health impacts associated with sub-optimal air quality. Once the air problems have taken hold, other reduction methods need to be applied utilising a more reactive approach.

Proactive Reduction Control Methods Proactive reduction methods can be achieved through improved configuration and management of livestock buildings, adequate ventilation, decreased stocking density, and management of the animals contained in these buildings (Banhazi et al., 2005; Banhazi et al., 2009). Key areas of interest being:

- Humidity and Temperature
- Seasonal changes
- Hygiene and effluent management
- Feed management

Humidity and Temperature

Increasing the humidity can reduce the concentration of airborne particles, while increased temperatures usually aid the generation of airborne dust. Too much humidity, however, may result in increased concentrations of bacteria and endotoxins (Banhazi et al., 2009).

Increasing the ventilation for higher temperatures may result in the removal of airborne particles faster than they are generated; however, farm managers should not rely on the ventilation rates alone. Well designed ventilation system, effective control of airflow and elimination of sources of airborne pollutants are all essential in good building management.

Season changes and ventilation Seasonal changes can have an impact on the health of the livestock and farm staff, particularly in the warmer months where ventilation systems are in continual use in order to keep the temperature down to an acceptable level. Bønløkke et al. (2009) confirmed there were more moderate negative effects on lung function and the immune system during summer periods when compared to winter in swine farm workers.

Hygiene and effluent management Hygiene and effluent management is also important. One of the main drivers of air quality in a livestock building is its hygiene level. Farming staff need to keep the building environment dry, implement animal flow management that will facilitate regular cleaning. The control of the ventilation and hence the temperature will also ensure that adequate hygiene standards are met.

Minimising nitrogen excretion should be considered as the first approach into reducing NH_3 emissions from livestock operations. It is feasible to maintain acceptable levels of NH_3 with proper manure management through dietary modifications and adequate ventilation and heating in all livestock buildings (Choiniere 1993). Several approaches have been suggested and evaluated for reducing NH_3 emissions; some potential control strategies for NH_3 emission are summarised in Table 3. In practice, to achieve adequate NH_3 abatement, a combination of these control strategies should be considered. Combining the nutritional strategies alone, it is possible to achieve a total reduction of around 70% in ammonia emission (Aarnink & Verstegen 2007).

Table 3. Summary of Ammonia Abatement Strategies in Concentrated Animal Feeding Operations (Ndegwa et al. 2008)

	Source or location			
	Excreted manure & urine	Confinement facilities	Treatment & storage	Land application
Control practice	Reduce N excreted by reduced protein diets or improved balance of amino acids Dietary electrolyte balance, affecting urinary pH, e.g. adding acidifying salts into the diet to lower the pH of urine	Minimise emitting surface area Remove manure frequently Filter exhaust air (bioscrubbers, biofilters, or chemical scrubbers) Manure amendments (acidifying compounds, organic materials, enzymes, and biological additives)	Cover to reduce emissions or collect gas NH_3 stripping, absorption, and recovery Chemical precipitation Biological nitrification (aerobic treatment) Acidifying manure	Injection or incorporation into soil soon after application Application method to reduce exposure to air (e.g. low-pressure irrigation near surface, drag, or trail hoses) Acidifying manure

<u>Feed</u> Airborne particles can be generated from livestock feed; the amount of airborne particles produced from the feed depends on the type of feed, the delivery method and the feed composition (Bundy & Hazen 1975).

Some of the pro-active control methods and the presumed effectiveness associated with these methods are listed in Table 4.

Table 4. Proactive control strategies and their rating (Banhazi, Rutley & Pitchford 2008a)

Pro-active Control Strategy	Rating
Impregnation or spraying of bedding material with oil/water mixture	Highly effective
Manage stock rate	Effective
Manage humidity, temperature and ventilation at optimal levels	Effective
Improved management in the cleanliness of the livestock building	Highly effective
Manage effluent to reduce opportunities from fermentation	Effective
Add oil/fat to feed or coat pellets	Highly effective
Match protein requirements for the livestock	Highly effective
Lower pH of urine and manure by nutritional strategies.	Highly effective
Improve management of feed system	Effective
Introduce liquid feeding systems	Moderately effective
Use good quality pelleted feed with appropriate ingredients	Moderately effective
Careful hygiene management of buildings in summer	Highly effective

A number of recent (Nimmermark 2004; Cambra-López et al., 2009; Millner 2009) research papers stated that while there is a number of strategies available to reduce particulate matter in livestock production systems, further research is still needed into optimising these technologies to the point where precise livestock farming can be managed effectively. Cambra-Lo´pez et al (2009) summarised their study on airborne particulate matter from livestock production systems as being one of the *'most poorly characterised sources in terms of pollutants and emissions'*, highlighting two main areas of deficiency being (1) particulate matter characterisation and (2) factors which influences the characterisation.

Reactive Reduction Control Methods Reactive reduction methods target pollutants after they have been produced. They include methods such as oil-spraying, filtration and electrostatic precipitators can be used to deal with existing airborne pollution problems (Banhazi et al. 2009).

<u>Oil Spraying</u> Zhang (1998) demonstrated that periodically sprinkling small amounts of vegetable oil in swine facilities can reduce dust and gas concentrations substantially. The concept involved utilising a simple but effective sprinkling system at low pressure (30psi) to produce a shower like effect rather than the use of a fog like spray system (Banhazi 2005). Utilising this concept reduced respirable dust by approximately 80% and inhalable dust in the air by approximately 85%. For an operation marketing 4,000 pigs per year, the estimated cost is approximately USD$1.14 per pig, of which 70% of the cost is for labour (Zhang 1998).

Similar studies conducted in Australia (Banhazi et al., 1999a; Banhazi, Laffrique & Seedorf 2007; Banhazi et al., 2002; Banhazi et al., 1999b) and by overseas researchers such as Pedersen (1998) identified that spraying rapeseed oil (canola oil) mixed with water was more effective at reducing aerial dust concentrations, than adding 4% fat to the swine diet, resulting in 75% and 50% reductions in dust, respectively.

Takai (2007) noted that a number of studies have demonstrated varying dust reduction efficiencies, from about 20% to 90% One method involved spraying a small amount of oil-water mixture just enough to bind the sediment dust particles so as not to disperse during livestock activity. When applied in a typical pig-finishing building in Denmark, calculations showed that the oil concentrations in the oil-water mixture should be greater than 20%. The spray droplets must also fall quickly onto the surfaces in order to bind the sediment dust. To ensure this, the terminal velocity of the droplets should be comparable with the air velocity normally found in livestock buildings (0.2 to 0.5 ms^{-1}), yielding a droplet diameter greater than 150 μm, which corresponds to terminal velocity of 0.46 ms^{-1}.

Aarnink et al. (2008) investigated the effect of oil spraying in a broiler house utilising varying concentrations. Although the results showed reductions of 60 to 90% for PM10 and 70 to 80% for PM2.5 concentrations and emissions respectively, the number foot-pad lesions however increased with increasing oil spraying levels. The results drawn from both Aarnink et al (2008) and Takai (2007) highlight the importance in understanding the effects of oil spraying, including the periodicity and concentrations to reduce dust concentrations and emissions to a safe level.

A recent survey conducted by Banhazi (2008b) demonstrated that the concentrations of inhalable and respirable particle are significantly higher in bedded systems. To overcome the negative effects of bedding on air quality, it was suggested that spraying a mixture of oil and water directly onto the floor inside the building could significantly reduce airborne particle concentrations (Banhazi, Holmes & Purton 2007).

Vegetable oil, such as canola, has been utilised to reduce dust (and odour) in livestock because they are readily available, economical, and biologically safe to the animals. The effectiveness of the oil was considered by Kim et al. (2008) by evaluating a number of additives that can be mixed with water to determine their masking effectiveness into reducing odour emissions in a pig building. Out of all the additives utilised, the results highlighted the effectiveness of artificial spice and essential oils. The odour intensity and offensiveness showed reduction from 60% to 80%. Additionally, the essential oil had a significant effect on reducing sulphuric odorous compounds up to 24 hours after spraying.

Biofiltration Biofiltration offers the most economical and environmentally safe method for air pollution control when dealing with the removal of odorous and toxic contaminants (Ozis, Bina & Devinny 2005). Odours from livestock farm facilities arise from the manure decomposition, particularly when the manure has undergone anaerobic decomposition. Other sources that contribute to the odour include rotting feed materials and dead animals.

Biofilters can be utilised to reduce gases such as H_2S and NH_3. A biofilter has contaminated/waste air that passes through the filter bed medium (compost, peat, etc) into a microbial biofilm/liquid phase where the microbes convert the contaminant into clean air (CO_2) and water. Biofilters can reduce on average 95% of H_2S and 65% of NH_3 emissions from swine industry facilities (Ozis, Bina, & Devinny 2005**)**. In 1997, a case study was conducted into the effectiveness of a biofilter arrangement in a sow facility; after three years of continuous operation, the biofilter demonstrated 92% and 57% reduction in H_2S and NH_3 respectfully. The cost to implement this biofilter was approximately USD$0.22/livestock, making the biofilter an efficient means into reducing H_2S and NH_3 (Ozis, Bina, & Devinny 2005**)**.

Biological air treatment is however limited to compounds that can be transformed to harmless products by the action of micro organisms; efforts are well under way into biological methods for treating NH_3 (Jeong Hak Choi et al. 2003).

Electrostatic Precipitator Removing the dust particles, particularly those less than PM5, will assist in the reduction of the health issues associated with the dust. One such way of removing the dust is with an electrostatic precipitator (ESP). This concept is similar to the portable air ionizers that can be purchased for an office space. The ESP removes particles from an airflow utilising an induced electrostatic charge. In reference to Figure 4, ionization of the gas occurs when the dust passes through the negative charged grid area, which generates an electric charge on the particles. The charged particles drift towards a positive charged collecting plate where they are deposited on the electrode, thus becoming neutralized. The particles along with the carriers are no longer attracted to the positive plate and are deposited into a dust collector.

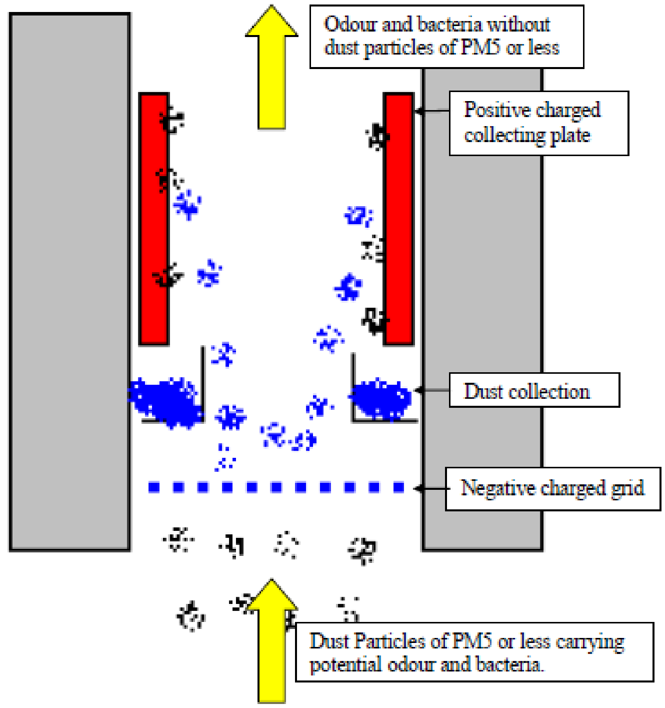

Figure 4. Principle of an Electrostatic Precipitator

Elec0trostatic precipitators (ESPs) have been used for over 90 years in the control of industrial particulates. EPS has also been utilised within submarines as an effective means into generating clean air within the confine space. (Trion & Sanford 1982).

Recent studies have demonstrated that fine tuning of the ESP can result in increased efficiencies into the removal of dust. Chai et al. (2009) utilised the traditional industrial ESPs and improved the design by incorporating a higher turbulence flow, shorter residence time and lower corona power ratio (power consumption) to yield an overall dust removal efficiency ranging from 37% to 79% for particles less than 2.1mm. These results are also supported by Electrostatic Space Charge Systems (ESCS) (Richardson et al., 2003; Ritz et al., 2006). Summarised in Table 6 is a comparison of the parameters for both the ESP and the improved prototype model. Reviewing these results highlights the efficiency gains that are achievable from a lower specific collection area and Corona Power Ratio. The Corona Power Ratio was also extremely low, which equated to power consumption of less than 12W for all the conditions.

Table 6. Comparison of the Improved ESP with Industrial ESP (Chai et al., 2009)

Parameters	Industrial ESP	Improved ESP
Gas Velocity (m/s)	1.5-2.5	1.7
Reynolds number (Re)	5,000-25,000	45,000-68,000
Resident Times (s)	1-20	0.0015
Collecting area (m^2)	460-7,000 (per section)	1.332
Specific Collection Area ($m^2(m^3/min)$)	0.25-2.1	0.200
Corona Power Ratio ($W(m^3/min)$)	1.75-17.5	0.01-0.27
Corona Power Ratio ($\mu A/m^2$)	50-750	28-140

Another key advantage of the ESP is the low cost to build and the simplicity in maintenance. The cost to manufacture the prototype improved ESP was in the order of USD$6,000, which is likely to be much less when commercialised.

CONCLUSIONS The combination of a number of airborne pollutants in high concentrations can compromise the efficiency of livestock production and the health of the farm staff.

A key requirement for the control of concentration of airborne pollutants to an acceptable level is to be able to conduct real-time measurements of these pollutants, including the use of accurate and continuous measurements.

Undertaking dust particle measurements in the livestock environment is however 'still far away from being capable of giving precise and reliable emission estimates' (Cambra-López et al., 2009). There exists potential opportunities to undertake further studies into the accurate measurement of airborne emissions, which will aid the development of strategies to reduce emissions.

There are a number of technologies available to make sure that exposure to airborne pollutants is kept minimal through both proactive and reactive means. Understanding the benefits of both concepts will reduce airborne pollutants.

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