Anim. Prod. Aust. 2002 Vol. 24: 387-393

HYGIENE AND AIR QUALITY IN INTENSIVE HOUSING FACILITIES IN AUSTRALIA

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SUMMARY

The standard of air and surface hygiene in intensive animal houses has a significant effect on animal health and production efficiency, as well as influencing the respiratory health of employees. Over the past decade, sub-optimal air quality and surface hygiene have been associated with increased prevalence and severity of enteric and respiratory disease in animals, as well as reduced growth rate. The key pollutants include gases such as ammonia, carbon dioxide and hydrogen sulphide, and airborne particles and bioaerosols, consisting of a range of material from organic and inorganic sources. These include minerals and ash, undigested feed, cellular components of gut epithelium, grain mites, dried dung, skin and feather dander, as well as a collection of micro-organisms and their cellular components and metabolic products. The major source of the gases and bioaerosols is the animals and their effluent. While the effect of the pollutants on animals is not fully understood, it has been demonstrated that a number of pollutants are capable of initiating an inflammatory response in tissues of the respiratory system. Various combinations also appear to be capable of triggering immune responses and physiological changes in animals that result in reduced feed intake and depressed growth rates. It is also hypothesised that protein and energy are diverted from the development of muscle to maintain the immune response. The key to improving air quality and surface hygiene is to eliminate pollutants at their source, or reduce their production. The important factors that have a negative influence on air and surface hygiene include the farming system practiced, the species farmed, and the size and behaviour of the animals housed. Other factors include building characteristics, the shed environment, and husbandry. The characteristics of the building that influence hygiene and air quality include the shape and dimensions of the building, the ventilation and heating system used and effluent management. Shed environmental factors include the level of cleaning and disinfection, the state of the pen floors, and watering and feeding systems, as well as the quality of water used for cleaning and effluent removal. Husbandry factors include stocking rate and density and shed population size.

Keywords: air quality, surface hygiene, animal housing

INTRODUCTION AND BACKGROUND

Hygiene and air quality in intensive animal housing is a major concern to producers, employees, housing and farming specialists, and veterinarians involved in the intensive livestock farming industries. In recent years a number of reports have highlighted the negative effects of sub-optimal air quality and hygiene on the health and production of animals, as well as the health of workers (Iversen and Pedersen 1990; Hartung 1994; Donham 1995; Cargill 1999; Cargill and Hartung 2001).

The standard of surface and air hygiene within animal houses depends on a series of complex interactions between building design and animal management and behaviour. Shed design factors include the shape and dimensions of the building, the type of system used for ventilation, thermal control, and effluent management, and the type and quality of the bedding used. Animal management factors include the type of production system, as well as the stocking density (animals/m^3) and the age of the animals. Behavioural traits, such as dunging patterns, animal activity, aggression and social interaction can also influence hygiene and air quality (Cargill *et al*. 1997a; Cargill and Banhazi 2002).

The link between respiratory disease and air quality is well established (Massabie *et al*. 1991; Donham 1991; Robertson *et al*. 1990; Cargill and Skirrow 1997) and several factors appear to be involved in the process. High stocking levels have been associated with reduced air quality, increased prevalence of respiratory disease, and reduced growth rate (Donham 1991; Skirrow *et al.* 1995; Cargill and Skirrow 1997; Cargill *et al.* 1998; Banhazi *et al.* 2000). In other studies (Murphy *et al*. 2000), increased stocking density was associated with reduced growth rate in the absence of respiratory disease, as well as an increase in the concentration of airborne bacteria.

Ventilation is a key factor in reduced air quality and in a majority of buildings ventilation rates are designed to optimise air temperature. However, in most situations this results in a build up of airborne pollutants (Banhazi *et al*. 2000). In general, as ventilation rate increases, the level of air pollutants decreases and air quality improves (Nicks *et al*. 1989). However, this only applies when a high standard of surface hygiene is maintained and stocking rates are optimal. In sheds with dirty floors, increasing ventilation rates will reduce air quality and it has also been demonstrated that ventilation rates cannot compensate for sub-standard hygiene (Banhazi *et al*. 2000).

Air quality also raises major occupational respiratory health concerns for the intensive farming industries (Cargill *et al.* 2001). In a review by Donham (1995), and in a number of European countries (Sisgaard pers comm.), occupational health issues are regarded as more important than the adverse effects of poor air quality on animal production.

The key airborne pollutants include dust and airborne particles, gases, and a range of micro-organisms. However in reality, the airspace is filled with the gases, inorganic dust and a mixture of bioaerosols from several sources (Cargill and Skirrow 1997; Pedersen *et al.* 2001).

THE MAJOR SOURCES OF POLLUTANTS

Gases

Ammonia is the most important gas present in animal houses and although the current target for pig sheds in Australia is less than 7 ppm (Pointon *et al*. 1995), concentrations on most farms are between 3 and 20 ppm (Skirrow *et al*. 1995; Banhazi *et al*. 2000).

The main source of ammonia is dung and effluent, and high levels of ammonia can be an indicator of both poor effluent disposal, as well as poor ventilation. Because sheds are ventilated for temperature control, the concentrations of ammonia tend to peak in the early morning (Cargill and Skirrow 1997). As concentrations are highest at slat level, animals in sheds with totally slatted floors are exposed to maximum concentrations whenever they are recumbent (Cargill and Banhazi 2002; Aarnink and Swierstra 1995; Gerber *et al.* 1991). By comparison, with partially slatted floors, animals lying on clean solid floor receive minimum exposure. However, if floors are dirty and covered with dung, exposure levels may be higher (Cargill and Banhazi 2002). Other factors that increase ammonia levels include air movement across the surface of the slurry, and increasing pH and temperature of slurry (Pedersen 1993). Concentrations of ammonia vary in deep litter systems, and are highest when animals or humans disturb the litter (Banhazi *et al.* 2000).

Carbon dioxide is the other major gas in sheds and it serves as a good indicator of ventilation efficiency. However, in the majority of sheds monitored, levels are within acceptable ranges (Banhazi *et al*. 2000). Problems with hydrogen sulphide, although recorded in overseas countries, have not been identified in Australia.

Airborne particles and bioaerosols

Dust can be classified as inorganic (dry matter, ash minerals) and organic bioaerosls. The bioaerosols or particulate matter may include undigested feed, grain mites, feed additives, dried dung and urine, skin dander, viable and non-viable bacteria, bacterial cell wall components (endotoxins, 1,3 beta-glucan and peptidoglycan), fungal elements and spores, mycotoxins, and microbial proteases and tannins.

Using gravimetric methods, total dust usually refers to all airborne particulate matter in the airspace with a particle size of less than 20 μm. Inhalable dust is measured using an Institute of Occupational Medicine (IOM) sampler and contains particles of greater than 20 μm (Pedersen *et al*. 2001). While inhalable and total dust are not exactly the same, the majority of particles in these fractions will be trapped in the upper respiratory tract. Respirable particles are those of less than 5 μm and may be deposited in the alveoli and air sacs of the lungs (Cargill and Skirrow 1997). The percentage of the respirable fraction in Australian pig sheds has been recorded as 14% for growers and 15% for farrowing houses, up to 18% for finisher sheds (Banhazi and Cargill 1999).

The major sources of bioaerosols are the animals, their excretions, feed and bedding. They include undigested feed, cellular components of gut epithelium, grain mites, feed additives, as well as a collection of micro-organisms and their cellular components and metabolic products (Donham 1995; Cargill and Skirrow 1997). Gram-positive organisms are the most common airborne bacteria found in pig and poultry sheds (Skirrow *et al*. 1995; Cormier *et al*. 1990) and by far the majority are non-pathogens (Cargill and Banhazi 1996). Only about 10% of the organisms present are viable (Cargill and Skirrow 1997). In Australian studies, high levels of Streptococci spp have been recovered in air samples from pig buildings (Skirrow *et al*. 1995) and a close association has been demonstrated between the concentration of viable streptococcal organisms and pleurisy prevalence, as well as viable bacteria and growth rate (Murphy *et al*. 2000). The current recommendation for maximum levels of viable airborne bacteria in Australian buildings 100,000 colony forming units (cfu's)/m^3. Concentrations of respirable endotoxin, ranging from 23 EU/m^3 in farrowing sheds to 34 EU/m^3 in finisher sheds and 85 EU/m^3 in straw based shelters, have been recorded in Australian pig sheds (Banhazi *et al*. 2000). These levels are above the current level of 23 EU/m^3 recommended for animal houses in the northern hemisphere (Donham and Cumbro 1999). The recommended maximum level for total endotoxin is 600 EU/m^3 (Donham and Cumbro 1999).

As mentioned previously, a strong correlation exists between stocking density (animals/m^3 airspace) and concentrations of airborne bacteria (Wathes 1994; Cargill and Banhazi 1996). Doubling the airspace has the same effect on levels of airborne bacteria as increasing air exchange rates from 6 to 30 air changes/hour. In most naturally ventilated sheds it is much easier to reduce stocking density than increase air exchange (Skirrow *et al*. 1995). A number of other factors have been shown to influence the level of particulate matter and bioaerosols in sheds. These include the type and size of shed, the management and production system, the standard of surface hygiene, the season, ventilation rate, effluent management, bedding, temperature, humidity, and various interaction between these factors (Skirrow *et al*. 1995; Gustafsson 1994; Banhazi *et al*. 2000; Cargill *et al*. 1997b, 2000). Levels fluctuate from day to day, as well as during the day, with high levels being associated with animal and human activity (Cargill *et al*. 1997a). The highest levels are associated with feeding, sweeping and removal of effluent and bedding, and moving and weighing animals. Low humidity, as well as very high and low levels of ventilation, result in increased dust levels (Pedersen 1989). Interestingly, as the ventilation rate increases, the concentrations of airborne particles decrease at first, but then increase as ventilation increases further (Banhazi and Cargill 1999). Increasing ventilation will only reduce ammonia levels if hygiene is good. (Banhazi *et al*. 2000).

THE EFFECTS OF POLLUTANTS ON ANIMALS AND HUMANS

Ammonia

Short-term exposure to concentrations above 35ppm can induce inflammatory changes in the respiratory mucosa of animals, as well as reducing bacterial clearance from lungs (Johannsen *et al*. 1987). There is no clear consensus on the physiological effects of lower concentrations but ammonia may also interact with other biological agents to enhance inflammatory changes (Gustin *et al*. 1994). Humans experience respiratory symptoms when ammonia concentrations are around 7 ppm, especially in dusty conditions (Gerber *et al*. 1991), and suffer severe eye and nose irritation at levels above 35 ppm.

Bioaerosols

The role of airborne non-pathogenic bacteria on the health of animals and humans is unclear. The percentage of organisms that are inhaled into the lungs will vary from shed to shed and will depend on the percentage of the particles containing organism that are respirable. It is hypothesised that the organisms themselves, and their products and components, are capable of triggering immune responses and physiological changes in animals. In the case of birds, this may be a reduction in feed intake, as well as a diversion of protein and energy away from the development of muscle to the immune system (Kelly *et al*. 1987; Klasing *et al*. 1987; Klasing and Barnes 1988). Several *in vivo* and *in vitro* studies have demonstrated that endotoxins, moulds, and organic dust activate the epithelial cells and alveolar macrophages (Robinson 1994; Rylander 1994). Aerosol exposure to endotoxins and 1,3 beta-glucan also modifies the cell population present in the respiratory tract (Fogelmark *et al*. 1994). In humans, exposure to bioaerosols has also been shown to cause a broncho-constriction, hyper-responsiveness and increased inflammatory cells in bronchial alveolar lavage fluids in naïve human subjects (Malberg and Larsson 1992). Experiments using nasal lavage show that pig house dust containing different concentrations of endotoxins increases the inflammatory reaction of the nasal mucous membranes of humans significantly (Nowak *et al*. 1994). Endotoxins provoked prominent reactions associated with an inflammatory response, whereas dust, which was free of endotoxins, did not. The broncho-constrictive effects of bioaerosols have also been demonstrated in guinea pigs (Zuskin *et al*. 1991) as well as stockpersons in Sweden and north America (Donham 1995).

CONTROLLING AND REDUCING IN-DOOR POLLUTION

The levels of airborne pollutants present in animal houses are dependent on the relationships between the "sources" and the "sinks" within the building (Wathes 1994). Hence the most effective strategy for reducing the concentration of airborne particles is to eliminate their source or minimise their production. In recent studies in Australia, emphasis has been placed on identifying the key building, husbandry and environmental factors that increase levels of pollutants, with emphasis on factors that have a negative influence on surface and air hygiene (Cargill and Banhazi 2002).

The husbandry and production system operated on the farm has a key influence on air and surface hygiene. Although all-in/all-out systems have been used effectively to control disease and improve hygiene standards in the broiler industry for several decades, they have only been used in pig farming in Australia during the last decade. However, recent research has confirmed the value of adopting more innovative management systems to improve air and surface hygiene in both new and existing sheds (Banhazi *et al.* 1999a; Cargill *et al*. 1997a; 1998; 2000). Systems such as batch farrowing and age-segregated rearing, which incorporate all-in/all-out management and cleaning between batches, enable higher standards of hygiene and air quality to be achieved. Provided good dunging patterns are maintained, a high standard of air hygiene is also maintained (Banhazi *et al*. 2000). All-in/all-out management system also provide an opportunity for carrying out maintenance to repair broken slats, leaking pipes and drinkers, and broken feeders, all of which can have a negative effect on hygiene and air quality. Other husbandry factors that improve hygiene include reducing stocking rate (kg animal/m^2) and stocking density (kg animal/m^3), limiting shed population size and encouraging good dunging patterns.

Stocking rate (kg animal/m^2) has been shown to impact on pen hygiene and has been identified as a risk factor for both enteric disease (Madec and Leon 1999) and respiratory disease (Skirrow *et al*. 1995). Overcrowding is also associated with poor dunging patterns, which in turn reduce hygiene standards (Banhazi *et al.* 2000). The finding that stocking density may reduce air quality in terms of increased bacterial load, and hence reduce growth rate in the absence of respiratory disease (Banhazi and Cargill 1998; Murphy *et al*. 2000), is significant and emphasises the importance of providing adequate airspace for animals.

The key housing factors that influence air and surface hygiene include shed volume and ventilation rate, the size of the ridge vent and sidewall shutters (in naturally ventilated sheds), and the depth of effluent channels. Assessment of air quality in a large number of sheds in Australia indicates that the maximum width of a naturally ventilated shed should not exceed 12 metres. The evidence suggests that 10 metre wide sheds perform the most efficiently. In 26 sheds assessed for air quality in previous projects, the correlation between shed width and concentrations of bacteria was -0.54 ($P<0.01$) (Cargill and Banhazi 2002).

Shed height determines the amount of airspace provided, as well as the angle of the roof pitch and the space available for sidewall openings. All of these factors influence ventilation rate (Cargill and Skirrow 1997). Other factors include the width of the ridge vent, and the height of the ridge cap. Currently it is recommended that sidewall openings should be a minimum of 20% of the width of the shed and the width of the ridge vent at least 10% of the width of the shed. The recommended angle fort the roof pitch is a minimum of 15% (Cargill *et al.* 2000).

Although the majority of sheds are designed to maintain a constant temperature, and limit diurnal variations, the evidence is that most sheds fail to achieve these goals (Banhazi *et al*. 2000). Because ventilation is set to maintain an optimal thermal environment, it also fails to reduce the concentration of pollutants to acceptable levels. One strategy to overcome the problem is to include a flushing cycle in the automated shutter controls, so that the shed is flushed with fresh air during the night. This approach requires further validation to determine the time sheds need to be opened to flush the shed with clean air without compromising room temperature. Purging or flushing the airspace, by increasing ventilation rates or opening shutters for short periods, is considered useful as it will clear not only excess carbon dioxide but ammonia as well, without a long term drop in temperature (Cargill and Banhazi 2002).

Modifying ventilation systems, so that air inlets are at human head hight and outlets are below the slats, has successfully reduced the exposure level of humans to both respirable and total dust (Klooster *et al*. 1993). Air filtration systems have been used, but these are difficult to assemble and operate in naturally ventilated sheds. Ionisation of the airspace as a method to reduce airborne dust levels has not been widely examined under commercial production methods.

Because effluent is a major source of a number of key airborne pollutants, factors such as the type of effluent system, the use of recycled water, and the distance between the surface of the slurry and the base of the slats (Madec and Leon 1999) all impact on air and surface hygiene. Broken and blocked slats, as well as air entering the shed through openings over the pits at the end of the sheds will exacerbate the problem. Modifying diets by lowering protein levels and improving amino acid balance and adding yucca extracts and enzymes, (Cole 1994) will also reduce ammonia emissions.

Ensuring that effluent disposal systems operate efficiently is important. One of the best solutions is to use slatted floors over effluent channels and to remove dung frequently using a scraper followed by flushing. An alternative is to flush effluent channels frequently with a large quantity of fresh water (Groenestein 1994). In Australia, where fresh water adds a significant cost factor to the operation, the use of recycled water is desirable from an economic viewpoint, but it can creates with air quality (Cargill and Banhazi 2002).

Cleaning is an essential part of all-in/all-out production and the value of cleaning pens has been confirmed in Australia (Cargill and Banhazi 1998). Although air quality and pen hygiene will deteriorate over time, sequential studies have demonstrated that it will take several weeks before the concentrations of pollutants reach pre-cleaning levels (Cargill and Banhazi 1998). In the few studies recorded where scraping, hosing and pressure hosing have been compared, it was found that both hosing and pressure washing are significantly superior to scraping, but that pressure washing is only marginally better than hosing (Arboleda *et al*. 2001). However, in pens that have not been cleaned for some time, pressure washing is essential (C. Cargill unpublished data).

Using disinfectants following cleaning will also have a positive effect on subsequent hygiene (Madec and Leon 1999; Arboleda *et al*. 2001), especially on old and cracked floors. However, as many disinfectants are inactivated by organic material (dung etc), cleaning must be thorough (Cargill and Banhazi 2002).

Although the reasons for poor dunging patterns are not well understood, overcrowding, draughts or air movement over the pens, and wet floors are known to be significant causes. To achieve and maintain good dunging patterns, it is essential that floors are dry before pens are re-stocked and that all draughts are eliminated. Watering systems need to well maintained to prevent wet floors and wet litter, and feeding systems need to be designed to avoid damaging pellets (Cargill *et al*. 1995) and to deliver feed into covered bins (Cargill and Banhazi. 2002).

While the use of bedding is common in the broiler industry, it is limited to deep litter systems in the egg and pig industries. However, litter can be a major source of airborne particles and bioaerosols (Banhazi *et al*. 2000).

Spraying feed with vegetable oil, or adding it to the diet, has also been recommended, but while total dust levels may be reduced, there appears to be little effect on respirable particles (Welford *et al*. 1990; 1992). A more promising alternative is to spray pigs and floors with mixtures of oil and water (Takei *et al*. 1995; Banhazi *et al.* 1999b; Banhazi *et al*. 2001). Banhazi *et al.* (1999c) have also pioneered the method for reducing airborne particles and bioaerosols in deep litter systems housing pigs. A similar system, which sprinkles the shed with vegetable oil only, at a rate of 5 to 20 ml/square metre of floor space/day, has been developed in Canada (Zhang 1996).

Regular fogging of sheds with products such as Virkon S®, at recommended rates can also help reduce bacterial levels. However, the results tend to vary from shed to shed and the effects tend to be more dramatic in sheds with high bacterial loads than in sheds where levels are only slightly above target levels (Cargill and Skirrow 1997). Fogging with Virkon S certainly appears to be superior to fogging with water only.

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