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Air-Polluted with Particulate Matters from Livestock Buildings

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1. Introduction

Livestock production has a harmful effect on the environment during the breeding period, such as the emittance of dust, odour and ammonia into the surrounding environment through the ventilation system as well as its harmful influence on the animals and workers inside these animal houses.

Airborne dust is normally considered to be one of the contaminants in livestock buildings. Particle matter reduces the air quality within the livestock buildings compromising the health of farmers and animals, (Hinz et al., 2007).

Commercial livestock production facilities are always associated with some level of airborne particles. High concentrations of airborne particles could affect the external environment, production efficiency, health and welfare of humans and animals, (Banhazi and Seedorf, 2007).

The improvement of the farm animal health is an important goal to ensure proper livestock production. Apart from management factors the internal environmental conditions play a key role for ensuring the well-being of intensively housed livestock and farm workers. Livestock farmers are exposed to dust concentrations inside their animal houses that are a factor of 10 to 200 times higher than those of the outside air, (Aarnink and Ellen, 2007).

The ventilation system of a building discharges dust particles into the environment, considering the high dilution rate with the outside air, the following discussion focuses on the dust level and control inside the livestock building. Requirements for good management and ventilation in animal husbandry systems ensure that the quality of indoor air is acceptable for animals' and humans' health, (Haeussermann et al., 2007).

2. Harmful effect of the dust on human and animal health

It is generally assumed that dust particles are capable of transporting different chemical compounds and microorganisms from one livestock building to the other, or from a livestock building to the farmhouse and to the neighboring houses. This may cause increased risks of airborne infections of animals and malodour problems. Farmers in animal houses are exposed to gases and a complex aerosol of bacteria, fungi, endotoxin and organic dust, which are linked to the development of respiratory diseases in farmers' lungs, (Takai et al., 2002).

2.1. Air quality requirements

According to the federal pollution control law people, animals, plants, soil, water, atmosphere and other cultural assets need to be protected from harmful environmental effects. This is determined in the administrative regulation (TA-Luft, 2002) (technical instructions for cleaning the air) by specifying limits for the emission mass flow and the mass concentration of harmful substances in concrete.

According to the statutory mandate, it is a goal of (TA-Luft, 2002) to provide authorities with up to date information on nationwide guidelines in order to carry out an evaluation of the emissions and immissions especially within licensed facilities. In order to indicate the values in (TA-Luft, 2002) the terms emission and immission are defined with the pertinent defaults using standardized evaluation criteria. "Emissions are defined within these administrative rules as those of air pollution" (TA-Luft, 2002).

The emissions are thus indicated on the one hand as the mass of the emitted substances or groups of substances related to the volume and mass concentrations. The mass indication of emitted substances or groups of substances is related to the unit time (emission mass flow). The dust contained in the exhaust emissions should not exceed a 20 mg/m^3 mass concentration or 0.20 kg/h of mass flow. There are other values in the MAC list (Maximum Acceptable Concentration) published from the senate committee of the German research council, (DFG, 2006). The "maximum workplace concentration value" in (GefStoffV, 1999) defines the value of substances permissible in workplace atmospheres, in order not to affect the health of workers within an eight hour daily work schedule. This value differentiates between two groups of dust, the respirable ($< 5 \mu\text{m}$) and the alveolar dust ($< 1.1 \mu\text{m}$). The respirable group may not exceed a concentration of 4 mg/m^3 and for the alveolar group the limit value is 1.5 mg/m^3 , (DFG, 2004). In case of non-compliance with these limits in animal barns protective arrangements should be employed for the staff such as breathing masks, (Scheuermann, 2004). Under Danish conditions a consistent relationship between environmental exposure in livestock buildings, lung function changes and/or respiratory symptoms in workers and identified exposure-response thresholds for workers on the basis of exposure response thresholds for poultry and swine confinement buildings has been observed by Pedersen et al. (2000). The limit recommendations for humans are 2.4 mg/m^3 of total dust, 0.23 mg/m^3 of respirable dust with a total of 800 EU/m^3 (EU = endotoxin unit) and 7 ppm of ammonia (Pedersen et al. 2000).

2.2. Particle influence on the respiratory system of animals and humans

Keder (2007) reported that the particles suspended in the air enter the human body by breathing. These particles include natural materials such as bacteria, viruses, pollen, sea salt, road dust, and anthropogenic emissions. The hazard caused by these particles depends on their chemical composition as well as where they deposit within human respiratory system. Hence, understanding the deposition of aerosol in the human respiratory system is critical to human health, so that the deposition of "bad" aerosol must be reduced. The respiratory system works essentially as a filter. The viscous surface of the airway wall almost guarantees the deposition without re-entrainment when a particle is in contact with it. The most important mechanisms are impacting, settling, diffusion and interception. A particle entering the respiratory system is subject to all the deposition mechanisms previously mentioned. The actual deposition efficiency of a given particle size has been determined experimentally. Several models have been developed to predict the deposition. Over 700.000 people in the United States are exposed to hazardous levels of swine dust each year, and over 60 % of these suffer from various respiratory disorders including organic toxic dust syndrome, chronic bronchitis, hypersensitivity pneumonitis and occupational asthma (Rosentrater 2004). There are significantly higher prevalences of chronic cough, chronic phlegm, chronic bronchitis and chest tightness in poultry workers than in control workers (Eugenija et al. 1995 & Iversen et al. 2000).

2.3. Transportation of harmful substance inside animal buildings

Particulate matter can be considered as a good media to absorb odour and other harmful gases such as ammonia. It can then transfer inside the animal buildings and to the environment by ventilation. The airborne dust is one of the primary means by which disease-causing organisms are spread throughout a poultry house. Reductions in airborne dust levels have been associated with even greater reductions in airborne bacteria. Poultry (meat and eggs) contaminated with *Salmonella* continue to be important vehicles for *Salmonella* infections in humans. Pathogens, such as *Salmonella* can be introduced into the food chain at any point. Airborne transmission of *Salmonella* is a major factor for the spread of *Salmonella* from bird to bird and hatching eggs in breeder houses. It has been shown to be a major factor in the spread of disease in hatching cabinets (Mitchell et al. 2004). A significant proportion (15 to 23 %) of airborne ammonia in enclosed livestock facilities is associated with dust particles (Reynolds et al. 1998). The dust particles in swine buildings may be responsible for a considerable portion of odourant emissions from the buildings and odour perceptions by downwind neighbours of swine farms. Therefore, controlling the odour will require a reduction of dust emissions from buildings (Robert 2001). Ammonia and odours may be absorbed by the dust particles. Viable bacteria and viruses carried into the air by dust particles may have a greater ability to survive (Takai et al. 1998).

3. Definition of the particle

The Dust is defined according to ISO (1995) as small solid particles conventionally taken as those particles below 75 µm in diameter which settle out under their own weight but may

remain suspended for sometime. On the other side, IUPAC (1990) defined it as a small, dry, solid particles projected into the air by natural forces such as wind, volcanic eruption and by mechanical or man-made processes such as crushing, grinding, milling, drilling, demolition, shovelling, conveying, screening, bagging, and sweeping. Dust particles are usually in the size range from about 1 to 100 μm in diameter, and settle slowly under the influence of gravity.

4. Particles characterization

4.1. Chemical properties of dust particles

Dust is analyzed according to its chemical composition into inorganic and organic (viable and non-viable) components. The chemical composition of airborne and the settled dust from different sources have nearly the same concentrations of dry matter, ash, N, P, K, Cl and Na (Pedersen et al. 2000). From the chemical analysis of the airborne and settled dust in broiler houses and pig rooms, the dust from broiler houses was higher in its chemical composition than that from the pig barns (Ellen et al. 2000).

The dust from poultry houses contains the highest amounts of protein. This is caused firstly by the relatively high protein content in the feed which is usually between 20 and 25 %. Secondly the other proportion of up to 45 % comes probably from feathers and claw abrasion. Also in the pig house the dust percentage of about 20 % seems to come from the skin and the hair of the animals (Hartung and Saleh, 2007).

4.2. Biological properties of dust particles

The particles, especially large particles, act as carriers of other air pollutants such as bacteria, viruses, odour and gases (Zhang et al. 2005). The dust within livestock buildings has viable microorganisms, fungi and absorbed toxic gases (Wang et al. 2000). There are larger amounts of airborne microorganisms in alternative housing systems of poultry houses. These high concentrations of viable fungi in the multiple level systems may be caused by using wood shavings in the bedding area that might have been contaminated with fungal spores. The dust and microorganisms with different admixture are abundant in the air of livestock houses (Bakutis et al. 2004). The dust can carry and promote large aggregations of microorganisms including viruses and bacteria (both gram-positive and gram-negative), especially Salmonella, Staphylococcus, Micrococcus, Endotoxin, and Rotavirus.

4.3. Physical properties of dust particles

The dust particles are subjected to a variety of physical processes according to their density, size and shape. The most important physical effects are sedimentation, agglomeration, aerodynamics, adsorption and resuspension (Rosenthal et al. 2007). There is a strong influence of the particle size, density, surface and shape on the distribution of airborne particles (Schmitt-Pauksztat 2006).

5. Sources of the dust inside the livestock buildings

The dust particles in animal housing may originate from feed (80 to 90 %), litter (55 to 68 %), animal surfaces (2 to 12 %), feces (2 to 8 %) and from structural elements in the house such as the walls and floor (Hartung and Saleh 2007 & Seedorf and Hartung 2000). It is also primarily generated from feed grains, dried fecal materials and excrements, animal dander (skin cells and hair), feathers, insect parts, mold, pollen, grain mites, mineral ash, and dead micro-organisms which are comprised of viable organic compounds, fungi, gram-negative bacteria, endotoxins, absorbed toxic gases and other hazardous agents (Wang et al. 1999a & Jay et al. 1994). The amount of dust released is proportional both to the number of animals and to their weights. This fact indicates that a considerable part of the dust can be generated from the animals themselves (Gustafsson 1997). A small amount of particles could also enter the animal house with the incoming ventilation air.

6. Indoor dust concentration and emission rate in livestock buildings

The concentration of both airborne inhalable and respirable fractions was overall higher in pig and poultry buildings than in cattle houses. Dust concentrations and emissions were affected significantly by several things such as housing type, the season of year and day/night time (Takai et al. 1998). The inhalable and respirable dust concentrations in poultry buildings were higher in winter than in summer season (Takai et al. 1998). The low level of dust concentration in warmer seasons was related to the high humidity and high exhausted ventilation (Zhu et al. 2005). The mean inhalable dust emission rates were higher in summer season than in winter season. The highest concentration of the total dust and respirable fraction in the laying hens houses were during June. This result can be explained by the fact that during this period the birds molted thus, increasing the amount of dust. Moreover, the increased ventilation due to the higher temperatures on the one hand helped extracting dust from the unit but on the other stirred up previously deposited dust. This indicates the enormous importance of the systematic general cleaning of the unit (Guarino et al. 1999). The diurnal change has a big influence on the concentration of airborne dust in a commercial animal houses. There is a variation in number of different sized particles during the day with constant ventilation rate in a building. A clearly increase in the dust particle number during daytime when the animal activity is higher than at night-time (Gustafsson 1997). The highest dust concentrations were measured at 5:00 O'clock and the lowest dust concentrations were found at 14:00 O'clock (Hessel and Van den Weghe 2007). The dust levels in livestock houses were consistently low during the night-time hours and high during the afternoon is correlated to animal activity, operation of feed delivery equipment and worker activity (Nannen and Büscher 2007 b). There is a high variation in the pattern of spatial dust distribution in mechanically ventilated animal buildings. Thus, the ventilation systems have direct effects on the spatial dust concentration whereas the increase of the ventilation rate will not necessarily reduce the overall dust level effective because the dust production rate will increase with increasing ventilation (Pedersen et al. 2000). A comparative study of respirable dust concentration between European countries and the state of Texas in the USA has been presented by Redwine et al. (2002). The dust

concentration in European countries ranges in the literature from 0.4 to 9.7 mg.m⁻³, on the other side, it ranges from 0.1 to 0.3 mg.m⁻³ in Texas, which is slightly less than comparable data from European studies. These results return to the warm climate of Texas as mentioned by the authors. This warmer climate requires a higher ventilation rate and the use of evaporative cooling systems. A higher ventilation rate may dilute the dust concentration and the evaporative coolers may suppress dust emission rates by maintaining a higher relative humidity in livestock buildings. The number of different sized particles in the animal houses have indicated that increased ventilation rate mainly reduces the number of particles larger than 1.0 µm and had only a limited effect on the number of particles smaller than 1.0 µm (Gustafsson 1997).

7. Quantifications of dust concentration

7.1. Planning and preparation of the measurements

According to (VDI 2066, 1975) placement of the equipment and accessibility of the test points affect the dust determination. In new installations the requirements of the measuring sections and test points must be considered in the planning stage. These requirements are as following:

1. The flow in the measuring sections should be as undisturbed as possible.
2. The measurement cross section should be placed within a straight measuring section and have an inlet and outlet free of any interference.
3. The length of the inlet and outlet sections should be at least three times the hydraulic diameter of the measuring cross section.
4. The test place should be easily accessible by the measuring staff and for transport of the instruments.
5. The test place should be protected against external effects (rain, wind, heat, etc.) and it must comply with the accident prevention regulations.

7.2. Dust concentration measuring methods

The determination of dust concentrations with the help of filters has been explained by VDI 2066 (1975) and VDI 2463 (1999). Different procedures for measuring the particles in gases or liquids such as the Coulter Counter have been explained by Cox and Wathes (1995).

Schmitt-Pauksztat (2006) explained the different procedures to measure the dust concentration such as:

1. Aerodynamic procedures
 - Elutriator
 - Inertia impactor
 - Particle size analysis
2. Optical procedures
 - Mie theory

- Laser particle counter
- White light method
- Influence of the particles form and structure

Gustafsson (1997) measured the dust concentration using the following methods:

1. Gravimetric measurements of the amount of total dust (mg/m^3) with 37 mm diameter Millipore filters at a flow rate of 1.9 l/min.
2. Gravimetric measurements of the amount of respirable dust (mg/m^3) with a millipore filter after separation of larger particles with a SKC cyclone.
3. Counting the number of different sized particles with a Rion optical particle counter.
4. Weighing the settled dust on 0.230 m^2 settling plates.
5. Measuring the ventilation rate with an Alnor hot wire anemometer in the exhaust air ducts.

The particulate matter (PM) in the ventilation exhaust air could be measured by using a tapered element oscillating microbalance (TEOM). The instrument draws aerosol through an exchangeable filter attached to a hollow tapered oscillating glass rod at a constant flow rate. The real-time PM concentration is based on a sample flow rate coupled with gains in mass on the filter measured by its effect on the oscillation frequency. Each TEOM system consists of controller and sensor units, figure (1). The sensor unit contains a mass transducer and is heated to 50°C to minimize moisture effects. The PM_{10} sample inlet is attached to the sensor unit and can be replaced with $\text{PM}_{2.5}$ inlets. Sample flow is split isokinetically into a main flow passing through the filter and a bypass flow each controlled by a mass flow controller (Lim et al. 2003 and Kosch et al. 2005).

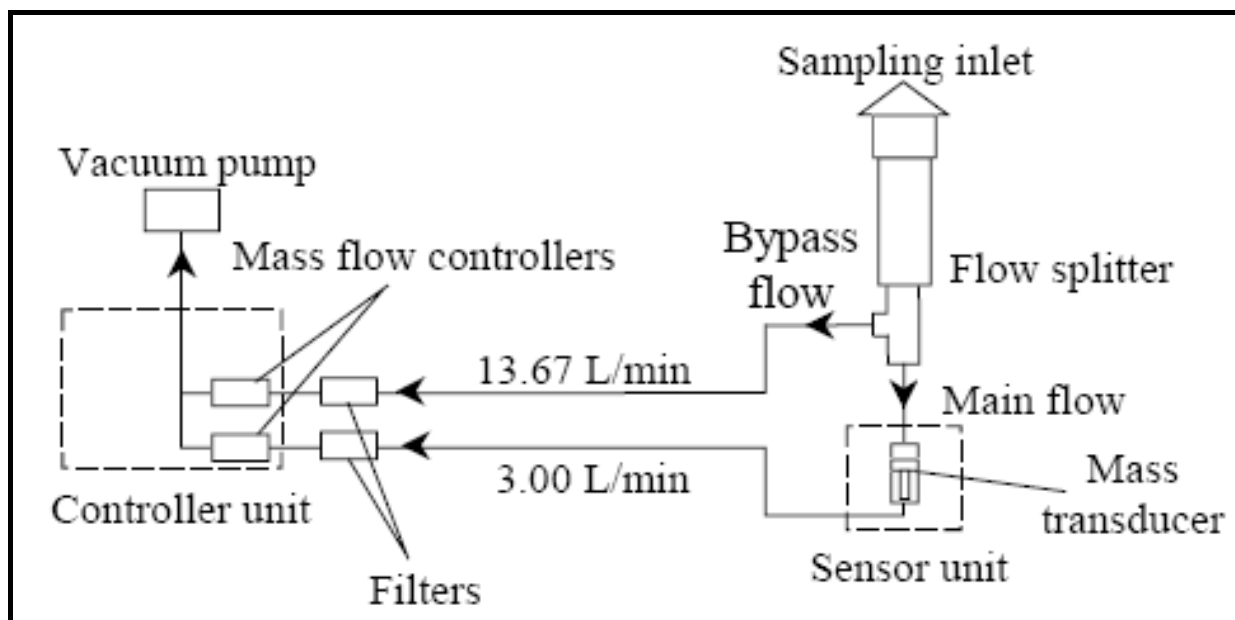


Figure 1. Schematic layout diagram of the tapered element oscillating microbalance (Lim et al., 2003)

A multi-point dust sampler has been developed by Wang et al. (2000) and Wang et al. (1999a) to measure the spatial dust distribution at different ventilation rates in a mechanically ventilated airspace using an array of critical venturi orifices for controlling the airflow rate at each sampling point, figure (2). It consists of a commercially available vacuum pump, a pressure monitor, a pressure regulator, an array of filter holders, filters, critical venturi orifices and sampling heads. When air is drawn through the sampling head and the filter the volumetric flow rate remains constant for all venturi orifices even though the pressure may vary as long as the pressure across the venturi orifices is higher than the critical pressure drop. Since the critical pressure drop of the venturi was below 11 kPa, the pump operated at a sufficiently high vacuum (approximately 35 kPa) and a constant flow through the filters was maintained. This multi-point sampler was used in this study to measure the dust mass concentration in a cross-section of the ventilated airspace.

The technical set-up and measuring method of Optical Aerosol Spectrometers (OAS) including the device characteristics has been explained by (Mölter and Schmidt 2007). The set-up principle of an OAS in forward scattering is presented in figure (3).

During forward scattering, the light scattered by particles as shown in figure (4) towards 180° is collected by the light source with a light sensitive detector, e.g. a photomultiplier. At the 90° scattered light detection the photomultiplier is attached orthogonally to the image plane.

The height of the scattered light impulse is a measure for the particle diameter, while the number of impulses supplies the information on the concentration since the volume flow is known. With the help of a lens system the light is focused on the desired measuring volume size. Before the receiver optics a light collector in forward scattering must be installed. This protects the light detector against direct irradiation. Due to diffraction actions of the light and of the scattered light the light collector leads to an ambiguous calibration curve also when using white light. However, a source of white light in connection with a 90° scattered light detection secures a clear calibration curve for many refractive indices.

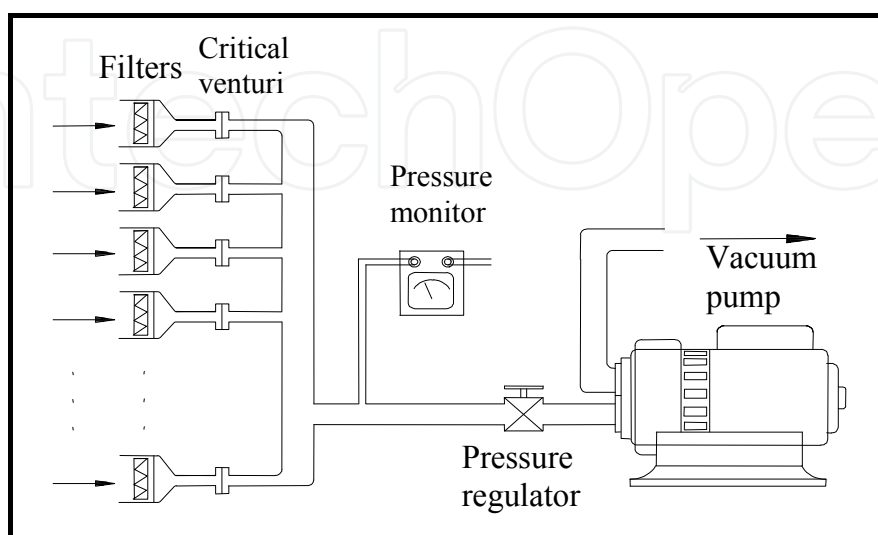


Figure 2. A schematic diagram of the multi-point dust sampler (Wang et al., 2000 and Wang et al., 1999a)

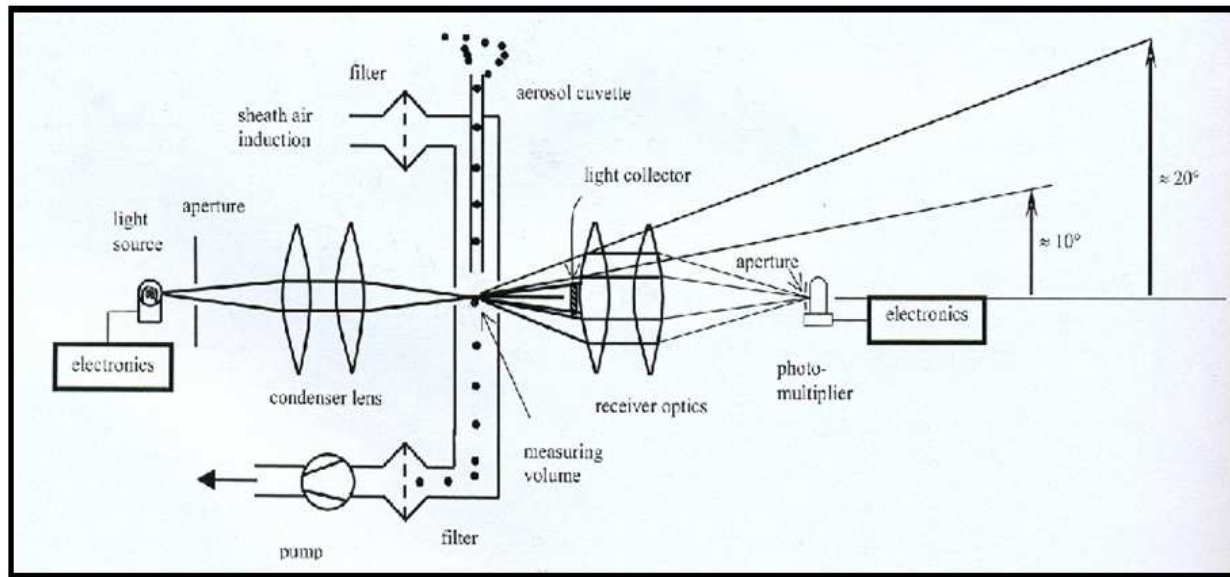


Figure 3. Optical aerosol spectrometer (Möller and Schmidt, 2007)

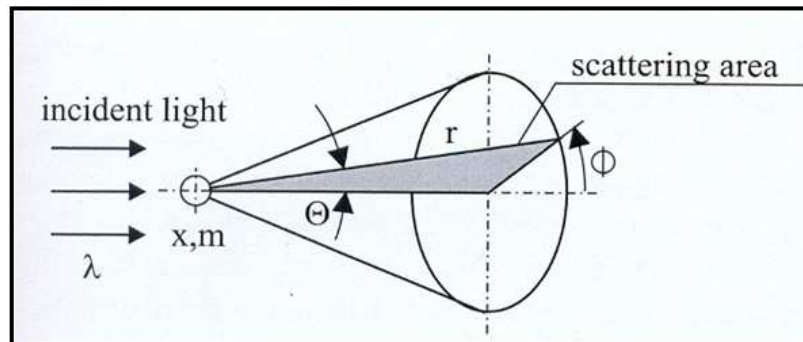


Figure 4. Principle of incident light scattering (Möller and Schmidt, 2007)

The measurement of the emission rates of particulate matter from mechanically ventilated livestock buildings in the laboratory, using a test chamber and at the exhaust duct, using three air sampling methods (Predicala and Maghirang 2004):

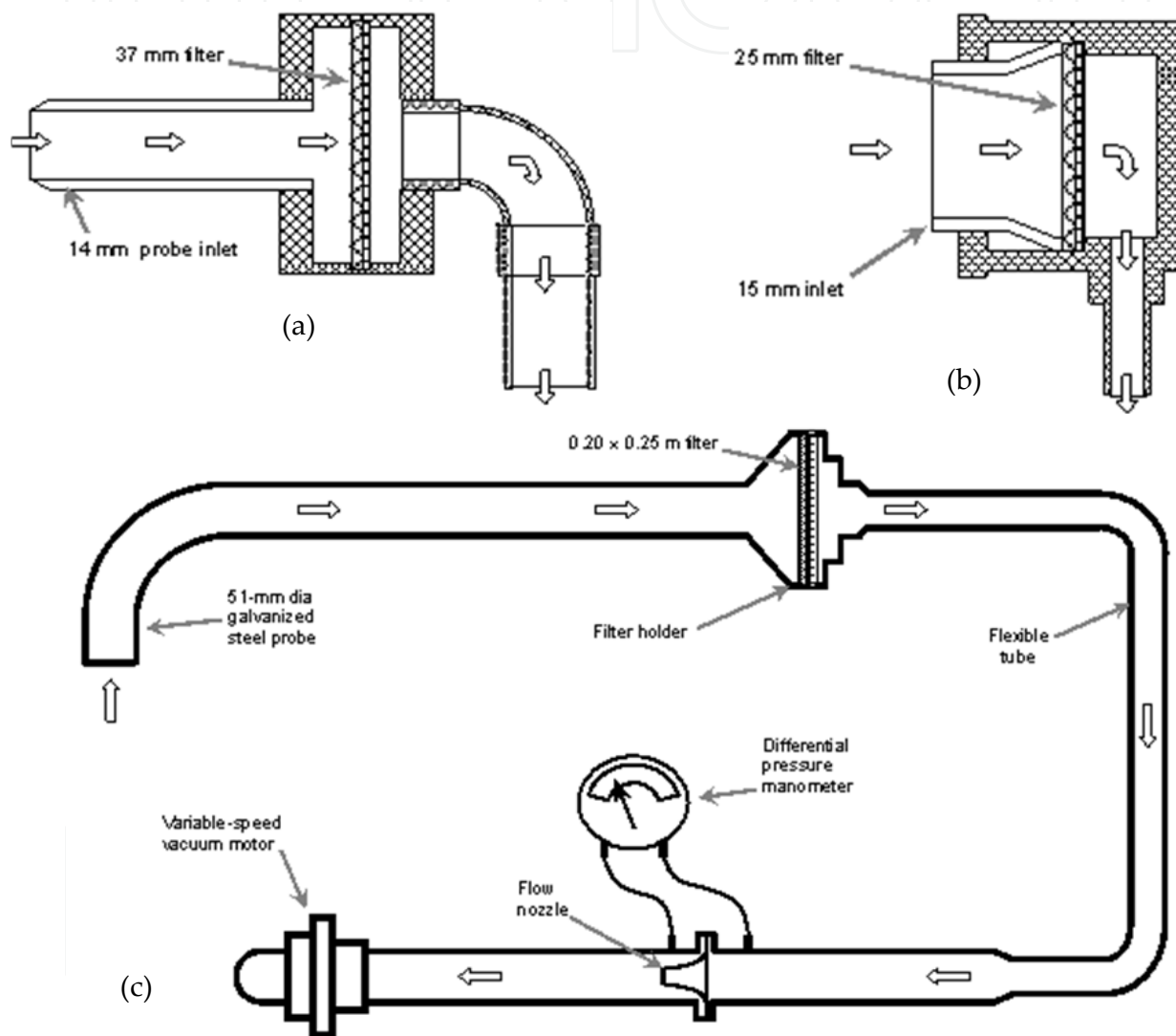
1. Low-volume traverse under isokinetic conditions.

This method used a sampling head with a 14 mm probe inlet diameter and a 37 mm filter assembly, as shown in figure 5a. The sampling head was attached to a 0.80 m long rigid tube which was connected by flexible tubing to a flow meter with a flow control and a vacuum pump. The sampling flow rate was adjusted to isokinetic condition. Isokinetic sampling was achieved by varying the sampling flow rate to match the air velocity at the inlet plane of the sampler with the air stream velocity outside the sampler. The required sampling flow rates for isokinetic sampling were determined by conducting a velocity traverse at the sampling plane prior to sampling.

2. Fixed sampling at specific locations within the duct cross-section.

This method used a 14 mm sampler and an Institute for Occupational Medicine (IOM) sampler, as shown in figure 5b. The 14 mm sampler was similar to that in the low-vol

traverse method, while the IOM sampler was a commercially available inhalable PM sampler, operated under either isokinetic conditions or at the recommended flow rate of 2 l/min (sub-isokinetic sampling). The IOM sampler was typically used to assess occupational worker exposure in livestock buildings; thus, its possible application for measuring PM concentrations to determine PM emission rates was investigated. Sampling was sub-isokinetic when the actual sampling flow rate was lower than the required isokinetic sampling flow rate. A velocity traverse was also conducted prior to sampling to determine the required isokinetic sampling flow rate.



a) The low-volume traverse method, b) The fixed sampling method, c) The high-volume sampling train

Figure 5. Schematic diagram of three air sampling methods (Predicala and Maghirang, 2004)

3. Hi-volume traverse under isokinetic conditions.

This method is considered as the reference method for this study. The sampling train consisted of a 51 mm diameter probe, a 0.20 x 0.25 m filter holder, a flow nozzle and a variable-speed vacuum motor presented in figure 5 c. Similar to the low-vol traverse

method PM was also extracted isokinetically at specified sampling locations within the sampling plane. The sampling flow rate indicated by the differential pressure across the flow nozzle was adjusted by varying the speed of the vacuum motor. After sampling, the probe and the front part of the filter holder were rinsed with acetone to collect the PM deposited along the probe and filter holder walls. The acetone was allowed to evaporate and the residual PM was added to the PM mass collected on the filter. The sampling duration at each traverse point was determined by preliminary tests so the total collected PM mass was at least 100 mg.

The low-volume traverse and fixed sampling under isokinetic conditions agreed well with the high-volume traverse (mean difference ranging from 7 % to 14 %). Methods involving room sampling, fixed sampling at exhaust and high-volume traverse at exhaust were also compared in a swine finishing barn. Room sampling overestimated concentrations at the exhaust by an average of 30 % and PM concentration from fixed sampling did not differ significantly ($p > 0.05$) compared to the high-volume traverse method. It appears that fixed sampling under isokinetic conditions can be used as an alternative to the high-volume PM traverse method to accurately measure PM concentrations at the exhaust from which the PM emission rate can be determined.

8. Means for reduction of dust in/from animal houses

Several methods for dust control such methods include spraying or sprinkling oil or oil-soap solution in the airspace accelerating dust sedimentation onto the floor by investigating the air ionization systems and separating dust from the air stream with air cleaning devices and ventilation. There are number of mechanical methods for dust control. These methods include fiber filters, water or oil scrubbers, electrostatic precipitators and traditional cyclones (more particles smaller than 10 microns can't be separated by the conventional cyclones because of the strong turbulence associated with the high pressure typically higher than 500 Pa) but these methods may be associated with the ventilation system in the barns (Zhang et al. 2001). The different methods used for reducing the indoor concentration and dust emission rate as following:

8.1. Dust suppression with spraying oil and /or water

Indoor dust concentration inside animal houses could be reduced by spraying a mixture of oil and water. This method proved to be very effective to reduce dust at relatively low costs. The main effect of oil/water spraying is preventing dust on surfaces to become airborne. With a good design dust reduction could be reach up to 90 %. Designing this system, the following items are important to be considered:

- Oil concentration should be at least 20 %. With this concentration the relative humidity inside the animal house slightly increased (< 2 %).
- Oil drops should be bigger than 150 μm to descend to the floor at a fast speed to increase efficiency. Furthermore, small droplets might affect the respiratory health of animals and humans when the small droplets are inhaled.

- Generally, all kinds of vegetable oils can be used although some remarks have to be made:
 - It is not necessary to use purified oil however the oil should be free of particles.
 - Oil with a strong odour is less suitable because of possible effects on animal behaviour.
 - Oil should contain a low concentration of Iodine.
- The dust binding effect of the oil is long lasting (some days). Frequent spraying is needed (Aarnink and Ellen 2007, and Pedersen et al. 2000).

The oil applications could be on the feeding materials for reducing dust concentrations by livestock industries. A variety of vegetable oils including canola, corn, sunflower, flax, soybean and rapeseed oils along with mineral oils have been used to control dust from feed sources and building floors. Soybean oil reduced dust counts by as much as 99 % following 0.5, 1.0 and 2.0 % additions to dry feed (Ullman et al. 2004, Pedersen et al. 2000 and Takai 2007). Although oil sprayed on birds is not recommended and application would be an incompatible practice with broiler rearing. Due to high bird density oil sprinkling may still hold promise as an effective dust control technique. The technical parameters regarding the spraying of oil-water mixtures on surfaces in pig buildings to enable consistent dust reduction efficiency with the least possible oil application rate could be concluded as following (Takai 2007):

1. Number of treatments within the range of 1 and 14 per day does not have an influence on dust reduction efficiency.
2. Oil concentration in the oil-water mixture should be higher than 20 %.
3. Droplet diameter should be greater than 150 μm .
4. Further development of methods to prevent plugging in the spray system is desired.

An ultra sonic sprayers unit (USSU) as shown in figure 6 has been used to reduce the dust concentration in an enclosed experimental layer and floor feeding broiler house. For laying hens 1 and 2 % solutions of emulsified canola oil (weight base) were sprayed by (USSU) once a day after feeding. However for the floor feeding broiler house 2 % solutions of emulsified canola oil (weight base) were sprayed by (USSU) every hour for 10 minutes (75 g were sprayed) or when a dust concentration detector detected a threshold concentration which was 5.0×10^8 particles/ m^3 with less than 5 μm in aerodynamic diameter. Spraying 2 % solution of emulsified canola oil with the ultra sonic sprayer unit in the enclosed layer house reduced the concentration of dust with $0.5 \leq \text{aerodynamic diameter} < 2 \mu\text{m}$ and with $10 \leq d < 30 \mu\text{m}$ to 58 by 51 %, respectively. On the other side, 1 % oil spraying in the layer house reduced the dust concentration to about 20 %. This spraying method could reduce the dust concentration to a daily average of 47 % in the floor feeding broiler room, but concentration itself was 100 times higher than in the layer house (Atsuo 2002).

Showering water on the floor surfaces in the walking alleys reduced the total dust concentration with 9% average and spraying salt solution (KCl) in the air with nozzles reduced the total dust concentration by 41%. Spraying water droplets gave different results depending on the type of nozzles used. The use of high pressure nozzles (ultrasound

nozzles) which created droplets in the size range of 5-10 μm resulted in a significant increase of both total and respirable dust (Gustafsson 1997). An aerosol application unit has been used to distribute an oil mixture-emulsion under high pressure inside a pig barn. The oil mixture contained different types of essential oils (to reduce airborne germs and fungi) and a carrier oil. By operating the aerosol application unit every 30 minutes, it was possible to obtain an almost continuous indoor air treatment within the barn. In comparison with the reference pig barn (same building, different compartment; *ceteris paribus* conditions), an average indoor concentrations were reduced to an average by 59 % for total dust and 54 % for PM_{10} . Emissions reduced to 68% for total dust and 65 % for PM_{10} (Hölscher 2006).

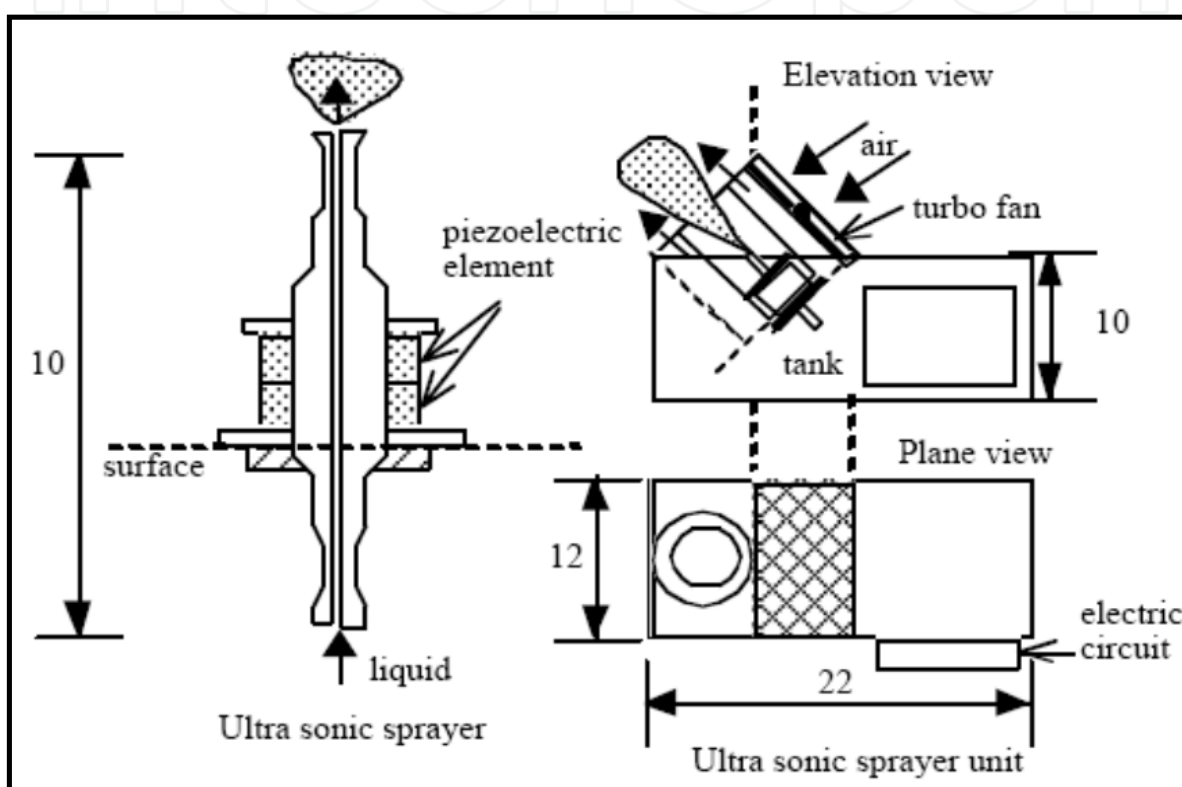


Figure 6. Ultra sonic sprayer unit (Atsuo, 2002)
(All units in cm)

8.2. De-dusters

There are two aerodynamic uniflow de-dusters (a cyclone type particle separator & gas remover with airflow capacity 188 l/s and 1,880 l/s) have been developed with low pressure requirement and high particle separation efficiency. This development is based on fluid dynamics, particle mechanics and sensitivity analysis.

- The small model de-duster employs a set of turbine-type vane guides, an involute separation chamber and a flow converging section to minimize turbulence and reduce the pressure loss. As shown in figure 7, dusty air is drawn from the air inlet passing through a set of vanes to establish a spiral flow pattern. The air then passes through the involute chamber and converges at the exit section above the dust bunker. Particles are

collected in the dust bunker and clean air is exhausted through the blower. This device, as shown in figure 2.30, unlike the conventional cyclones, can remove respirable particles at pressures of 50 Pa.

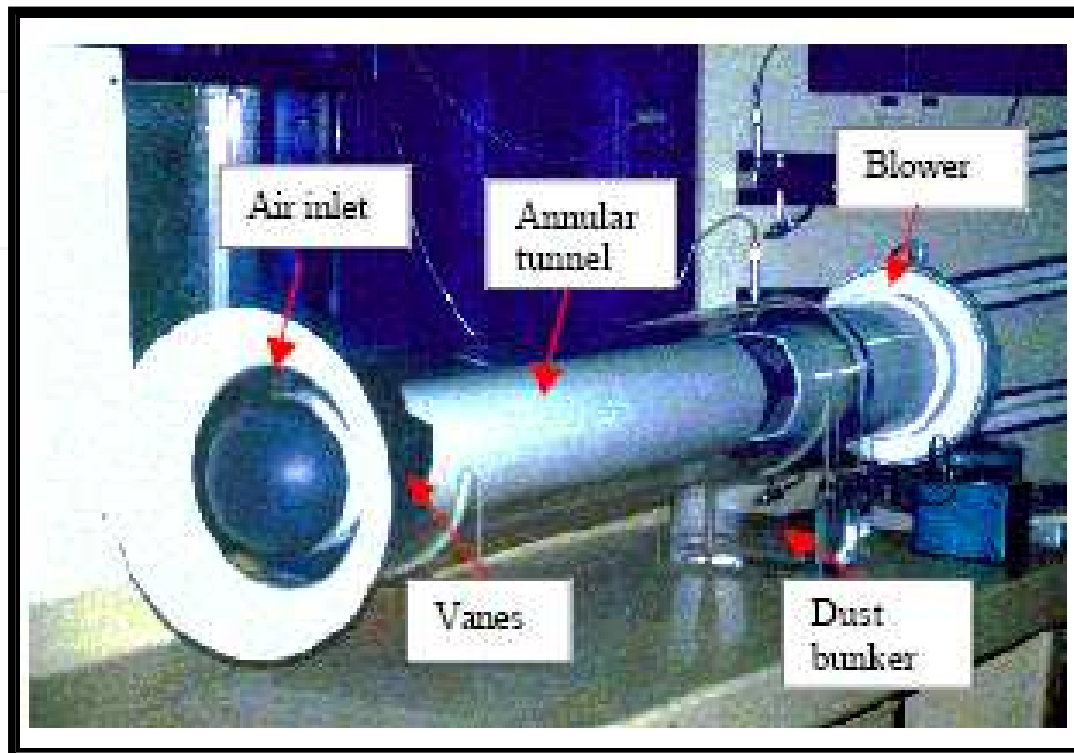


Figure 7. The prototype of the uniflow deduster fabricated based on the sensitivity analysis (Zhang et al., 2001)

- The large model de-duster contains three concentric de-dusters. The outer cylinder of the smaller de-duster serves as the inner cylinder of the bigger de-duster. Thus, the total cross sectional area is increased to allow air delivery and the volume of the unit is minimized as shown in figure 8. The fan speed can be varied via a frequency controller so that the performance at different airflow rates can be evaluated (Zhang et al. 2001). An automatic dust flushing system was developed to periodically clean the dust in the dust bunker. The new design is aimed at reducing dust emissions for exhaust fans with large air flow rates. The dust mass concentration was measured at the inlet and the outlet of the de-duster using filter collectors during 24-h periods. The results showed that the dust mass removal efficiency was 91 % at the 60 % power level. The dust reduction efficiency was 89 % at 100 % power level. From the study of dust concentration reduction through cleaning the air using aerodynamic de-dusters, the ratio of air flow rate through the de-duster to the ventilation room is 32 % with a dust removal efficiency of 85 %. The large flow rate for the de-duster is required to improve the room air cleaning efficiency (Wang et al. 1999a). The effectiveness of air cleaning devices on dust concentration is dependent not only on the airflow through the device but also on the ventilation rate in the building (Gustafsson 1997). Considering the mass balance of the dust it is obvious that the air cleaning equipment needs large airflow

capacities if the dust concentration in the air is to be affected. The airflow through an air cleaner has the same influence on the dust concentration as an equally large increase in the ventilation rate in the building. The particle separation efficiencies of this de-duster were 50, 77 and 90 % for particles diameter of about 4, larger than 7, and larger than 10 μm respectively. In terms of mass concentration measured using mass samplers, the particles separation efficiency was 85 %. Because most of the dust mass is attributed to the larger particles, the number separation and mass separation efficiency agreed very well (Gustafsson 1997).



Figure 8. The large de-duster prototype (Zhang et al., 2001)

8.3. Ionization

Ionization is the physical process of converting an atom or molecule into an ion by adding or removing charged particles such as electrons or other ions. This process works slightly differently depending on whether an ion with a positive or a negative electric charge is being produced. A positively charged ion is produced when an electron bonded to an atom (or molecule) absorbs enough energy to escape from the electric potential barrier that originally confined it, thus breaking the bond and freeing it to move. The amount of energy required is called the ionization potential. A negatively charged ion is produced when a free electron collides with an atom and is subsequently caught inside the electric potential barrier releasing any excess energy. An electrostatic space charge system was shown to remove up to 91 % of artificially generated dust and 52 % of dust generated by mature White Leghorn chickens in a caged layer room. An apparatus consisting of 2 negatively charged needles located 0.25 m above the floor and a positively charged aluminium collector plate (0.76 m high by 1.4 m long) located in front of the door, charged at 12 and 8 kV, respectively, was tested at a livestock facility. Ionization was approximately 6 times

greater at dust removal than gravity alone. Relative humidity had no apparent impact on reductions in dust concentrations (Ullman et al. 2004). The ionization in pig houses has resulted in a 20–30 % decline in dust concentration (Gustafsson 1997). Electrostatic collectors are devices that impart electric charges to dust particles and then push them out of the air stream using electromagnetic force. They typically exhibit low operating costs and high removal efficiencies. The electrostatic ionization could produce airborne swine dust removal rates of up to six times greater than gravitational sedimentation alone. The ability of the electrostatic precipitator system in figure 9 to remove airborne particles has been tested. This electrostatic precipitator consisted of a discharge electrode which was constructed from a single strand of stainless steel wire and a grounded collection electrode pipe positioned 17.8 cm below the wire. The discharge wire and the collection pipe were supported by PVC end plates. Additionally, an ionization guard was located above the wire to direct electrons and charged dust particles down toward the collection electrode. The entire unit was 3.05 m in overall length. To charge the precipitator and provide negative ionization at the discharge wire (which imparts electrical charges to passing dust particles). The electrode wire was connected to a -20 kV, 50 mA, and rectified a.c. power supply unit (Rosentrater 2004).

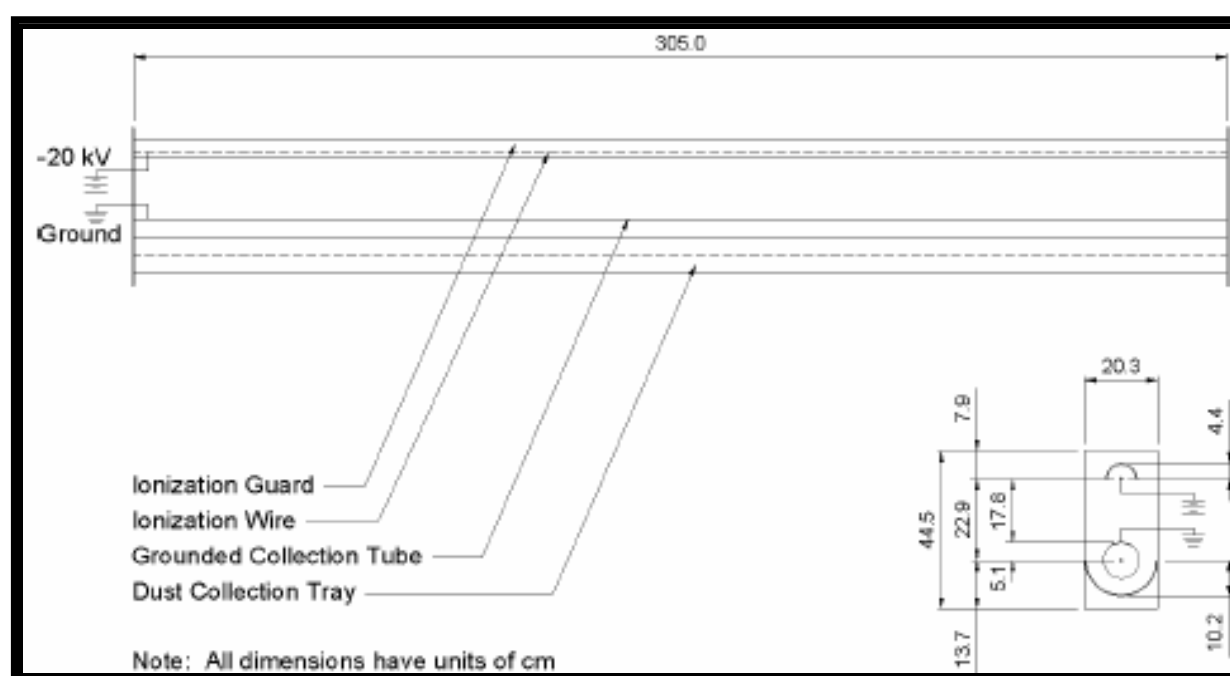


Figure 9. Schematic of electrostatic precipitator unit (Rosentrater, 2005)

An electrostatic space charge system (ESCS) has been used by Mitchell et al. (2004) to demonstrate the effectiveness of this system in the breeder/layer farm environment for reducing airborne dust in a several month long study. The system as shown in figure 10 used ceiling fans to distribute negatively charged air throughout the room and to move negatively charged dust downward toward the grounded litter where most of it would be captured. The dust concentration was reduced by an average of 61 % over a period of 23 weeks.

Mitchell and Baumgartner (2007) used previous ESCS for reducing the dust particle concentration in poultry production houses and a hatchery. The effectiveness of ESCS for PM₁₀ dust reduction ranged from 78 % in commercial poultry hatcheries to 47 % in commercial caged layer houses. The effects of airflow on the distribution for negative air ions using three types of ion generators has been studied by Mitchell (1997) as shown in figure 11, which have potential for dust reduction in animal house or hatchery applications. All of the devices used limited current power supplies which restricted the current to 2 mA or less for safety and the ozone output was limited to less than 0.1 ppm. The first type was a self-contained Ceiling Ionizer that was designed to hang from the ceiling in the middle of a room where a space charge was desired. The second was a Room-Ionizer-System (RIS) consisting of a metallic bar with external power supplies operated at -8 kVDC, or -15 kVDC. Both of these devices require an external air moving device. The third type was an ionizer which is designed to be used inline in a duct or with a self-contained air source to charge clean outside air prior to injecting it into a treatment area. This device will be referred to as the IDI (in-duct-ionizer). These devices could be effectively used to reduce dust and microorganisms in a variety of applications with air moving devices.

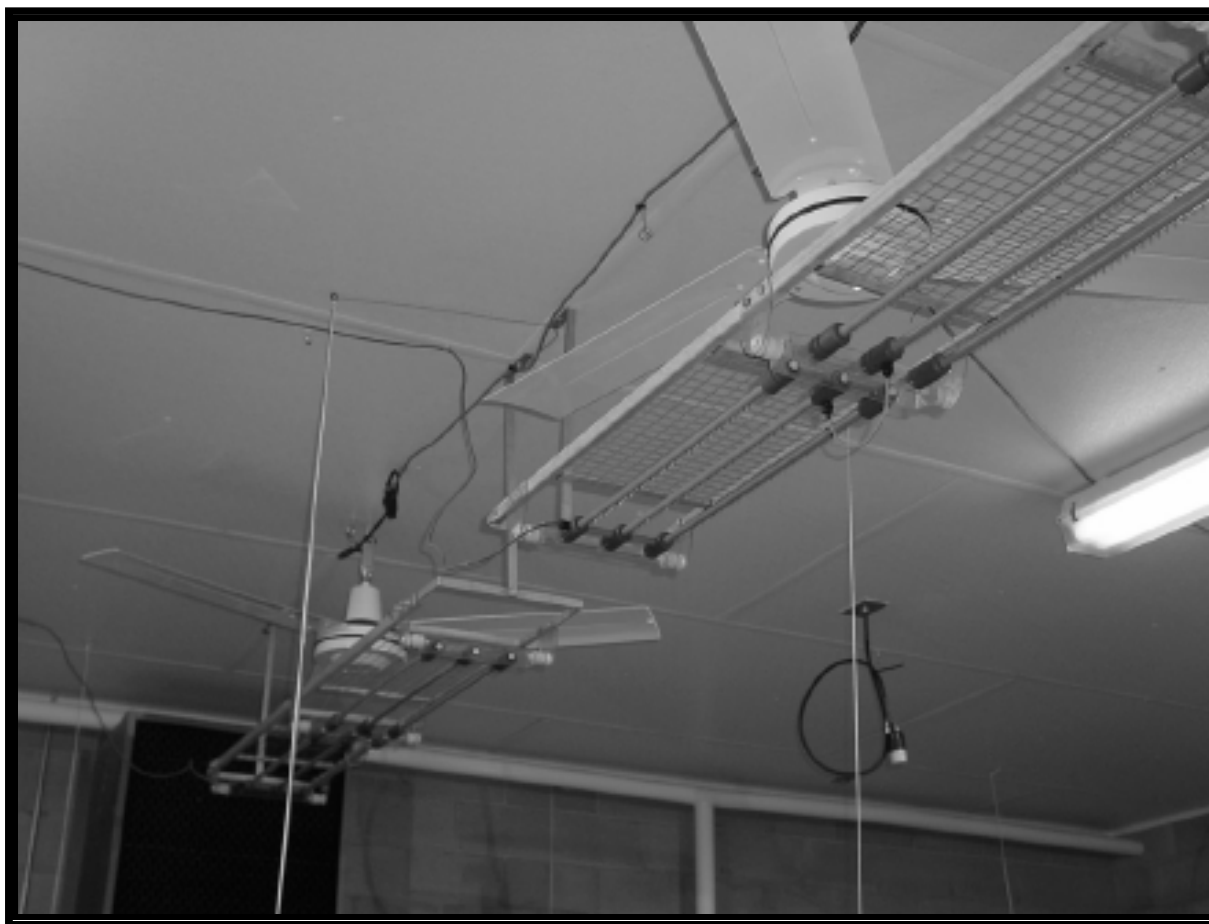


Figure 10. ESCS units suspended below the ceiling fans in the treatment room (Mitchell et al., 2004)

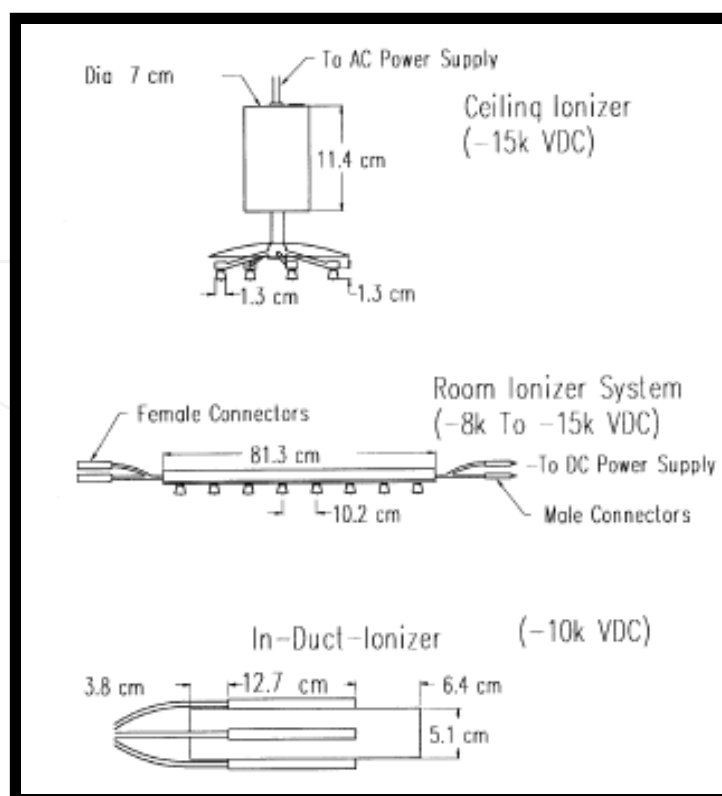


Figure 11. Ionizer configurations (Mitchell, 1997)

8.4. Oxidants

An oxidant can be defined as a chemical compound that readily transfers oxygen atoms or a substance that gains electrons in a chemical redox (short for reduction/oxidation reaction) reaction. Cleaning the air by oxidation has been used for decades using oxidizing agents such as ozone, potassium permanganate, chlorine and chlorine peroxide. Evaluation of an indoor ozone system for dust control effectiveness proved that the total dust concentrations decreased by 60 % at the fan exhaust under maximum tunnel ventilation compared with a nearby building without any ozone treatment (Ullman et al. 2004).

8.5. Windbreaks

A windbreak or shelterbelt is a plantation usually made up of one or more rows of trees planted in such a manner as to provide shelter from the wind. Two hundred operations in Taiwan have constructed walls downwind of tunnel-ventilated poultry buildings and had seen reduced dust emissions off-site. The effectiveness of module walls constructed of 3 x 3 m pipe frames covered securely with tarpaulins was determined by collecting aerial dust particles and demonstrating airflow from exhaust fans using smoke. An increase in the vertical height of the smoke plume subsequent to reaching the windbreak demonstrated the potential for reduced dust concentrations downwind of animal facilities. Elbows placed on exhaust fans designed to redirect fan airflow upward produced some plume rise. However, dispersion models indicated that tall stacks may offer further effectiveness (Ullman et al.

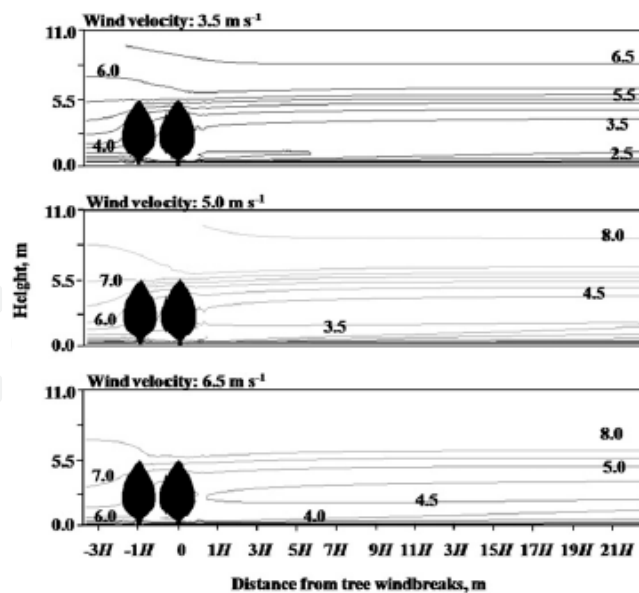


Figure 12. The velocity contour profile (ms^{-1}) at varied wind velocity of 3.5, 5.0 and 6.5 ms^{-1} measured at 1.0 m height for two-rows of trees arranged alternately with 0.5m gap distance between trees, where H is the tree height (Bitog et al. 2012).

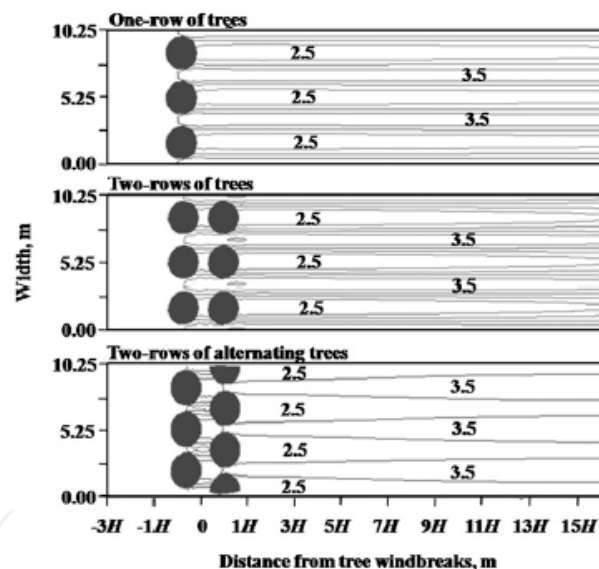


Figure 13. Visualisation of the velocity contour (ms^{-1}) of the tree windbreak at varied rows of trees and their arrangement (Top view at 1.0 m height; maximum velocity is 8 ms^{-1}) Bitog et al. 2010.

2004). Windbreak walls placed at 3 and 6 m, respectively, from the building deflected the airflow from the exhaust fans in the upward direction similar to other wind barriers, thus providing surfaces for dust deposition. The vertical height at which the plume would flow over a downwind lagoon under low wind conditions was increased by building a windbreak wall. As a result, the dust levels in the area downwind from the windbreaks were lowered (Pedersen et al. 2000). Natural windbreaks such as trees are very efficient barriers to high velocity winds. The windbreaks exert drag force causing a net loss of momentum and thus disturb the characteristics of flow. The main factors which can affect

the efficiency of the windbreaks are tree height, width, tree arrangement, porosity, etc. (Bitog et al. 2011). The simulation provides analysis of the effect of gaps between trees, rows of trees, and tree arrangements in reducing wind velocity. The simulations revealed that 0.5 m gap between trees were more effective in reducing wind velocity, figure (12). Two-rows of alternating trees were also found to be more effective than one-row and two-rows of trees as shown in figure 13 (Bitog et al. 2012).

8.6. Scrubbers and filters

The scrubbers consist of towers packed with a contact media, gas or liquid-driven venturi systems. These venturis and spray towers offer a more instantaneous removal of dust particles (Ullman et al. 2004). The wet pad scrubber placed in the animal house 1.2 m upwind from the exhaust fans achieved modest reduction in dust emission from animal buildings in warm weather. The results demonstrated that these control methods did not substantially challenge the existing ventilation systems by causing excessive resistance to airflow and they would therefore be practical and useful emission control methods (Pedersen et al. 2000). The bioscrubber system could be used to perform at a higher level of efficiency to reduce emissions in consideration of the huge amounts of airflow in poultry production. The working principle of the exhaust scrubber as shown in figure 14 is the continuous spraying of the partition grill with a high specific area. The spraying is done with three pumps (1.5 kWh) which discharge 75 m³/h of water at a height of 5 m. The cleaning water wets the synthetic partition grill evenly and causes the removal of dust particles. The efficiency of reduction for suspended dust is 45 % (Kosch et al. 2005).

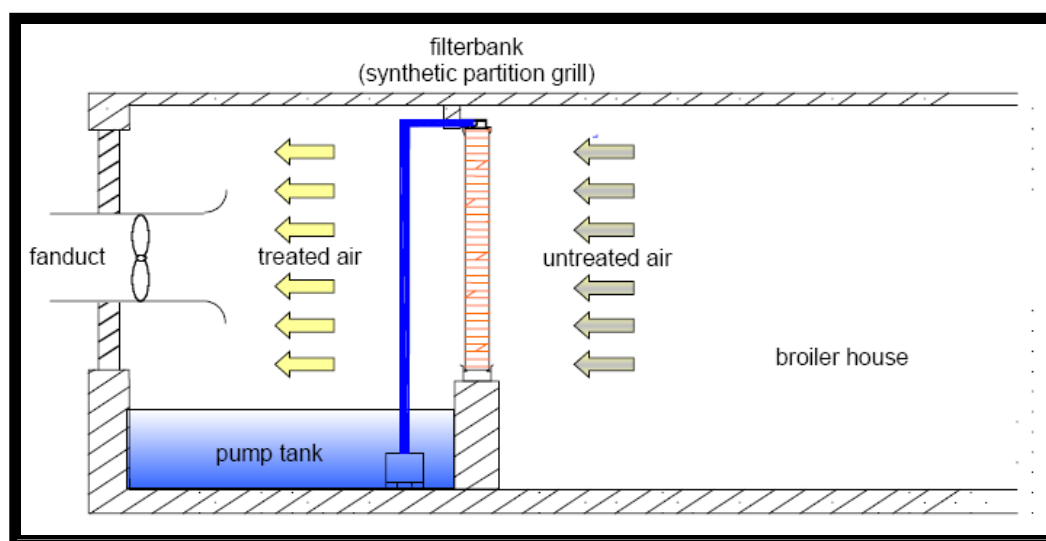


Figure 14. Schematic of the exhaust air cleaning system for a poultry house (Kosch et al., 2005)

The exhaust air cleaning system as shown in figure 15, based on a bioscrubber where the exhaust air flows horizontally to the house gable and passes through the fans to enter the filter which is located outside the stable. In the beginning the air is humidified and then flows into the first filter bank which consists of so-called pads. In this stage the dust is

washed out of the air and transported downwards by the water and the air flows through the second filter bank. In this filter the pH value of the water is regulated by acid to eliminate NH_3 , fine dust and odourous substances which cannot be washed out in the first filter bank. The water from both filters is collected and smoothed so the solid matter deposits on the ground of the basin and the water is then pumped up to flow over the pads again. The result of the dust concentration measurements shows that more than 80 % of the airborne dust was removed by the filter (Snell and Schwarz 2003).

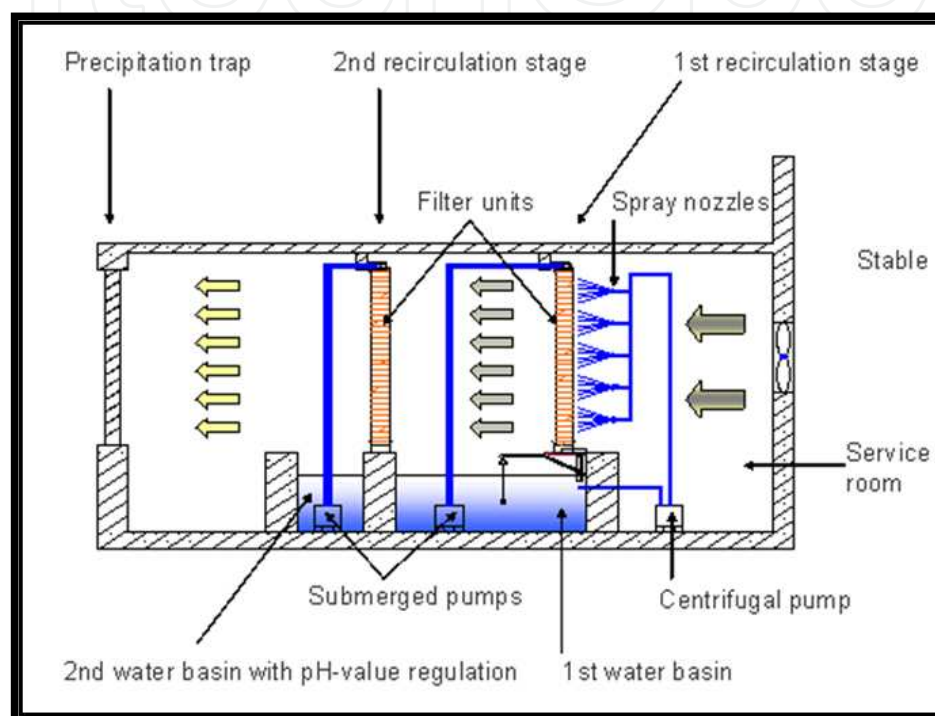


Figure 15. Schematic of the exhaust cleaning system (Snell and Schwarz, 2003)

The reduction of dust concentration in animal buildings using a filter provides an alternative method to air scrubbers for broiler operations. Dust became entrapped in fibers through a number of physical mechanisms. The traditional filter systems used in broiler operations reduced the dust content by up to 50 %. Clogging of traditional filter systems by dust and feathers in broiler facilities became problematic to a point when poultry operators found to forego filters over airconditioning units rather than deal with the required maintenance. To overcome such problems filters should be placed in a series with the first (i.e., upstream) filter consisting of a fairly coarse strainer primarily intended to remove feathers. The authors also used the Biofilter which operates by forcing air through a moist packing material to provide an alternative to traditional filter systems for broiler facility dust emission reduction. It is recommended that biofilters used at poultry facilities should be installed with dust removal equipment as dust accumulates on fans (Ullman et al. 2004). The reduction of dust emission rate from a pig barn with 515 pigs using two air scrubbers by recycling the air inside the building has been studied by Hölscher (2006). The measurements

over a three month period indicated that emissions can be reduced on average by 54 % for total dust and by 51 % for PM₁₀, compared with a reference pig barn. Indoor concentrations have been reduced on average by 63 % for total dust and by 60 % for PM₁₀. Dry filter system has been presented by Mostafa and Buescher 2011 is showed high indoor dust reduction efficiency in comparison with wet filter system.

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9. References

- Aarnink A.J.A. and H.H. Ellen (2007): Processes and factors affecting dust emissions from livestock production. International Conference How to improve air quality. 23-24 April, Maastricht, the Netherlands.
- Atsuo I. (2002): Ultra sonic sprayer controlling dust in experimental poultry houses. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript BC 01 002. Vol. IV. October.
- Bakutis B., E. Monstvilienė, G. Januskeviciene (2004): Analyses of airborne contamination with Bacteria, Endotoxins and Dust in livestock barns and poultry houses. Acta. Vet. Brno 73: 283-289.
- Banhazi T. and J. Seedorf (2007): Airborne particles within Australian and German piggeries – What are the differences?. International Conference How to improve airquality. 23 - 24 April, Maastricht, the Netherlands.
- Bitog J.P., Lee I.-B., Hwang H.-S., Shin M.-H., Hong S.-W., Seo I.-H., Kwon K.-S., Mostafa E., Pang Z. (2012): Numerical simulation study of a tree windbreak. Biosystem Engineering Journal. 111: 40-48.
- Bitog J. P., Lee I.-B., Hwang H.-S., Shin M.-H., Hong S.-W., Seo I.-H., Mostafa E., Pang Z. (2011): A wind tunnel study on aerodynamic porosity and windbreak drag. Forest Science and technology. Vol (7):1, 8-16.
- Cox, C. S. und Wathes, C. M. (1995): Bioaerosols Handbook, Lewis Publishers, ISBN 087371-615-9.
- DFG (Deutsche Forschungsgemeinschaft) (2006): MAK- BAT-Werte-Liste 2006. Senatskommission zur Prüfung gesundheitsschädlicher Arbeitsstoffe, Mitteilung 42. Wiley-VCH Verlagsgesellschaft mbh, Weinheim, Deutschland.
- Ellen H. H., R.W. Bottcher, E. von Wachenfelt and H. Takai (2000): Dust levels and control methods in poultry houses. Journal of Agricultural Safety and Health 6(4).
- Eugenija Z., J. Mustajbegovic, E. N. Schachter, J. Kern, N. Rienzi, S. Goswami, Z. Marom and S. Maayani (1995): Respiratory function in poultry works and pharmacologic characterization of poultry dust extract. Environmental research 70: 11-19.
- GefStoffV (1999): Gefahrstoffverordnung vom 15.11.1999, BGBl. I S. 2233.

- Guarino M., A. Caroli and P. Navarotto (1999): Dust concentration and mortality distribution in an enclose laying house. *ASAE*. Vol.42(4):1127-1133.
- Gustafsson G. (1997): Investigations of factors affecting air pollutants in animal houses. *Ann Agric Environ Med* 4:203–215.
- Haeussermann A., E. Hartung, A. Costa, M. Guarino, E. Vranken, and D. Berckmans (2007): Estimate Particulate Emissions by Intermittent Measurements: A Feasibility Study. International Conference How to improve air quality. 23 - 24 April, Maastricht, the Netherlands.
- Hartung J. and M. Saleh (2007): Composition of dust and effects on animals. International – interdisciplinary – conference. Particulate matter in and from agriculture, 3-4 September, Braunschweig, Germany.
- Hessel E. F. and H. F. A. Van den Weghe (2007): Airborne Dust (PM10) concentration in broiler houses as a function of fattening day, time of the day, and indoor light. International Conference How to improve air quality. 23 - 24 April, Maastricht, the Netherlands.
- Hinz T., S. Linke, P. Bittner, J. Karlowski and T. Kolodziejczyk (2007): Measuring particle emissions in and from a polish cattle house. International – interdisciplinary – conference. Particulate matter in and from agriculture, 3-4 September, Braunschweig, Germany.
- Hölscher R. (2007): Nachrüstlösungen zur Emissionsminderung dezentral entlüfteter Stallungen zur Schweinemast. Dissertation. VDI-MEG-Schrift 446.
- ISO (1995): Air Quality - Particle Size Fraction Definitions for Health-related Sampling. ISO Standard 7708. International Organization for Standardization (ISO), Geneva.
- IUPAC (1990): Glossary of atmospheric chemistry terms. International Union of Pure and Applied Chemistry, Applied Chemistry Division, Commission on Atmospheric Chemistry. *Pure and Applied Chemistry* 62 (11):2167-2219.
- Iversen M., S. Kirychuk, H. Drost, L. Jacobson (2000): Human health effects of dust exposure in Animal confinement buildings. *Journal of Agricultural Safety and Health* 6(4): 283-288.
- Jay H.D., R. Zhang and H. Xin. (1994): Human health concerns livestock and poultry housing. National Poultry Waste Management Symposium, Athens, Georgia, October 31. July 1994, AEN-159.
- Kosch R., V. Siemers, H. Van den Weghe (2005): Efficiency of a bioscrubber system for the reduction of ammonia and dust emissions in a broiler house. *ASAE Annual International Meeting*, ASAE Tampa Convention Center Tampa, Florida.
- Lim T.T., A. J. Heber, J.-Q. Ni, J. X. Gallien, and H. Xin (2003): Air quality measurements at a laying hen house: particulate matter concentrations and emissions. Proceedings of the 12-15 October 2003 Conference (Research Triangle Park, North Carolina USA), Air Pollution from Agricultural Operations III, ASAE Publication Number 701P1403, ed. H. Keener. pp. 249-256.

- Mitchell B.W. (1997): Effect of airflow on ion distribution for potential dust reduction applications. *Journal of Agricultural Safety and Health* 3(2): 81-89.
- Mitchell B. W. and J. W. Baumgartner (2007): Electrostatic Space Charge System for Reducing Dust in Poultry Production Houses and the Hatchery. International Conference How to improve air quality. 23 - 24 April, Maastricht, the Netherlands.
- Mitchell B. W., L. J. Richardson, J. L. Wilson and C. L. Hofacre (2004): Application of an Electrostatic Space Charge System for Dust, Ammonia, and Pathogen Reduction in a Broiler Breeder House. Vol. 20(1): 87-93.
- Möller L. and M. Schmidt (2007): Advantages and limits of aerosol spectrometers for the particle size and particle quantity determination stables and air exhaust ducts. International – interdisciplinary – conference. Particulate matter in and from agriculture, 3-4 September, Braunschweig, Germany.
- Mostafa E., and Buescher W. (2011): Indoor air quality improvement from particle matters for laying hen poultry houses. *Biosystem Engineering journal*. 109 (1):22-36.
- Nannen C. and W. Büscher (2007) : Particle emissions from German livestock buildings - influences and fluctuation factors. International – interdisciplinary conference. Particulate matter in and from agriculture, 3-4 September, Braunschweig, Germany.
- Pedersen S., M. Nonnenmann, R. Rautiainen, T. G. M. Demmers, T. Banhazi and M. Lyngbye (2000): Dust in pig buildings. *Journal of Agricultural Safety and Health* 6(4): 261-274.
- Predicala B. Z. and R. G. Maghirang (2004): Measurement of particulate matter emission rates from mechanically ventilated. *ASAE Vol.* 47(2): 557-565.
- Redwine J. S., R. E. Lacey, S. Mukhtar, J. B. Carey (2002): Concentration and emissions of ammonia and particulate matter in tunnel-ventilated broiler houses under summer conditions in Texas. Vol. 45(4): 1101-1109.
- Reynolds S. J., D. Y. Chao, P. S. Thorne, P. Subramanian, P. F. Waldron, M. Selim, P. S. Whitten and W. J. Popendorf (1998): Field Comparison of methods for Evaluation of Vapor/Particle Phase Distribution of Ammonia in Livestock Buildings. *Journal of Agricultural Safety and Health* 4(2): 81-93.
- Robert W.B. (2001): An environmental nuisance: odour concentration and transported by dust. *Chem. Senses* 26: 327-331.
- Rosenthal E., W. Büscher and B. Diekmann (2007): Physical aspects of aerosol particle dispersion. International – interdisciplinary – conference. Particulate matter in and from agriculture, 3-4 September, Braunschweig, Germany.
- Rosentrater K. (2004): Laboratory analysis of an electrostatic dust collection system. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development*. Manuscript BC 03 008.
- Scheuermann, H. (2004): Persönliche Schutzmaßnahmen. In: *Luftgetragene biologische Belastungen und Infektionen am Arbeitsplatz Stall*. KTBL-Schrift 436, S. 194-199

- Schmitt-Pauksztat, G. (2006): Verfahren zur Bestimmung der Sedimentationsgeschwindigkeit von Stäuben und Festlegung partikelspezifischer Parameter für deren Ausbreitungssimulation. Dissertation. VDI-MEG-Schrift 440.
- Seedorf J. and J. Hartung (2000): Emission of airborne particulates from animal production. Workshop 4 on sustainable animal production, Hannover.
- Snell H.G.J. and A. Schwarz (2003): Development of an efficient bioscrubber system for the reduction of emissions. ASAE annual international meeting, ASAE, Las Vegas, Nevada, USA. 27-30 July.
- Takai H. (2007): Factors influencing dust reduction efficiency of spraying of oil-water mixtures in pig buildings. International Conference How to improve air quality. 23 - 24 April, Maastricht, the Netherlands.
- Takai H., K. Nekomoto, P. Dahl, E. Okamoto, S. Morita and S. Hoshiba (2002): Ammonia contents and desorption from dusts collected in livestock buildings. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development*. Manuscript BC 01 005. Vol. IV.
- Takai, H., S. Pedersen, J.O. Johnsen, J.H.M. Metz, P.W.G.G. Koerkamp, G.H. Uenk, V.R. Phillips, M.R. Holden, R.W. Sneath, J.L. Short, R.P. White, J. Hartung, J. Seedorf, M. Schroder, K.H. Linkert, and C.M. Wathes (1998): Concentrations and emissions of airborne dust in livestock buildings in Northern Europe. *J. Agric. Eng. Res.* 70(1): 59-77.
- TA-Luft (Technische Anleitung zur Reinhaltung der Luft) (2002): Erste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 24. Juli 2002, GMBI. 2002, Heft 25 – 29, S. 511-605
- Ullman J. L., S. Mukhtar, R. E. Lacey and J. B. Carey (2004): A Review of Literature Concerning Odours, Ammonia, and Dust from Broiler Production Facilities: 4. Remedial Management Practices. *Journal of Appl. Poult. Res.* 13:521–531
- VDI 2066, Blatt 1 (1975): Messen von Partikeln; Staubmessungen in strömenden Gasen; Gravimetrische Bestimmung der Staubbeladung; Übersicht, Beuth-Verlag, Berlin.
- VDI 2463, Blatt 1 (1999): Messen von Partikeln – Gravimetrische Bestimmung der Massenkonzentration von Partikeln in der Außenluft – Grundlagen, BeuthVerlag, Berlin.
- Wang X., Y. Zhang and G. L. Riskowski (1999a): Dust spatial distribution in a typical swine building. In *Proc. Int. Symposium on "Dust Control for Animal Production Facilities"*, Jatland, Denmark, 30 May–2 June 1999. pp: 48-55.
- Wang X., Y. Zhang, L. Y. Zhao, G. L. Riskowski (2000): Effect of ventilation rate on dust spatial distribution in mechanically ventilated airspace. *ASAE*, vol. 43(6): 1877-1884.
- Zhang Y., J. A. Polakow, Xinlei Wang, G.L. Riskowski, Y. Sun and S.E. Ford (2001): An aerodynamic deduster to reduce dust and gas emissions from ventilated livestock facilities. *Proceedings of the sixth international symposium*, 21-23 May (Louisville, Kentucky, USA) ASAE Publication Number 701P0201, eds. Richard R. Stowell, Ray Bucklin and Robert W. Bottcher. pp. 596-603.

- Zhang Y., Z. Tan and X. Wang (2005): Aerodynamic deduster technologies for removing dust and ammonia in air streams. Proceedings of the seventh international symposium, 18-20 May (Beijing, China) ASAE Publication Number 701P0205, ed.T. Brown-Brandl. pp. 224-229.
- Zhu Z., H. Dong, X. Tao and H. Xin (2005): Evaluation of airborne dust concentration and effectiveness of cooling fan with spraying misting systems in swine gestation houses. Proceedings of the seventh international symposium, 18-20 May (Beijing, China) ASAE Publication Number 701P0205, ed. T. Brown-Brandl. pp. 224-229.