International Commission of Agricultural Engineering
Commission Internationale du Génie Rural

AERIAL ENVIRONMENT IN ANIMAL HOUSING

Concentrations in and Emissions from Farm Buildings

Working Group Report Series No 94.1

AERIAL ENVIRONMENT IN ANIMAL HOUSING

Concentrations in and Emissions from Farm Buildings

Report of CIGR Working Group No 13
"Climatization and Environmental Control in Animal Housing"

CIGR Working Group Report Series No 94.1

Content

1 Preface

Encouraged by the importance and usefulness of an international working group the Board of Section II of CIGR (President Professor A. Jongebreur, The Netherlands) decided at the 1989 Congress in Dublin that the Working Group on "CLIMATIZATION IN ANIMAL HOUSES" should be renamed as CIGR Working Group No 13 on "CLIMATIZATION AND ENVIRONMENTAL CONTROL IN ANIMAL HOUSING". The topic for the next report was to be "AERIAL ENVIRONMENT IN ANIMAL HOUSING" with the subtitle "concentrations in and emissions from farm buildings". Dr Krister Sällvik, Sweden, was asked to continue as chairman for the Working Group and Ed van Ouwerkerk, The Netherlands, was asked to serve as Secretary.

1.1 Purpose and scope

The purpose and the objective of the third report is to provide both scientists and advanced advisers with information and basic facts about:

- production and dispersion of dust (airborne particles) and gases inside livestock buildings
- emissions of particles (pathogens excluded), gases and odour from livestock buildings to their surroundings. Emissions from storages of manure are excluded in this report.
- practical and useful measurement methods of measuring the contaminants
- effects of the contaminants on humans and animals
- methods to reduce indoor production, concentrations and emissions of contaminants

The report also aims to improve the consciousness of environmental responsibility within animal production. The report will not deal with animal comfort and engineering aspects of manure handling inside or outside the building.

The work by the Group is carried out in such a way that the Group as a whole has agreed upon specific problem areas. For each chapter it appointed the most qualified member in the Group to take the responsibility for collecting material and writing the chapter. However, subsections were also delegated to another person within the group. The group as a whole has discussed the content of the different chapters during the annual meetings where the progressing content has been presented. Also the final manuscript with corrected English has been approved by the members before printing the report. Consequently the Group as a whole will have a "multifactorial" responsibility for the report.

Each author or group of authors prepared the text and figures on disks. Then the material was collected by the secretary Ed van Ouwerkerk who also prepared the preliminary as well as the final manuscript. The English language was checked by Martin Sommer at CRB, Aberdeen. The printing of the report was sponsored and carried out by CEMAGREF with assistance from Philippe Marchal.

The revision of the first report was decided to be a separate matter since this Group did not have the proper competence. The revision should be a responsibility for the Chairman Krister Sällvik together with interested members of the original Working Group.

1.2 Members of the group

Each member from the previous Working Group on "CLIMATIZATION OF ANIMAL HOUSES" was invited to continue in the newly-established working group on "CLIMATIZATION AND ENVIRONMENTAL CONTROL IN ANIMAL HOUSING" working on a report on "AERIAL ENVIRONMENT IN ANIMAL HOUSING". Resigning members were asked to propose successors. Compared to the former Group, 9 out of 13 members are new. In order to enlarge the interests of the work, new countries were invited to join the Group. Finland was the only new country to join. The following persons have been members of the Working Group:

Member	Responsible for chapter #
Dr. Krister Sällvik, Sweden (chairman)	1; 2; 3; Summary
Ing. Ed van Ouwerkerk, The Netherlands (secretary)	4; 5.3-5.8
Prof. Hans-Friedrich Wolfermann, Germany	
Ir. Kees van 't Klooster, The Netherlands	5.2
Dr. Stéfano Guercini, Italy	
Dr. Irene Kollmann, Austria, 1989-1992	
Dr. Günther Schauberger, Austria, 1993-	4.3; 6.4
Mr. Lauri Tuunanen, Finland 1989-1993	
Mr. Philippe Marchal, France	
Mr. Jamie Robertson, Scotland	3.3; 7 (assistent)
Dr. Willy Jeksrud, Norway	5.3-5.8
Ing. Mireille Colanbeen, Belgium	4.3; 5.1; 6.1-6.3; 6.5-6.6
Dr. Søren Pedersen, Denmark	7 (main)

2 Summary of Report 1 and Report 2

2.1 The first report, 1984

In 1976 CIGR Section II (Farm Buildings), initiated a Working Group named CLIMATIZATION OF ANIMAL HOUSES. All together 14 different countries took part in the Working Group, where Dr M Rist, Switzerland was chairman and Dr K Sällvik, Sweden, secretary. The areas covered concerned important parameters when calculating heat, moisture and gas balances in livestock buildings during different outside and inside climatic conditions.

The First Report was to provide facts to calculate barn climate (temperature, humidity and CO_2) under different conditions such as type of animal, production level, insulation of the structure and outside climate.

The Working Group presented its First Report at the 10th CIGR Congress in Budapest, Hungary, 1984. The report was published by and can be ordered from:
The Centre for Rural Building, Scottish Agricultural College, Craibstone, Bucksburn, Aberdeen, AB2 9TR Scotland.

Content of the first report

The First Report on Climatization of Animal Houses consists of following chapters:

Fundamentals. Comparisons of expressions for total animal heat production used in different countries. Equations for lower critical temperature for cattle and pigs and CO_2 production.

Practical values. "CIGR-equations" for total heat animal production for cattle, sheep and goats, swine, horses, poultry (layers and broilers) and rabbits. Equation for the proportion between sensible and latent heat (non sensible) dissipation inside a livestock building at different temperatures. Recommended maximum and minimum relative humidity as a function of inside temperature.

CIGR recommendations for maximum concentrations of noxious gases in animal houses Recommendations are given for NH_3, CO_2, H_2S and CO.

Outside temperature and relative humidity. Climatological statistics with probabilities for low and high temperatures from following European countries are presented; A, B, CH, D, DK, F, I, N, NL, S, UK.

Heat losses through the structure. Values for inside and outside surface resistance for different building parts in different countries. Method of calculating heat loss through the floor. General expression for heat losses through the structure.

Ventilation calculation methods. Physical properties of air and CO_2. Formulas to determine air flow based on enthalpy-, heat-, CO_2- and moisture balance respectively. Examples from pig and broiler houses.

Adaptation of the CIGR recommendations into national standards or recommendations and updating of basic equations

In the working group the representative for a certain country has no official authority to approve or disapprove the proposed standard. The utilisation of the "CIGR-Standard" is a matter for the responsible board or authority in each country. In many countries (Austria, Denmark, Sweden, Norway) and in the DIN-Norm (Germany) the CIGR standard has been adopted to a very large extent. The report has also been translated into French.

The updating of equations and data in the First Report will be done, it is hoped, in a special revised version of the First Report.

2.2 The second Report, 1989/1992 - 2nd and revised edition

The aim of the work for the Second Report was to cover the more practical aspects of climatization systems in livestock buildings. The work was carried out between 1984 and 1992. Chairman of the group of 11 countries was Dr K Sällvik, Sweden and secretary was Dr. ir. J P A Christiaens, Belgium.

The report contains basic information which is considered necessary for advisors in public service and in private companies. Since completeness cannot be achieved in this matter the recommendations or statements in the report are the responsibility of the author(s) of each of the 8 chapters.
The report was presented at the 11th CIGR Congress in Dublin 1989. The report is published by and can be ordered from:
The "Centre for Climatization of Animal Houses" (IWONL), Faculty of Agricultural Sciences, State University of Gent, B-9000 GENT (Belgium).

Contents of the Second Report

Modelling the heat balance of pigs at animal and housing levels
E N J van Ouwerkerk, The Netherlands

Based on a computerised model of the heat balance of pigs and ventilation, different thermal factors in the environment can be evaluated with regard to animal comfort and well-being. The critical temperatures are given particular examination.

Moisture production and correction factors for sensible heat
S Pedersen, Denmark

In the First Report it was mentioned that the equation giving the proportion between sensible and latent heat as a function of temperature was not accurate for all species and temperatures. A table with provisional correction factors for the sensible heat loss was therefore introduced. The correction factor varied between 1.0 to 0.8 depending on application to cattle or pigs, dry or wet feed and floor type. Basic research on animal heat balance shows it is necessary to take into account production level (e. g. feed energy intake) and the physical laws for heat transfer in- and outside the animal when estimating the proportion between latent and sensible heat dissipation. It is suggested that the original

CIGR equation should be adjusted with a term containing the lower critical temperature for the actual animal and its production level.

Design of ventilation systems
K Sällvik, Sweden
H Bartussek, Austria (Calculation of natural ventilation)

A brief review of main aspects for consideration when designing a ventilation system: biological-technical-climatic-economical.
A comparison between under-, over- and neutral-pressure systems concluded that:
- during winter either equal- or under-pressure system is the best system
- during summer equal or over pressure should be preferred getting higher air velocities inside to relief animal from heat stress and/or to ensure air distribution when windows or doors are open.

Incoming air may be characterized by physical properties such as air velocity and temperature profile in the jet. Equations can be used to describe these factors as well as the jet projection and the comfort parameters at animal level.

Air inlets and fans are discussed form the aspects of the relationship between flow and pressure drop and also by their influences on the thermal environment. Air inlets in particular are examined and characterised according to their effect on recirculating inside air and air inlet velocity. Entrance velocities below 0.2 m/s (i.e. porous ceiling) having no influence on air movements in the barn. Special attention is given to how to design and locate outlets to avoid or diminish contamination of the interior air by manure gases. A calculation method for exhausting ducts for manure gas exhausting are presented.

For natural ventilation, both theoretical and practical expressions are presented for stack effect (winter) and wind effect (summer). An example is given for an insulated barn for 200 fattening pigs resulting in inlet area=outlet area=12.3 m^2.

Minimum ventilation problems in confined animal rooms
H Lilleng, Norway

The consequences of too high a minimum ventilation rate are analysed as are the causes i.e. leakages through a non-airtight construction reinforced by wind and thermal buoyancy, and air infiltration. The importance of installing adequate sizes of fan and using an appropriate control method is pointed out.

Energy recovery in animal houses
M Rist, Switzerland

Different types of air to air heat exchangers are analysed with respect to different types of efficiency e.g. enthalpy and temperature. The energy efficiency will remain constant at 34% while the temperature effectiveness will decrease by increased air flow, assuming constant "delta T". Increasing the temperature difference will increase heating capacity: however, freezing will occur as soon as outside temperature is below -10°C. For a heat pump, the coefficient of performance, COP, is presented for a winter period.

Cooling in animal houses
U Chiappini, Italy & J P A Christiaens, Belgium

The thermal requirements for different animals are reviewed. Means of cooling in livestock buildings are presented e.g. evaporative cooling, cooling air in underground pipes and cooling by showers.

Ventilation and heating control in animal houses
J P A Christiaens, Belgium

The theoretical considerations regarding characteristics of the house and the control equipment (e.g. proportional, "three point" and controls for heating especially floor heating) as discussed.

Dust and gases
S Pedersen, Denmark

Practical methods for measuring dust and gases are reviewed. The filter method for dust and the detection tube for gases are still used the most. Results from dust measurements in different countries:
-Pig houses, farrowing: 1.4 - 1.8 mg/m^3
-Pig houses, finishing: 0.8 - 10 mg/m^3
-Houses for laying hens, battery: 1.5 mg/m^3
-Houses for laying hens, floor housing: 6 - 40 mg/m^3

Practical methods for reduction of indoor dust are reviewed and some results given:
Ionisation: depending of concentration of ions and fraction of the dust, gives 10% and 30% reduction of total and respirable dust respectively.
Electrofilter: the air flow through the filter should be equal or greater than the air flow by ventilation to get a reasonable dust reduction.
Oil spraying: gives a reduction to 10 - 50%; the most effective method.

Information on the influence of dust and gases on the health of both animals and humans and the CIGR recommendations for maximum gas concentrations are given. Notably, the prevalence of asthma and bronchitis is doubled for pig farmers as compared to dairy farmers.

Results from *ammonia measurements* in different countries:
- Pig houses, farrowing: 6 - 40 ppm
- Pig houses, finishing: 2 - 50 ppm
- Houses for laying hens: 1 - 50 ppm
- Houses for cattle: 0 - 25 ppm

3 General effects of aerial contaminants

Emissions in and from livestock buildings must be identified and analyzed with regard to potential detrimental or hazardous effects on the atmosphere, man, animals, buildings and environment. It is also important to describe the theory behind the causes and the effects of the contaminants. The emissions being dealt with in this report are categorised as gases, odour, airborne particles and noise but the report also considers the synergetic effects between different compounds.

The individual factors which constitute a problem can seldom be considered in isolation. Any problem should be viewed as part of a complex system, and can often be addressed by analysis of that system using circulation and mass balance models. Analysis of the system model also reduces the possibility of simply converting a problem at one stage in the production cycle to another different problem. A major strategy in all cases should be to minimise the source of emissions, e.g. feed composition and manure handling system.

Some of the emissions from livestock housing become integrated with the complex mix of natural and man-made gases which make up the lower atmosphere. Some of these complex reactions are considered to have negative influence on atmospheric stability by contributing to the acid rain cycle and the so called "greenhouse effect". Since animal production is global and atmosphere knows no borders, the various problems should be solved from an international perspective.

Emissions from livestock buildings can cause problems at a local level, especially where the traditional rural community and the urban population are in close proximity. Present farming systems have to consider the movement of people into the rural spaces for recreation and housing, and the concerns of those people. However, the analysis of both problems and available solutions may well have different requirements in different countries.

3.1 Effects on the environment

Vegetation, soil, surface and ground water are directly affected by ammonia emissions from animal production units. 80% of ammonia to the atmosphere originates from agriculture. Simple calculations by Ferm & Grennfelt (1986) show that an important fraction of ammonia emitted from farming is deposited within a distance of 100 km from the source. Long distance transport of ammonia as a gas is never observed, but that is more likely to occur as ammonium.

Nitrogen in the form of ammonia or ammonium is an important nutrient in nature, affecting many biological processes, directly or indirectly. At low levels nitrogen will have a growth stimulating effect on plants, fungi and micro-organisms. Nitrogen will also change soil processes and partly influence the competition between organisms. High deposition of nitrogen oxides and ammonium contribute, together with SO_2 and volatile organic compounds, to an acidification of both soil and water. The soil effects can be attributed to a change in the nutrient balance between nitrogen and other important nutrients. This enrichment of soil and water contribute to eutrophication (changes in the vegetation due to increased availability of nitrogen).

The effects of emissions of particulates from livestock buildings are predominantly restricted to the immediate environment around the buildings. Most particulates are precipitated on the surrounding structures and vegetation, and the effect is usually confined to a general unsightly visual impact and a possible negative effect on hygiene. However, some particles, including pathogens, can travel considerable distances and there is circumstantial evidence that pathogenic bacteria may remain viable over a distance of 3km. (Goodwin, 1985)

3.2 Effects on animals

The effect on animals of the actual emissions or compounds are described in each chapter. Many of the effects will be multifactorial in origin and direct relationships between air quality factors and animal health can be difficult to measure. There is, however, substantial evidence to show that some gases and particulates have a negative effect on the health and productivity of animals. As a general strategy, production techniques should aim to reduce exposure to aerial contaminants to the lowest practical level.

The possibility of an interaction between air quality and livestock health is related to the systems of animal production in use. Many modern production systems involve genetically similar animals under considerable environmental pressure, characterised by high stocking densities, high physiological growth rates and social pressures. The opportunity for disease transmission is high, and any environmental pressure which may compromise the immune status of livestock can be considered a production problem (Kelley, 1985)

The evolution of current production methods has concentrated on maximising output from each unit of input. One effect of this has been engagement in methods for which the primary measures of output, such as growth rate, are well researched, but where secondary effects are not well understood. The effects of gases and dusts arising from intensive husbandry methods are a good example of secondary production problems.

The practical constraints of any production method have to be a primary consideration when approaching the general production problem of air quality in livestock housing. Methods vary substantially both within and between countries. Climate will influence available food and bedding materials available, and their quality. The duration of housing and design of individual buildings will depend to some extent on the range of climatic conditions in an area. Design criteria related to climate are available for many countries. Examples of outside temperatures and humidity from different European countries are given in the CIGR report "Climatization of Animal Houses, 1984".

3.3 Effects on humans

The Report considers the effect on humans from two aspects; firstly the effect of aerial factors on persons within a building, and secondly the effects on those living nearby. Persons working in livestock buildings are exposed to a complex mixture of aerial contaminants, and some can develop respiratory problems. Typical problems include hypersensitivity, pneumonitis, chronic bronchitis, acute inflammation, occupational asthma and toxin fever (Donham, 1978; Rylander,1986). Exposure to gases has a variety of negative effects, from mild irritation of the respiratory tract through to death. Exposure to hydrogen sulphide gas from slurry handling operations can be lethal (Donham et al., 1982) Medical problems occur significant more frequently in people managing liquid manure as compared to those who manage solid manure (Ruth, 1987).

The general philosophy towards reducing the risk of harm from aerial contaminants is to reduce exposure. Exposure can be reduced or eliminated, depending on the strategy applied. The first consideration is to eliminate or reduce the production of the contaminant at source. Thereafter the application of engineering control methods or changes to work practice which will reduce exposure should be considered. The final approach has to be the provision of protective clothing and equipment which is suitable for the contaminants present. However, although the use of protective clothing is a common and apparently low-cost solution it makes no acknowledgement of the exposure problems of the livestock or the problems created by emissions.

The exposure to odour, dust and noise from livestock buildings by persons living nearby must not be ignored by the agricultural industry. Some people exposed to these factors suffer severe irritation and may suffer psychologically. The increased interest in and application of legislation which oversees emissions is evidence of popular concern about agricultural pollution. In some countries legislation is being invoked which places on any business which produces emissions a requirement to assess the concentration of those emissions and to reduce them to acceptable levels.

The following chapters of the Report attempt to describe current knowledge on the production, behaviour and effects of the main air quality factors in livestock buildings, with a view to reducing some of the problems which have evolved with modern production techniques. The problems and the potential solutions are varied and concern many contributory factors, and new factors may emerge. The current interest in animal production systems which address animal welfare may produce unwelcome new problems in terms of air quality, whilst environmental concerns will produce new production constraints. The agricultural engineer is well placed to understand and provide solutions to these problems. This report deals with the effect on humans from two aspects

- working inside a livestock building
- living close to a livestock building.

Humans exposed to gases and air pollutants can develop allergic reactions or respiratory diseases (Iversen & Takai, 1980) and suffer from direct toxic effects, sometimes at lethal levels. People exposed to odour and noise from livestock buildings may suffer (psychologically) and their situation should be taken seriously and precautions taken.

References

Donham, K.J., 1978. Respiratory hazards of livestock confinement workers. Proc. VII Int. Conference of Rural Medicine. Salt Lake City, Utah, p. 224-234.

Donham, K.J., L.W. Knapp, R. Monson & K. Gustafsson, 1982. Acute toxic exposure to gases from liquid manure. J of Occupational Medicine 24(2): 142-145.

Ferm, M. & P. Grennfelt, 1986. Atmosfärisk transport och deposition av ammoniak (in Swedish). Statens Naturvårdsverk Rapport 3188, Solna.

Goodwin, R.F.W., 1985. Apparent reinfection of enzootic pneumonia free pig herds: Search for possible causes. Veterinary Record 116: 690-694.

Iversen, M. & H. Takai, 1980. Lung function studies in farmers during work in swine confinement units. Zentralblatt für Arbeitsmedizin, Arbeitsschutz Prophylaxe und Ergonomie, 40 (1980), p. 236-242.

Ruth, W., 1987. Felplanerade arbetslokaler och val av arbetsmetod som orsak till svavelväteförgiftning vid flytgödselhantering (in Swedish). Forskningsrapport TULEA 187:19.

Rylander, R., 1986. Lung disease caused by organic dusts in the farm environment. American J. of Industrial Medicine 10: 221-227.

4 Air flow, air flow patterns, measurements and theory

4.1 Introduction

Air movements in livestock buildings are caused by pressure differences, which are initiated by sources such as animal heat production, cold structure surfaces and in some circumstances, heaters and external wind. Air movements are also created by incoming air jets from the inlets. The influence of exhaust openings on air movements in a free air space is limited to about two diameters from the opening.

The aim of the air distribution in a ventilation system is to obtain a good thermal and gaseous environment for the animals. Thermal environment includes both air temperature and air velocity. In winter, the incoming air will "drop" easily from a baffled inlet, whereas in summer the jet will have a very long throw. Randall, 1975 and Sällvik, 1979, give some guidelines for prediction of air flow patterns in livestock buildings.

When trying to obtain a desired airflow pattern under different outside temperatures, i.e. with a difference between temperatures inside and outside the building, Δt, the system imposes restrictions on what is obtainable. The airflow rate, normally based on heat balance, "cooling", through the building, is a function of Δt. In systems with exhaust ventilation with no recirculation of inside air, the air velocity in the inlet is a function of Δt. The velocity of the incoming air and the impulse of the incoming jet are effected by adjustment of opening and inlet characteristics. Since inlets must be evenly distributed and the pressure drop cannot exceed 20 Pa, inlet air velocity is restricted to a maximum of about 3 m/s when Δt exceeds 15°C. Consequently it is not possible with a baffled inlet to maintain a stable airflow pattern during all seasons (Sällvik, 1979).

Randall and Battams (1979) conclude that stable air flow patterns exist when the Archimedes number (ratio depending on buoyancy and dynamic pressure) is less than 30 or greater than 75. Intermediate values should be avoided to prevent unstable patterns and unstable environmental conditions near the animals. The Archimedes number has been shown useful to predict airflow pattern stability in some instances (Leonard et al., 1986), however, research has not yet proven the Archimedes number to be a useful criterion for airflow pattern stability in animal housing ventilated by slotted inlets (Albright, 1990). Berckmans et al. (1992) and Zhang et al. (1993) modelled airflow patterns for imperfect mixed ventilation control in livestock buildings using physical laws. Obstructions in air streams mostly influence main airflow direction (King et al., 1972; Randall & Battams, 1976; Choi & Albright, 1988).

Numerical models using finite-volume solution (Patankar, 1980) and k-ε models are being developed to predict air flow patterns in livestock buildings for temperature distribution and air speeds (Timmons et al., 1980; Christensen, 1993; Van Ouwerkerk et al., 1994), for contaminant distribution (Janssen & Krause, 1988; De Praetere & Van der Biest, 1990; Hoff & Bundy, 1993) or for particle transport (Maghirang & Manbeck, 1993).
In calculations and simulations the value of the coefficient of discharge (Wilson et al., 1983) at inlet openings (Klooster, van 't & van 't Ooster, 1993), porous ceilings and

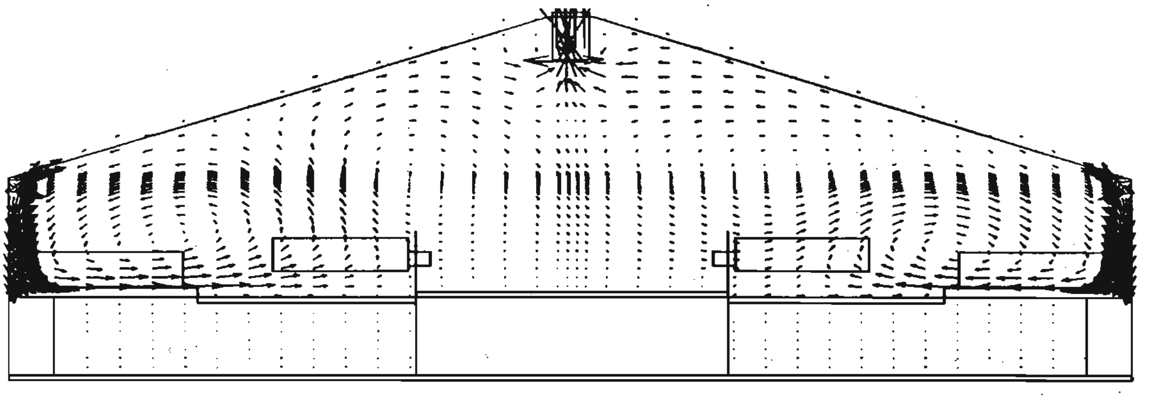

Figure 4.1 Example of airflow pattern of a mechanically ventilated dairy building with slatted floor and large manure pits in winter, derived from numerical simulation

slatted floors (Schulte et al., 1972; Yu et al., 1991) is of major concern for the results of the prediction of airflow patterns.
For three-dimensional, non-isothermal conditions with living animals in realistic situations, these models are still in the development stage and not yet widely available as a design tool.

4.2 Inside buildings

Visualisation of air flow patterns

The visualization of air flow patterns is an important and often essential step before any measurements of gas concentration, temperature or air speed in the house are made. It is impractical to measure at every point, and measurements are often limited to average, minimum and maximum values of relevant parameters at locations near the animals. In finding the locations with minimum and maximum values, it is highly advantageous to know the air flow pattern. The air flow pattern can be found either by measuring the air speeds and air temperatures or by mixing smoke with air. The temperature of the smoke should be close to the air temperature so as to avoid thermal effects on the air flow pattern. When introducing smoke it is important that the smoke is in the inlet stream and directed perpendicular to the inlet flow, in order to avoid the smoke influencing the air jet. Another problem that can be made visible with smoke is the air flow beneath the slats in animal buildings. When such air flows pass through the slots, they may carry high concentrations of ammonia and other gases to the farm animals' environment.

A commercially available type of smoke device is the "Minimist". Other possibilities are the use of smoking powder, the use of titanium tetrachloride liquid or the combination of ammonia and sulphuric acid. They create some health risks for the operators. Smoke pots as used in beekeeping, although cheap, are difficult to control and may release sparks and create fire risks. For very local measurements of air flow patterns, small smoke generating tubes are available. Suppliers include Dräger. Smoke tests can also be used to establish the air leakage of a building by introducing large amounts of smoke to places that may be leaking. Another technique that can be useful is the use of an infra-red scanner which visualizes the temperature profile in the building: this technique is however more expensive.

Measuring exhaust air flow

The ventilation rate in a building is normally controlled at the exhausts. The air distribution pattern is influenced by the ventilation rate. For a stable air flow pattern in the building it is important therefore to be able to control the ventilation rate. For the control ventilation rate and estimating emissions form the building it may be necessary to measure the ventilation rate. For on-line measurement of ventilation rates there are several techniques available. In mechanically ventilated livestock buildings the measurement of fan speed gives an indication of the ventilation rate, but unless the exact pressure difference over the fan is known, no accurate measurement of the ventilation rate is possible. A full size anemometer in the exhaust chimney can measure the ventilation rate (Berckmans et al., 1991), provided cylindrical chimneys are used and the pressure gradient is always in the same direction parallel to the axis of the chimney. In buildings with natural ventilation it is not possible to measure directly the air speed because of the large openings and low air speeds. Indirect methods include measuring the carbon dioxide balance of the house, which may be used when the carbon dioxide production of animals and manure is known (Feddes et al., 1984; Ouwerkerk, van & Pedersen, 1994; Klooster, van 't & Heitlager, 1994). Other alternatives that are currently under investigation include a heat balance, the use of tracer gas, or measuring pressure gradients, where the resistance coefficients of openings must be known (Ooster, van 't, 1994; Heiden-de Vos, van der, et al., 1994; Scholtens & van 't Ooster, 1994).
For occasional measurements of air speeds (and ventilation rates) several types of instruments are available. For measurement of low air speeds (0.1 m/s and upwards) the use of thermal or hot-wire anemometers is recommended. The direction of the air speed is normally not measured, although a thin thread attached to the probe is quite helpful, but special versions of these instruments are available at considerable cost, that can measure the air direction as well as the speed. Cup anemometers and small propeller anemometers are suitable for measuring airspeeds at inlets and outlets. They measure from above 0.2 up to 2.0 m/s depending on type. Pitot tubes are not recommended in livestock buildings. Measurement of the pressure difference as an indicator of ventilation rate with inductive, capacitive, piezo-electrical sensors or with strain gauges are (still) not very suited for the rough and dusty conditions in livestock buildings that are combined with small pressure gradients.

4.3 Outside buildings

The air flow pattern outside a livestock building, as caused by the location of ventilation exhausts, follows the same physical laws as in the house, but is mainly influenced by mass flow, temperature and direction of the exhaust flow and by the ambient meteorological conditions. This dispersion process is important in studying the effects of offensive odours released from the building to the immediate surroundings. In chapter 6 (odour), methods are given to predict or calculate the dispersion. One practical method to reduce the nuisance caused by noise and odour is to use vertical exhaust chimneys positioned as high as possible and create high air speeds in the exhaust chimneys. The noise and odour levels will be considerably reduced at the perception point. The exhaust point could also be moved to the corner of the building that is opposite to adjacent human habitation. In extreme cases it is even possible to locate the exhaust point of mechanically ventilated buildings at a distance from the building, but this requires additional investment and consumes more energy.

Turbulence processes are the main driving forces for the dispersion and dilution of gaseous pollutants. A certain emission will be dispersed in the atmosphere, depending upon some well-known meteorological parameters, such as wind-velocity and wind-direction. But another important factor is the stability of the atmosphere : the greater this stability, the more dispersion will be prevented. Several authors (Pasquill, 1974 ; Turner, 1974; Klug, 1966) have created their own stability categories, depending upon different meteorological parameters. In the Centre for Nuclear Research in Belgium the mean vertical temperature gradient (± 1.0 °C/100 m) and the wind velocity are used to obtain seven stability classes (Bultynck et al., 1970).
Trying to predict possible air pollution assumes knowledge of all these factors that lead to a certain concentration of those gases which may be annoying or even harmful. The aim of dispersion models is to develop reliable methods for calculating the atmospheric dilution of pollutants in order to prevent or avoid nuisance. The formula used to predict a certain concentration is a solution of Fick's differential equation for dispersion:

$$\frac{dC}{dt} = K \left[\frac{\delta^2 C}{\delta x^2} + \frac{\delta^2 C}{\delta y^2} + \frac{\delta^2 C}{\delta z^2}\right]$$

where:

C	=	concentration (odour units/m^3)
t	=	time (s)
x, y, z	=	coordinates
K	=	coefficient of turbulent diffusion

A possible solution of this equation is given by the so-called Bi-Gaussian plume-model which is often used to describe or to evaluate the atmospheric dispersion. Any odour discharged into the atmosphere is carried along by the wind and diluted by the turbulence which is always present in the atmosphere. Due to dispersion a plume of polluted air is produced which is roughly shaped with the apex toward the source.

$$C(x,y,z;H) = \frac{Q}{2\pi \bar{u}\sigma_y\sigma_z} \cdot e^{\frac{-y^2}{2\sigma_y^2}} \cdot e^{-\frac{(z-H)^2}{2\sigma_z^2}} + \rho \cdot e^{-\frac{(z+H)^2}{2\sigma_z^2}}$$

where:

C	=	concentration (o.u. /m³)
Q	=	odour emission rate (odour units/s)
$\bar{u}$	=	wind-velocity (m/s)
x	=	horizontal distance from source in the wind-direction (m)
y	=	horizontal distance across the source (m)
z	=	vertical distance from the source (m)
σ_y	=	horizontal coefficient of dispersion (m)
σ_z	=	vertical coefficient of dispersion (m)
H	=	effective emission-height (h + Δh) (m)
ρ	=	coefficient of reflection (0->1).

For the two coefficients of dispersion σ_y and σ_z different schemes are in use. For a rural environment some of these schemes were compared by Carrascal et al. (1993). Most of the parameters for calculating both coefficients are defined for a distance greater than 100 to 150 m approximately. Therefore the concentration C cannot be calculated for the area between this distance and the source.

For this area, the diffusion close to a building, the concentration can be estimated by following equation:

$$C = \frac{K\,Q}{u\,l^2}$$

where C is local concentration, K is a dimensionless concentration coefficient depending on the distance to the source and the geometric situation (source, building), Q is the source strength, u is wind speed at a reference level and l is the distance from the source measured along the axis of the plume. Briggs (1973) used a coefficient K=4 for his approximation, whereas Scorer and Barret (1962) used a value K=2.

Meroney (1982) gives a good overview of the concentration field produced by a source in the vicinity of a building.

For larger distances (> 10 - 15 km) wet deposition and chemical reactions change the concentration of observed pollution.

The calculation of the coefficient of reflection is described in VDI 3782 Part 1 (1992). By using this factor sedimentation and deposition is taken into account to guarantee mass conservation in the plume model.

The equation of the Gaussian plume distribution can be simplified to give the concentration at ground level i.e. $z = 0$ and taking full reflection ($\rho = 1$) into account :
This Gaussian model supposes that the concentration of a gaseous compound is normally

$$C\ (x,y,0;H) = \frac{Q}{2\ \pi\ \bar{u}\ \sigma_y\ \sigma_z} \cdot e^{\frac{-y^2}{2\sigma_y^2}} \cdot e^{\frac{-H^2}{2\sigma_y^2}}$$

distributed in the horizontal and vertical direction around the average value. The formula is used for point-sources, but in many cases the source itself is rather line-shaped. In this case the above equation is modified :

$$C\ (x,0,z;H) = \frac{Q}{(2\ \pi)^{0.5}\ \bar{u}\ \sigma_z} \cdot [\ e^{-\frac{(z-H)^2}{2\sigma_y^2}} + e^{-\frac{(z+H)^2}{2\sigma_y^2}}]$$

The line source is considered to be along the y axis and of infinitite length. The direction of the wind is perpendicular to this line source. This equation can be simplified to give the concentration at ground level from a linear source, i.e.
z = 0 (Carney & Dodd, 1989) :

$$C\ (x,0,z;H) = (\frac{2}{\pi})^{0.5} \cdot \frac{Q}{\sigma\ \bar{u}} \cdot e^{-\frac{H^2}{2\sigma_z^2}}$$

Carney & Dodd (1989) state that when the odour is dispersed from an area (e.g. a field spread with slurry) the linear model gives good agreement with the experimental values if the model is used with an effective width of 10 m. However, it is not suggested that this effective width of 10 m will hold true in all cases.
In general, the prediction of concentrations of different gases will be possible using above mentioned theory. So it is possible to identify the area of land likely to be affected by malodours from a proposed livestock building (Carney & Dodd, 1989). Nevertheless it is possible to obtain results that do not agree 100 % with the real situation.

References

Albright, L.D., 1990. Environment control for animals and plants. ASAE, St. Joseph, Michigan.

Barber, E.M. & J.R. Ogilvie, 1982. Incomplete mixing in ventilated airspaces. Part I. Theoretical considerations. Canadian Agricultural Engineering 24 (1), pp. 25-29.

Barber, E.M. & J.R. Ogilvie, 1984. Incomplete mixing in ventilated airspaces. Part II. Scale model study. Canadian Aricultural Engineering 26 (2), pp. 186-196.

Berckmans, D., Ph. Vandenbroeck & V. Goedseels, 1991. Sensor for continuous measurement of the ventilation rate in livestock buildings. Indoor Air 3:323-336.

Berckmans, D. M. de Moor & V. Goedseels, 1992. Modelling the air flow pattern in livestock buildings. AgENG 1992 Int. Conf. paper 9202111, Uppsala.

Briggs, G.A., 1973. Diffusion estimation for small emissions. ATDL Contribution File No. 79, NOAA, Oak Ridge, Tennessee.

Bultynck, H., L. Malet, L.N. Sharma & J. van der Parren, 1970. Atmospheric dilution factors and calculation of doses in the environment of SCK/CEN Mol for short and long duration stock discharges. SCK-reports BLG 434 and BLG 446.

Carney, P.G. & V.A. Dodd, 1989. A comparison between predicted and measured values for the dispersion of malodours from slurry. J. agric. Engng. Res.44:67-76.

Carrascal, M.D., M. Puigcerver & P. Puig, 1993. Sensitivity of Gaussian plume model to dispersion specification. Theor. Appl. Climatol. 48, 147-157.

Choi, H.L. & L.D. Albright, 1988. Modelling effects of obstructions in slot-ventilated enclosures. In: Chistianson, L.L. (ed.), Building System: Room Air and Air Contaminant Distribution, ASHRAE, pp. 127-130.

Christensen, K.S., 1993. Numerical prediction of buoyant air flow in livestock buildings. In: E. Collins & C. Boon (eds.), Proceedings Livestock Environment IV, ASAE, St. Joseph, Michigan.

Feddes, J.J.R., J.J. Leonard & J.B. McQuitty, 1984. Carbon dioxide concentration as a measure of air exchange in animal housing. Canadian Agricultural Engineering, vol. 26, no. 1, p 53-56.
Heiden-de Vos, J.J.C. van der, R. Scholtens & A. van 't Ooster, 1994. Mass balance methods for measuring ventilation rates and ammonia emission from naturally ventilated livestock houses. Poster XII CIGR World Congress and AgEng'94 Conference on Agricultural Engineering, Milan, Italy.
Hoff, S.J. & D.S. Bundy, 1993. Comparison of contaminant dispersion modelling approaches for swine housing. In: Collins, E. & C. Boon (eds.), Proceedings Livestock Environment IV, ASAE, St. Joseph, Michigan.
Janssen, J. & K.-H. Krause, 1988. Numerical simulation of airflow in mechanically ventilated animal houses. Proceedings of the ASHRAE Conference: Building systems: room air and air contaminant distribution (L.L. Christianson, editor), Dec. 5-8, 1988, p. 131-135.
King, F.C., G.M. White & J.N. Walker, 1972. The effect of surface obstructions on air wall jets. Transactions of the ASAE, pp. 361-365.
Klooster, C.E. van 't & A. van 't Ooster, 1993. Ventilation openings efficiency for pig houses with natural ventilation. In: E. Collins & C. Boon (eds.), Proceedings Livestock Environment IV, ASAE, St. Joseph, Michigan.
Klooster, C.E. van 't & B.P. Heitlager, 1994. Determination of minimum ventilation rate in pig houses with natural ventilation based in carbon dioxide balance. J. agric. Engng Res. 57: 279-287.
Klug, W., 1966. Ein Verfahren zur Bestimmung der Ausbreitungsbedingungen aus synoptischen Beobachtungen. Staub - Reinhalt - Luft 29, 4: 143-147.
Lam, C.K.J. & K.A. Bremhorst, 1981. Modified form of the k-e model for predicting wall turbulence. J. of Fluids Eng., 103, p. 456-460.
Leonard, J.J. & J.B. McQuitty, 1986. The use of Archimedes Number in the design of ventilation systems for animal housing. Conf. on Agric. Engng, Adelaide, Aug. 24-28, 1986.
Maghirang, R.G. & H.B. Manbeck, 1993. Modelling particle transport in slot-inlet ventilated airspaces. Transactions of the ASAE, Vol. 36(5):1449-1459.
Ooster, A. van 't, 1994. Using natural ventilation theory and dynamic heat balance modelling for real time prediction of ventilation rates in naturally ventilated livestock houses. Paper XII CIGR World Congress and AgEng'94 Conference on Agricultural Engineering, Milan, Italy.
Ouwerkerk, E.N.J. van, J.P. Voskamp & Y. Aliskan, 1994. Climate simulation and validation in an aviary system for laying hens. Paper XII CIGR World Congress and AgEng '94 Conference on Agricultural Engineering, Milan.
Ouwerkerk, E.N.J. van & S. Pedersen, 1994. Application of the carbon dioxide mass balance method to evaluate ventilation rates in livestock buildings. XII World Congress on Agricultural Engineering, Milano, August 29 - September 1, Proceedings, p. 516-529.
Pasquill, F., 1974. Atmospheric diffusion. Wiley, New York.
Patankar, S.V., 1980. Numerical heat transfer and fluid flow. Hemisphere Publishing, New York.
Praetere, K. de & W. van der Biest, 1990. Airflow patterns in piggeries with fully slatted floors and their effect on ammonia distribution. J. agric. Engng. Res. 46:31-44.
Randall, J.M., 1975. The prediction of airflow patterns in livestock buildings. J. of Agric. Engng. Res. 20:199-215.
Randall, J.M. & V.A. Battams, 1979. Stability criteria for airflow patterns in livestock buildings. Agric. Engng. Res. 24:361-374.
Randall, J.M. & V.A. Battams, 1976. The observed influence of surface obstructions on the airflow pattern within livestock buildings. Agric. Engng. Res. 21:33-39.
Sallvik, K., 1979. Principles for mechanical exhaust ventilation systems in animal houses. Swedish University of Agriculture Sciences, Dept. of Farm Buildings, Lund, Report No.8.
Scholtens, R. & A. van 't Ooster, 1994. Performance and accuracy of methods for measuring natural ventilation rates and ammonia emission. Poster XII CIGR World Congress and AgEng '94 Conference on Agricultural Engineering, Milan, Italy.
Schulte, D.D., J.A. DeShazer & C.N. Ifradi, 1972. Effect of slotted floors on airflow characteristics in a model swine confinement building. Transactions of the ASAE 1972, 947-950.
Scorer, R.S. & C.F. Barrett, 1992. Gaseous pollution from chimneys. Int.J. Air Wat.Pol. 6, 49-63.
Timmons, M.B., L.D. Albright, R.B. Furry & K.E. Torrance, 1980. Experimental and numerical study of air movement in slot-ventilated enclosures. ASHRAE Transactions, Vol. 86, Part 1, pp. 221-240.

Turner, D.B., 1974. Wordbook of atmospheric dispersion estimates - Washington. Department of Health, Education and Welfare.

VDI 3782 Part 1, 1982. Gaussian dispersion model for air quality management. Beuth Verlag, Berlin.

Wilson, J.D., L.D. Albright & J.N. Walker, 1983. Ventilation air distribution. In: Hellickson, M.A. & J.A. Walker (eds.), Ventilation of agricultural structures, ASAE monograph no. 6, St. Joseph, Michigan.

Yu, L., C. Zhang & E.M. Barber, 1991. Measuring air exchange through slotted floors. ASAE Paper 91-4550, St. Joseph, Michigan.

Zhang, G., S. Morsing & J.S. Strom, 1993. An airflow pattern control algorithm for livestock buildings. In: E. Collins & C. Boon (eds.), Proceedings Livestock Environment IV, ASAE, St. Joseph, Michigan.

5 Gases

5.1 Introduction

Gases in livestock buildings originate from the animal's respiration, but the main source from changes in microbial composition of the faeces and urine (i.e. manure decomposition). The gases of concern are ammonia, methane, hydrogen sulphide and carbon dioxide (end products of manure decomposition). Next to these fixed gases, there are also many other gases that arise as intermediate breakdown products in the anaerobic decomposition of stored manure. The decomposition is moderated by a complex population of anaerobic bacteria, grouped as acid formers and as methane producers, that obtain the energy for their life processes by degradation (Merkel et al., 1969). The main manure constituents are proteinaceous material, carbohydrates and fats. Biochemistry and organic chemistry have been useful in indicating the classes of compounds that one might find in a manure storage pit where anaerobic decomposition is taking place : organic acids, alcohols, aldehydes, amides, amines, sulphides, etc. Temperature, pH and water activity are three crucial factors affecting the metabolism of the micro-organism population, and thus have an influence on the breakdown process.

Physical chemistry indicates those compounds most likely to be important as atmospheric contaminants; in particular, vapor pressure and solubility are two important parameters in evaluating a compound's contribution to the atmospheric pollution. Within a specific homologous serie, the higher the molecular weight of a compound, the lower its vapour pressure. Thus, the smaller members of any series are normally the more important with respect to atmospheric composition (Merkel et al., 1969). The solubility of a compound influences the volatilization process : insoluble gases like methane escape immediately after production while soluble ones, like ammonia, carbon dioxide and hydrogen sulphide can be retained in available solutions and react with other, already present, substances. Solubility of many compounds is influenced by the solution's pH. Besides pH, temperature also plays a decisive role in volatilisation. Relatively small increases in the temperature of broiler houses give rise to substantial changes in ambient ammonia levels (Elliot & Collins, 1982).

Research has identified a host of organic compounds in the air near manure storages. Many of these compounds are known to be odorous in trace concentrations. Their odour nuisance is considerably more critical than their menace to health.

Under conditions with adequate ventilation there has been no evidence that these gases can reach harmful concentrations for animals and humans. However, insufficient ventilation and the release of gases when stored anaerobic waste is removed or agitated can lead to accidents. Solid manure does not release gases in quantities injurious to animals and humans (Skarp, 1975). Liquid manure set in motion by pumping, mixing or cleaning-out releases large amounts of gases, particularly H_2S, which sometimes appear in lethal concentrations (Taiganides and White, 1969).
More detailed information regarding the fixed gases NH_3, CO_2, CH_4, etc. is found in the following paragraphs, while the other odorous gases (the previously mentioned intermediate breakdown compounds) are discussed in chapter 6 "Odours".

5.2 Ammonia and other nitrogen containing volatiles

Introduction

Animals need protein for maintenance and production processes in their bodies. Producers attempt to provide their livestock with diets with adequate levels of the essential amino acids. The nitrogen in these diets is partly retained in the animal body and partly excreted. In Figure 5.1 the nitrogen flow is given for growing pigs. The excreted nitrogen in the form of manure may release gases within the livestock building of which ammonia is a large part but other gases like amines, nitrous oxide and nitrogen monoxide may also be released. Analysis of air samples from pig production units showed that methylamine (mono-, di- and trimethylamines) was present in all units (Miner & Hazen, 1969; Kliche, 1980).
Nitrogen from feed or skin or manure particles, may become aerial contaminants in the form of quatenary ammonium compounds as part of aerosols. Ammonia has received much more attention than the other nitrogen containing contaminants because of the relatively high concentrations of ammonia. Ammonia concentrations within livestock buildings affect human and animal health. Especially in winter with low ventilation rates, concentrations may reach high levels (Kangas et al., 1987; Robertson, 1992). Ammonia emissions from intensive livestock production buildings contribute to environmental damage at local and global levels. Over 80% of ammonia production originates from agriculture (Döhler & van der Weghe, 1990).
As the nitrogen in the feed diet is the primary source of ammonia and other nitrogen containing volatiles, varying the diet composition, including appropriate amino acids, is an important possibility for reducing the production of these aerial compounds. This principle has been verified (Gatel & Grosjean, 1992) and has been compiled in mathematical models (Aarnink et al., 1992; Dourmad et al., 1992).

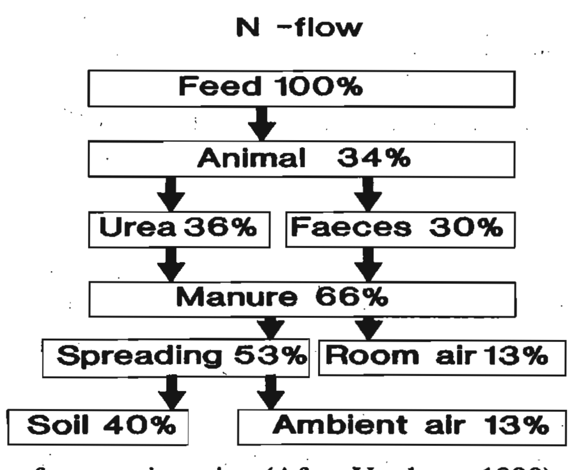

Figure 5.1 Nitrogen flow for growing pigs (After Verdoes, 1990).

Production of ammonia

In this section some basic principles of ammonia production from animal urine and faeces are covered. A much more detailed coverage of this subject is given by Groot Koerkamp et al. (1990).

Manure may contain undigested proteins and N-compounds in the faeces and end products of protein degradation which have been excreted through the kidneys (urea by mammals and urine-acid by birds). Urea is only found in poultry manure when urine-acid ($C_5H_4O_3N_4$) is broken down to urea ($CO(NH_2)_2$).

Chemical, enzymatic or microbial processes can transform nitrogen-containing compounds into other nitrogen containing compounds, like ammonia. The various nitrogen

containing compounds may be divided into three categories:
- N_m: nitrogen in mineral form: NH_3, NO_3^-, NH_4^+, NO_2^-
- N_e: nitrogen that is released within one year from organic nitrogen compounds
- N_r: nitrogen that is released in subsequent years by mineralisation of the organic matter.

For the production of ammonia in livestock buildings the nitrogen in mineral form is important. When manure is stored within the building N_e can also play a role.
Total ammonium produced ($Q_{NH_4^+}$) is estimated by Aarnink et al. (1992) as being dependent on feed intake (F_i), digestible and total crude protein (dcp and cp) in the feed and protein retention by the pigs (G_p) and the percentage of organic matter already converted into volatile fatty acids and biogas (A_{COD}). Typical ranges are between 1 and 10 g/day per pig.

$$Q_{NH_4^+} = 0.194\ (dcp \cdot F_i - G_p + 0.01 \cdot A_{COD} \cdot (cp - dcp) \cdot F_i) \quad \text{kg/day per pig}$$

Ammonia (NH_3) is a gas that may be present in air, or it can be dissolved easily in water. Ammonia dissolved in water is called aqueous ammonia. Ammonium is the NH_4^+ ion; it is easily soluble in water and can be present in air when ammonia reacts with other compounds.

NH_4^+ (as ammonium salt)
Air $\Updownarrow$
NH_3 (ammonia)
$\Updownarrow$
Liquid $NH_3 + H_2O \rightleftarrows NH_4OH \rightleftarrows NH_4^+ + OH^-$
ammonia — aqueous ammonia — ammonium

The aerobic degradation of urine to urea in poultry manure has been described by Carlile (1984). During this process, which involves several reactions, water and oxygen must be available and for each molecule of urine acid one molecule of carbon dioxide and two molecules of ammonia are released.
The velocity and degree of conversion depend on temperature, for which an optimum at 37°C is presumed, on pH (optimum at pH = 9 according to Vogels & van der Drift (1976)) and on water activity.

Urea can be transformed into ammonium:

$$\underset{\text{urea}}{H_2N\text{-}\overset{O}{C}\text{-}NH_2} + \underset{\text{water}}{3\ H_2O} \xrightarrow{\text{urease}} \underset{\text{ammonium}}{2\ NH_4^+} + \underset{\text{hydroxyl-ion}}{2\ OH^-} + \underset{\text{carbon dioxide}}{CO_2}$$

The enzyme urease is present in faeces. Most of the urea is in the urine. Mixing urine and faeces therefore enhances the production of ammonium. Reaction velocity also depends on pH, concentration of urea and temperature. A pH between 7.8 and 8.8 gives the quickest conversion of urea to ammonium, according to Mothes (1973).

Nitrogen-containing compounds in manure can be transformed by microbial processes under anaerobic circumstances into mainly CO_2, CH_4, H_2, H_2S, NH_3, amines, indole, skatole and butyric acid (Oldenburg, 1989). High concentrations of ammonium may indirectly inhibit methane production (Wiegant & Zeeman, 1986). The anaerobic degradation processes in manure are given in Figure 5.2.

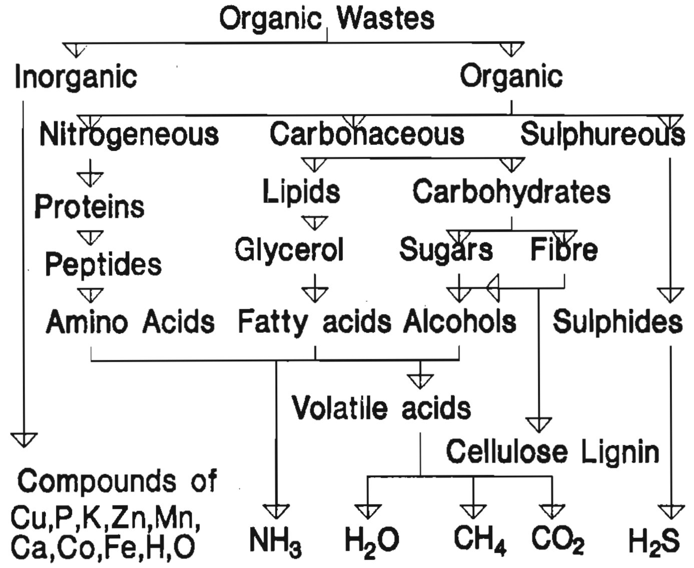

Figure 5.2 Schematic representation of anaerobic decomposition processes in manure (Taiganides, 1987).

Aerobic decomposition of nitrogen-containing compounds in manure is possible and may generate heat (composting). Nitrogen is in this case mainly converted into ammonia. This ammonia may escape to the air or may be embedded in bacterial protein or, through nitrification, be converted into NO_3^-. Production of bacterial protein requires carbon and nitrogen in a ratio roughly above 20 to 1. Full conversion of nitrogen into bacterial protein is only possible with large amounts of carbon, e.g. 5000 kg straw would be necessary per dairy cow per annum (Kirchmann & Witten, 1989).

Nitrification of ammonium requires oxygen:

$$NH_4^+ + OH^- + 2\,O_2 \Rightarrow NO_3^- + H_3O^+ + H_2O$$

During nitrification the pH decreases and at a value of approximately 5.5 the process stops because the nitrifying bacteria cannot tolerate acid environments (Evans et al., 1986). When, during or after nitrification, oxygen is no longer available, denitrification - an anaerobic process - may res6ult in products as follows:

$$2\,NO_3^- + 10\,H_3O^+ + 10\,e \Rightarrow N_2 + 2\,OH^- + 14\,H_2O$$

Besides N_2 another intermediate product, N_2O, may also be released during the denitrification process.

Aqueous ammonia and ammonium are in a chemical equilibrium in liquids. The fraction (F) present as ammonia depends on temperature (T in °Kelvin) and pH of the liquid. Van Helvoort (1988) gives the following equation:

$$F = 1/(10^{(0.09018 + 2792.92/T - pH)} + 1)$$

F is small for low pH values and for low temperatures. In manure, pH is typically around 8. Freney et al. (1983) have studied the equilibrium between aqueous ammonia and ammonium in liquids. They found that the ammonia fraction increases with an increase in temperature. The equilibrium between ammonia in air and in liquid is affected by the concentrations of ammonia in air and in liquid. Ventilation patterns in livestock buildings may cause constant low aerial concentrations of ammonia directly at the evaporating surface and stimulate ammonia volatilization. The flux of ammonia from liquid to air also depends on the surface area. For poultry manure the effect of moisture content on ammonia emission is given in Figure 5.3.

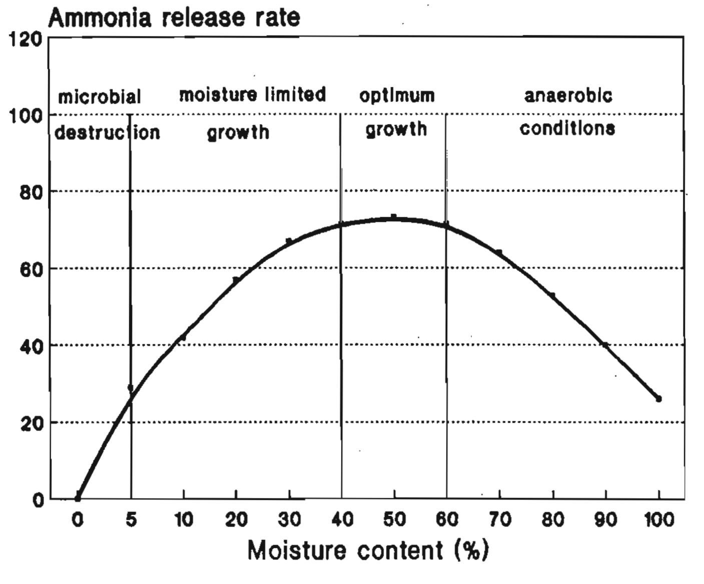

Figure 5.3 The influence of moisture content on the emission of ammonia from poultry manure (Elliot & Collins, 1983).

Diffusion of ammonium, aqueous ammonia or ammonia in liquids will occur when concentration gradients are present. The nitrogen losses from manure storages have been modelled by Muck & Steenhuis (1982). Ammonium may also be adsorbed by clay minerals, organic matter, etc.

The following conclusions can be drawn:
- Ammonium is readily produced from urea in urine from cattle and pigs and from urine acid from poultry. Production of ammonium from faeces (organic matter) is much slower.

- Early separation of urine and faeces can reduce ammonia volatilization in cattle and pig manure.
- Contamination of areas with manure increases the air/manure surface area and therefore the ammonia production rate.
- A pH value below 6 would virtually eliminate ammonia emission from manure. Storage of manure at temperatures below 10 °C also strongly reduces ammonia emissions. Lack of air movement directly above the manure surface reduces ammonia losses from the manure.
- Nitrification and subsequent denitrification can convert ammonium into N_2 but may also release undesirable intermediate products like N_2O and NO.

Behaviour and dispersion of ammonia in air

Several investigations have been carried out to survey the dispersion of manure gases in livestock buildings. Wide variations in concentrations over various locations have been reported by several authors (Simensen, 1981; Aengst et al., 1983; Conceicao, 1989). O'Connor et al. (1988) reported concentrations of from 17 to 123 ppm in broiler buildings.
Some studies include modelling the behaviour and dispersion of ammonia. Anderson et al. (1987) have modelled the volatilization of ammonia from homogeneously mixed manure. Zhang et al. (1990) refined this model by distinguishing an aerobic, a microaerobic and an anaerobic zone in the manure. The dispersi6on of ammonia in the air in livestock buildings has been modelled by Janssen & Krause (1990) and Krause & Janssen (1991). They use so-called eddy diffusion coefficients to calculate mass flux vectors in an Eulerian coordinate system. The relation between volatilization and air speed has been discussed by de Praetere & van der Biest (1990).
The air movement will greatly influence the ammonia concentrations. As production takes place at or below floor level concentrations in a pig building will generally decrease with height (Figure 5.4). Gustafsson & Mårtensson (1990) demonstrated, for stables with laying hens with deep pit manure storage, that an increase in ventilation reduced the ammonia concentration but increased the total emission of ammonia from the building.

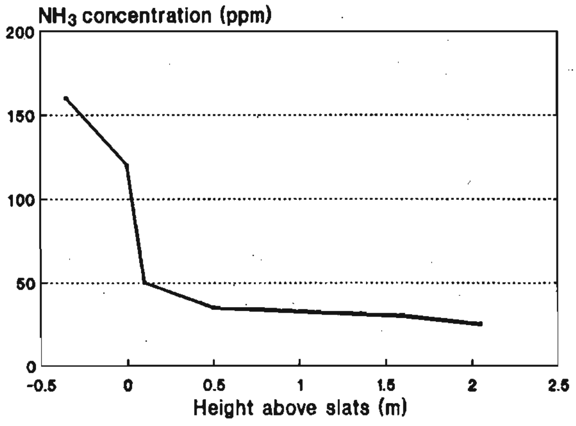

Figure 5.4 Concentrations of ammonia at different heights above the manure in a pig building with a manure level at 0.4 meter under the slats.

Diurnal and seasonal variations in ammonia concentrations occur (Clark & McQuitty, 1987; Leonard et al. 1984; Mårtensson & Lundqvist, 1991). The effects of ventilation on the concentration, dispersion and emission of NH3 is very complex and generalization should be avoided (Anderson et al., 1987).

Ammonia can be converted in the air into ammonium containing compounds. In livestock buildings, concentrations of negative ions in the air are low and ventilation rates are high. Conversion of ammonia into ammonium within the building will therefore hardly take place. In the external atmosphere, however, this conversion does take place.

High concentrations of aerial ammonia in combination with condensation of water vapour may result in nitrite formation in the condensed water. Under commercial conditions, dripping of this water and subsequent ingestion by broilers has caused deaths through nitrite poisoning. The conditions included low ventilation rates, high ammonia concentrations (70-100 ppm), and high moisture levels, causing NH3 conversion to nitrites (6000 - 16000 mg/l) and nitrates (1630-1700 mg/l) (Litgens & van Eykelenburg, 1987).

Measurement of ammonia concentrations and emissions

The measurement strategy for measurement of ammonia concentrations depends on the effects to be studied in an investigation. Effects on humans, animals, and the environment should include measurements of ammonia concentrations at, respectively, the nose level of humans, near the noses of animals, and at the air outlets of a building. Spot measurements to detect "average" conditions within a building or malfunctioning of ventilation systems are easier to make and can use simpler techniques than determination of averaged concentrations over time, or continuous measurement of concentrations to establish diurnal patterns or to measure emissions under varying ventilation rates.

For environmental studies, the total output of ammonia has be determined and the air flow 8leaving the building must also be measured. Various techniques can be used to measure ammonia concentrations and emissions (Ouwerkerk, van, 1993).

Gas detection tube

Gas detection tubes are widely used for spot measurements because of their low cost. A known volume of air is drawn through a tube containing a chemical whereby a reaction of ammonia with the chemical causes a changed in colour of the chemical. The tube length where the colour has changes is related to the amount of ammonia. The tube has a scale that can be used to read the ammonia concentration. Gas detection tubes are easy to carry and to use, are cheap and give instant readings. Some other components of the air may produce interference. The readings give an indication of the concentration, but accuracy is $\pm$ 15%. Suppliers of gas detection tubes include Dräger, Kitagawa and Gastec.

Impinger

Ammonia concentrations in gases can be measured by drawing gas through three absorption flasks. The first flask is for collecting the ammonia, the second to check for saturation and the third (empty) flask collects any liquids, thereby protecting the pump. The ammonia is trapped in acid. At a laboratory the samples are analyzed by HPLC spectrophotometric techniques, by titrametric techniques or other analytical techniques. Impinger sampling can be used for spot measurements. Sampling time is usually around 20 minutes, and the calculated concentration is an average concentration over that period.

To calculate the ammonia concentration in the sampled gas in ppm (v/v) the following equation can be used:

$$C_g = \frac{C_l \, V_l}{t \, F_g} \cdot \frac{R \, T}{P} \cdot \frac{1}{M_w}$$

where

C_g	=	ammonia concentration in gas, ppm (v/v)
C_l	=	ammonium concentration in acid, mg/l
V_l	=	volume of acid, l.
t	=	sampling time, min.
F_g	=	gas flow rate, m^3/min.
R	=	gas constant, 8.2054×10^{-2} litre atm.K^{-1} mole
T	=	gas temperature, K.
P	=	atmospheric pressure, atm.
M_w	=	Molecular weight, gr.$mole^{-1}$.

To compare the various measurements the results are recalculated to standard temperature and atmospheric pressure.
The impinger method is accurate but labour intensive and requires laboratory facilities.

Infrared (IR) gas analysis

The analyzer utilizes infrared light in its operating principle. The sample is drawn into the cell by the integral air pump and absorbs energy from an infrared beam. One speaks of Non Dispersive InfraRed (NDIR) analyses if one particular wavelength is used. The amount of this absorption is measured by the detector and converted into concentration units. Some types have a double beam whereby autocalibration is possible. One type can measure the absorption at five different wavelengths, whereby cross-compensation from interfering components is possible. With Fourier Transform InfraRed (FTIR) Spectroscopy the entire infrared spectrum can be scanned, then analyzed for their specific absorption characteristics. FTIR can be far more discriminating than conventional spectroscopy and can detect, identify and measure several different gases simultaneously. Suppliers of IR analyzers include Brüel & Kjær, Miran, ADC, Siemens and MDA. Auxiliary equipment is necessary for calibration and correct utilisation of IR gas analyzers. The analyzers themselves may also be expensive.

Electrochemical sensor

The cell consists of a pair of polarized electrodes isolated from the ambient air by a gas permeable membrane. As the target gas diffuses into the sensor, a redox reaction occurs, generating a current proportional to the gas concentration. Suppliers of electrochemical sensors include EIT, MDA, Ecolyser, Interscan, Sensidyne and Dräger. Some suppliers are working on versions that are suitable for livestock buildings. The sensors are designed as an alarm system that detects high concentrations under normally negligible background concentrations. This type of equipment is often portable. For use in livestock buildings the durability, reliability and accuracy of these sensors can be very limited.

NH_3⇒NO convertor and chemiluminisence nitrogen oxides analyzer

At the sampling point a NH_3⇒NO convertor is located. The convertor is kept at a temperature of 750°C. Stainless-steel is used as catalytic active metal. At this temperature NH_3 and NO_2 are converted into NO. A generated excess ozone concentration reacts with NO whereby photons are produced. It measures NO concentrations based on the reaction:

$$NO + O_3 \rightarrow NO_2 + O_2 + h\upsilon$$

The NO concentration is directly proportional to the measured photon flow. During transport some NO may oxidize to NO_2. A convertor converts any NO_2 into NO at high temperatures prior to entering the reaction chamber. In a dual-channel system the first channel with NH_3 convertor measures NH_3 and NO_2 and NO and the second channel without NH_3 convertor can measure the ambient air for NO and NO_2 concentrations, when the concentrations of NO and NO_2 in ambient air are not negligible.
This principle can be used for continuous measurement of ammonia concentrations and is used in ammonia emission measurements (Scholtens, 1990). It requires auxiliary equipment. It is too expensive to use for spot measurements.

Passive samplers

A passive sampler is a cylinder of inert material with a surface at the bottom that reacts to the specific gas, in this case ammonia. Willems & Hofschreuder (1990) describe the technique as low-cost for material, but laboratory analysis of the samples is necessary. A variation coefficient within duplex samples of 5% is given.

Ammonia emission measurements

For the measurement of ammonia emissions from livestock buildings it is necessary to combine a technique that allows (semi-) continuous measurement of ammonia concentration with a technique that can measure continuously the air flow through a building. Besides the techniques mentioned above, a special electronic sensor is also reported to be able to measure ammonia concentrations continuously (Krause & Janssen, 1989). To save on the costs of ammonia concentration measurement it is common practice to use a multiplexer to serve several sampling points with one analyzer. This means however that air has to be transported from the sampling point to the analyzer and ammonia is a gas that is readily absorbed in the transport line. FEP is a tubing material with low absorption of ammonia, but it is expensive. Condensation within the transport line must be avoided at all times. The measurement of air flow through a livestock building can be measured in mechanically ventilated buildings when a full size anemometer is used near the fan (Berckmans et al., 1991). The full size anemometer can give accurate results under static conditions. Accuracy under dynamic conditions, such as natural ventilation, is not yet established (Berckmans et al., 1992). Reports on techniques for measurement of ammonia emissions are available (Kessel, 1990; Anon., 1993).

Effects of ammonia

Effects on humans

The significance of ammonia on human and animal health is that it acts as an irritant at a cellular level within the respiratory tract. The frequency of exposure to gaseous ammonia in agriculture at concentrations which are immediately harmful to health, will be very low. Present data suggests that, although histological change occurs in the upper respiratory tract at 50 ppm, there are no gross effects on health. Severe health effects have only been measured above 50 ppm.

The major point about atmospheric ammonia is that it can be harmful to health in combination with other aerial pollutants or respiratory pathogens. Experimental work has demonstrated that ammonia, in the presence of other agents, can have a significant effect on health at concentrations which are frequently recorded in intensive livestock buildings.

In a study of dust and ammonia in pig buildings and stockmen's respiratory health, 21% (6/29) of workers reported headache. This nonrespiratory symptom was attributed in all cases to the presence of ammoniacal odour. All spot measurements of ammonia made during the study were below 25 ppm (Robertson, 1992).

In pig housing ammonia levels above MAC-values are found (Donham et al., 1977). The additive and possibly synergistic effects of ammonia and dust may require lower permissible levels in animal housing as compared to industrial hygiene standards (Donham, 1991).

Effects on livestock

The results of studies which examine the direct effect of ammonia on animal health remain inconclusive. Pigs subjected to 10, 50, 100 and 150 ppm showed no effect on the efficiency of feed conversion, although there was a highly significant negative effect on feed consumption and average daily gain (Stombaugh et al. 1969). A negative effect of increased ammonia concentrations on the growth rate of young pigs was also found by Drummond et al. (1981). The presence of high levels of ammonia has been shown to delay the onset of puberty in gilts. In one trial, gilts raised with ammonia concentrations of 20 ppm attained puberty eight days later than those in buildings with 10 ppm ammonia (Malayer et al., 1988).

Chickens exposed to 60 to 100 ppm of ammonia showed a reduction in growth rate, appetite, feed consumption and egg production (Charles & Payne, 1966). However, neither respiration rate nor measured blood parameters in calves were significantly effected by short periods of exposure to 50 or 100 ppm atmospheric ammonia.

Synergetic effects

Ammonia, dust and microorganisms have been shown to be additive in their negative effect on animal health. The relevance of this in practice is that ammonia may be damaging at lower concentrations than the 50-100 ppm conditions used in the experimental conditions described above. The hypothesis is that dust and ammonia create a physical and chemical burden on the respiratory system, which in turn compromises the immune system and greatly facilitates the entry and multiplication of infectious micro-organisms in the respiratory tract.

An example of the synergistic effect of aerial pollutants is given by Oyetunde et al. (1978) although the ammonia and dust concentrations used in the experiment are extremely high. They demonstrated that the effects of *E. Coli* on turbinates/trachea/lung and alveoli lesions were further increased by either ammonia or dust, but not by dust and ammonia interaction. Further studies of the effect of dust and ammonia on turkeys (Wolfe et al., 1968) found that the incidence of airsacculitis was significantly affected by high dust levels, but not by ammonia or a dust/ammonia interaction. Ammonia concentrations were 0-8 ppm (low) and 20-30 ppm (high), and dust concentrations were 3.5-14 mg/m3 (normal) and 21-35 mg/m3 (high).

The interpretation of the various results may be simplified by the suggestion that aerial pollutants only have a gross affect on livestock performance in the presence of a respiratory pathogen. In a study of 1117 pigs from 12 commercial pig units, there was a significant linear but not proportional relationship between the mean ammonia concentration in the farrowing building and the incidence of enzootic pneumonia (E.P.) and the severity of atrophic rhinitis of the piglets once they had reached slaughter weight (Robertson et al., 1990). They could also relate E.P. to ammonia and dust concentrations.
It was concluded that the presence of the relevant pathogen is required to produce a positive relationship between the concentration of ammonia (or dust) and the severity of disease, and that the relationship is only valid when the ammonia is present during the development stage of the disease.

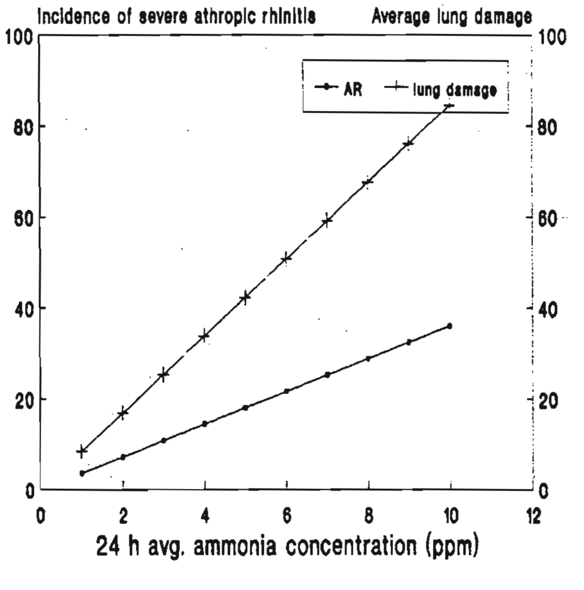

Figure 5.5 Relationship of ammonia concentration to respiratory disease in pigs.

An influence of NH_3 on vaccine efficacy has also been found. The addition of superphosphate to broiler litter, which produced 'almost optimal' NH_3 concentrations in the air, improved the antibody titre to Newcastle disease vaccination compared with a control group. Two weeks after vaccination, mean antibody levels were 1:128 in the control group as compared with 1:256 in the experimental group (Semen & Demchuk, 1985).

Ammonia at both 50 ppm and 100 ppm reduced both the systemic and local resistance to infection under experimental conditions for unweaned pigs (Neumann et al., 1987).

Effects on the environment

Nitrogen oxides and ammonia contribute, together with SO_2 and volatile organic compounds, to an acidification of the natural environment. Nitrogen oxides and ammonia emissions also contribute to an eutrophication of the natural environment. This enrichment of the environment with nitrogen stimulates growth and can disturb natural cycles. The effects are described by Anon. (1989). In some parts of Europe, like the Netherlands, the effects on the natural environment are quite severe and call for a reduction in ammonia emissions from agriculture (Anon., 1987; Döhler & van den Weghe, 1990).

Reduction technology

The concentration of ammonia in livestock buildings depends on type of feed, type of animal, organization of the building, season, ventilation principles, manure handling, hygiene, etc. The choice of a particular t4echnology to reduce ammonia levels and/or emissions has to take into account the fact that a technology may change the proportions and concentrations of other pollutants (dust, CO_2, H_2S, etc), may have an effect on health and performance of pigs, should have low investment and operating costs and should provide a healthy and safe environment for the farmers. At the moment some scientific results are available but information is still partial and incomplete. The various stages where ammonia volatilization may be reduced are given in Figure 5.6.

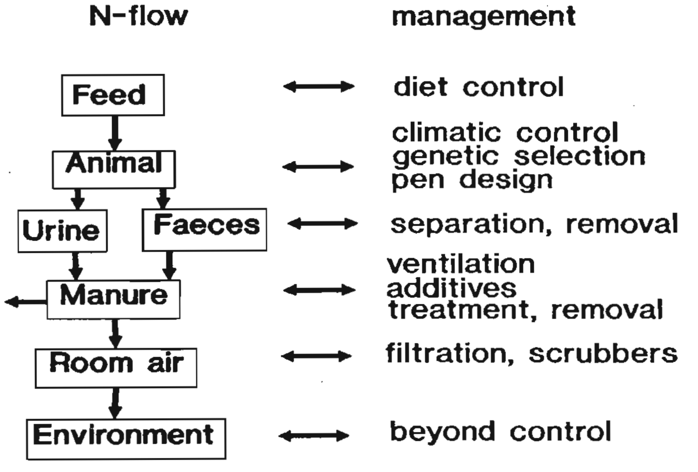

Figure 5.6 Management possibilities in livestock buildings to minimize the volatilization of ammonia.

The primary source of ammonia is nitrogen in the feed. The better nitrogen is utilized by an animal, the less nitrogen will be excreted by the animal. It is recommended that the exact amounts of amino acids in the diet be provided to meet the nitrogen requirements of the animals. One of the practical problems encountered in following this recommendation is that the amino acids requirements of animals change with age and weight. Feed delivery systems that can adjust the daily composition of a diet by varying ratios between two or more feed formulas are available (Beers et al., 1991) but usually require additional investment. Additives to the feed (or the manure) generally do not show a reduction in amounts of ammonia released from the manure under practical conditions (Kemme et al., 1993; Krieger et al., 1993). Where the effects of additives were positive, it was often in situations where ammonia concentrations were extremely high.

When manure is produced the release of ammonia within a livestock building can be minimized by control of the following factors:
- Evaporating surface
- Separating urine and faeces
- Storage period
- Temperature
- Lowering of nitrogen concentration in manure
- Air velocity above surface
- pH

The type of slats, the animals' behaviour, the ventilation system and the manure handling system all influence one or more of the above-mentioned factors. It is generally expected that the larger the percentage of slotted area, the less surface is available for evaporation and the lower the ammonia volatilization will be. A wide slot (0.08 m) between wall and slats has also given encouraging preliminary results in partly slatted pig buildings. Animal behaviour may influence floor fouling. Ventilation systems are recommended which create a comfortable microclimate in laying areas and a slightly colder microclimate in intended dunging areas (Randall, 1980). In mechanical ventilation systems the extraction of air from beneath the slats may reduce the ammonia concentrations in a livestock building and therefore create a better environment for humans and animals in the building. Because of higher airspeeds and lower concentrations of ammonia in the air directly above the manure surface, it may however increase the release and emission of ammonia to the environment. Stable air flow patterns with low air speeds in the building generally prevent air exchange with air from manure pits. A minimum distance of approximately 30 cm between slats and manure levels is also expected to reduce the volatilization of ammonia (Sällvik, 1994). Regular smoke tests to check air flow patterns should be incorporated as a routine in livestock buildings.

Once ammonia is released from the manure and is present in the air above the manure, the exposure of humans and animals to ammonia can be minimized by correct air flow patterns and/or extraction of the ventilation air close to the ammonia emitting surfaces. The exhaust air of the ventilation system emits ammonia to the environment; this emission can be reduced by scrubbing or filtering the exhaust air. Biofilters and wet scrubbers are effective in reducing ammonia and odour emissions from livestock buildings (Scholtens & Demmers, 1991; Pearson et al., 1992; Colanbeen & Neukermans, 1992b), but do not protect humans or animals within buildings against ammonia inhalation. Increases in ventilation rates reduce the exposure of humans and animals to ammonia and, conversely, reductions in ventilation rates reduce the emission of ammonia to the atmosphere (Gustafsson & Mårtensson, 1990).

Some manure systems are more effective at containing the ammonium within the manure than others (Tomescu & Marschang, 1977). Flushing systems have reduced ammonia volatilization of ammonia in pig buildings by 60% (Hoeksma et al., 1992), but require substantial processing of the manure outside the building. Other types of chemical and physical treatment are currently being researched (Klooster, van 't & Voermans, 1994). Frequent removal of poultry manure by conveyor belts reduced the ammonia emission by 60 % (Oosthoek et al., 1990).

The applicability of techniques mentioned above depends strongly on the type of housing. For cattle buildings the following techniques can, depending on building design, be used to reduce ammonia volatilization in practice (Döhler & van der Weghe, 1990):
- Sloping floor with scraper and urine gutter
- Sloping floor with scraper under the slats
- Flushing system above slats
- Flushing system on solid floor
- Addition of acid in storage of manure
- Flushing system under the slats
- Mechanical lock on storage of manure
- Reducing contact surface between manure and air
- Use of extra straw in the building

For pig buildings the following techniques can be used in practice to reduce the volatilization of ammonia in pig buildings:
- Scraper under slats with or without separation of urine and faeces
- Reduce emitting surface in the slurry pit, e.g. pans and gutters (Verdoes et al., 1993)
- Shallow pits under slats, with reduced storage periods
- Sewage pipes for frequent removal of manure to external storage
- Flushing system with level floor or sloping floor (Hoeksma et al., 1993)
- Create specific dunging locations within pens
- Reduce slat surface
- Wide slot between wall and slats
- Deep litter systems, layers of 0.4 m and over using sawdust, straw, etc. where the heat released by the composting process evaporates water (Voermans, 1992).
- Smooth surfaces, easy to clean
- Oligolyse (Colanbeen & Neukermans, 1992a)

In poultry buildings, three techniques can successfully reduce ammonia levels in practice:
- Drying of manure in the building
- Frequent removal of manure from the building
- Insulation (and heating) of the floor (Ouwerkerk, van & Voermans, 1985).

5.3 Carbon dioxide

Introduction

The production of carbon dioxide is related to the animals' metabolism, and can be used as an indicator gas for air quality in buildings. With knowledge of CO_2 production from the animals and the CO_2 concentration of the ambient air, we can calculate the air flow rate simply by measuring the CO_2 concentration of the exhaust air. The gas is easy to measure, and can be used to examined local air quality at the animal level. In naturally ventilated cold buildings, measuring air flow rates by CO_2 is one of the few methods possible.

Production and origin

The total CO_2 production is a sum of three components: animal respiration, rapid breakdown of urea in urine and anaerobic breakdown of dry matter in the slurry. Production from animals' respiration is the dominant part, forming over 96% of the total carbon dioxide production (Ouwerkerk, van & Pedersen, 1994).
In Europe, carbon dioxide production in livestock buildings is usually calculated using the German code (DIN, 1974) or the CIGR equations (CIGR, 1984). The German code DIN 18910 (1974) gives figures for carbon dioxide production levels of 0.15 l h^{-1} W^{-1} for lactating cows, 0.15 - 0.17 l h^{-1} W^{-1} for fattening pigs and only 0.13 l h^{-1} W^{-1} for laying hens, which seem to be very low. By comparison, Schneider (1988) found carbon dioxide production for lactating cows and fattening pigs of 0.163 l h^{-1} W^{-1}, the same as given by CIGR (1984), and Hilliger (1982) found a figure of 0.216 l h^{-1} W^{-1} for pigs. Others found fattening pigs to have a carbon dioxide production of 0.2146 - 0.000406 m (l h^{-1} W^{-1}) ($s=8.8$ and $R^2=0.69$), where m: body weight (kg) (Pedersen, 1992 derived from data obtained from Thorbek et al., 1984). Clearly, there is a need for more applied research to resolve these disparities.
The carbon dioxide production from livestock buildings is about 0.17 to 0.20 l h^{-1} W^{-1} of total heat production, if the respiratory quotient RQ is taken into account (Ouwerkerk, van & Pedersen, 1994). RQ ranges from about 1.0 to 1.2 at normal to high production levels. For fattening pigs the carbon dioxide production from urine is (Ouwerkerk, van & Aarnink, 1992):

$$M_{CO_2,\ urine} = 0.251\ (dcp \cdot I_f - G_p)$$

where $M_{CO_2,\ urine}$:carbon dioxide production from urine (kg), dcp: digestible crude protein content (kg/kg), I_f: feed intake (kg) and G_p: protein retention (kg).
Regarding the production from anaerobic breakdown of dry matter in the slurry when not agitated, for fattening pigs Van Ouwerkerk & Aarnink (1992) give:

$$M_{CO_2,\ biogas} = 0.62\ GP_B$$

where GP_B: biogas production (kg).

The biogas production (kg) is (Ouwerkerk, van & Aarnink, 1992):

$$GP_B = \frac{4}{LR} \cdot \frac{a_{COD}}{100} \cdot t \cdot (1 - df_{om}) \cdot I_{om}$$

where LR: loading rate (%), a_{COD}: relative percentage of organic matter converted into biogas per day of storage(%), t: storage time (days), df_{om}: digestibility factor of organic matter and I_{om}: organic matter intake (kg).
The total range of carbon dioxide from urine and biogas varies from 0% to about 4% of the total carbon dioxide production in the piggery (Ouwerkerk, van & Pedersen, 1994).
For pigs, Gustafsson & Mårtensson (1988) found a total (animals and manure) CO_2 production (g/h per pig) of:

$$M_{CO_2} = 19.5 + 1.756\ m$$

where m: body weight (kg). For chickens on straw, Gustafsson & Mårtensson (1990) gives (g/h per bird):

$$M_{CO_2} = -0.38 + 4.4\ m$$

If the birds are young the amount of carbon dioxide released by fermentation of the straw or litter can reach much higher levels< up to 50% of the total carbon dioxide production (Beek, van & Beeking, 1992).
The production of CO_2 has diurnal variations. First of all, carbon dioxide production by animals depends on activity (Hel, van der, et al., 1986; Verstegen et al., 1986; Schrenk & Marx, 1982; Ouwerkerk, van, 1987; Ouwerkerk, van & Pedersen, 1994). Especially, activity is increased during and after feeding times. Less is known about diurnal variations of carbon dioxide production from manure. Increased animal activity, with more droppings in the manure, may result in extra agitation of the manure.

Dispersion

In livestock buildings gases are undergoing a continuous mixing process. There are differences in airflow pattern between summer and winter conditions. Temperature differences on building surfaces and airspeed from air inlets are the two main factors governing air flow in insulated buildings. In naturally ventilated cold buildings, wind speed and direction are the major factors together with the area and location of openings. The main factor in the mixing process is the heat production from the animals. They are heating up air which becomes lighter and a upward air stream is often established. Because of mass flow balance, a equal amount of air moves downward in areas with fewer or no animals. Air velocities of about 0.1 m/s are quite usual because of heat convection from the animals. How these factors are distributed, whether they are pulling the air in the same or opposite direction to each other is important for the mixing process. Since the density of CO_2 is 1.98 kg/m^3 which is heavier than air (1.29 kg/m^3), CO_2 should be at the highest concentration at floor level. This assumption has not taken into consideration that CO_2 is emitted in the warm exhaled air from the animals. CO_2 dispersion related to time and location for some livestock buildings is measured and reported on by Sällvik (1973) and Norén (1974).

Measurement

It is important to take into account the time of day when carbon dioxide concentration will be measured because of the aforementioned animal activity which affects the production of carbon dioxide. It is also important to realize that persons entering the livestock building to measure carbon dioxide may cause increased activity of the animals, especially pigs, and hence influence the measurement.
Carbon dioxide can be measured either continuously or incidentally. Incidental measurement may be carried out as a routine check or as a useful tool in diagnosing ventilation faults. Infrared analysis and gas detection tubes will be discussed in this section.

Infrared analysis

An amount of air is heated and led through a chamber. In the chamber a beam of infrared light of a specific wavelength is sent through the air sample. The percentage absorption of this beam is measured and converted into a carbondioxide concentration. Accuracy of determination is approximately 1.5% of full scale. Stability of reading is usually about 10% of the full scale over 3 months after calibration. No references on possible cross interference have been found.

Infrared gas analyzers can be equipped with tubes carrying air from the sample point to the analyzer. T-junctions, with two equal length of tube, can be used to mix air from a few sample points in the livestock building.

Gas detection tube

A chemical reaction can be used to determine the concentration by means of colorimetry. The measurement has a relative standard deviation between 10% and 15%. Systematic errors can be made in the calibration during manufacture, chemical changes may occur in tubes during storage, or an improper amount of air can be passed through tubes. Cross interference by other gases or vapours is not a problem with carbon dioxide. Tubes should be stored below 30°C, and pumps should be checked before use on leakage. Basic information on gas detection tubes is given in BSI (1976), Council of Europe Resolution AP (74), Drägerwerk (1986) and supplier information from Gastec and Kitagawa.

Effects on animals and humans

Under normal conditions in livestock buildings carbon dioxide concentration level is between 500 and 3000 ppm. There is no health risk to humans or animals at this level. The threshold limits is set to 3000 ppm by Council of Europe. Since CO_2 is easy to measure, it is used as an indicator gas for other more dangerous gases in livestock buildings.
Although CO_2 is rarely life threatening, some effects are reported for animals exposed to 3000 - 10000 ppm for a longer period (Mehlhorn, 1979). Hoffmann (1979) kept chickens in an aerial environment with 3500 ppm CO_2 for 36 days and found one of the blood-parameter (alkaline phosphatase) significantly increased. Effects of high CO_2 on the immune system are reported by Veit et al. (1985).

Reduction technology

The concentration of CO_2 in a room can be reduced by increasing the ventilation air flow rate.

5.4 Methane

Introduction

Under normal conditions methane is a harmless gas in livestock buildings, but is one of the "greenhouse effect" gases. Methane is an explosive gas at higher concentrations. It can build up in poorly ventilated manure storages facilities.

Production and origin

Methane is produced by anaerobic breakdown of manure. There is some CH_4 emission from cattle, because of CH_4 producing bacteria in their stomachs. Considerable work has been carried out on methane production in biogas reactors during anaerobic digestion of manure for energy purposes.
Van der Honing, (1984) found that a cow's stomach production was about 37 litres of CH_4 per kg dry matter of feed intake. If the cow takes 17 kg dry matter a day, the release of CH_4 will be about 0.5 m^3/day.
Methane release from pigs is not a respiratory process, as with cattle. Demeyer & Van Nevel (1975) refer to Barker in their description of methanogenesis. Production of methane takes place in the gut by bacterial breakdown of glucose (in diets with a lot of fibre) by which CO_2 i6s reduced into CH_4. Crutzen *et al.* (1986) estimate the methane production while using energy rich diets at about 0.6 % of the gross energy intake GE, based on digestion and respiration experiments with fattening pigs (Schneider & Menke, 1982). Verstegen (1971) gives a value of 0.5 % at a body weight of 20 kg and about 1% at body weights of 80-100 kg. The energy content of methane is 55.65 MJ/kg (Crutzen *et al.*, 1986). The gross energy intake is, according to the equations of the Oskar Kellner Institute at Rostock (Van Es & Boekholt, 1986):

$$GE = (24.2\ cp + 36.6\ cl + 20.9\ cf + 17\ nfe) \cdot I_f \quad (MJ)$$

where cf: crude fibre (kg/kg), cl: crude fat (kg/kg), cp: crude protein (kg/kg), nfe: nitrogen free extract (kg/kg) and I_f: feed intake (k2g).
The gut-generated methane production is:

$$M_{CH_4,eg} = \frac{0{,}006 \cdot GE}{55.65} \quad (kg)$$

The methane fraction of biogas is about 65% by volume, 40% by weight (Hoeksma, 1984; Voermans & Van Asseldonk, 1992). The average biogas production that is produced during storage is given by Aarnink et al. (1992).

The CH_4 production from biogas is:

$$M_{CH_4,biogas} = 0.40 \cdot GP_B \quad (kg)$$

The total CH_4 production for piggeries is the sum of gut methane production and the methane fraction from biogas:

$$M_{CH_4} = M_{CH_4,cg} + M_{CH_4,biogas} \quad (kg)$$

Dispersion

In livestock buildings methane may build up when buildings are poorly ventilated. Concentrations between 5000 to 15000 ppm are explosive. Several explosions have occured due to ignition of methane-rich air in livestock buildings (Donham et al., 1977).

Measurement

Methane can be measured by infrared analysers with wavelength of 7.70 μm and minimum detection limit of 1.0 ppm, or by wet chemical methods.

Effect on animals and humans

Methane is not considered to be toxic. High concentrations of methane may lead to lack of oxygen.

5.5 Hydrogen sulphide

Introduction

Hydrogen sulphide is a highly toxic gas. When liquid manure is stored for some time, the toxic gas H_2S is produced. Both animal and humans have been killed by this gas. This is the most toxic gas found in livestock buildings.

Production and origin

Hydrogen sulphide is produced by anaerobic breakdown of liquid manure after some time in storage. The gas is stored in the manure as gas bubbles.

In Germany, it has been known since 1928 that the toxic gas hydrogen sulphide is present in buildings with liquid manure handling systems.

In aqueous solution, the weak acid, H_2S_{aq}, is partially ionized to H^+ and HS^-.

$H_2S \leftrightarrow HS^- + H^+ pK_1 = 7.04 K_1$: Equilibrium constant, $K_1 = 1/K_a$

$HS^- \leftrightarrow S_2^- + H^+ pK_1 = 11.96$ K_a: Acid-dissociation constant, $pK_1 = -\log K_1$

Each of the three forms of sulphide change rapidly with pH. At pH=8, less than 10% of the total soluble sulphides exist as dissolved hydrogen sulphide while at pH=6, more than 90% of the total soluble sulphides are in the form of dissolved H_2S.
When silage effluent is added to the liquid manure, the release of H_2S is much more intensive.

Desorption of dissolved H_2S aqueous and gaseous:

$(H_2S)g \leftrightarrow 1/a\ (H_2S)aq$

The absorption coefficient "a" is a function of temperature. Kretschmar (1974) showed that liquid manure containes four time more gas at 30°C than at 20°C.

About 0.1 to 0.8% by volume or 0.5 % by mass of biogas from pig slurry contains gases other than methane and carbon dioxide. Hoeksma (1984) found that this part is mainly hydrogen sulphide. H_2S production when slurry not agitated can be estimated by:

$$M_{H_2S} = 0.005\ GP_B \quad (kg)$$

The average biogas production that is produced during storage is given by Ouwerkerk, van & Aarnink (1992). In normal well ventilated livestock buildings hydrogen sulphide is not present in measurable concentrations. Different handling and storage systems for manure have an influence on production of gas.
When liquid manure is stored inside a building or storage connected by the same airspace, there is a high possibility of hydrogen sulphide entering the zone occupied by humans and animals.
In these cases safety precautions should be carried out:
- provide maximum ventilation
- use natural wind direction
- don't enter the area.

Dispersion

Release of dissolved H_2S is immediate and rapid when stirring the manure. Gas concentrations decrease with prolonged mixing as the dissolved gas is depleted from slurry.
The degree of manure turbulence during mixing may be the dominant factor in H_2S gas release and the concentration inside barns, as compared to other factors such as animal diet, ventilation conditions, etc. (Patni 1990).

Hydrogen sulphide is reported to follow the natural air movements in the buildings.
In a fattening pig building with slatted flooring over of a slurry channel, Robertson (1971) found that when the manure channel was depleted that H_2S was rapidly released. Figure 5.7 gives details of the release of H_2S adjacent to the sluice gate when the fans were shut off.

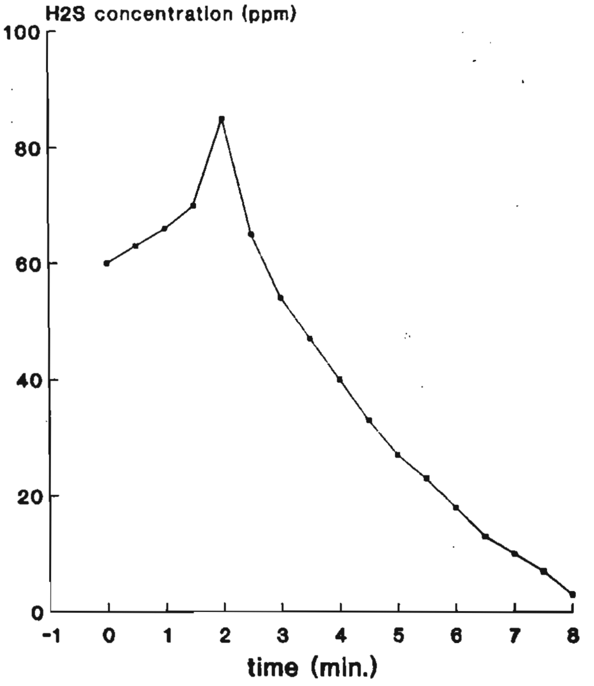

Figure 5.7 Hydrogen sulphide concentration at pig level adjacent to the sluice gate when emptying the manure channel when the fans were shut off (Robertson, 1971).

If the liquid manure handling system is not designed taking H_2S into account, dangerous situations for animals and humans can occur. Skarp (1971) and Sallvik (1969) describe dispersion of H_2S by location and time for many situations. Figure 5.8 gives the vertical gas concentration profile close to an unsubmerged return pumping nozzle in a cow barn. High H_2S concentrations occur in the respiration zone when manure is mixed. In some situations, cold air streams can enter the manure tanks and displace H_2S rich air back to the livestock area (Skarp, 1971).

Measurement

Electrochemical cells (toxic gas monitors) for measuring H_2S are easy to use, and some have a range of 1-1000 ppm with resolution of 1 ppm. The repeatabillity can be 2% of reading $\pm$ 2 times of the least significant digit. The cell will burn out after some years, and they should be calibrated every 6 months. They can be supported by a flow adapter, gas tube and an air pump. With this arranegment it is possible to measure high concentrations without risking any health hazard.
Gas detector tubes can measure in the range 0.1 ppm to 4 %, with a resolution of 10 % of low scale value, repeatability of 5 - 10% For remote sampling a 5-10 m rubber hose can be places between the pump and the glas tube. Tubes should be used within 2-3 years of production.
Gas washing in bottles with reactive solution (using calci6um chloride and reading the difference in conductivity) is a labour intensive method, but the resolution and accuracy of the method is good.

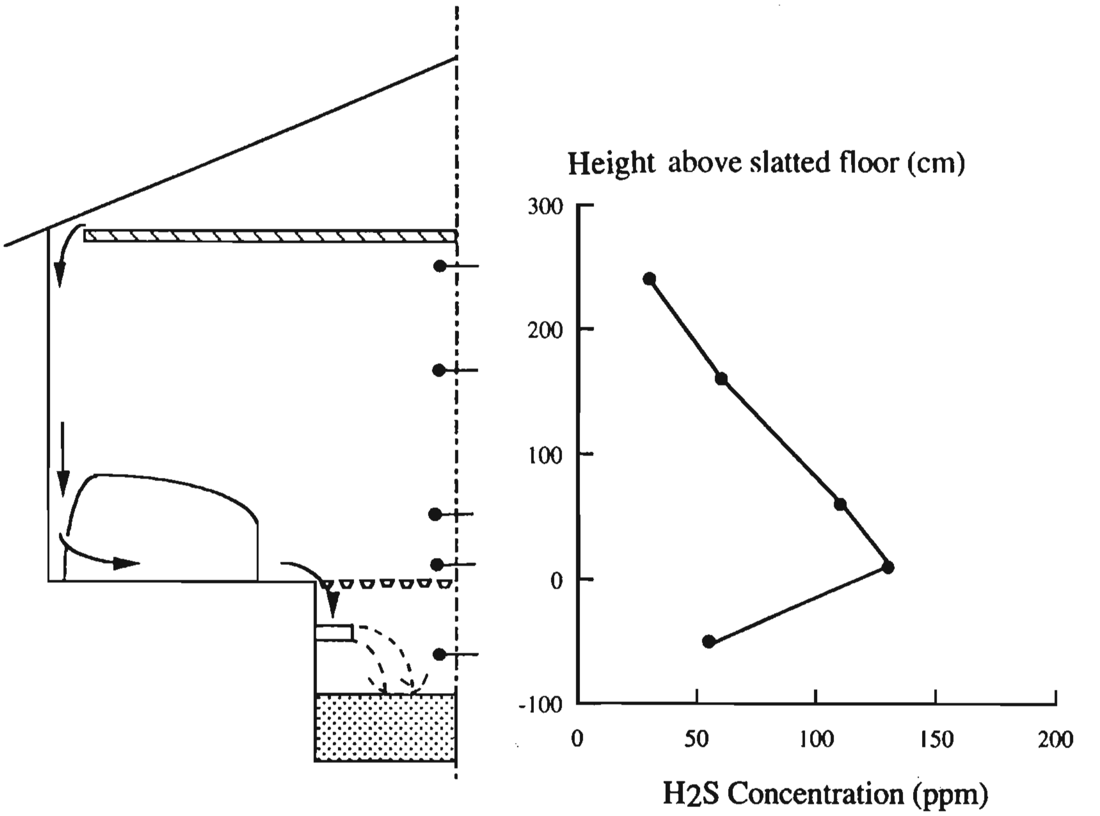

Figure 5.8 Distribution of H_2S concentrations between floor and ceiling in a cattle barn with slatted floor on top of a slurry tank.

Time-weighted average concentration values of H_2S gas are of little value in terms of gas hazard indication while mixing manure in livestock buildings (Patni, 1990). The response time of the measurement sholud be short (5 seconds), to detect rapid concentration changes.

H_2S is released when stirring slurry which has been stored for some time (10 days or more). If manure is stored underneath the animal housing, H_2S should be measured at slatted floor level and at the animals' nose level. The measurement should be taken close to where the manure is most intensively stirred. The gas is expected to follow the airflow-pattern in the room. Smoke can be used to follow airstreams around the area of the H_2S release.

Effects on animals and humans

Hydrogen sulphide is a toxic gas for animals and humans; de Boer (1988), Donham et al. (1977) report many fatal accidents to animals and humans. In cow barns higher respiration rates and some higher pulse rates were found after mixing manure by return pumping (Sallvik, 1973 and 1974; Hogsved, 1968). Human health effects are given in Table 5.3 (Nordstrom, 1976).

Table 5.3 Physiological response of adult humans to hydrogen sulphide (Nordström, 1976)

Effect	Concentration(ppm)
Least detectable odour	0.01 - 0.7
Offensive odour (rotten egg)	3 - 5
Eye irritation	10
Irritation of mucous membranes and lungs	20
Irritation of eyes and respiratory tract (1 hour)	50 - 100
Olfactory-nerve paralysis, fatal in 8-48 hours	150
Headaches, dizziness (1 hour) nervous system depression	200
Nausea, excitement, insomnia, unconsciousness, possible death (30 min)	500 - 600
Respiratory paralysis, death	700 - 2000

Council of Europe threshold limit is 5 ppm and the CIGR-report (1984) recommendations were 0.5 ppm and intermittently, when dunging out, 5 ppm.

Reduction technologies

When we are planning buildings and manure handling systems, it is important to have a good strategy for H_2S-safety.

From the operator and animal safety point of view, it is highly advisable to use a submerged recirculation pipe for mixing, and to prevent conditions of free-falling or splashing manure. This would also reduce odour nuisance when manure is pumped from the stable into a remote, outdoor, open storage tank. There should be a gaslock (submerged pipe) in the slurry channel towards the livestock building and the storage tank to prevent the backflow of gas.

Reducing the production of H_2S is possible by adding lime to liquid manure. It will reduce the free gas phase of H_2S by increasing the pH.

Temperature decreases the anaerobic breakdown process and H_2S production. Further technical reduction methods are described by Skarp (1971).

When emptying manure storage facilities, the safety procedures recommended as good practice in each country should be followed.

5.6 Hydrogen cyanide

Introduction

Animals that have died during or after mixing manure are usually said to have died because of H_2S. However, fresh manure contains sufficient cyanides to be able to generate high air concentrations. HCH is a toxic and explosive gas. There are few reports on HCH measurements in livestock buildings.

Production

Little is known about factors contributing to the release of HCH, except that it is released together with H_2S during mixing of manure. Counotte (1988) measured concentrations up to 400 ppm (single measurements) and up to 114 ppm average concentration over 15 minutes.

Measurement

Hydrogen cyanide can be measured by gas detection tubes or by chemical methods, as well as with gas chromatography coupled with a mass spectrometer.

Effects on humans

The MAC-concentration for HCH is 10 ppm. It is a very toxic gas and is easily taken up by breathing, swallowing or through the skin. Concentrations in air between 5.4 and 46.6% are explosive (Counotte (1988).

5.7 Carbon monoxide

Introduction

Carbon monoxide can be produced from incomplete combustion of fuels inside buildings. The gas is toxic to humans and animals.

Measurements

Donham (1987) described four measurement methods for CO detection.

Gas detection tubes

The reagent inside the tube is specific for the type of gas being measured. Tubes are available in different sensitivities. They are used with a syringe to draw an instantaneous sample of air. They provide an immediate reading by means of a colour change. This method is preferred.

Dosimeter tubes

This sampling device utilizes permeation and diffusion of gases into silica gel. The gas concentration is determined by the length of the colour stain. The system is too slow for detection of toxic levels. High humidity and high temperature can reduce the adsorption capacity of the collection medium.

Electrochemical sensors

Devices for monitoring gases (e.g. CO) with an audible alarm system. Preferable for continous monitoring.

Sensing badges or tapes

Chemically impregnated, after a period of exposure to air they are evaluated visually, or by light transmission or reflection in the laboratory. Badge readings are less accurate than gas detector tube readings.

Effects on animals and humans

Carbon monoxide is rapidly absorbed into the blood, causing systemic intoxication (Proctor, 1978). It ties up blood haemoglobin by forming carboxyhaemoglobin. McAllister (1966) reported that CO can cause death in adult pigs at concentrations of approximately 4000 ppm and in chickens at 2000 ppm. However, much lower sublethal concentrations have been showed deleterious effects on unborn and young piglets. The threshold limit for CO is 10 ppm, as given by the Council of Europe.

5.8 Other gases

Beside the gases discussed in this report, there is a large group of gases present in livestock buildings. O'Neill (1992) compiled a list of 168 volatiles identified in the air of livestock buildings.

References

Aarnink, A.J.A., E.N.J. van Ouwerkerk & M.W.A. Verstegen, 1992. A mathematical model for estimating the amount and composition of slurry from fattening pigs. Livestock Production Science 31: 121-132.

Aengst, C., H.G. Hilliger & E. Rokicki, 1983. Zur Durchfuhrung von Stalluftuntersuchungen aus tierarztlicher Sicht. Deutsche Tierarztliche Wochenschrift 90: 509-512.

Anderson, G.A., R.J. Smith, D.S. Bundy & E.G. Hammond, 1987. Model to predict gaseous contaminants in swine confinement buildings. J. agric. Engng Res. 37: 235-253.

Anonymous, 1987. Interim evaluation of acidification policy (in Dutch). Ministry of Housing, Planning and Environment, Ministry of Traffic and Water Affairs & Ministry of Agriculture, Nature and Fisheries. The Hague.

Anonymous, 1989. Emissionen von Ammoniak - Quellen, Verbleib, Wirkungen, Schutsmaßnahmen. Arbeitsmaterialien des Bundesamtes für Ernährung und Forstwirtschaft. Frankfurt/Main.

Attwood, P., R. Brouwer, P. Ruigewaard, P. Versloot, R. de Wit, D. Heederik & J.S.M. Boley, 1987. A study of the relationship between airborne contaminants and environmental factors in Dutch swine confinement buildings. Am. Ind. Hyg. Assoc. J. 48: 745-751.
Beek, G. van & F.F.E. Beeking, 1992. Carbon dioxide emission of litter in poultry houses. Proceedings World Poultry Congress, Amsterdam, 20-24 September 1992, p. 277-281.
Beers, S., P.A. Kemme & C.M.C. van der Peet-Schwering, 1991. Effect of feeding method and decreased minaral content in the diet on mineral excretion and performance of growing pigs. Phase 1: Feeding to the requirement of phosphorus with multi-phase feeding. Report IVVO-DLO 231, Lelystad.
Berckmans, D., Ph. Vandenbroeck & V. Goedseels, 1991. Sensor for continuous measurement of the ventilation rate in livestock buildings. Indoor Air 3: 323-336.
Berckmans, D., C.E. van 't Klooster & E. Vranken, 1992. Field test of a ventilation rate sensor in a natural ventilated livestock building. ASAE paper 924047, St.Joseph, MI.
Boer, S.D., de & W.D. Morrison, 1988. The effects of the quality of environment in livestock buildings on the productivity of swine and safety of humans: a literature review. Dep. of Animal and Poultry Science, Guelph, Canada.
British Standards Institution, 1976. British Standard for gas detector tubes. BS 5343. BSI, London.
Carlile, F.S., 1984. Ammonia in poultry houses: a literature review. Worlds's Poultry Science Journal 40 (2): 99-113.
Charles, D.R. & C.G. Payne, 1966. The influence of graded levels of atmospheric ammonia on chickens. I. Effects on respiration and on the performance of broilers and replacement growing stock. British Poultry Science 7: 177-187.
CIGR, 1984. Climatization of animal houses. Report from working group. Scottish Farm Buildings Investigation Unit, Aberdeen.
Clark, P.C. & J.B. McQuitty, 1987. Air quality in six Alberta commercial free-stall dairy barns. Canadian Agricultural Engineering 29: 77-80.
Colanbeen, M. & G. Neukermans, 1989. Desodorisation de l'air des poulaillers par filtration biologique. In: V.A. Dodd & P.M. Grace. "Agricultural Engineering: Proceedings of the 11th International Congress on Agricultural Engineering", Balkema, Rotterdam, p. 1005-1013.
Colanbeen, M. & G. Neukermans, 1992a. Mestbehandeling door oligolysebewerking (in Dutch). Landbouwtijdschrift 45(4): 701-716.
Colanbeen, M. & G. Neukermans, 1992b. Stankbestrijding van ventilatielucht door het gebruik van biofilters en biowasfilters (in Dutch). Landbouwtijdschrift, 45(5): 909-927.
Conceicao, M.A.P., 1989. Spatial inhomogeneity of aerial pollutants in a poultry house. Aerosol sampling in animal houses. In: C.M. Wathes & J.M. Randall (Eds), Proceedings of a workshop, University of Bristol, Department of Animal Husbandry, 26-28 July 1988, p. 38-43. Report No. EUR 11877, CEC, Luxembourg.
Council of Europe, 1974. Resolution AP (74) u, On the manufacture of detector tubes to control the atmosphere in work places.
Counotte, G.H.M., B. van Keulen, G.W. Lieben, E. Mulder, L.T. van der Veen, D. Verbiesen & P. Zandstra, 1988. Dangers of mixing manure in cubicle dairy houses, the release of hydrogen sulphide (H_2S) and hydrocyanic (HCH) (in Dutch). Gezondheidsdienst voor Dieren, Drachten, The Netherlands, 27 pp.
Crook, B., J.F. Robertson, S.A. Travers Glass, E.M. Botheroyd, J. Lacey & M.D. Topping, 1991. Airborne dust, ammonia, microorganisms, and antigens in pig confinement houses and the respiratory health of exposed farm worker. American Industrial Hygiene Assosiation Journal 52: 271-279.
Crutzen, .J., I. Aselmann & W. Seiler, 1986. Methane production by domestic animals, wild ruminants, other herbivorous fauna, and humanS. Tellus 38B (1986), p. 271-284.
Demeyer, D.I. & C.J. van Nevel, 1975. Methanogenesis, an integrated part of carbohydrate fermentation, and its control. In: I.W. McDonald & A.C.I. Warner (eds.), 1975. Digestion and metabolism in the ruminant, Proc. IV. Int. Symp. Ruminant Physiology, Univ. of New England, Publishing Unit, Armidale, Australia, p. 366-382.
DIN 18910, 1974. Klima in geschlossenen Ställen. Beuth Verlag GmbH, Berlin/Köln.
Döhler H. & H. van den Weghe (Eds), 1990. Ammoniak in der Umwelt. KTBL Darmstadt.
Donham, K.J., M. Rubino, T.D. Thedell & J. Kammermeyer, 1977. Potential health hazards to agricultural workers in swine confinement buildings. Journal of Occupational Med. Vol 19(6): 383-387.

Donham, K.J., 1987. Health hazards of air in swine buildings: state of the art. Proc. Am. Assoc. Swine Practitioners. Indianapolis, Indiana, U.S.A.
Donham, K.J., 1991. Association of environmental air contaminants with disease and productivity in swine. Am. J. Vet. Res. Vol 52: 1723-1730.
Dourmad, J.Y., D. Guillou & J. Noblet, 1992. Development of a calculation model for predicting the amount of N excreted by the pig - effect of feeding. Livestock Production Science 31: 95-107.
Drägerwerk, 1986. Früfröhrchen- Taschenbuch (6. Auflage). Lübeck.
Drummond, J.G., S.E. Curtis, R.C. Meyer, J. Simon & H.W. Norton, 1981. Effects of atmospheric ammonia on young pigs experimentally infected with Bordetella bronchiseptica. American Journal of Veterinary Research 42: 463-468.
Elliot, H.A. & N.E. Collins, 1983. Chemical methods for controlling ammonia release from poultry litter. ASAE paper 83-4521. St. Joseph, MI.
Elliot, H.A. and Collins, N.E., 1982. Factors affecting ammonia release in broiler houses. Transactions of the ASAE, 22, 413-418 and 424, 1982.
Es, A.J.H. van & H.A. Boekholt, 1986. Intermediary gas exchange (in Dutch) KA 1, Agricultural University, Wageningen.
Evans, M.R., M.P.W. Smith, E.A. Deans, I.F. Svoboda & F.E. Thacker, 1986. Nitrogen and aerobic treatment of slurry. Agric. Wastes 15.
Freney, J.R., J.R. Simpson & O.T. Denmead, 1983. Volatilization of ammonia. Developments in Plant and Soil Sciences 9:1-32.
Gatel, F. & F. Grosjean, 1992. Effect of protein content of the diet on nitrogen excretion by pigs. Livestock Production Science 31:109-120.
Groot Koerkamp, P.W.G., N. Verdoes & G.J. Monteny, 1990. Towards animal housing with reduced ammonia emission (in Dutch). Part 1 and 3. DLO, Wageningen.
Gustafsson, G. & L. Mårtensson, 1988. Gas reducing methods in pig houses. Dept. of Farm Buildings, Report 57, Lund.
Gustafsson, G. & L. Mårtensson, 1990. Gases and dust in poultry houses. Dept. of Farm Buildings, Report 68, Lund.
Hel, W. van der, R. Duijghuisen & M.W.A. Verstegen, 1986. The effect of ambient temperature and activity on the daily variation in heat production of growing pigs kept in groups. Netherlands Journal of Agricultural Science 34: 173-184.
Helvoort, M. van, 1988. Ammonia emission during storage of pig manure (in Dutch). Report of a stage, IMAG-DLO, Wageningen.
Hilliger, H.G., 1982. Untersuchungen in einem Schweinemaststall zur Wasserdampf-, Kohlendioxid- und Wärmebildung. In: Stallklima und Geruchsbelästigung, Teil II, KTBLSchrift 272, Landwirtschaftsverlag GmbH, Hiltrup, p. 14-22.
Hoeksma, P., 1984. Biogas in livestock husbandry (in Dutch). IMAG-publication 199, Wageningen.
Hoeksma, P., J. Oosthoek & N. Verdoes, 1993. Reductie van ammoniak emissie mit varkenstallen door mestspoelen met belachte mestvloeistof (Reduction of ammonia emission from pig housing by flushing with aerated slurry). IMAG-DLO Report 93-23, Wageningen.
Hoeksma, P., N. Verdoes, J. Oosthoek & J.A.M. Voermans, 1992. Reduction of ammonia volatilization from pig houses using aerated slurry as recirculation fluid. Livestock Production Science 31: 121-132.
Hoffmann, T., 1979. Die Auswirung der DIN 18910 "Klima im geschlossenen Stall" tolerierten Grenzkonzentrationen von CO_2 auf Mastküken, Diss. vet. med. Giessen.
Hogsved, O., 1968: Manure gases - a literature study and practical experience. Forhandsmeddelande nr 311, LBT, Lund, Sweden.
Honing, Y., van der, 1984. Personal communication, IVVO-DLO, Lelystad, Netherlands.
Janssen, J. & K.-H. Krause, 1990. Messung und Simulation von Ammoniakkonzentrationen in Ställen. In: H. Döhler & H. van den Weghe (Eds) "Ammoniak in der Umwelt". KTBL Darmstadt.
Kangas J., K. Louhelainen & K. Husman, 1987. Gaseous health hazards in livestock confinement buildings. Journal of Agricultural Science in Finland 59:57-62.
Kemme, P.A., A.W. Jongbloed, B.M. Delaert & F. Krol-Kramer, 1993. The use of a yucca schidigera extract as urease inhibitor in pig slurry. In: Nitrogen flow in pig production and environmental consequences. EAAP publ. 69. Wageningen, p. 330-335.

Kessel, M., 1990. Überblick zu Meßtechniken für gasförmiges Ammoniak. In: H. Döhler & H. van den Weghe (Eds) "Ammoniak in der Umwelt". KTBL Darmstadt.
Kirchmann, H. & E. Witten, 1989. Ammonia volatilization during aerobic and anaerobic manure decomposition. Plant and Soil 115:35-41.
Kliche, R., 1980. Der Nachweis und die Bestimmung von Schadgasen und Geruchsstoffen in Tierproduktionsanlagen. Wissenschaftliche Zeitschrift der Karl-Marx Universitat Leipzig, Mathematisch-Naturwissenschaftliche Reihe; 29:449-461.
Klooster, C.E. van 't & J.A.M. Voermans, 1994. European perspectives - how are they solving their problems? Proc. Symp. "Meeting the environmental challenge". National Pork Producers Council, Des Moines, Iowa.
Krause, K.-H. & J. Janssen, 1989. Kontinuerliche Ammoniakmessungen in Ställen. Grundlagen der Landtechnik 39:52-65.
Krause, K.-H. & J. Janssen, 1991. Modelling the dispersion of ammonia within animal houses. In V.C. Nielsen et al. (Eds) "Ammonia and odour emissions from livestock production" p71-80. London.
Krieger, R., J. Hartung & A. Pfeiffer, 1993. Experiments with a feed additive to reduce ammonia emissions from pig fattening housing - preliminary results. In: Nitrogen flow in pig production and environmental consequences. EAAP publ. 69. Wageningen, p. 295-300.
KTBL, 1990. Ammoniak in der Umwelt. Münster.
Leonard, J.J., J.J.R. Feddes & J.B. McQuitty, 1984. Air quality in commercial broiler housing. Canadian Agricultural Engineering 26:65-71.
Litgens J.B. & F. van Eykelenburg, 1987. Tijdschrift voor Diergeneeskunde 112 (1): 27-28.
Malayer J.R., K.E. Brandt, M.L. Green, D.T. Kelly, A.L. Sutton & M.A. Diekman, 1988. Influence of manure gases on the onset of puberty of replacement gilts. Proc. of the British Soc. for Animal Production 46:277-282.
Mårtensson, L. & P. Lundqvist, 1991. The working environment in a house for loose laying hens. Dept of Farm Buildings, report 71, Lund.
McAllister, J.S.V., 1966. Gases from dung under slats. Farm Buildings 11:23-24.
Mehlhorn, G., 1979. Lehrbuch der Tierhygiene. Verlag Gustav Fischer.
Merkel, J.A., Hazen, T.E. and Miner, J.R., 1969. Identification of gases in a confinement swine building atmosphere. Transaction of the ASAE, 12:3, 310-315, 1969.
Miner J.R. & T.E. Hazen, 1969. Ammonia and amines: components of swine building odor. Transactions of the ASAE 12:772-774.
Mothes, E., 1973. Stallklima-Leistungsfaktor der Tierproduktion. VEB-Deutscher Landwirtschaftsverslag, Berlin.
Muck. R.E. & T.S. Steenhuis, 1982. Nitrogen losses from manure storages. Agric. Wastes 4:41-54.
Neumann R., G. Mehlhorn, I. Buchholz, U. Johannsen & D. Schimmel, 1987. Experimental studies of the effect of chronic aerogenous toxic gas exposure of unweaned piglets with ammonia of various concentrations. J. Vet. Med. 34: 241-253.
Nordström, G.A. & J.B. McQuitty, 1976. Manure gases in the animal environment. A literature review. Research Bulletin 76-1. Dep. of Ag. Eng, University of Alberta, Canada, 80 pp.
Nóren, O., 1975. Noxious gases and odours. JTI-Rapport nr 17, Uppsala.
O'Connor J.M., J.B McQuitty & P.C. Clark, 1988. Air quality and contaminant loads in three commercial broiler breeder barns. Canadian Agricultural Engineering 30: 273-276.
Oldenburg, J., 1989. Geruchs- und Ammoniak-Emissionen aus der Tierhaltung. KTBL-Schrift 333, Darmstadt.
O'Neill, D.H. & V.R. Phillips, 1992. A review of the control of odour nuisance from livestock buildings: Part 3, Properties of odorous substances which have been identified in livestock wastes or in air around them. Appendix: Volatile organic compounds and gases identified in livestock wastes. J. agric. Engng Res. 53: 23-50.
Oosthoek, J., W. Kroodsma & P. Hoeksma, 1990. Betriebliche Maßnahmen zur Minderung von Ammoniakemissionen aus Ställen. In: H. Döhler & H. van den Weghe (Eds) "Ammoniak in der Umwelt". KTBL Darmstadt.
Ouwerkerk, E.N.J., 1993. Measurement methods for ammonia emissions from livestock buildings. (in Dutch). DLO Ammonia Series 16, Wageningen.

Ouwerkerk, E.N.J. van & J.A.M. Voermans, 1985. The effect of insulating broiler house floors on odour emission. In: V.C. Nielsen, J.H. Voorburg & P. l'Hermite (eds.), "Odour prevention and control of organic sludge and livestock farming". Elsevier Applied Science Publishers, p. 175-180.
Ouwerkerk, E.N.J. van, 1987. Physical factors affecting diurnal variation in temperature demand for growing pigs (in Dutch). IMAG-DLO Report 88, Wageningen, 8 pp.
Ouwerkerk, E.N.J. van & A.J.A. Aarnink, 1992. Gas production of fattening pigs. AgEng, Uppsala 1992. Lecture number 9202 07. Institute of Agricultural and Environmental Engineering, IMAG-DLO, Wageningen.
Ouwerkerk, E.N.J. van (ed.), 1993. Measurement methods for ammonia emissions from livestock buildings (in Dutch), DLO-Ammonia Series 16, Agricultural Research Department, Wageningen, 178 pp.
Ouwerkerk, E.N.J. van & A.J.A. Aarnink, 1994. Gas production in piggeries; model of source productions for estimating indoor gas and vapour concentrations and emissions; preliminary study (in Dutch). IMAG-DLO Report (in press), Wageningen.
Ouwerkerk, E.N.J. van & S. Pedersen, 1994. Application of the carbon dioxide mass balance method to evaluate ventilation rates in livestock buildings. XII World Congress on Agricultural Engineering, Milano, August 29 - September 1, Proceedings, p. 516-529.
Oyetunde, O.O.F., R.G. Thomson & H.C. Carlson, 1978. Aerosol exposure of ammonia, dust and Escherichia coli in broiler chickens. Canadian Veterinary Journal 19:187-193.
Patni, N.K. & S.E. Clarke, 1990. Transient hazardous conditions in animal buildings due to manure gas released during slurry mixing. ASAE Publication 05-90. Proceedings of the Sixth International Symposium on Agricultural and Food Processing Wastes, Chicago.
Pearson, C.C., V.R. Phillips, G. Green & I.M. Scotford, 1992. A minimum cost biofilter for reducing aerial emissions from a broiler chicken house. In: A.J. Dragt & J. van Ham (Eds) "Biotechniques for air pollution abatement and odour control policies", Amsterdam, p. 245-254.
Pedersen, Søren, 1992. Estimation of air renewal in livestock buildings on the basis of exhausted carbon dioxide. DK-report 1 on EC-project PL 900703.
Praetere, K. de & W. van der Biest, 1990. Air flow patterns in piggeries with fully slatted floors and their effect on ammonia distribution. J. agric. Engng Res. 46:31-44.
Proctor, N.H. & J.P. Hughes, 1978. Chemical hazards of the workplace. J.B. Lippincott Comp., Philadelphia, Toronto.
Randall, J.M., 1980. Selection of piggery ventilation systems and penning layouts based on the cooling effects of air speed and temperature. J. agric. Engng. Res. 25:169-187
Robertson, A.M., 1971. Effect of ventilation on the gas concentration in a part-slatted piggery. Farm Building R & D Studies (1) May 1971 p.17-28, Scottish Farm Buildings Investigation Unit.
Robertson, J.F., D. Wilson & W.J. Smith, 1990. Atrophic rhinitis: the influence of the aerial environment. Anim. Prod. 50:173-182.
Robertson, J.F., 1992. Dust and ammonia in pig buildings. Farm Building Progress 110:19-24.
Sällvik, K., 1974: Manure gases and their effect on livestock health. International Livestock Environment Symposium, Lincoln, Nebraska.
Sällvik, K., 1994. Personal communication.
Sällvik, K., P. Wigström & S. Steineck, 1973. Liquid manure - ventilation. Trials to diminish the risk of liquid manure gas poisoning in cow- and pighouses (in Swedish). The Royal Agricultural College of Sweden. Meddelanden serie A nr 193, Uppsala, Sweden.
Scholtens, R. & T.G.M. Demmers, 1991. Biofilters and air scrubbers in the Netherlands. In V.C. Nielsen et al. (Eds) "Ammonia and odour emissions from livestock production", London, p. 92-96.
Scholtens, R., 1990. Ammoniakemissionmessungen in zwangbelüfteten Ställen. In: H. Döhler & H. van den Weghe (Eds) "Ammoniak in der Umwelt". KTBL Darmstadt.
Semen, L.V. & M.V. Demchuk, 1985. Veterinaria, Moscow, 12: 32-33
Simensen, E., 1981. Climatic conditions and their relation to housing factors in Norwegian dairy barns with special reference to dairy cows. Acta Agriculturae Scandinavica 31:261-266.
Skarp, S.-U., 1971. Safer handling of liquid manure gas and air currents in livestock buildings. Swedish Institute of Agricultural Engineering, Special Report 20, Uppsala.
Schneider, W. & K.H. Menke, 1982. Untersuchungen über den energetischen Futterwert von Melasse--Schnitzein in Rationen für Schweine. Z. Tierphysiologie, Tierernährung und Futtermittelkunde 48, 233-240.

Schneider, B., 1988. Computergestützte kontinuierliche Erfassung der Wärme-, Wasserdampf- und Kohlendioxidproduction in Nutztierställen. Dissertation, Universität Hohenheim.

Schrenk, H.-J. & D. Marx, 1982. Der Aktivitätsrhythmus von Ferkeln und seine Beeinflüssung durch Licht und Futtergabe. Berl. Münch. Tierärztl. Wschr. 95: 10-14.

Skarp, S.U., 1975. Manure gases and air currents in livestock housing, In: "Managing livestock wastes".Proceedings of the 3rd international symposium on livestock wastes. Ilinois, 362-365, 1975.

Stombaugh, D.P., H.S. Teague & W.L. Roller, 1969. Effects of atmospheric ammonia on the pig. J. Animal Science. 28:844-847.

Taiganides, E.P., 1987. Animal waste management and wastewater treatment. In: Strauch (Ed.) World Animal Science B6, Animal production and environmental health. Elsevier, Amsterdam.

Taiganides, E.P. and White, R.K., 1969. The menance of noxious gases in animal units. Transactions of the ASAE, 12:3, 359-367, 1969.

Thorbek, G., A. Chwalibog & S. Henckel, 1984. Nitrogen and energy metabolism in pigs of Danish Landrace from 20 to 120 kg live weight. Norm for protein and energy requirements for maintenance and growth (in Danish). Report no 563, National Institute of Animal Science, Denmark, 114 pp.

Tjernshaugen, O., 1975. Gas concentrations in housing for domestic animals. Univ. of Norway. Dept. of Agric. Structures, Report 83.

Tomescu V. & F. Marschang, 1977. Observations on the correlation between the dung disposal systems and the concentration of ammonia in the air of animal houses. British Veterinary Journal; 133:629-634.

Veit, H.P., E.T. Kornegay & E.R. Collins, 1985. Air quality, pig health and performance in triple deck nurseries. Transactions of the ASAE 28: 1259-1262.

Verdoes, N., J.H.M. van Cuyck & G.M. den Brok, 1993. Mestpannen in kraamstallen (Slurry pans in fattening rooms). Report P1.94, Research Institute for Pig Husbandry, Rosmalen.

Verstegen, M.W.A., 1971. Influence of environmental temperature on energy metabolism of growing pigs housed individually and in groups. Ph.D Thesis, Agricultural University, Wageningen, 115 pp.

Verstegen, M.W.A., W. van der Hel, R. Duijghuisen & R. Geers, 1986. Diurnal variation in the thermal demand of growing pigs. J. therm. Biol. 11 (2): 131-135.

Voermans, J.A.M. (Ed.), 1992. Proc. of a European workshop on deep-litter systems for pigs. Rosmalen.

Voermans, J.A.M. & M.M.L. van Asseldonk, 1992. Psychrophilic digestion of pig slurry (in Dutch). Report P 1.69, Research Institute for pig husbandery, Rosmalen, The Netherlands, 32 pp.

Vogels, G.D. & D. van der Drift, 1976. Degradation of purines and pyrimides by micro-organisms. Bacteriological Reviews 40:403.

Wiegant, W.M. & G. Zeeman, 1986. The mechanism of ammonia inhibition in the thermophilic digestion of livestock wastes. Agricultural Wastes 16:243-253.

Willems, J.J.H. & P. Hofschreuder, 1990. A passive monitor for measuring ammonia. In: EEC Air pollution report 37, Roma, p. 99-119.

Wolfe, R.R., D.P. Anderson, F.I. Chems & W.E. Roper, 1968. Effects of dust and NH_3 air contamination on turkey response. Transactions of the ASAE 515-518,522.

Zeeman, G., 1991. Mesophilic and psychrophilic digestion of liquid manure. PhD Thesis, Agricultural University Wageningen.

Zhang, R.H., D.L. Day & K. Ishibashi, 1990. Generation and transport of gases in and out of liquid swine manure in under-floor pits. Proc. 6th Intern. Symp. on Agricultural and Food Processing Wastes.

6 Odour

6.1 Introduction

Odour is characterized by a totally different behaviour compared to gases, suspended particles (aerosols) and depositing dust. Odoriphores themselves, as chemical compounds, can be treated as for all other airborne pollutions. Thus chemicals which must be gaseous or dissolved in volatile substances and must be soluble in water or fat are the basis for the human reaction called odour. This sensation as a physiological reaction is evaluated by the emotional situation of the individual. Nuisance from odour may be manifested as complaint, depending on the psychological and socio-economic situation of the person. These different steps show the complexity of the concept of dour.

Animal waste management research has been encouraged by a variety of environmental pressures and public concern about the impact of livestock production on environmental quality. Nowadays there is an acute need for effective methods of odour control. If livestock industries are to co-exist with their neighbours such control measures will have to put into operation. Moreover, conflicts between livestock producers and the public concerning odour complaints are now being reflected in rules and regulations designed to protect the public from malodours generated by livestock production units. These rules and regulations can be applied as additional restrictions on the location, design and operation of animal housing.

6.2 Origin

Odour is the effect of a complex gas mixture of various chemical substances, many of which are still unknown. It is important to remember that only volatile compounds have an odour (a few common exceptions are the gases N_2, O_2, Ar, CO_2, CH_4), which enables them, if present in sufficient concentration, to be responsible for bad smells.

Several researchers have, in the course of years, identified more than 150 volatile compounds in piggery waste (Merkel et al., 1969; Schaefer et al., 1974; Yasuhara et al., 1983). Some of them will, based on their concentration, threshold value or odour character, contribute more to the odour than others.

Much more literature is available about identification of gases and odours in piggery wastes and in confinement swine buildings than about the bad smell produced by laying hens and broilers. However, generally it is said that there is no major difference between those two "kinds of odours". The odorants which form the odour produced by livestock farming belong to different classes of chemical compounds: the volatile fatty acids, phenols, nitrogen derivates (ammonia, amines, indole, skatole, etc.) and reduced sulphur compounds (thiols, sulphides, disulphides, thiophenes, etc.). Schaefer et al. (1974) reported that in sensory tests the odour from mixing phenol, p-cresol, indol, 3-methylindole, butanoic acid and 2, 3-butanedione is the most similar to the odour of piggery wastes in sensory tests.

Odour is a product of bacterial action. There is a difference between the bacterial activity in the animal (conversion of feed to wastes) and the anaerobic degradation of the mixture of urine and faeces during storage (Spoelstra, 1979, 1980). Urine contains dissolved low molecular weight substances (urea/uric acid [1*], glucuronides, hippuric acid, sulphate,...) whereas the faeces are composed of products of microbial catabolism (fatty acids, etc.), unchanged plant fibre fractions and bacteria (10^{11} bacteria/g faeces). During storage of the mixture of faeces and urine (= manure) a microbial fermentation takes place leading to the accumulation of volatile constituents (Spoelstra, 1979, 1980). In table 6.1 a summary is made of the main odorous substances found in animal manure.

Table 6.1 Origin of the main odorous compounds

Odour compound	Origin
fatty acids (acetic, propionic, butyric acid ....)	degradation of plant fibre and protein
phenols (phenol, p-cresol, 4-ethylphenol...)	anaerobic degradation of tyrosine
indoles (indole, 3-methylindole)	anaerobic degradation of tryptophane
sulphur containing compounds	anaerobic degradation of cystine, cysteïne,...
amines	anaerobic degradation of proteins

(Allison, 1978; Spoelstra, 1977, 1978; Yasuhara et al., 1984; Travis & Elliot, 1977; Miner & Hazen, 1969; Banwart & Bremner, 1975; Kadota & Ishida, 1972)

Research by Oldenburg (1989) in a large number of livestock buildings shows that high odour concentrations in the waste air do not necessarily mean that the ammonia concentration is also high and vice versa (Figure 6.1).
The reason for this is found in both the very different systems of production as well as the different physical characteristics of odour and ammonia.

There is a positive correlation between ammonia and other odour compounds, but the degree of association can be highly variable. The odour emission of different animal housing systems for the same type of animal can vary a lot. VDI 3471 states that full slatted floors in pig houses cause less odour emission than partly slatted floors; Mannebeck (1986), conversely, measured higher odour emissions in pig houses with full slatted floors. One thing is sure, the odour emission (as well as the ammonia emission) increases with increasing fattening period (Figure 6.2).

(*) = urea : for pigs and cows ;
uric acid : for poultry.

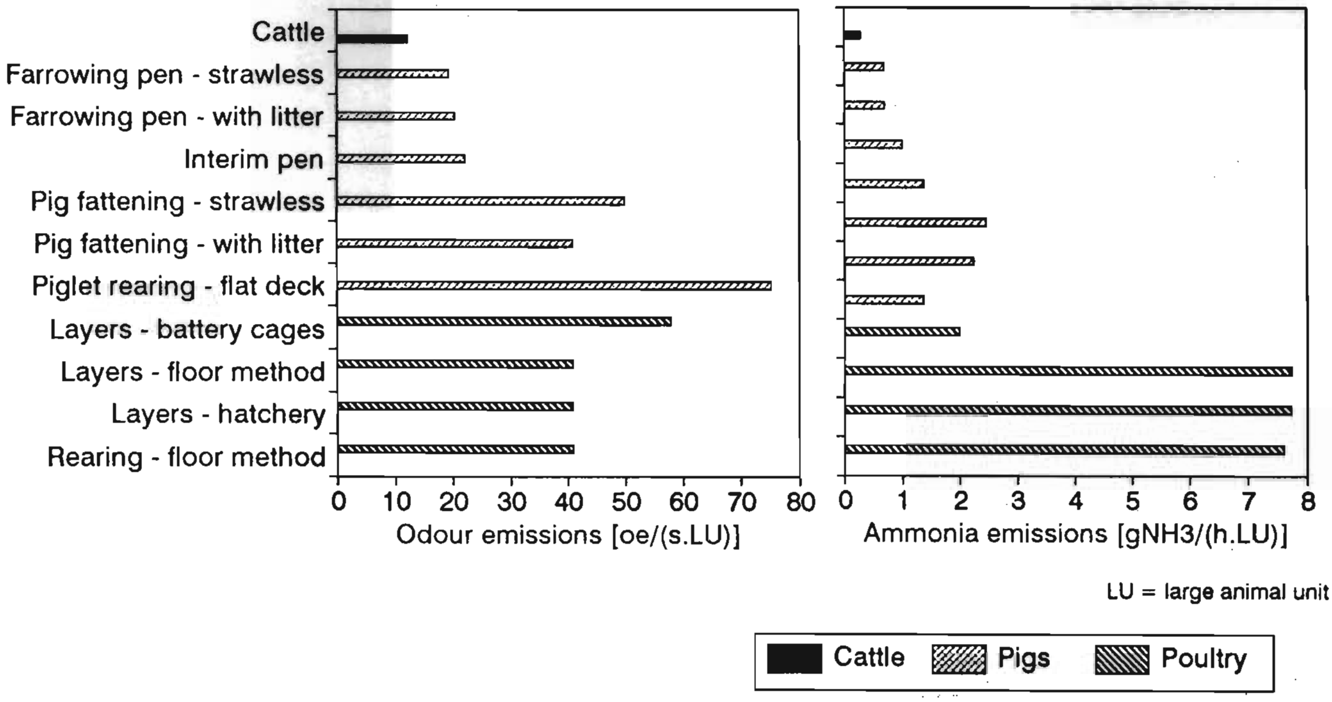

Figure 6.1 Comparison of odours and ammonia concentrations of various species of animals and breeding methods (according to Oldenburg, 1989) (LU = 500 kg live mass)

6.3 Measurement

Complaints about offensive odours caused by the animal industry form a large proportion of the total number of environmental complaints since a lot of livestock buildings are located near residential areas. In the past decades far more effort was focused on other forms of pollution (water pollution, presence of toxic compounds in soils, etc) because:
- offensive odours are not really harmful and
- there existed a lack of reliable and efficient odour measurements.

Nobody can deny that odour is a very complex and subjective phenomenon which cannot be easily expressed in ordinary figures, which is probably the main reason for the non-existence of "the" real odour measurement. Odour and odour problems are examples of a complex dose-response relationship (Schamp & Van Langenhove, 1987); the dose is the appearance of odorous substances above their threshold value while the response (the effect) is, first of all, the odour perception. Based on this odour perception, individual and/or collective odour nuisance can occur. It would be very interesting if there existed some kind of relationship between dose alteration and the corresponding change in response. However, the relationship between both is extremely complex due to the in-

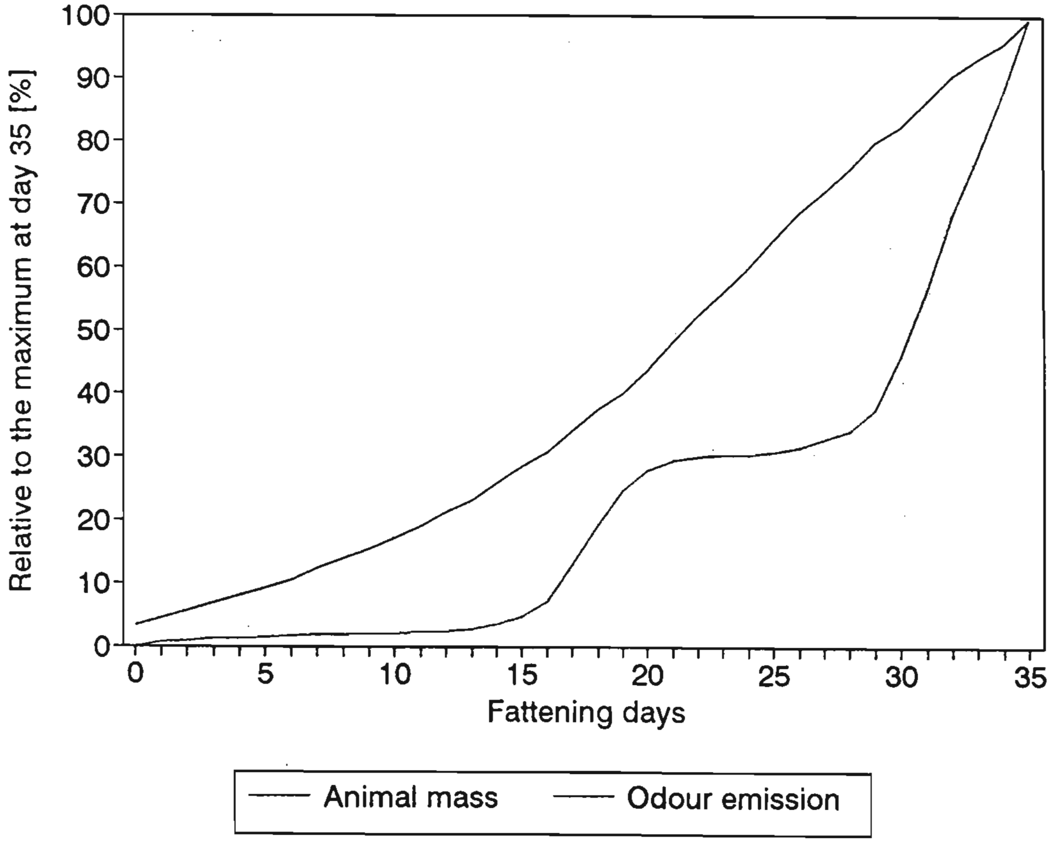

Figure 6.2 Odour emission from a broiler house with an increasing fattening period (according to Oldenburg, 1989)

fluence of several physiological, psychological, psychophysical and sociological parameters. This lack of fundamental knowledge has great impact on odour measurement. One can measure the dose and therefore use chemical analytical techniques or one can measure the response (odour perception) and so use sensory analyses. Moreover, sociological methods are required for further research concerning odour nuisance. It is important to notice that applying chemical or psychophysical (sensorial) or sociological methods only covers a part of the whole field of odour determination. These three approaches to odour research are truly complementary to each other; the methods together provide more or less complete information about odour.

Sensory odour analyses

To perform a sensorial technique one needs one or more observers and a dilution apparatus i.e. an olfactometer. An olfactometer (olfaction = perception of smell) dilutes odorous air with odour-free air in order to determine the number of dilutions required for odour to be only just detectable by 50 % of the members of a panel. Basically the result of an olfactometric analysis is expressed as an odour dilution ratio (a dimensionless value i.e. Z_k - the ratio of two volumes of air).

$$Z_k = 1 + \frac{Q_o}{Q_n}$$

where
Z_k : dilution number of the k-concentration step in a measuring sequence
Q_o : volume flow rate of the odorous sample
Q_n : volume flow rate of neutral air

However, in the literature more often another term is used. For each stimulus there exists a liminal quantitative value below which no consious sensation will be caused. For the sense of smell this value is known as the olfactory threshold i.e. the concentration of a compound which can be perceived by 50 % of the panel; it is a value derived from observations under laboratory conditions of extreme mental concentration. It is customary to express threshold concentrations in mg (μg) per cubic meter or in ppm (ppb) while the odour concentration itself is expressed as odour units per cubic meter (o.u./m^3) (VDI 3881, VDI 3882). One odour unit is the quantity of odorants in one cubic meter of air at odour threshold level. According to this definition the threshold value of a substance equals an odour concentration of one odour unit/m^3 (VDI 3881, 3882).

There are some advantages in using this effect-related method: the human sense of smell is superior in sensitivity to most physical-chemical field instruments for measuring odour substances. Even if the odorant concentration is below the detection limits of these measuring methods, odour sensation may be observed.
Generally a mixture of gases and odoriphores are involved. In the present state of analytic art the determination of such odorant mixtures is very often unfeasible. There are no well-known relationships between the odorant concentration and the perception of odour. By using olfactometry as an empirical method, the relationship can also be determined for unknown odorant mixtures.

Both static and dynamic sampling procedures are used for olfactometric measurements. Static olfactometers dilute, step by step, a sample of odorous air in a sampling vessel (plastic bag, glass vessel) using syringes or on-line tubing. Dynamic olfactometers dilute the odorous gas continuously by mixing known flow rates of two gases (odour-free and odorous air). By varying the flow rates different dilution levels are obtained.

Static sampling procedures are the oldest methods providing dilution levels and seem to be the easiest ones. However, there exists one serious problem : sample losses due to adsorption, desorption and condensation. Adsorption and desorption (i.e. bleeding of trace components from the wall of the vessel or tube) can be minimized by the choice of material (PTFE, polyvinylfluoride, etc.) and preflushing. Condensation can be avoided by the predilution of the sample vessels (bags) with dry, odour-free air. Naturally, it is important to know precisely the volume of dry air and the amount of the odorous sample for odour unit or odour threshold determination. In order to minimize reactions between compounds in the gas phase the storage time must be kept as short as possible (< 24 h).

Using dynamic sampling, surface effects, mentioned earlier, can also occur but the risk is considerably smaller; nevertheless, the following aspects should be kept in mind :
- use short and inert sampling tubes (PTFE, glass, etc.),
- preflushing,
- predilution with dry odour-free air,
- if required, use heated sampling tubes and dust filters.

Though nowadays dynamic sampling methods are preferred, static procedures are still often used (they are less expensive).
Over the years various olfactometers have been used and commercialised (Mannebeck-TO4 and -TO6, a WSL olfactometer, a sniffcar, etc.). These devices can differ greatly in design and in method of application. In Belgium there are neither guidelines nor officially approved methods for measuring the sensory properties of odour. Therefore, applying olfactometer measurements in Belgium is based on one of the four guidelines available in the EC :
- Geurnormering (the Netherlands) - 1983
- AFNOR X 43 - 101 (France) - 1982
- VDI-Richtlinie 3881, part 1, 2, 3 and 4 (Germany) - 1983 - '84
- Odour control - a concise guide (United Kingdom) - 1980

Methods for field measurement of odorous air pollution vary in the measuring strategy (when, where ?), the selection and composition of the panel (panel size - how to select ?) and set-up of a measurement (based upon detectability - odour intensity?). VDI 3940 (1989) gives an extended discussion on panel members. Panelists should, according to the VDI 3940, be between 18 and 50 years of age; sex and smoker/non-smoker is of no importance. A more fundamental criteria for selecting panel members is based on the individual thresholds of perception and panelists with a threshold which differs too much from the average value are excluded. In France (AFNOR standard) the selection is based on the individual threshold for five pure compounds; panelists with a threshold which is more than a factor of 10 smaller or larger than the average for any compound are excluded. It need hardly be said that this kind of selection of panelists is a very time consuming, labour intensive and expensive matter.

Because olfactometers use the human nose as a sensor the possibilities and limitations of the instrument are to a large extent determined by the possibilities of the human subject. Human limitations of odour measurement were reviewed by Barth (1973) and Summer (1971) and include fatigue, adaptation, personal habits, physical condition, etc. It is well known that the sensitivity of men to odorants varies within a large range. By selecting the panelists at one extreme of the sensitivity distribution the result can be falsified. However, by choosing a large number of panelists, this effect can be minimized but this is often not suitable in practice. Hangarter (1985) has reviewed the selection of panelists and he concluded that 8 people is the right size for a panel. Although panels can never be standardized, selection criteria and training can guarantee fairly good reproducibility.

Selection of panel members still remains one of the most difficult tasks. Large variations of threshold data (differences of one or two orders of ten) are largely expected due to this problem. However, it is also well-known that different types of olfactometers produce different odour detection threshold values. It seems that the airflow of an olfactometer is one of the major parameters affecting the results, so in comparing the results of various olfactometers the effects of flowrate difference should be kept in mind (Klarenbeek, 1985). In the literature, recommendations are found regarding olfactometric measurements (Nielsen & Pain, 1990).

Chemical analysis

On the one hand, an odorous air sample contains a lot of substances which do not contribute to the offensive smell because their concentration is far below to the threshold. On the other hand, due to the sensitivity of the olfactory system with thresholds as low as a few ppb or even less, concentration of the volatiles, mainly volatile organic compounds (VOC), prior to identification remains necessary. In order to perform a chemical analysis successfully a systematic procedure must be followed :

- Sampling and concentration: cryogenic trapping, solvent absorption and adsorption on porous polymers are well-known concentration techniques;
- Chemical separation: gas chromatography (GC) or high pressure liquid chromatography (HPLC) are classical separation methods;
- Detection and identification: identification is mainly based on mass spectrometry (MS), infrared spectrometry and chromatographic data.

Naturally, it is desirable that with only one chemical analysis a broad spectrum of malodorants contributing to offensive odours is found. In the past gas chromatography has been succesfully used to identify and measure the concentrations of odorous compounds released from animal manure (Burnett, 1969) .The combination of GC and MS nowadays permits separation of complex mixtures of organic compounds and structure identification of these substances even at 10 ng amounts. (Yasuhara et al., 1984). It is therefore the best available method for the identification of volatiles.

Adsorption-desorption of an odorous air sample combined with GC/MS results in a long list of identified chemical substances. A lot of them do not contribute to the odour pattern, e.g. hydrocarbons from automobile exhausts, some effluent gases from factories etc. The selection of odorants implies searching for odour threshold data (despite the fact that those values have to be viewed with scepticism) and comparing the identified compounds with existing information on volatiles generally present in odorous air from livestock buildings. Another method of selecting malodorants from a complex mixture of volatile organics is an odorogram analysis. The GC is now not provided with a mass spectrometry system but with an FID. Moreover, the instrument works with a splitter, which conducts part of the sample to the detector and part to the open air. An analyst, observing the FID signal, sniffs at the column eluate and writes down any observed odour character of that single component. An analyst, observing the FID signal, sniffs at the column eluate and writes down any observed odour character of that single component. Making an odorogram analysis in the only appropriate method to select odorous compounds from a matrix of identified substances (Van Langenhove, 1987). Finally, odorous compounds have to be quantitatively determined. There is no real problem with quantification as far as emission concentrations are concerned. However, measuring immission[2] amounts is much more difficult because first of all the concentrations are much smaller (order of magnitude : ppb) and secondly, there are greater problems concerning interferences with other compounds. So, for immission measurements the analytical technology has still to be improved.

Quantitative measurement of odorant concentrations often confirms the thought that the odour perceived from livestock production enterprises is a result of the mixture of odorous compounds, since most of the measured compounds are present in concentrations below their threshold; so they would not be detectable by the human nose were they not accompanied by other odorous substances.

Translating a quantitative analysis into odour perception is not at all straightforward. Efforts have been made in the past to correlate the odour level with the concentration of a certain odorant (or odorants). Bell (1970) described a relationhip between the VOA (volatile organic acid) content of poultry manure and the odour offensiveness. Schaefer (1977) found that p-cresol was the best odour indicator of piggery slurry and Spoelstra (1980) concluded that p-cresol and volatile fatty acids to a large extent meet the requirements for indicator compounds. Jongebreur & Klarenbeek (1990), on the other hand, declared that complex odours, such as emanate from livestock facilities, cannot be characterized by a single or even a few compounds.

Sociological measurements

The nuisance value of odour is mainly influenced by the perception of the stimuli, the odorant concentration. Therefore it is not possible to use physiological or physical methods to determine nuisance. In addition there are no simple cause/effect relationships between emission of an odorant substance, the odour sensation and the nuisance.

There are different methods to assess the odour annoyance. First, by collecting data about odour annoyance for a complaint statistic analysis. Such complaints data suffers by the fact that complaint are ungraded yes/no answers and mostly made in cases of great odour impact. The individual effect depends widely on the readiness to accept odour sensation. Therefore complaints cannot be used as a representative method to assess odour annoyance. Only in the case of accidents or sudden events caused by operating faults are they a good indicator.

Secondly, by systematically questioning a sample of residents in a defined area by using a questionnaire to measure the degree of annoyance. This can be done on a single occasion or for a longer period. This method of questioning is suggested by Koller and Schmidlin (1988) for odour nuisance from animal farms (Figure 6.3). For general use VDI 3883 Part 2 (1983) describes in detail how to set up such an investigation, giving examples of the questionnaire (Figure 6.4), examples of the reply cards to the panel members and a sample calculation. This method of questioning has been performed successfully in

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[2] "Immission" is defined here as referring to "emission concentration at a receptor or detection point".

practice in the Netherlands and in France. For annoyance caused by the emission of odorants from animal farms this method was used in Austria (Strauß et al., 1986).
From the questionnaire used by Koller and Schmidlin (1988) and from VDI 3883 Part 2 (1993) it is possible to calculate an annoyance index as suggested by VDI 3883 Part 2 (1993):

$$I_k = \frac{1}{N_k} \sum_{i=0}^{n} W_i \, N_{i,k}$$

where I_k is annoyance index of the k-th observation (day of questioning) in the interval [0; 100], N_k is the total number of the k-th observation, i annoyance category (eg. 0 to 10 by Koller and Schmidlin (1988) or 0 to 5 by VDI 3883 Part 2 (1993)), W_i is weighting factor of the annoyance category i and $N_{i,k}$ is the number of observations in the annoyance category i for the k-th observation.

Table 6.2 Example for weighting factor W_i for a 6 grade scale (VDI 3883 Part 2 (1993).

Annoyance category	i	W_i
no odour	0	0
not annoying	1	0
slightly annoying	2	25
annoying	3	50
very annoying	4	75
extremely annoying	5	100

By calculating the annoyance index it is possible to determine the spatial and temporal distribution of the odour annoyance. Furthermore it is possible to calculate the relationship between annoyance and the distance between the odour source and the point of perception, as well as the influence of meteorological parameters like wind (speed and direction) and stability of the atmosphere. Depending on the objectives the duration of such sociological investigation differs. Short-term investigations covers a period of about ten weeks, with at least one test time per day. A long-term investigation covers about one year, with at least one test time per week.

1. Are you able to perceive odour from the named farm where animal are kept odour from the outlet air?

yes	○
no	○

(If you answer this question with no then you can stop here.)

2. How long are you able to smell the odour of this animal farm?

nearly never	○
rarely	○
about 1 hour per day	○
some hours per day	○
day and night	○

3. Assume that this is a meter for measuring how intense (strong) you are disturbed at home by the odour from this animal farm. Which value would you choose?

never disturbed ... intolerable

0 1 2 3 4 5 6 7 8 9 10

4. Is this annoyance at home:

reasonable	○
not reasonable	○

5. When are you mostly disturbed by the named odour of the animal house:

during spring	○	morning	○
during summer	○	evening	○
during fall	○	day time	○
during winter	○	night time	○

during following month: ....

6. Which wind force are prevailing when you perceive the odour?

calm	○
weak	○
strong	○

7. How often does the named odour cause:

	often	sometimes	rare	never
slight uneasiness/discomfort	○	○	○	○
queasiness	○	○	○	○
irritation/anger	○	○	○	○
irritation of the throat	○	○	○	○
closing windows	○	○	○	○

8. Are you during day predominantly?

at home ○ outside (work) ○

Figure 6.3 Questionnaire to investigate the annoyance of odour caused by the emission of an animal farm (from Koller and Schmidlin, 1984).

Please carefully sniff the environmental air.

Do you smell anything yes ○
no ○

If yes, is the smell you perceive:
- not annoying ○
- slightly annoying ○
- annoying ○
- very annoying ○
- extremely annoying ○

Figure 6.4 Text for the questionnaire used as a prepaid reply post card by VDI 3883 Part 2 (1993).

6.4 Dispersion

The prediction of immission of odorous compounds depends upon which aspect of odour has to be observed.

The concentration of odoriphores can be handled like other volatile emissions. The dispersion of such substances can be described by well-known dispersion models, like the Gaussian model. Then immission at a receptor point is calculated as a mean value of the concentration of odoriphores for a defined period (eg. half-hour, 3-hours mean value). The calculation of the odorant concentration itself is not meaningful if odour has to be evaluated. This is due to the fact that odour is not an attribute of an odoriphore, but a reaction of humans. Odour sensation is a complex phenomenon (Summer, 1970).

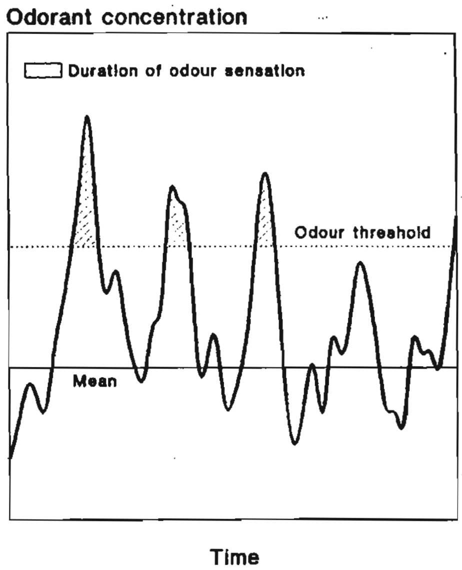

Figure 6.5 Temporal variation of odorant/odour concentration and the relationship to odour sensation (VDI 3782 Part 4, 1992)

The odour sensation is triggered by the odour stimulus and characterized by intensity and frequency. To predict these parameters it is necessary to consider short-term fluctuations of odorant concentration at the receptor point. Odour sensation can only be observed if the odorant concentration is higher than the odour threshold of the substances. Due to these fluctuations an odour sensation can take place even if the mean odorant concentration is lower than the odour threshold (Figure 6.5).

The next step is the problem of annoyance caused by an odour sensation which depends on the individual and sociological situation of a person. Therefore empirical models are developed, mainly for administrative procedures. The objective of these models is the determination of a protection distance to avoid excessive annoyance by odour.

Models used to predict and assess odour sensation as well as the annoyance caused by odour are summarized by Krause (1992). Here only two different types of models are presented to predict immission concentration of odour at a receptor point.

Analytical Models

The basis of the described analytical models for predicting the intensity and duration of odour sensation are Gaussian dispersion models. Therefore it is assumed that the odorant compounds behave like an inert gas. Normally, half-hour mean immission values of odorant concentration are calculated by these models (eg. VDI 3782 Part 1, 1992).
To overcome the discrepancy between odorant concentration and odour sensation as shown in Figure 6.7, an additional approximation has to be appended to evaluate the calculated immission value.

In this second step the fluctuations have to be taken into account. This can be done by a parametrization or by an analytic approach. Smith (1973) suggested a parametrization for the ratio of fluctuations to the mean value depending on the time scale. For an interval of about 100 seconds Smith (1973) specified the ratio between 10 and 3.5, for high insolation and cloudy, windy weather, respectively. From the TA Luft (1986) the value of 10 is selected.

The relevant odorant immission concentration which provokes an odour sensation is calculated by the multiplication of the mean odorant concentration (as result of the Gaussian dispersion model) and this factor.

By using the odour threshold as an off-set value, the distance can be determined where no odour sensation can be expected. This can be done for different meteorological situations to get an emission/immission climatology of the site.

The VDI 3782 Part 4 (1991) guide-line uses the calculated emission/immission concentration of odoriphores by the Gaussian dispersion model as mid-point of a probability density function for the odorant concentration. The fluctuations have to be taken into account in addition to the predicted mean value at a receptor point. The probability of an odour sensation is determined by the coefficient of variation, the mean of the odorant concentration and the odour threshold.

The parametrization of the coefficient of variation is based on the dispersion parameter of the Gaussian dispersion model and a parameter found by olfactometric calibration of the model (VDI 3782, Part 4, 1991). A similar approach is suggested by de Bree & Harssema (1988) using the meandering movement around the average horizontal position of the plume to determine the probability of odour sensation.
The limitations of some existing models have been investigated (Smith, 1993). The sensitivity to variation of the concentration predictions in the various model parameters was assessed. There were significant differences between models. The wind speed and odour emission rate were shown to be the most important variables in the prediction of downwind concentration.

Empirical models

To reduce odour nuisance, one must assess the necessary distance between the livestock building as a source of odour and residential areas. Some European countries use different procedures. In Germany there are standards for poultry (VDI 3473, 1986) and pigs (VDI 4371, 1986). Schirz (1989) and Paduch (1988) have given useful comments on how to use both standards. For Switzerland, Koller and Schmidlin (1988) developed a guide-line for all kinds of farm animals. In Austria (Eder et al., 1994) a draft of a guide-line is under negotiation, in which the influence of the meteorological conditions of the site of emission is taken into account.
The basis of all of these standards is a rough estimation of the source by the following parameters: number of farm animals, their use and the way they are kept; the geometry of the outlet air; the vertical velocity of the outlet air; the manipulation of manure inside the livestock building and the kind of manure storage. The guidelines cover only the summer period because complaints appear mainly in this time in middle Europe.

Table 6.3 Livestock unit LU (animal mass normalized at 500 kg) for different animals (Schirz, 1989; Paduch, 1988).

Animal		LU per animal
Pig		
Sow and boar for breeding		0.3
Young sows and boars for breeding		0.15
Sow with piglets after 4 weeks		0.4
Sow with piglets after 8 weeks		0.5
Weaners < 15 kg		0.01
Weaners < 25 kg		0.02
Fattening pigs (all in all out)		
	First period (< 40 kg)	0.06
	Last period (40 to 105 kg)	0.15
Fattening pigs (continuous) 25 to 105 kg		0.12
Poultry		
Broiler	one stage of age	1/420
	two or more stages of age	1/625
Laying hens	one stage of age	1/310
	two or more stages of age	1/330
Dairy	sheep (> 1 year)	0.1
	cattle (< 1 year)	0.3
	dairying cattle, cattle (> 1 year)	1.0

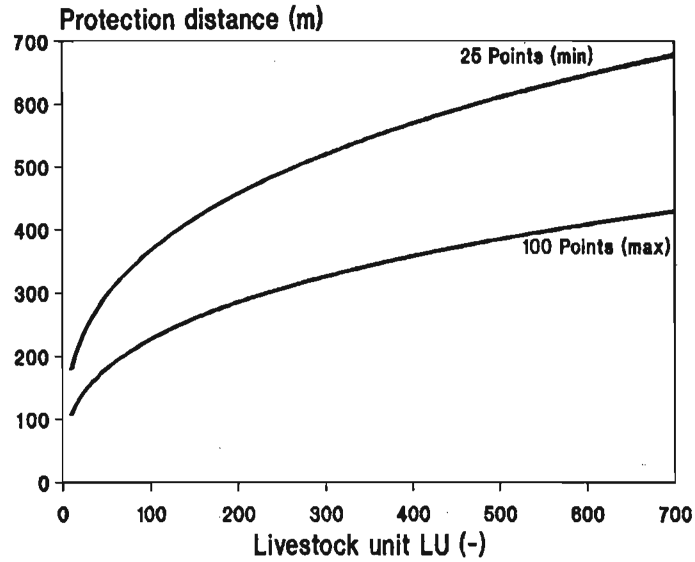

Figure 6.6 Relation between livestock units LU to assess the size of odour emission and the protection distance D for pigs (VDI 3472, 1986).

In the two German guide-lines for pigs and poultry, the protection distance is calculated as a function of livestock units (animal mass normalized at 500 kg). Table 6.3 gives the relationship between livestock units, type of animals and how they are kept. In Figure 6.6 are two graphs. The 100-points-line is the optimum score for keeping animals with low odorant emission. The second line gives the protection distance for livestock buildings with high emission. If the score is lower than 25 points, and therefore the emission level is high, a special assessment is required to determine protection distances above this curve.

The 100-points line is the function for a low level emission, the 25-points line is the worst case (Figure 6.6). The two curves were described by following functions (see also Krause, 1992):

for 25 points: $D = 86.3\ LU^{0.32}$
for 100 points: $D = 50.2\ LU^{0.32}$

Tab. 6.4 Scoring criteria to evaluate the odorant emission level for pigs (VDI 3472, 1986).

Criteria	Points
A) Manure handling and storage	
1) Handling of manure and litter (deep bedding)	
a) Accumulating litter	60
b) Mechanical dung removal onto	
- dung stack with walls at three sites	50
- transport vehicle	40
- open dung cone	20
2) Removal of manure without litter	
- floor perforation > 45 %	10
- floor perforation < 45 %	5
- removal by slide	0
3) Sludge storage	
- tank with closed cover (+ pressure-balancing device)	50
- tank with simple cover	30
- tank with closed natural floating cover	30
- tank without cover	0
- storage inside the pighouse	30
B) Ventilation of the building	
1) Maximum ventilation rate in summer according to DIN 18910 (1992)	
Temperature difference _ 2 K	10
Temperature difference _ 3 K	5
Temperature difference > 3 K	0
2) Exhaust air outlet	
a) vertical, above the roof	
- height _ 1,5 m above the top of the roof	15
- height < 1,5 m above the top of the roof	5
b) lateral outlet, natural ventilation	0
3) Exhaust air speed at maximum ventilation rate in summer and vertical outlet at the roof	
_ 12 m/s	25
_ 10 m/s	20
_ 7 m/s	10
< 7 m/s	0
C) Other criteria	
1) Reduction for special feed	
- dry waste	0
- kitchen refuse and feed with low inherent odour up to	-10
- whey, slaughterhouse waste and similar feed with strong inherent odour up to	-25
2) Influences by the site	±20
3) Liquid manure storage capacity	
_ 6 months	10
_ 5 months	5
_ 4 months	0

This scoring of the emission level is based on emission measurements in various sections of a farm (Tab. 6.4 and 6.5). The main part of the scoring can easily be done by this schema. Some aspects like topographic and meteorological situation of the site have to be evaluated by experts.

Table 6.5 Scoring criteria to evaluate the odorant emission level for poultry (VDI 3471, 1986).

Criteria	Points
Manure handling and storage	
Manure with litter and floor heating dry manure with ventilation in a manure cellar	80
Manure with litter/dry manure	60
Manure beginning to dry in the henhouse	45
Fresh manure in tanks with fixed cover	40
Manure beginning to dry on transport vehicles	35
Settled manure in the henhouse	30
Fresh manure on transport vehicles	15
Liquid manure:	
Tank with fixed cover	30
Tank with closed permanent floating cover	20
Tank with protection from rain and sunshine	5
Open tank / open storage inside henhouse	0
Maximum ventilation rate for summer according to DIN 18910 (1992)	
Temperature difference < 1 K	20
Temperature difference < 1,5 K	15
Temperature difference < 2 K	10
Temperature difference _ 2 K	0
Exhaust air	
vertical, over the roof	
height > 1,5 m above the top of the roof	15
height _ 1,5 m above the top of the roof	5
lateral outlet (only at distance _ 300 m)	0
Velocity at maximum ventilation rate and vertical outlet at the roof	
_ 12 m/s	20
_ 10 m/s	15
_ 7 m/s	5
_ 7 m/s	0
Topographic and meteorological situation by the site	±20

If different kinds of animals are kept on one farm a conversion for one of the two guide-lines (pig and poultry) can be done. The conversion ratio of livestock units LU for different kinds of animals are (Schirz, 1989):

$$1 \text{ LU pigs} = 0.8 \text{ LU poultry} = 4 \text{ LU cattle}.$$

From the Swiss guide-line, the protection distance to avoid odour annoyance is calculated as a function of the size of the odour source. The source is estimated by the number of animals and an animal-specific factor, describing the emission of odorant compounds by that animal (Table 6.6).

Table 6.6 Animal specific factor describing the emission of odour compounds by animals (Koller and Schmidlin, 1988).

Animal	Factor
Pigs	
Breeding and fattening pigs 25-60kg	.15
Breeding and fattening pigs 25 -110kg	.20
Breeding and fattening pigs 25 -110kg	.25
Breeding pigs > 110kg	.30
Sow with weaners	.35
Poultry	
Breeding and fattening hens	.007
laying hens, turkeys < 5kg	.010
turkeys > 5kg	.015
Cattle	
fattening calves < 100kg	.20
fattening calves >= 100kg	.25

The multiplication of these two figures gives the odour load OL. The protection distance D (in meters) is calculated by the following function, if the dimensionless odour load OL > 4:

$$D = 43 \ln OL - 40$$

This basic distance has to be modified by the correction factors summarized in Table 6.7.

Table 6.7 Correction factors for different fields influencing the emission of odorant compounds (Koller and Schmidlin, 1988)

	Range of factor		
Topography	1.0	-	1.2
Height above sea level	.8	-	1.2
System of animal housing	.8	-	1.0
Handling of manure	.9	-	1.1
Cleanness	1.0	-	1.2
Type of feed	1.0	-	1.3
Ventilation system	.7	-	1.2

The structure of the Austrian guide-line is similar to the Swiss, whereby the meteorological situation of the site (wind climatology and estimation of predominant local winds. eg. mountain-valley circulation) and the legal claim to protection by the surrounding residential areas are additionally taken into account.

6.5 Effects on animals and humans

Hippocrates once said "Air is the father of human life and of human diseases". The harmfulness of odorous air (gases) has mainly been studied regarding human beings. However, little data is known about the effects on animals. Recently, intense research has been done concerning the effects of one particular gas, namely ammonia, on poultry and pigs (see chapter 5.2 NH_3). MAC (Maximum Allowable Concentration) - values have existed for decades for some odour compounds. These values are based on the assumption that industrial workers are exposed to this atmosphere eight hours a day. Corresponding MAC-levels for animals do not exist. It is generally accepted, however, that standards for animals should be more severe because animals are constantly exposed to certain concentrations. In the report of the CIGR-Working Group on Climatization of Animal Houses (1984) recommendations are given for maximum concentrations of noxious gases.

The effects of odours upon animals has not yet been determined, but odours in and around intensive animal production units can be very objectionable to the operator, his associates, not forgetting the neighbourhood. Odour annoyance manifests itself at the physical-mental level as a feeling of unpleasantness, of discomfort. The neighbourhood near an odour-producing unit is no longer appreciated; people move away to avoid these surroundings. Enquiries show that due to the fact of odour nuisance, people are obliged to shut windows, they cannot garden or relax properly, guests complain about the odour, etc; all these things intensify the feeling of unpleasantness.
However, there are important practical benefits associated with some odour components in the air of animal buildings. The presence and detection of olfactory components from boars in piggery air is a vital requirement for early attainment of puberty in female pigs. Pheromones play an important role in the breeding behaviour of animals, and odour plays a large part in the establishment of the maternal/offspring bond (Fraser & Broom, 1990).

Besides physical-mental effects, several more severe physiological reactions like headache, difficulties in sleeping and loss of appetite can occur. The toxicity of odours is a complex and delicate topic. Perception of an offensive odour is also often associated with danger or toxicity (Schamp & van Langenhove, 1987). An odorous compound can, like many other substances, be toxic if present in excessive concentrations (for example percutaneous absorption of p-cresol may produce digestive disturbances, nervous disorders with faintness, vertigo and skin eruptions). However, this doesn't mean that the total odour (i.e. mixture of several gases) must be toxic. Moreover, a direct relationship between toxicity (pathogenic effects) and the odour of compounds has not yet been proved (Schamp & Van Langenhove, 1987).

6.6 Reduction technology

Naturally, the primary approach to odour control is preventing that odour production taking place. So, the slogan "Prevention is better than cure" applies to the world of odour problem. However, this is easier said than done. As mentioned in the beginning of this chapter, odour is mainly a result of microbial fermentation taking place in the manure. Destroying or inhibiting the bacteria and enzymes responsible for the production of odorous compounds can be seen as a logical means to avoid bad smells. Various chemical agents (formaldehyde, orthodichlorobenzene, chloramines working as bacteriostats) and biological agents (dried bacteria and enzyme cultures) have been tested (Cole et al., 1975). Some are very effective in poisoning the microflora, others have no significant effect at all.

The second approach to odour abatement includes the reduction of odour emissions. A distinction is made between odour control techniques and odour control chemicals.

Odour control techniques

These techniques can generally be divided into three groups: reduction techniques focused on the liquid manure or slurry (aerobic treatment, anaerobic digestion and separation of urine and faeces), reduction techniques focused on the ventilation air, and physical control of odorant release.

Reduction techniques focused on the slurry

Under aerobic conditions odorant-producing decomposition of slurry is most often inhibited :

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

The aeration can take place inside the livestock building itself (oxidation ditches located beneath the slatted floors) or in a manure storage tank outside the stall (the manure wash system : fresh manure is frequently washed away underneath the slats by a small amount of aerated slurry).

The main objectives of this treatment are :

- good deodorisation of the livestock building itself and/or the neighbourhood (no offensive ventilation air),
- landspreading without odour annoyance (stabilised manure),
- improvement of hygienic farm conditions.

The Centre for Climatisation in Animal Houses (State University Ghent, Belgium) has done a lot of research in this field; Neukermans et al. (1977, 1979) concluded that aerobic treatment of slurry is technically possible but high investment and operating costs have a negative impact on the practicality of aeration as a waste management tool. Further research is still going on in order to make the whole treatment more attractive.

Besides the aeration of slurry, anaerobic treatment (anaerobic digestion) can be seen as an important technique, changing the microbial activity and reducing the emission of malodours. During anaerobic fermentation complex materials (volatile fatty acids, aromatic compounds, etc.) are broken down resulting in the formation of biogas, H_2O and some NH_4OH. Because of the breakdown of the malodourous compounds the slurry has lost its typical smell. Voermans (1990) states that although the total balance is not known exactly the emission of odours can be reduced by 90 %. This process is highly influenced by the temperature (optimum temperature 30 - 35 °C), presence of O_2 and the presence of compounds inhibiting methanogens. Most western countries have studied anaerobic digestion stimulated by the possibility of producing a renewable energy source. Currently there are 10 large collective biogas plants operating in Denmark which are constructed as combined energy and environmental plants. These collective plants appear to be approaching a commercial breakthrough though there are still no results available to support this assertion fully (Christensen, 1992). Figure 6.7 illustrates centralised digestion plants in Europe.

Kroodsma (1980, 1985) has studied the separation of faeces and urine as a method of manure handling and odour reduction in pig buildings. A filter net placed under the slats and containing the faeces is removed daily from the house. If the pigs eat wet feed,

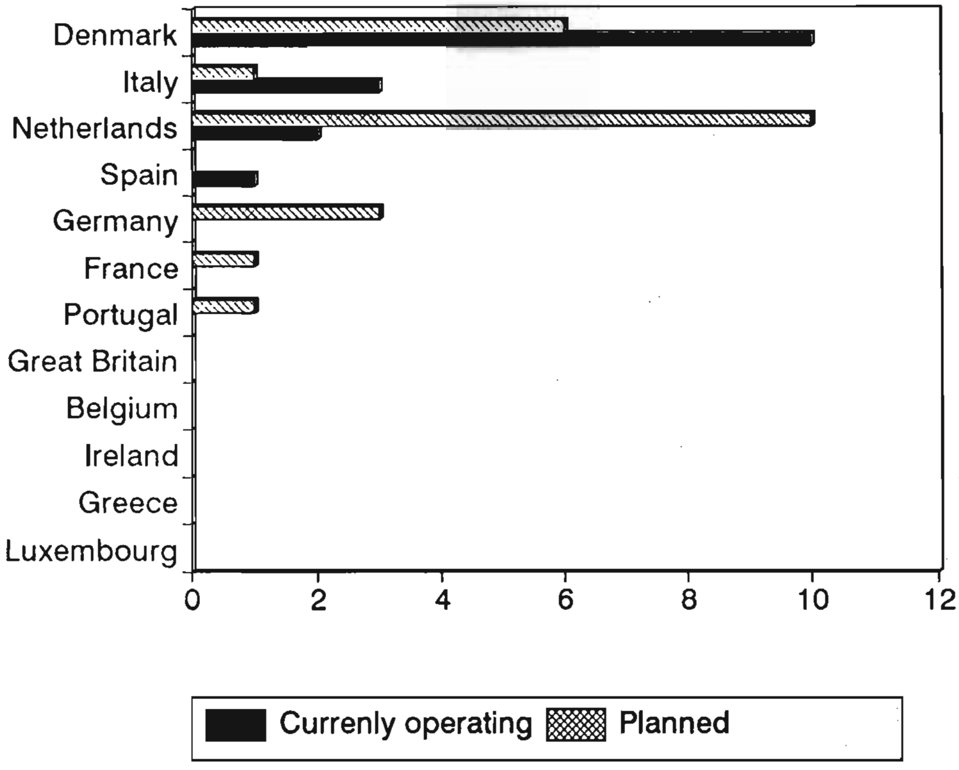

Figure 6.7 Centralised digestion plants in Europe

without drinking nipples, about 35 % of the total production of faeces and urine is seperated as a solid. After mixing faeces with some straw, it is stackable (Kroodsma, 1985). The remaining liquid flows continuously to a pit outside the house. Odour measurements (olfactometry) indicate a considerable reduction in odour emission per pig (± 50 %) compared to piggeries with underslat slurry storage.

Reduction techniques focused on the ventilation air

In contrast to industry where physico-chemical waste gas treatment processes (incineration, chemical scrubbing, etc) are frequently preferred, in agriculture biological deodorization processes are most commonly used to clean the ventilation air. Biofilters and biological scrubbers have the widest applications. These processes are based on the fact that a lot of microbes, mainly bacteria, are able to break down waste air components and thus purify the odorous air.
Biofilters consist of an organic filter material (compost, peat, etc) through which the polluted ventilation air is passing : the micro-organisms settle on this porous matrix. Microbial degradation is preceded by absorption of the waste air components in the moisture film of the filter material. Therefore it is necessary (especially during the summer) to provide the biofilter with a gas humidification system. Normally a minimum moisture level of 30 % is proposed; the optimal moisture of the filter matrix depends on the structure and absorptive capacity of the material. The main advantages of biofilters are simple construction, more-or-less low costs and appropriateness for waste air components

of low solubility.
Their weaknesses include :
- the requirement for a lot of space,
- rapid deterioration of some organic materials (i.e. high counter-pressure),
- slow adaptation to changing composition of the crude gas.

It is recommended that the organic filter material be well moistened periodically in order to keep the pressure head across the filter within "normal values". It should be turned several times a year. Table 6.8 gives some process parameters of biofilters.

Table 6.8 Main process parameters of biofilters

	Netherlands (Scholtens & Demmers, 1990)	Belgium (Colanbeen & Neukermans, 1992)
Material	Peat/heather	Peat/heather
Surface load ($m^3/m^2.h$)	300	442
height of bed (m)	0.5	0.5
max. pressure (Pa)	<120	135
moisture content (%)	-	65
odour removal (%)	>75	90
NH_3-removal	>85	95

Bioscrubbers containing a synthetic filter material are mainly suited to the treatment of odorous air pollutants which are water soluble (hydrophilic). The microbiota responsible for the regeneration of the washing water and for purification of the odorous ventilation air are suspended in an aqeous solution (activated sludge) and adsorbed on the synthetic matrix.
The main advantages are :
- a compact structure,
- easy control of pH and temperature,
- the use of an inert filter material,
- a more-or-less rapid adaptability to changing odorous gas composition.

On the other hand bioscrubbers are more expensive and more complicated as compared to biofilters and are inappropriate for waste air components of low solubility. The process water which has to be drained contains high concentrations of nitrate and nitrite up to 2 g N/l which makes it very toxic. This effluent remains one of the major disadvantages of scrubbers. Further research is currently under way on purifying the effluent by denitrification or by reverse osmosis (no data available yet). More detailed information is found in VDI guideline 3477 (biofilters) and 3478 (bioscrubbers).

With both the biobed and the air washing system (bioscrubber), reductions of 90 % in odour and ammonia emission are reached (Colanbeen & Neukermans, 1988 ,1992; Noren, 1985; Scholtens & Demmers, 1990; Schirz, 1990). It must be stressed however that these biological treatment processes do not address the cause of the presence of malodorous; they only eliminate or reduce the "symptoms". Moreover, these two techniques, together with all the possibilities previously mentioned to reduce (prevent) the odour, increase the

production cost but not the product quality (no higher sale prices).
According to Hartung (1985), filtering dust from the exhaust air has proved to reduce odour emission from pig housing by up to 65 %. As about 85 % of the dust in livestock housing originates from the feed, wet feeding is recommended to reduce the odour problem. Williams (1989) has tested the odour and dust relationships in broiler house air; he found no significant change in odour concentration by dust filtration, but dust mass was significantly reduced.

Jongebreur & Van Geelen (1983) have made a survey of the effects on odour emission of the most common methods (see table 6.9).

Table 6.9 Effects of different methods for odour reduction (according to Jongebreur & Van Geelen, 1983)

Method	Effect on		
	Ventilation air	Slurry storage	Slurry spreading
Bioscrubber	+	-	-
Biofilter	+	-	-
Separation faeces/ urine	+	+	+
Frequent removal of slurry	+	-	-
Aerobic treatment	+	+	+
Anaerobic treatment	-	+	+

Seven effective systems for controlling odours in ventilation air were compared on a cost basis (O'Neill et al., 1992). All the systems were prohibitively expensive for practical use, although biofilters were considered the best abatement technique on which to concentrate further development.

Physical control of odorant release

Physical control of odorant release offers a third potential for odour control. By reducing the air exchange over manure slurries, the volatilization of odorous gases is reduced. Covers on manure storage tanks and anaerobic manure treatment devices are effective in controlling the escape of odorants. Dutch research has demonstrated that floating impermeable foils, tents, or expanded polystyrene are good covering materials (Jongebreur & Monteny, 1989; Verdoes, 1990; De Bode, 1990). However this technology does not affect the total emission from the production system. Reductions in odour emission through covering the manure tanks from 0 to 72% are illustrated in table 6.10.

Table 6.10 Example of reduction (%) in odour emission by covering manure tanks (de Bode, 1990)

	Pig slurry		Cattle slurry	
	Summer	Winter	Summer	Winter
Tent	35	15	72	42
Corrugated sheets	50	28	28	15
Floating cover	28	0	43	41
Expanded polystyrene	40	10	39	16

Insulation of littered floors in poultry buildings prevents moisture condensing on the concrete surface and thus has an effect on the dry matter content of the litter. This effect can be expected wherever the ground water level is less than one metre below the surface. Other benefits of insulation are a reduction in ammonia and odour emissions (Ouwerkerk, van & Voermans, 1985).

Odour control chemicals

Considerable literature (Ritter et al., 1975; Miner, 1975; Cole et al., 1975) has been published concerning the control of odours from manure, manure storage tanks and/or animal feed in pig, poultry and dairy production units by the use of :

- strong oxidants like potassium permanganate (KMnO4), sodium hypochlorite (NaOCl), or hydrogen peroxide (H2O2) in order to suppress the release of odorous gases;
- pH-adjusting chemicals to control the release of volatiles; Klassink et.al. (1990) studied odour emissions after adding CaO to cattle slurry : increasing amounts of CaO (2,5 -> 7,5 kg/m3) caused increased pH, decreased odour emission and increased ammonia. The addition of superphosphate had no influence upon pH, but nitric acid decreased pH. Both chemicals had a negative effect on odour emission (especially HNO_3).
- chemicals such as zeolites able to convert a volatile compound to a less-or non-volatile form. Kapto, of Belgian origin, is a rather new product.. Kapto consists of CaO, MgO and CH_2O (formaldehyde) which should be able to reduce the ammonia emission by 85 % and the odour should also be eliminated (Verdoes, 1990; Vlassak et al., 1990).
- feed additives in order to modificy manure composition (and manure odour); the N-content in the feed is not only related to the NH_3-emission but also to the origin of several odourous N-containing compounds. N-restrictive feeding can lower the nitrogen content of the manure (less ammonia and less odour). A reduction of the crude protein intake of about 20 % resulted in a lower N-excretion of about 30 % (Henkel, 1989). The succes of additives (yucca saponines, etc) in feed and manure is still uncertain. There exist many positive reports (from the producer) but these are in opposition to most practical experiences;
- masking and neutralizing agents added not only to the manure but also to the polluted air; the results are inconclusive (Summer, 1963; Neukermans et al., 1988).

Not all chemicals tested were effective in reducing manure odours. Moreover, some products may possibly have side effects on humans, animals and crops and the economics of their use is questionable (large quantities are needed) (Pain et al., 1987). In any case, odour control by different kinds of chemicals never offers a sufficient solution to livestock producer problems. Careful management (hygiene) still remains the greatest potential for avoiding odour conflicts.

References

Allison, M.J., 1978. Production of branched-chain fatty acids by certain anaerobic bacteria. Appl. Environ. Microbial. 35: 872-877.

Banwart, W.L. & J.M. Bremner, 1975. Identification of sulphur gases evolved from animal manure. J. Environ. Qual. Vol. 4, 3 : 363 - 366.

Beard, W.E. & W.D. Guenzi, 1983. Volatile sulphur compounds from a redox-controlled cattle manure slurry. J. Environ. Qual., 12 (1) : 113 - 116.

Bell, P.G., 1970. Fatty acid content as a measure of the odour potential of stored liquid poultry manure. Poultry Sci. 49: 1126-1129.

Bode, M.J.C. de, 1990. Odour and ammonia emission from manure storage. In : "Odour and ammonia emissions from livestock farming". Edt. : Nielsen, Voorburg & l'Hermite. Elsevier applied science.

Bree F., de & H. Harssema, 1988. Field evaluation of a fluctuating plume model for odours with sniffing teams. In: Grefen K., Löbel J. (Eds): Environmental Meteorology. Kluwer, Dordrecht.

Burnett, W.E., 1969. Air pollution from animal wastes. Determination of malodours by gas chromatography and organoleptic techniques. Environ. Sci. and Tech. 3: 744-749.

Christensen, J., 1992. The commercialization of biogas production. In : "Proceedings - Collective biogas plants". European experience in combined manure and waste processing. CEC Seminar, Herning (Denmark), 22-23 October.

Colanbeen, M. & G. Neukermans, 1988. Désodorisation de l'air des poulaillers par filtration biologique. In: "Agricultural Engineering", V.A. Dodd & P.M. Grace (Eds), Proc. Int. Cong. on Agric. Eng., Dublin, p. 1005 - 1013.

Colanbeen, M. & G. Neukermans, 1992. Stankbestrijding van ventilatielucht door het gebruik van biofilters en biowasfilters. Landbouwtijdschrift, 45(5) : 909 - 927.

Cole, C.A., H.D. Bartlett, D.H. Buckner & D.E. Younkin, 1975. Odour control of liquid dairy and swine manure using chemical and biological treatments. In : Managing Livestock Wastes. Proc. 3rd Int. Symp. on Livestock Wastes, Illinois, p. 374-377.

DIN 18910, 1992. Wärmeschutz geschlossener Ställe. Beuth Verlag, Berlin.

Dobbelaere, A., 1990. Milieubewust aanwenden van varkensmengmest. Studiedag Varkenshouderij en Leefmilieu. Roeselare, p 1 - 27.

Eder J., H. Fiebiger, M. Köck, R. Lazar, F. Pichler-Semmelrock, M. Piringer, T. Quendler, G. Schauberger, M. Swoboda, G. Thiemann & J. Teufelhart, 1994. Richtlinie für den Schutz vor Immissionen aus der Nutztierhaltung in Stallungen. (draft) Bundesministeriums für Umwelt, Jugend und Familie, Austria.

Fraser, A.F. & D.M. Broom, 1990. Reproductive abilitation. In: Farm animal behaviour and welfare, Balliere Tindall, London, p. 168-174.

Hall, J.E., 1985. Machinery spreading: soil injection as a barrier to odour dispersion. In : "Odour prevention and control of organic sludge and livestock farming" - edited by V.C. Nielsen, J.H. Voorburg & P. L'Hermite, p. 55 - 60.

Hangartner, M., 1985. Selection and treatment of panelists for determination of odour thesholds. In : "Odour prevention and control of organic sludge and livestock farming" edited by V.C. Nielsen, J.H. Voorburg & P. L'Hermite, p. 55 - 60.

Henkel, H. 1989. Über die minimierung der N und P Ausscheidungen beim Schwein. In: "Influence of housing and livestock on ammonia release from buildings"- in : "Odour and ammonia emissions from livestock farming". Edt. : Nielsen, Voorburg & l'Hermite. Elsevier Applied Science Publishers.

Jongebreur, A.A. & G.J. Monteny, 1989. Perspectieven voor de aanpak van de mest en ammoniak-problematiek op bedrijfsniveau. Themadag mestbehandeling op de boerderij. Ede, p. 79-95.

Jongebreur, A.A. & M.A. van Geelen, 1983. Mogelijkheden voor de preventie en bestrijding van stank. Colloquim Luchtreiniging m.b.v. biologhische filters. Vrom - Utrecht.

Kadota, H. & Y. Ishida, 1972. Production of volatile sulphur compounds by microogranisms. Ann. Rev. Microbiol., 26 : 127 - 138.

Klarenbeek, J.V., 1985. Experiences with olfactometers. In : Odour prevention and control of organic sludge and livestock farming. Edited by V.C. Nielsen, J.H. Voorburg & P. L'Hermite, p. 113-117.

Klassink, A., G. Steffens & H. Kowalesky, 1990. Odour and ammonia emissions from grassland and arable land. In : "Odour and ammonia emissions from livestock farming". Edt. : Nielsen, Voorburg & l'Hermite. Elsevier Applied Science Publishers.

Koller, J. & A. Schmidlin, 1988. Empfehlungen für Mindestabstände von Tierhaltungsbetrieben. FAT-Berichte Nr. 350, Eidgenössische Forschungsanstalt für Betriebswirtschaft und Landtechnik, Tänikon.

Krause K.-H., 1992. Gegenüberstellung unterschiedlicher Immissionsprognoseverfahren. In: Geruchs- und Schadgasemissionen aus der Tierhaltung. Arbeitspapier 174, KTBL.

Kroodsma, W., 1980. Separation of pig faeces from urine using synthetic netting under a slatted floor. The Proc. 4th Int. Symp. on Livestock Wastes., 419 - 422.

Kroodsma, W. & H.R. Poelma, 1985. Mestscheiding, IMAG-publication 209, Wageningen.

Langenhove, H. van 1987. Chemisch-analytisch onderzoek van geurhinderproblemen. Proefschrift voorgedragen tot het bekoment van de graad van Doctor in de Landbouwkundige Wetenschappen. RUG, 1987.

Lindvall, T., O. Noren & L. Thyselius, 1974. Odour reduction for liquid manure systems. Trans. Am. Soc. Agric. Eng. 17: 508-512.

Mannebeck, H., 1986. Vergleichende Emissionsmessungen an Schweinezucht und Schweine-mastställen mit dem Olfactometer TO 6. VDI Berichte 561, Düsseldorf.

Merkel, J.A., T.E. Hazen & J.R. Miner, 1969. Identification of gases in a confinement swine building atmosphere. Trans. ASAE 12 : 310 - 313.

Miner, J.R. & T.E. Hazen, 1969. Ammonia and amines : components of swine-building odour. Trans. ASAE 12: 772-774.

Miner, J.R. , 1975. Management of odours associated with livstock production. In : Managing Livstock Wastes. Proc. 3rd Int. Symp. on Livestock Wastes. Illinois, p. 378-380.

Neukermans, G., H. Vanstaen, M. Debruyckere & W. Verstraete, 1977. Volledige verwerking van varkensmengmest door zure slibafscheiding. Praktijkervaringen - Megista Contactdagen voor Onderzoekers. Wageningen, p. 38 - 115.

Neukermans, G., K. Velghe, M. Debruyckere & W. Verstraete, 1979. Biologische stankbestrijding in een volroosterkraamstal. Landbouwtijdschrift, 32 (4), 359 - 971.

Neukeramns, G., J. Christiaens, W. van der Biest & S. Wauters, 1988. Klimaatbeheersing en milieuproblematiek in de veehouderij. Syntheseverslag van de onderzoekigen ondernomen tijden de periode 1 juli 1966 - 30 juni 1987 aan het Centrum voor de Studie van het Stalklimaat. IWONL, Brussel.

Norén, O. 1985. Design and use of biofilters for livestock buildings. In : "Odour prevention and control of organic sludge and livestock farming" edited by V.C. Nielsen, J.H. Voorburg & P. L'Hermite.

Oldenburg, J. 1989. Geruchs- und Ammoniak Emissionen aus der Tierhaltung. K.T.B.L.- Schrift 333, Darmstadt.

O'Neill, D.H., I.W. Stewart & V.R. Phillips, 1992. A review of the control of odour nuisance from livestock buildings: Part 2, The costs of odour abatement systems predicted from ventilation requirements. Journal of Agricultural Engineering Research 51: 157-165.

Ouwerkerk, E.N.J. van & J.A.M. Voermans, 1985. The effect of insulating broiler house floors on odour emission. In: "Odour prevention and control of organic sludge and livestock farming", eds. Nielsen, Voorburg & l'Hermite, Elseviers Applied Science Publishers, p. 175-180.

Paduch, M., 1988. Present state of VDI-guidelines on odour assessment. In: V.C. Nielsen, J.H. Voorburg & P. l'Hermité (Eds): Volatile emissions from livestock farming and sewage operation. Elsevier Applied Science, London-New York.

Pain, B.F., R.B. Thompson, L.C.N. Lande Cremer & L. ten Holte, 1987. The use of additives in livestock slurries to improve their flow properties, conserve nitrogen and reduce odours. In : "Animal manure on grassland and fodder crops. Fertilizer or waste ?" Int. Symp. of the European Grassland Federation. Wageningen, 229-246.

Pain, B.F. & T.H. Misselbrook, 1990. Relationships between odour and ammonia emission during and following the application of slurries to land. In : "Odour and ammonia emissions from livestock farming". Edt. : Nielsen, Voorburg & l'Hermite. Elsevier Applied Science.

Philips, V.R., B.F. Pain & J.V. Klarenbeek, 1990. Factors influencing the odour and ammonia emissions during and after the land spreading of animal slurries. In : "Odour and ammonia emissions from livestock farming". Edt. : Nielsen, Voorburg and l'Hermite. Elsevier Applied Science.
Ritter, W.F., N.E. Collins & R.P. Eastburn, 1975. Chemical treatment of liquid dairy manure to reduce malodours. In : "Managing Livestock Wastes". Proc. 3rd Int. Symp. on Livestock Wastes. Illinois, p. 381 - 384.
Schaefer, J., J.M.H. Bemelmans & M.C. ten Noever de Brauw, 1974. Onderzoek naar de voor de stank van varkensmesterijen verantwoorde componenten. Landbouwk. Tijdschr. 86 : 228 - 232.
Schaefer; J., 1977. Sampling, characterisation and analysis of malodours. Agric. Environ., 3 : 121 - 127.
Schamp, N. & H. van Langenhove, 1987. Geurhinder Monografieën van de Stichting Leefmilieu nu.
Schirz, S., 1989. Handhabung der VDI-Richtlinien 3471 Schweine und 3472 Hühner Emissionsminderung der Tierhaltung. KTBL Arbeitspapier Nr.126.
Schirz, S. 1990. Practical application of bioscrubbing technique to reduce odour and ammonia. In : "Odour and ammonia emissions from livestock farming". Ed. : Nielsen, Voorburg & l'Hermite. Elsevier Applied Science.
Scholtens, R. & T.G.M. Demmers, 1990. Biofilters and air scrubbers in the Netherlands. In : "Odour and ammonia emissions from livestock farming". Edt. : Nielsen, Voorburg & l'Hermite. Elsevier Applied Science.
Smith, M.E., 1973. Recommended guide for the prediction of the dispesion of air borne effluents. ASME, New York.
Smith, R.J., 1993. Dispersion models from ground level agricultural sources. Journal of Agricultural Engineering Research 54, 187 - 200.
Spoelstra, S.F., 1977. Simple phenols and indoles in anaerobically stored piggery wastes. F. Sci. Food Agric. 28 : 415 - 423.
Spoelstra, S.F., 1978. Degradation of tyrosine in anaerobically stored piggery wastes and in pig faeces. Appl. Environ. Microbiol. 36 : 631 - 638.
Spoelstra, S.F., 1979. Ophoping van vluchtige verbindingen in anaëroob bewaarde varkensdrijfmest. Megista Contactdagen voor onderzoekers. Wageningen, p. 72 - 84.
Spoelstra, S.F., 1980. Origin of objectionable odorous components in piggery wastes and the possibility of applying indicator compounds for studying odour development. Agric. Environ., 5 : 241 - 260.
Strauß, G., R. Cervinka & M. Haider, 1986. Erhebung über die Geruchsbelästigung in der Umgebung von Massentierhaltungen - eine Feldstudie. Inst. f. Umwelthygiene, Universität Wien, Vienna.
Summer, W., 1963. Methods of air deodorization. Elsevier Applied Science, 395 p.
Summer, W., 1970. Geruchlosmachung von Luft und Abwasser. Oldenburg, München.
Summer, W., 1971. Odour pollution of air causes and control. The Chemical Rubber Company Press. Cleveland, Ohio.
TA Luft, 1986. Technische Anleitung zur Reinhaltung der Luft. GMBl 1986 Nr. 7.
Travis, T.A. & L.F. Elliott, 1977. Quantitation of indole and skatole in a housed swine unit. J. Environ. Qual., 6 (4) : 407 - 410.
Van Langenhove, H. 1987. Chemisch-analytisch onderzoek van geurhinderproblemen. Proefschrift voorgedragen tot het bekomen van de graad van Doctor in de Landbouwkundige Wetenschappen. RUG, 1987.
VDI 3471, 1986. Emissionsminderung Tierhaltung - Hühner. Beuth Verlag, Berlin.
VDI 3472, 1986. Emissionsminderung Tierhaltung - Schwein. Beuth Verlag, Berlin.
VDI 3782 Part 1, 1982. Gaussian dispersion model for air quality management. Beuth Verlag, Berlin.
VDI 3782 Part 4, 1991. Ausbreitung von Geruchsstoffen in der Atmosphäre. (draft) Beuth Verlag, Berlin.
VDI 3881 Part 1, 1986. Olfactometry; odour threshold determination; fundamentals. Beuth Verlag, Berlin.
VDI 3881 Part 2, 1987. Olfactometry; odour threshold determination; sampling. Beuth Verlag, Berlin.
VDI 3881 Part 3, 1986. Olfactometry; odour threshold determination; olfactometers with gas jet dilution. Beuth Verlag, Berlin.
VDI 3881 Part 4, 1989. Olfaktometrie; Geruchsschwellenbestimmung; Anwendungsvorschriften und Verfahrenskenngrößen. Beuth Verlag, Berlin.
VDI 3882 Part 1, 1992. Olfactometry; determination of odour intensity. Beuth Verlag, Berlin.
VDI 3882 Part 2, 1992. Olfaktometrie; Bestimmung der hedonischen Geruchswirkung. Beuth Verlag, Berlin.

VDI 3883 Part 2, 1993. Effects and assessment of odours; determination of annoyance parameters by questioning; repeated brief questioning of neighbour panellists. Beuth Verlag, Berlin.
VDI 3940, 1991. Bestimmung der Geruchsstoffimmission durch Begehungen. Beuth Verlag, Berlin.
Verdoes, N., 1990. Naar stallen met beperkte ammoniakuitstoot. Deelrapport 3: varkens. DLO, Wageningen.
Vlassak, K., J. Martens & H. Bomans, 1990. Technieken voor de beperking van ammoniakvervluchtiging uit mengmest met Kapto. In : "Mestverwerking : hoe en hoeveel kost het ?". Studiedag, Antwerpen, 25 October 1990.
Voermans, J.A.M., 1985. Farm experiments of anaerobic digestion to control odours from slurry. In: "Odour and ammonia emissions from livestock farming". Ed. : Nielsen, Voorburg & l'Hermite. Elsevier Applied Science.
Williams, A. G. 1989. Dust and odour relationships in broiler house air. J. agric. Res. (1989) 44: 175-190.
Yasuhara, A., K. Fuwa & M. Jimbu, 1983. Isolation and analysis of odorous compounds in swine manure. J. Chromat., 281 : 225 - 236.
Yasuhara, A., K. Fuwa & M. Jimbu, 1984. Identification of odorous compounds in fresh and rotten swine manure. Agric. Biol. Chem. 48 (12) : 3000-3010.

7 Airborne Particles

7.1 Introduction

When animals are kept in confinement buildings under relatively dry conditions, as is normally the case for pigs and poultry, a great deal of of airborne dust is present in the indoor environment. Dusts are dispersed particles of solid matter in gases, which are generated during mechanical processes.

Airborne dust is one of the aerosol components in livestock buildings. This aerosol mixture includes microorganisms, gas, water vapour and other substances. Microorganisms may represent only a minor percentage ($<1\%$) of the number of airborne particles, but they are often harmful with respect to infectivity and allergenicity. Airborne particles also act as carriers of gases, microorganisms and toxins.

Inspirable aerosols are the fraction of airborne particles and droplets which enters the nose and mouth during breathing and are available for deposition anywhere in the respiratory tract.

Respirable aerosols are the fraction of airborne particles and droplets which penetrates to the gas exchange region of the lung, the alveoli.

In this chapter, "aerosols" refers to dust particles from the animals' surface (skin, hair etc.), feed and dry manure. The typical size range of different types of dust are shown in Figure 7.1.

Respecting behaviour, a dust can be characterised by:

Particle size	(mass)
Shape	(sphere, cylinder, flake etc.)
Density	(approx. 1000 kg/m^3)

The size, shape and density of a particle determines its behaviour, with respect to settling velocity. Therefore it is convenient to characterize dust particles by a single figure which takes into account these three qualities, hence the aerodynamic diameter is used. If a dust particle has the same settling velocity as a sphere with a certain diameter and density, the dust particle is said to have an aerodynamic diameter of the same size.

The relevance of aerodynamic size is that it allows standards to be set for measurement methods for particular dusts. The collection efficiency of any air sampler changes for different aerodynamic particle sizes. The ideal sampler is one which mimics the collection efficiency of the human (or animal) respiratory tract. The collection efficiency for particular size fractions, expressed as percentages of ambient particle concentrations, are shown in Figure 7.2. Thus the respirable fraction of dust in ambient air is defined as 100% of all 0.1μm particles, decreasing to approximately 40% of 5μm particles, and zero percent of 10μm particles. The collection efficiency for different particle sizes changes for different locations in the respiratory tract. Particles between 1 and 25μm are mostly

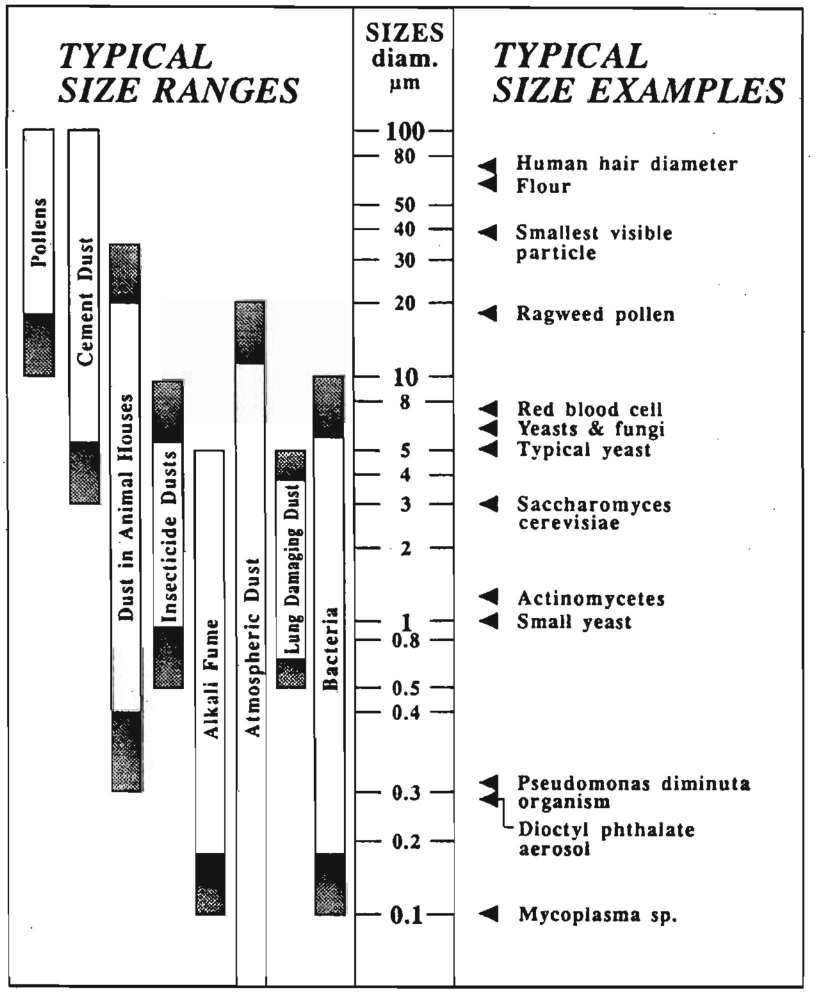

Figure 7.1 Size range of different types of dust

deposited in the trachea and bronchial region (TBF), and those between 2 and 200μm in the extra thoracic-region (ETF).

Typical distribution of different particle sizes in pig house air is shown in Figure 7.3.

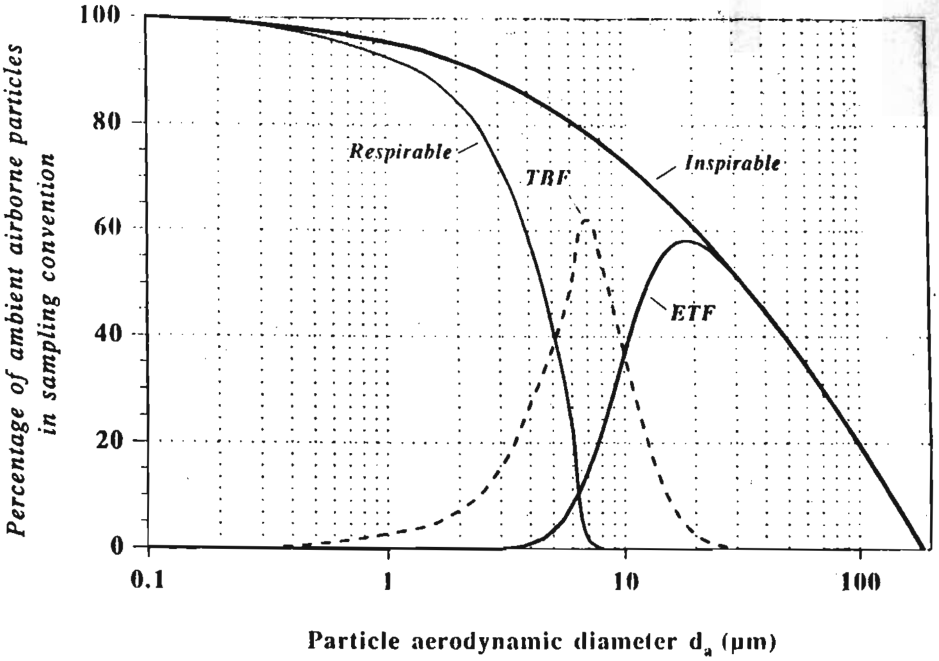

Figure 7.2 Percentage of ambient airborne particles in British Medical Research Council sampling convention

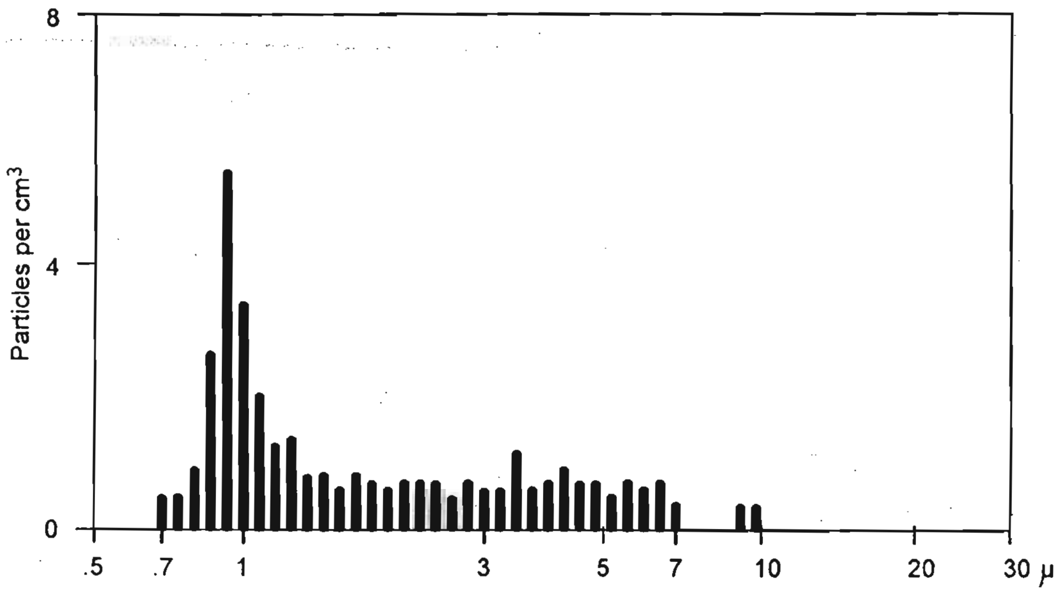

Figure 7.3 The concentration of different particle sizes in pig house air

For a confinement building the input and output of dust can be categorised as:

Dust sources (in)		**Dust removal (out)**
Dust in incoming air Dust from feed Dust from bedding Dust from the animals	} = {	Dust in outgoing air Settled dust Dust removed with manure

Dust sources

The quantity of dust in incoming fresh air is negligible compared to the potential amount in feed, bedding and from the animals. However, there may be pathogenic or allergenic particles introduced into the building by the incoming air.

The quantity of dust released from feed depends on the physical and chemical composition of the feed and on the way of handling it. With wet feeding, little dust is produced so long as the feed remains wet, but (for example) wet feed deposited on the surface of the animals, which then dries out, will release dust. Also, the fat content of feed influences dust release. It is possible to reduce dust release considerably by adding fat to the feed.

Bedding will only release large quantities of fine dust if the quality of the material is poor. However, the bedding may become progressively dusty as it remains in the pen and is manipulated by the animals.

Dust particles will also be produced by livestock, through their shedding skin particles, hair or feathers.

Dust removal

Mechanisms for the removal of dust from livestock buildings are indicated in the table above. There are two ways to get rid of airborne dust: by sedimentation and by ventilation. Part of the dust from animal feed and bedding will settle on dunging areas and be released as a part of the manure, and another part will settle on passages and fixtures.

A significant proportion of airborne dust will be removed through ventilation. The distribution of different particle sizes will depend on both the source of the dust and the method of removal.

Several experiments during the last ten years shows that it is difficult to recommend ways to reduce aerial dust in a traditional livestock building. For instance, choosing wet feed and no straw reduces airborne dust by a maximum of only 30%. The difficulties which arise in removing dust suggest that the major strategy to control airborne dust particles is to limit initial production.

Sedimentation

Sedimentation in still air follows Stokes Law, which takes into account the diameter and density of the particles. Settled dust will deposit on the floor, fixtures etc. In rooms with mechanical ventilation the smaller particles will be influenced by and follow the air movement in the building, and may remain airborne for longer periods than their settling velocity would suggest.

Table 7.1 Velocity of dust particles of different size, due to gravitation.

Diameter μm	Setting velocity mm
1	0.03
2	0.12
3	0.26
4	0.47
5	0.8
10	3.3
20	12

Even in rooms with no forced air stream, air movement caused by the thermal output of animals will be 0.05 m/s or more. This air velocity is much higher than the settling velocity of a particle of 20 μm diameter (0.012 m/s). This explains in part why smaller particles follow the movement of air in a confined space. For particles less than 1 μm in diameter it can be concluded that they will follow the air movement totally.

Ventilation

Aerial dust will be removed by the exhaust air, which contains the same amount of dust per unit volume as a unit volume of air within the house. The dust concentration should theoretically decrease as ventilation rate increases, due to dilution with incoming fresh air. However, the relationship between particle concentration and ventilation rate is complex. A change in ventilation rate will also influence the air velocity inside the building and may affect the relative humidity. More dust may be released from surfaces if the relative humidity is reduced. However, ventilation rate can rarely be increased without either accepting a lower inside temperature or using supplementary heating. The opportunity to reduce dust concentrations by manipulating ventilation rates is limited, but should not be ignored.

7.2 Production and behaviour of dust

The total amount of airborne dust in livestock buildings at any time is the equilibrium between all the various point sources of fine material (dust production) and the various removal mechanisms (dust removal). In most agricultural situations it is necessary to describe dust production and removal as complex processes. A simple model is shown in Figure 7.4.

There are a number of theories for describing the mass or particle concentration in an air space. Simple mass balance equations have been used (Carpenter & Fryer, 1990; Gustafsson, 1989). More complex models have been analyzed and compared to experimental results. See for example Liao & Feddes (1989). Other studies include dust generation rate (e.g. Qi et al., 1992) and dust removal mechanisms (e.g. Barber et al., 1991).

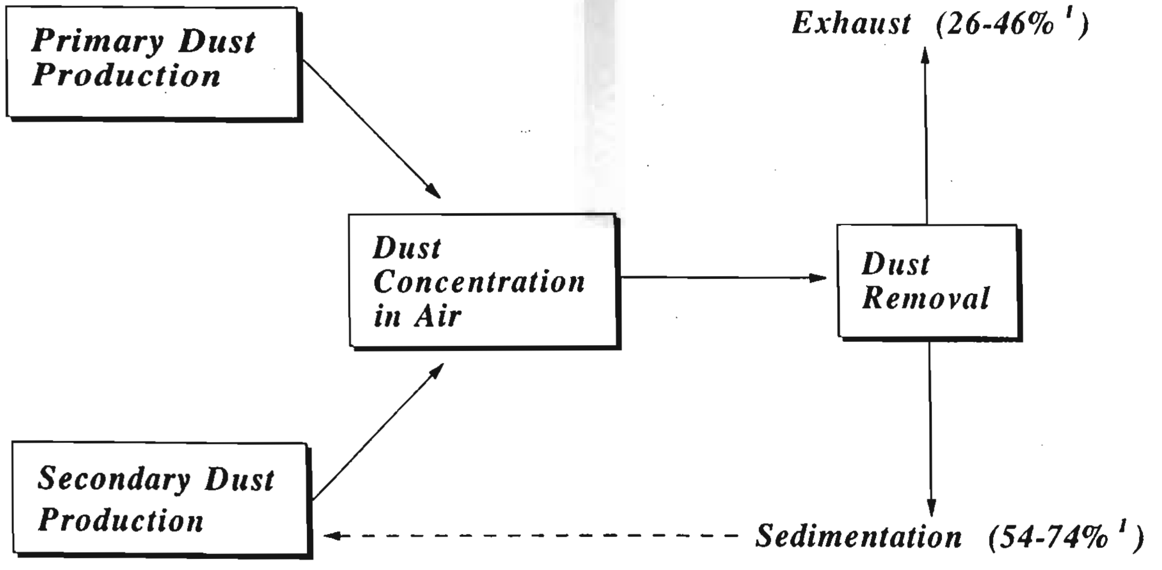

Figure 7.4 Dust production and removal

For the workers and the animals, only the dust concentration in the air is vital. Therefore the most important questions are:
- In which way can we minimize the release of dust from the primary sources?
- In which way can we minimize the release of dust from the secondary sources?
- In which way can we maximize the dust removal mechanisms?

A number of strategies can be implemented in order to influence the amount of airborne dust in a building. Present experience in agriculture suggests that more than one strategy is required to reduce airborne dust concentrations to acceptable levels.

Consideration of the sources of dust production can produce important benefits:
- it allows the individual sources of dust to be identified.
- it allows identification of the source materials that are most likely to have a biological activity which is detrimental to health.
- it allows for the application of suitable measurement procedures to quantify the individual source of dust production.

Information on the source, type and quantity of dust present allows management to consider the most appropriate strategy to reduce dust levels. The management need will depend on:

- The quantity of dust present and any legal implications (based on either animal welfare or human health considerations)
- Whether the system in use is intrinsically dusty or whether the system is badly managed or used.
- Suitable methods being available to reduce dust production.
- Whether any improvements are financially viable.

A reduction in dust production may not be possible in any one situation. The emphasis must then be placed on increasing the rate of removal of particles from the airspace. Reduction technology is discussed in section 7.5. However, following the model described in Figure 7.4, part of the airborne dust concentration is produced by the resuspension of particles which have previously been precipitated from the atmosphere. The resuspended particles form the secondary production cycle.

Primary dust production

Components of dust

The chemical and biological activity of dust is defined by the source materials. In livestock housing the composition of dust has frequently been described (e.g. Donham, 1986). The proportion of dust particles in any one building which are derived from a single dust source will be unique. Particles derived from animal debris will form a significant proportion of those present when dust concentrations are relatively low. Where dust concentrations are relatively high a substantial proportion of the mass will be derived from animal feed and bedding. Similarly, the concentration of airborne microorganisms will depend on a variety of factors which will be unique to any one building, e.g. cubic stocking density, relative humidity, bedding quality and ventilation rate. Typical sources of particles are described below.

Animal Debris
- Skin, hair, feathers
- Faeces, urine
- Gut bacteria, gut epithelial cells
- Respiratory bacteria, non-specific and pathogenic

Bedding materials
- Plant cells
- Moulds, endotoxins, pollen grains
- Insects, microorganisms

Feed particles
- Proteinases, proteases, minerals
- Moulds, endotoxins
- Insects, microorganisms

Atmospheric particles (produced external to a building)
- Pollen grains, bacterial spores
- Specific airborne pathogens

Associated gases and odours (See for example, Hartung, 1986)

Secondary dust production

Particles are removed from the air by a number of processes; one significant process is sedimentation. Any particle which is lying on a surface of a livestock building, and is not firmly attached to that surface, can be resuspended by animal activity, vibration of mechanical equipment, or air flow.
There is limited data available on the proportion of resuspended particles in airborne dust. Settled particles can be re-entrained into the air where air velocities are relatively high, e.g. in recirculation systems (Robertson, 1989).

Factors influencing dust production

Dust production is highly variable, both between and within buildings. The rate of dust production will depend on the particular system of livestock production used, and that in turn will be influenced by microclimate and weather factors. Reviews of the factors involved include Carpenter (1986) and Dawson (1990).

Systems considerations

Climate

External temperature can influence the requirement to house livestock, the stocking density, and the feed type used. Relative humidity can affect the ability of a surface to shed particles and also the viability of airborne microorganisms. The role of temperature and humidity in the survival of airborne bacteria is well recognised. (see for example Cox, 1987). Jones & Webster (1981) measured a significant reduction in the proportion of respirable bacteria in calf housing from 54 to 29%, which was concurrent with a period of cold dry weather. External temperatures will have a complex influence, and can affect animal behaviour and performance, ventilation rates, and consequently internal air velocities. The general climate during crop harvesting can influence the quality of grain and straw, and the subsequent emission of high concentrations of microorganisms.

Nutrition

Both the type of feed used and the method of feeding can influence the production of dust. Intensive housing systems typically use complete diets, with milled grain as the main energy source. Dust production may increase when finely milled products are used, and have been shown to decrease when the feed includes a binding agent such as oil or molasses. Larsson (1983) demonstrated that an increase in the moisture content of grain prior to grinding or crushing could reduce relative dust production by up to 78% and 82% respectively. In laboratory studies adding 0.5, 1.0 and 2.0% oil to pig feed, Heber & Stroik (1988) showed a reduction in dust mass of 76-99%. There was no significant decrease in respirable dust after the addition of rapeseed oil to pig feed (Welford et al., 1990), but a significant decrease in total dust mass and settled dust concentrations. Further results are described in section 7.5. Dust production can also decrease if the feed is presented as a wet or pelleted product. Study in big number of houses for fattening pigs (Baekbo, 1989) showed 2.6 mg/m^3 in average of total dust with dry feeding, but only 1.6 mg/m^3 with wet feeding.

The method of feeding can have a significant effect of dust production. In a comparison of floor feeding vs commercial pig feeders, the number of airborne respirable particles was reduced by 55% when using the feeders (Feddes et al., 1983). In a survey of 20 commercial pig buildings over a six month period, mean total dust concentrations were 4.6 mg/m^3 with ad libitum feeding compared with 10.0 mg/m^3 with restricted feeding (Robertson, 1992).

Certain types of dust production from conserved herbage and grain are particularly damaging to human and animal health. Grain, silage, hay and straw can all decay during storage to produce moulds and toxins. Mites can also be present and can cause serious respiratory irritation. Problems increase when wet conditions exist at harvest and material is put into store at a relatively low dry matter content. Systematic examination of dust from stored hay has shown 75 to 150,000 mites per gram of hay dust (Hage-Hamsten, van, et al., 1991). Mycological examination of mouldy hays has shown typical mould spore concentration of 5-250 x 16^6 spores per gram of hay (Gregory & Lacey, 1993).

Size of unit or building

The size of the air space in a building can, in commercial conditions, influence dust production. One example would be where a single air space contains different ages of livestock, and is consequently never emptied and completely cleaned.

Stocking density

A major influence on dust production is the stocking density; the higher the number of animals per unit space, the higher the amounts of feed provided and wastes produced. Stocking density is a function of animal requirements; e.g. breeding stock have a lower stocking density than fattening stock. Overstocking can increase animal activity through increased competition for space. Stocking density per unit area (kg/m^2) will also increase with the age of animals (eg. broiler housing), and can be associated with an increase in dust concentrations.

Webster (1990) has suggested that a 50% reduction in stocking density is 50% more effective in reducing contaminants in the airspace than a 10-fold increase in ventilation rates.

Animal activity

Competition can have an influence by increasing both the amount and intensity of activity, which causes an increase in the mechanical disturbance of particles. Factors include stocking density (see above), insufficient feeder space and mixing of different groups of animals. Animal activity will also increase at feeding time where ad libitum feed is not available, and where stockman intervention is disturbing to livestock (e.g. stock inspection, weighing). Diurnal patterns of animal activity or similar daily patterns can be positively associated with airborne dust levels.

Diurnal variation

Investigations have shown that airborne dust varies considerable depending on animal activity. Instant measurements by laser (Nilsson, 1982) indicate peaks with 5 times higher dust concentrations just before feeding and 3.5 times higher during feeding periods, as compared to the 24-hour average. Concentrations of dust from personal dust measurements were 1.7 times higher than the daily mean (Donham, 1986).

Day-to-day variation in dust

Investigations on airborne dust always show large variations in dust from day to day when using 24 hour measurements. In experiments at SjF in Denmark (Pedersen, 1993) the day-to-day variation, expressed as Coefficient of Variation (CV), was about 20 %.

At Silsoe, England a comprehensive study (Barber et al., 1991) was made in a grower-finisher piggery with measurements over 16 days at 16 locations. The results show a CV of 17.4 in respect to the daily variation, similar to the work noted above. The results also shows a CV of 21.7 from pen to pen, showing that variation from day to day in a piggery is of the same size as the variation from pen to pen.

The results of a study on a commercial pig farm (Møller & Takai, 1991), show a CV of about 100%, which is very high.

Simultaneous measurements of pig activity and dust concentration are shown in Figure 7.5. The activity measurements are made with a method developed at SjF in Denmark (Pedersen, 1993) based on a PID sensor (Passive Infrared Detector) and the dust concentration is measured with a Dust Detector, type Shibata. The measurements were carried out in a weaner house with 56 pigs at an average weight of 28 kg.

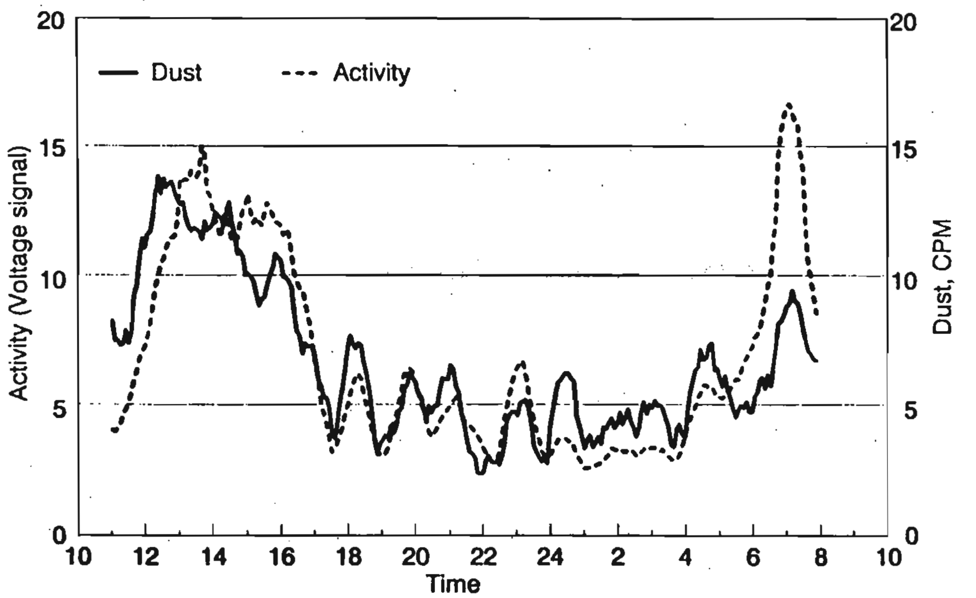

Figure 7.5 Activity and airborne dust in weaner house

Figure 7.5 shows that pig activity has a great influence on the actual dust concentration. These differences in dust level e.g. caused by fighting or active pigs can make it difficult to demonstrate the effect of any method applied to reduce the dust level. The figure shows that increased pig activity can explain most of the variation within the building.

Housing type

Systems which restrict animal movement (eg. pig tethers) may produce less dust than, for example, loose housed animals kept on straw, if all other factors remain unchanged. Housing type is often associated with flooring/bedding types; the dustiness of the litter will influence airborne dust concentrations. Slatted concrete floors are associated with less airborne dust than solid concrete floors due to a reduction in secondary dust production; particles falling through the void in the floor cannot be resuspended. In a study (Baekbo, 1989) in houses for fattening pigs, the amount of total dust was 2.5 mg/m^3 in houses with straw, but only 1.1 mg/m^3 in houses without straw. In a comparison of air quality in poultry housing with birds kept on either litter or raised netting (Madelin & Wathes, 1989) there was a reduction in both airborne bacteria and respirable dust concentrations in the buildings with raised netting.

Ventilation systems are associated with removal of dust, see Figure 7.4. However, both high speed jet systems and recirculation systems can increase secondary dust production by the reintrainment of settled particles from horizontal surfaces or ducting. The effect of a ventilation system is inevitably linked to the state of the external weather conditions. In a study of naturally ventilated and mechanically ventilated pig buildings, (Heber & Stroik, 1988), naturally ventilated buildings had significantly higher dust concentrations. The number and mass concentrations were both negatively correlated to outside temperatures (-10.6 to 33.9°C) and inside relative humidity (27 to 100% RH).

Dust production - additional factors
The primary concern which has created interest in dust reduction has been the influence of airborne dust on respiratory disease. However, there are additional factors that should be considered in all cases (see chapter 3).

7.3 Measurment Methods

Three principle questions need to be answered to choose the correct measurement method.

- What is to be measured? (respirable or inspirable fraction, bacteria etc?)
- Where is the measurement location? (ground level, head height, exhaust?)
- When is the measurement to be carried out? (am, pm, diurnal?)

The answers to these questions will dictate the choice of methodology, although many practical compromises will be made. There is no standard technique, although the measurement of certain aerosols, eg. the inspirable dust fraction, is usually carried out with specific equipment which has published performance characteristics.

A number of protocols exist for aerosol measurement, and a discussion document was published after a workshop on aerosol sampling in livestock buildings. The reliability of different techniques was discussed (Wathes & Randall, 1989) and recommendation were made.

A summary of those recommendations which do not refer to specific sampling methods includes:
- Standard sampling locations should be given for each animal species and related to behaviour and height.

- The degree of variability of aerosol characteristics at each site of interest should be measured (or understood) to establish how many samples are needed in order to obtain results of a predetermined accuracy.
- All measurements should include sampling over 24 hour periods or be relevant to a particular task.
- Frequent calibration of equipment is essential and the methods used reported in all publications.
- Desiccations of filters before weighing should be accepted as standard. The weighing method should eliminate hygroscopic effect and be reported in all publications.

Credibility of results depend on an accurate record of the many factors which affect aerosol characteristics (animal factors, building description, feeding method, manure handling, and environmental factors e.g. temperature).

When selecting a method for measuring the airborne dust concentration in livestock buildings, it is convenient to use a method which does not disturb the air and dust flow in a room. In reality it is rather difficult to get faultless values, because the measuring equipment normally is placed at the point where the dust content is to be measured. In this respect the laser beam which measures the average concentration along a line of some meters length has some advantages. However this method has other disadvantages with respect to calibration etc.; consequently it is not much used today.

The most interesting methods are discussed on the following pages.

Filter Methods

Different types of methods using filters are described in the literature, but most laboratories are currently using the cassette method with 25 mm filters. This method is used for measuring total dust and also, together with a cyclone, for measuring respirable dust.

Different types of equipment are available and used at different laboratories. The method used in the EU-project "Reduction of aerial pollutant emissions in and from livestock buildings", 1992-1996 with participants from Germany, Denmark, the United Kingdom and the Netherlands is described below. (Takai et al., 1993)

Total dust
Figure 7.6 shows an exploded view of the IOM dust filter.
The sampler was developed by the Institute of Occupational Medicine, Edinburgh, UK (Mark & Vincent, 1986). The sampler is designed for personal monitoring of dust, or IPM (Inspirable Particulate Mass) as recommended by the American Conference of Governmental Industrial Hygienists (ACGIH, 1985). The cassette has a 15 mm circular orifice and is equipped with a 25 mm filter. The sampler body and the cassette are made of conductive plastic. Sampling flow rate is 2.0 litre/minute.

Respirable dust

Figure 7.7 shows the SKC cyclone dust sampler.

Figure 7.6 The IOM cassette in exploded view

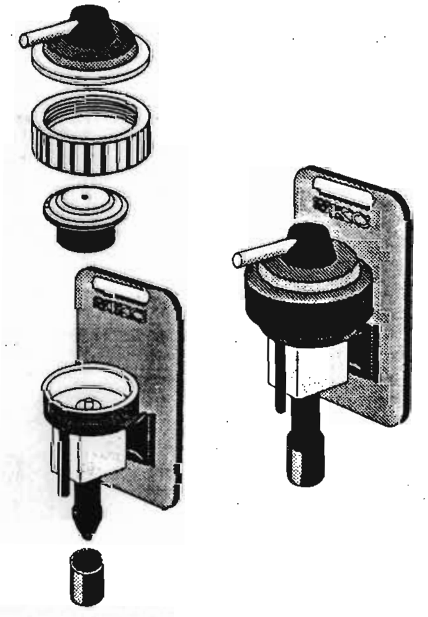

Figure 7.7 The SKC cyclone dust sampler for respirable dust in exploded view

The SKC cyclone dust sampler collects the respirable fraction, in accordance with the convention shown in Figure 7.2. The sampler consists of a cyclone and a snap-together filter cassette which is assembled on top of the cyclone using a two-piece cap. The cyclone includes a pipe stub for the air inlet and a lapel clip. The filter cassettes includes a 25 mm filter paper and a filter support grid of stainless steel. The cap includes a pipe stub for vacuum air and a screw ring for assembling. The cyclone and cap are made of conductive plastic. Sampling flow rate is 1.9 litre/minute.

The purpose of using the cyclone is to precipitate particles above 5 μm before they can reach the filter paper. In practice it is not possible to sort particles precisely by means of a cyclone. The shape of the sorting curve is defined at the Johannesburg Convention 1959 (MDHS 14, 1986), similar to Figure 7.2. Some particles bigger than 5 μm will be collected on the filter and some smaller ones will be sorted out by the cyclone, as shown in table 7.3.

Table 7.3 Sorting characteristic for respirable particles

Diameter µm	Passing cyclone %
1.6	95
3.5	75
5.0	50
6.1	25
7.1	0

The disadvantage of the filter method is that the measured dust concentration is the average dust concentration over a longer period, normally 24 hours. Therefore, it gives no information on the variation in dust concentration over time. Another practical problem is weighing accuracy, because the mass of the collected dust is calculated as the difference between two large mass values: the filter itself weighs approximately 45 mg and the collected respirable and total dust masses are 0.5 and 5 mg respectively.
Since the filter material is hygroscopic, it is important to use a well-documented weighing method. One of the methods is to dry the filters at 105 °C over a period of 14 hours. Another method is to stabilize the weighing condition over a period.

Organization of the Weighing Room

The space for handling and weighing of filters ought to be in a separate room, ideally equipped with air conditioning to control inside temperature and relative humidity.
The air conditioning system may include a humidifier and an electric heater, to provide a constant temperature ± 0.2 °C and a relative humidity of 50% ± 2 %.
The climate in the weighing room may be kept constant over a 24 hour period prior to preparation of the cassettes and the weighing procedure.

Particle Counter

Figure 7.8 shows a particle counter based on the Photocell method.

The instrument continuously gives values of dust at a certain point. The method can be used for relative measurements, but is not useable for measuring absolute values e.g. mg/m^3.

Particle sizing

Figure 7.9 shows the Andersen Stack Sampling equipment. It consists of 6 or 9 sieves with holes placed at a distances of 2.5 mm. The hole diameter decreases from the upper sieve to the lower, and therefore the air speed increases as it passes through the sieves. As shown in the figure, the holes in two neighbouring sieves are displaced with respect to each other. This means that the air has to change direction before entering the holes in the

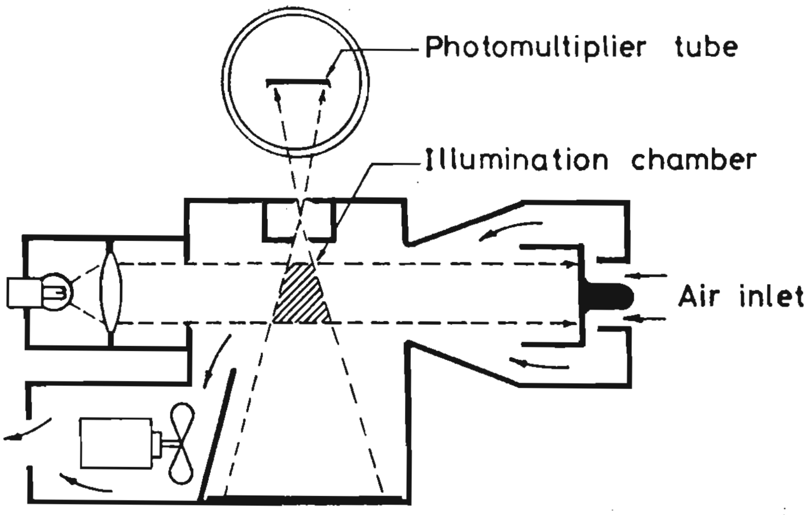

Figure 7.8 Optical particle counter

next sieve. At a specific speed, certain particle sizes will not change direction but be collected on the next sieve. In this way dust particles are divided into different sizes. This method can be used for collecting airborne microorganisms for impaction and subsequent culture on nutrient bases. However the efficiency of collection can be difficult to establish. There are a number of different methods for collecting and counting viable microorganisms, and they all have different levels of practicality and sampling efficiency (Crook et al., 1988).

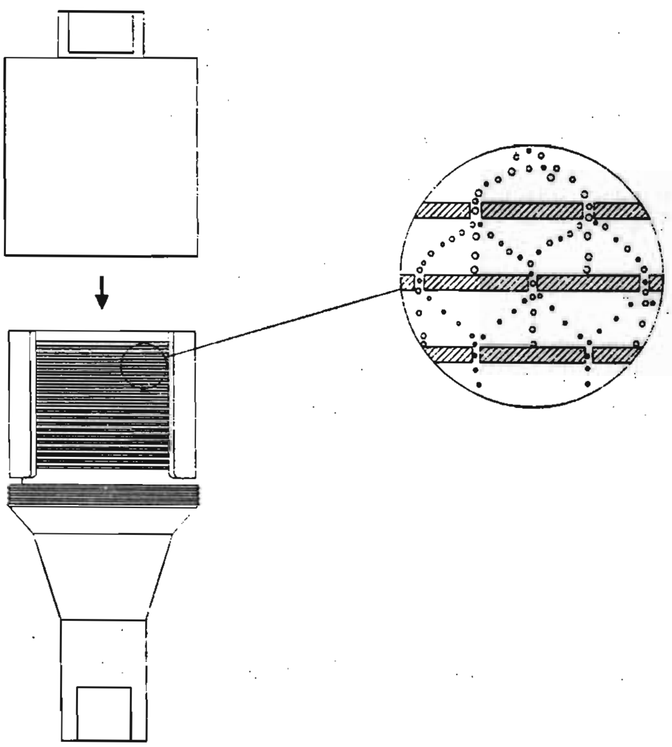

Figure 7.9 Anderson particle counter

Optical Particle Sizer

During the last decade different particle sizing units have been developed based on laser principles, where the air passes a laser beam at high velocity.

The particle sizer, e.g. from TSI (Minnesota) and Malvern (England), is characterized by a controlled flow. The air examined is accelerated up to a very high speed in a vacuum. At the end of the accelerating chamber the air passes a double laser beam, where a speed is obtained which correspond to the particle size, because small particles accelerate faster than bigger particles.

If the specific gravity of dust is known, the distribution of particle surface area and mass can also be obtained, derived from the distribution of different particle sizes.

7.4 Effects on animals and humans

Human health

There are still significant gaps in our knowledge about the precise relationships between the various components of agricultural dust and specific respiratory disorders. It is established, however, that organic dusts present in the farm environment may cause a series of lung cell reactions involving inflammation and immune responses. Based on the inflammation, clinical diseases related to this exposure may be divided into categories of acute and chronic inflammation. These may be accompanied by airway hypersensitivity. Individual clinical cases often present atypical or mixed symptoms that must be recognised as a work-related disease (Rylander & Peterson, 1988). The four main diseases associated with agricultural work are: allergic rhinitis and asthma, pneumonitis/alveolitis, organic dust toxic syndrome, and bronchitis.

Allergic rhinitis and Asthma

Allergenic material is common in the agricultural workplace. Storage mites, particles of oats and barley, and animal skin squames (epithelial cells) are all known to be allergenic in some cases.

Pneumonitis/Alveolitis

Hypersensitivity pneumonitis can be induced by the reaction of lung cells to inhaled materials via immunological mechanisms. The most widely known description of the symptoms is "farmers lung". The prevalence of this disease has been reported as being between 5.7 and 8.6%, but is generally considered to be below one percent for European and American farmers (doPico, 1986). The seriousness of the disease is that the risk of permanent lung damage increases with repeated exposure to the causative material.

Organic Dust Toxic Syndrome

Exposure to extremely high concentrations of organic dust, for example during grain handling, can lead to influenza-like symptoms. Although the causative agents can also be associated with hypersensitivity pneumonitis, the symptoms are different in that they may occur in a relatively high proportion of those exposed (30-40%), the symptoms are often delayed for 4-6 hours after exposure, and the individual may become tolerant to repeated exposure.

Bronchitis

Chronic bronchitis can be defined by the presence of cough and sputum for two years or more, and various studies have shown that it is a significant problem amongst agricultural workers. There can be a long-term reduction in lung function. The symptoms have been reported in a number of studies of intensive livestock workers.

Examples

There have been a range of studies to investigate the possible correlation between air quality in agriculture and human respiratory problems. A number of examples are given below. The subject has also been covered by numerous meetings; for example a range of studies of organic dusts and lung disease were covered in an international workshop (Rylander & Peterson, 1988).

- Aflatoxin in respirable dust - grain (maize) handling (Sorenson et al., 1981).
- Lung lesions probably caused by hypersensitivity pneumonitis. Tracheal and turbinate lesions are best explained as a reaction to chronic low-grade irritation. Donham & Leininger, 1984.
- 53% of pig farmers (n=183) reported one or more respiratory symptoms (Brouwer, 1987) (q.v. table of symptoms).
- In a study of poultry buildings and stockmen, 38% (10/26) of farmers had obstructive ventilatory lung function (Danuser, 1991).
- Between 1985 and 1989 in the UK there were 299 confirmed cases of leptospirosis, an infection caused by Leptospira bacteria. Half of those were farmers or agricultural workers, most of whom had contracted the infection by splash contact with contaminated cows' urine (Ferguson, 1991).
- Work-related respiratory symptoms were reported by 23 of 29 pig workers; eight had elevated specific IgE to the pig feed, indicating possible allergy (Crook et al., 1991).

Table 7.4 Symptoms reported by intensive livestock workers - pig farmers (%)

Symptom	Survey		
	Crook et al., 1991 n = 29	Brouwer, 1987 n = 183	Donham & Gustafson, 1982 n= 486
Nasal/eye irritation	69	-	45
Cough	52	20	67
Sputum	35	16	56
Chest tightness	45	10	36
Shortness of breath	-	9	30
Wheezing	-	22	27
Headaches	21	2	37

- Prevalence of Farmer's Lung in specific areas of Scotland recorded at 0.86% of the total population. Probably related to climate and agricultural methods which combine to give increased risks from mouldy hay (Grant et al., 1972).
- A number of studies investigating the dose/response relationship between grain dust and respiratory problems imply that exposure above 5 mg/m^3 is associated with a serious effect on lung function (Howarth, 1990).
- Specific antibody reactions to pig skin, urine and feed have been recorded in stockpersons in Finland (Virtanen et al., 1990).
- Clinical symptoms of possible respiratory impairment due to dust exposure, supported by measurement of reduced lung function, were evident in 10% of the stockmen taking part in a field study of poultry buildings and workers (Whyte et al., 1993).

The complex nature of the problem and the importance of non-work factors such as smoking make it difficult to provide definite guidance on the relationship between dusts and respiratory health. However, some researchers have concluded that maximum exposure limits for workers in livestock buildings should be reduced. Donham (1990) suggested that provisional guidelines for maximum exposure of livestock workers to total inspirable dust should be 3.8 mg/m^3.

Occupational exposure - risk factors

The dose-response relationship between exposure to dust and respiratory disease in humans is not well defined. However, the problem can be simplified by considering three main factors:
- The hazardous nature of dust. Material may be relatively toxic or pathogenic even at very low concentrations, or at the other extreme, biologically inert.
- The risk from dust will depend on work factors such as daily duration of exposure, duration of any previous exposure, whether exposure is intermittent or not, and degree of exertion during exposure.
- The susceptibility of any individual can be influenced by genetics (eg. family history of asthma/respiratory allergy), atopy (previous respiratory impairment), tobacco smoking, and short-term ill-health (reduction in immune function).

Dust and livestock health

Livestock kept in buildings are most at risk from dust. Although many modern buildings are described as environmentally controlled, dust control is seldom considered at the design stage. The relevance of dust to livestock health is twofold. First, and most important, is the ability of large numbers of particles to damage or compromise the respiratory tract. The second concern is that particles carry microorganisms and gases which cause damage to the respiratory system.

Some of the information that is available on the relationship between airborne particles and respiratory health remains contentious. However, there is no question about the importance of respiratory disease in livestock production. Pneumonia in intensively housed calves and cattle, and a range of chronic and acute respiratory diseases in pigs are obvious examples. During 1987, 29.7 million poultry were condemned in the U.S. due to respiratory problems.

Although a number of studies have demonstrated a significant relationship between air quality factors and the severity of respiratory disease, the effect is usually seen only when viable pathogens are also present. There also appears to be an effect where the time of exposure to dust during the development of respiratory disease is also crucial. For example, although there were significant relationships between dust measurements in both farrowing and weaner accommodation and the severity of atrophic rhinitis, the strongest relationship existed in the weaner housing when the pigs' immune system is most vulnerable (Robertson et al., 1990).

Some examples of studies which relate air quality factors to specific respiratory problems are given below. A broader view of the subject has been discussed by a number of workers or presented at meetings, e.g. Bruce & Sommer (1987), and Morrison et al. (1990). The complex relationship between the environment, building design and animal health has also been reviewed, e.g. Wathes et al. (1983).

Examples

- Birds on litter with higher incidence of lung damage and higher incidence of viable microorganisms in the lungs than birds kept on raised netting. Respirable dust and BCFU (Bacterial colony forming units) significant higher (Madelin & Wathes, 1989).
- Association between increased concentrations of airborne dust and cattle pneumonia (MacVean, 1986).
- Calves in sheds with internally filtered air were compared with calves in non-filtered sheds. Mean aerial bacterial concentration in sheds with filters was reduced by about 45% and the average area of lung consolidation in the calves reduced by 58% compared with the controls (Pritchard et al., 1981).
- Air hygiene and ventilation of stables has a significant influence on the respiratory health of horses (Clarke, 1991).
- In a study of 12 commercial pig units there were positive correlations between both the respirable and inspirable dust concentrations in the final housing stages and the average severity of lung damage in the pigs (Robertson, 1992 b).

7.5 Reduction technology

During the last ten years, many attempts have been made to reduce the levels of airborne dust in livestock buildings. Technologies can be applied to reduce the production of dust, increase the sedimentation or decrease the recirculation. In the following section different attempts are described.

Fat added to feed

At the University of Nebraska, (Chiba et al., 1985), experiments were carried out with 2.5% and 5% fat in diets for pigs. The airborne dust was measured with a four-stage cascade type impactor and the concentration of total dust varied from 10 to 20 mg/m^3. The reduction in aerial dust was 21 % and 50 % respectively. In later experiments, (Chiba et al., 1987) the fat content in diet was increased to 7.5 %. The amount of total dust was approximately 22 mg/m^3 and the reduction compared with control diets was 53%.

At SjF (National Institute of Agricultural Engineering) in Denmark experiments were carried out in 1993 (unpublished) with 4% organic fat added to the diet for pigs. The concentration of total dust in the reference house was approximately 4.5 mg/m^3 and the results show a reduction of 50 % in total dust.

Fogging with water

The effect of fogging the air with water depends very much on the type of nozzle, water rate and the fogging intervals. In a Swedish experiments with pigs using a fogging system with ultra-sound nozzles which produce very small water particles, the dust concentration was increased, probably because the animals were negatively influenced by the high frequency sound. When used in stores for potatoes, the dust burden was reduced to one third. When using nozzles which give larger water particles (douching) and shorter fogging intervals, the dust concentration was reduced by 50% in piggeries. (Gustafsson, 1993). However, the use of misting to increase R.H. from 53 to 75% and 34 to 68% in turkey sheds actually increased particle concentrations (Feddes et al., 1992).

Fogging with rape seed oil

A method of spraying a mixture of rape seed oil in each pen was developed at SjF in the middle of the eighties (Figure 7.10). Experiments were carried out on a conventional farm (Møller & Takai, 1991) and a reduction in respirable dust of 76% was obtained in weaner houses. In houses for young pigs the reduction was 54%, and in a house for fattening pigs the reduction was 52%. Later the spraying system was improved and in weaner houses, the dust concentration in the reference room was approximately 4 mg/m^3 (Test report 883, 1993). The results show a reduction of 78% in total dust and 90% in respirable dust at a dose of 10 gram rape seed oil per pig per 24 hours. In Sweden (Gustafsson, 1993) experiments were done with spraying rape seed oil and a 50% reduction in dust concentration was measured.

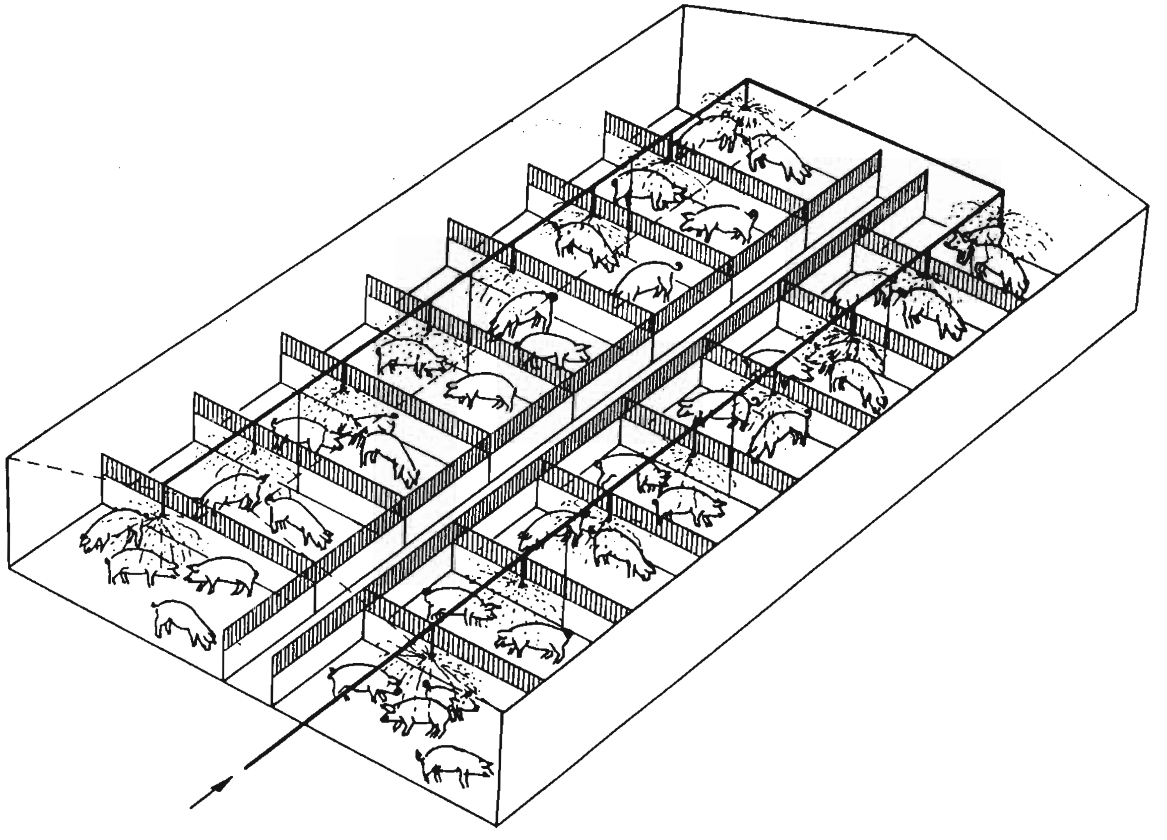

Figure 7.10 Fogging with a mixture of rape seed oil and water

Showering of floors and fixtures

At LBT in Lund (Nilsson & Gustafsson, 1987) experiments in pig buildings were carried out with showering of the floors and fixtures (Figure 7.11) but no significant difference in production, health or dust concentrations were found.

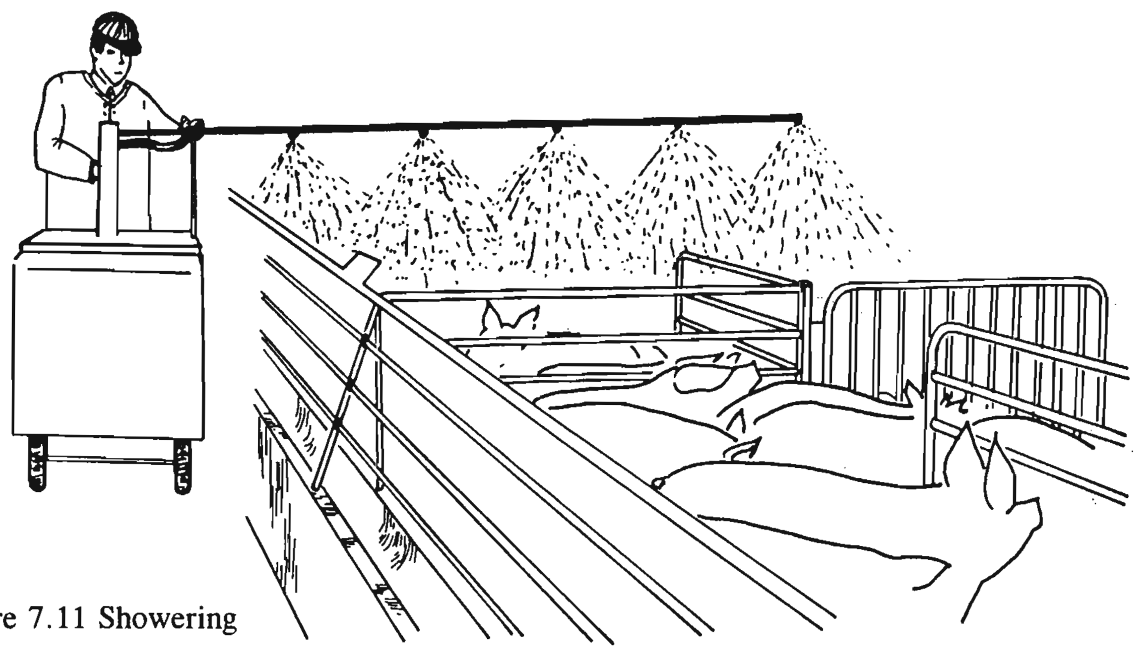

Figure 7.11 Showering

Later experiments (Ryhr-Andersson, 1990) in a pig building with 1.2 mg/m^3 of total dust showed a reduction in total dust of 15% and in respirable dust of 26% by showering with water two times per hour during day time and one time per hour during night time.

Weekly washing

At Rosmalen in the Netherlands (Klooster, van 't, et al., 1993b) experiments in weekly washing of weaner houses were carried out with four weeks old pigs. The dust level in the reference room was approximately 5 mg/m^3 and a reduction of 10% was measured.

Ionisation

At SjF in Denmark experiments with ionisation were carried out for some years (Møller, 1991). The principle is shown in Figure 7.12. In 1990/91 experiments were done with two identical houses for fattening pigs with approximately one pig/m^2, one house with and one without ionisation. In the house with ionisation, there were 30 000 - 80 000 negative ions per cm^3.

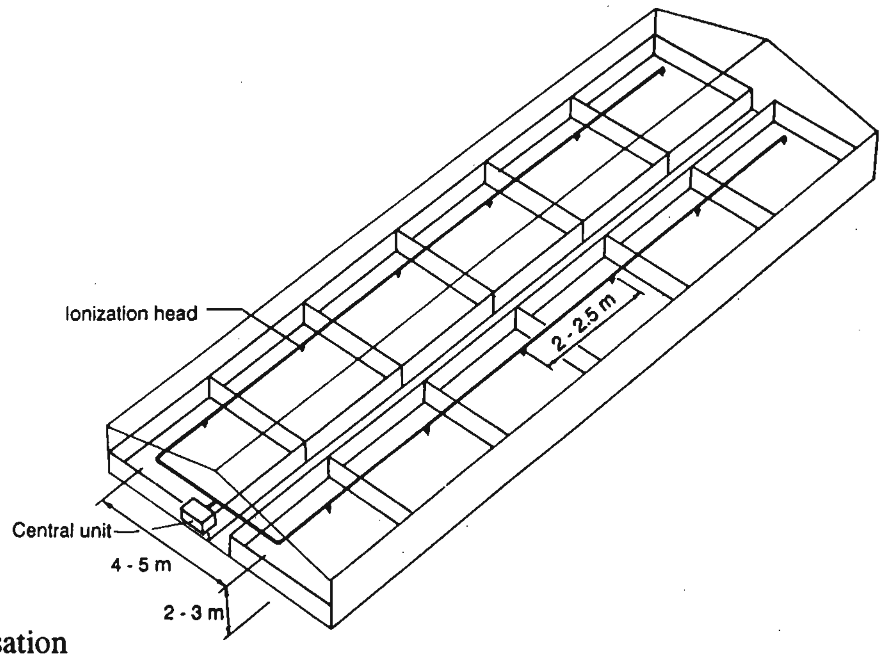

Figure 7.12 Ionisation

The inside temperature, relative humidity, and carbon dioxide were of the same levels. Measurements of total and respirable dust were performed 24 times per 24 hours at the same time in both houses. The concentration of total dust in the reference room was approximately 3 mg/m^3 and the reduction of dust by ionisation was 26% for respirable dust and 23% for total dust.

At the Agricultural University of Norway, the effect of ionisation was studied in three different houses for hens in cages (Lyngtveit & Eduard, 1992). The total dust was collected on filters and by stationary sampling. The amount of total dust was on average 1.3 mg/m^3 and the results show a reduction in total dust of 12%.

At the Swedish University of Agricultural Science (Ramvall, 1992), research was carried out in a poultry house for layers. The hens were kept in a loose system with approximately 16 hens per m^2. The house was equipped with nests in three layers on one side and eating and resting areas in three layers on the other side. Measurements of dust were carried out both two metres above the floor and with equipment carried by the worker. The concentration of total dust by stationary measurements was 4.3 mg/m^3. No effect was found on total and respirable dust, neither at one ioniser per 4 m^2 nor per 2 m^2 of floor.

Electrostatic filters

At SjF, experiments were done with electrostatic filters (Figure 7.13) with an air capacity of 3000 m^3/h in a house for 120 weaned pigs (Test report 819, 1991). No effect was found on the ammonia concentration. The amount of total dust without an electrostatic filter was 3.1 mg/m^3 and the reduction of dust was 43 % and 44 % for respirable and inspirable dust respectively.

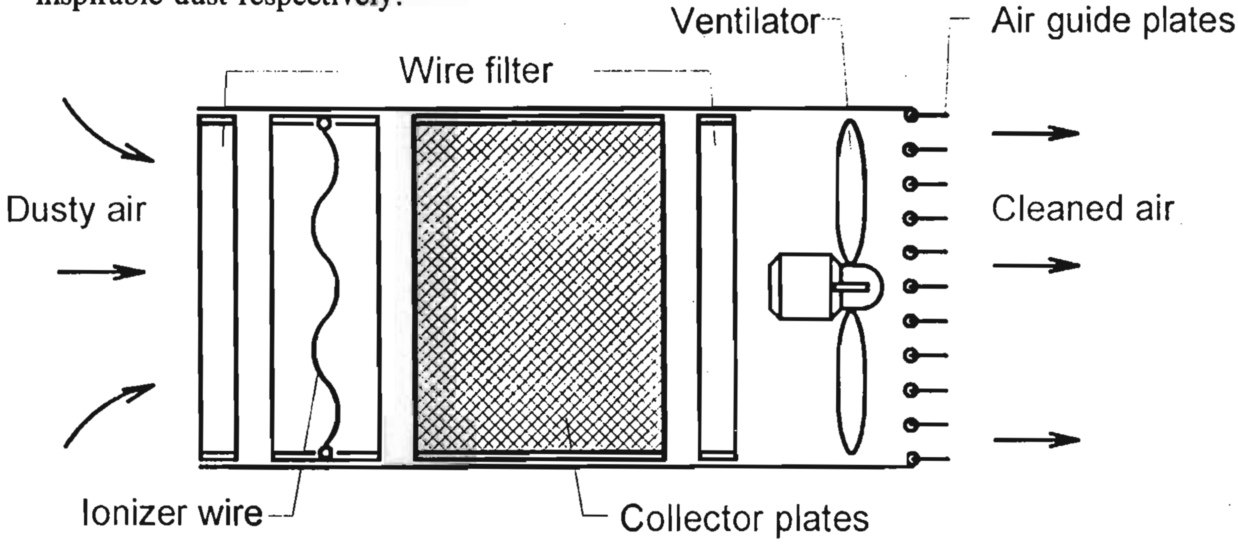

Figure 7.13 Electrostatic filter

Swedish experiences (Gustafsson & Mårtensson, 1990) show that the airflow capacity through air cleaning devices must be at least in the same range as the ventilation rate in the building if any significant effect is required.

Vacuum cleaning

At LBT in Lund (Nilsson & Gustafsson, 1987), experiments on vacuum cleaning in the passage showed little or no effect on dust concentrations in the building. Also, at Rosmalen in the Netherlands (Klooster, van 't, et al., 1993b), experiments on vacuum cleaning were carried out in a finishing house with pigs from 22 to 108 kg. The total dust concentration in the reference room was 2.5 mg/m^3. Using weekly vacuum cleaning, a reduction of 6% was measured. In experiments by the Centre for Rural Building, Scotland, to measure human exposure to total dust when cleaning poultry buildings, use of a vacuum cleaner reduced exposure by 74% compared with the brush, from 14.6 mg/m^3 to 3.8 mg/m^3 (Robertson, 1992 a).

Filtration and recirculation

At Rosmalen in the Netherlands (Klooster, van 't, et al., 1993b), experiments were carried out on filtration and recirculation (Figure 7.14) of the air in weaner houses with solid concrete in the laying area and metal slats in the dunging area. The total dust concentration in the reference room was 2.7 mg/m^3.
For a house with 70 four-week old pigs and a recirculated air volume of approximately 4000 m^3/h, the reduction in dust measured over 24 hour periods was 40%.

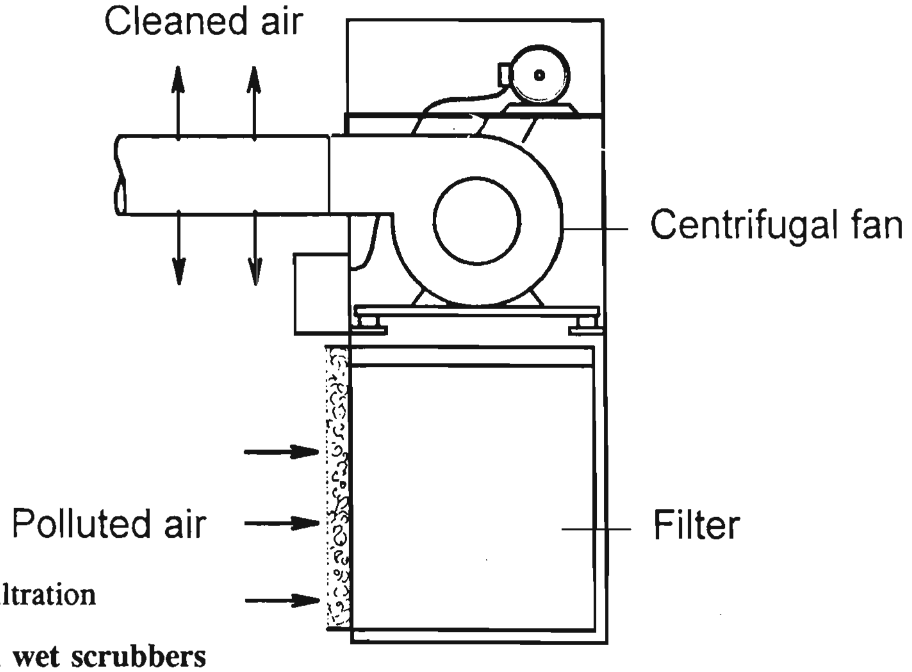

Figure 7.14 Filtration

Cleaning with wet scrubbers

At ADAS Farm Building Development Centre, Reading (Pearson, 1989) experiments with wet scrubbing of recirculated air were carried out in a weaner house with pigs from 3 to 7 weeks of age. Figure 7.15 shows a typical wet scrubber.

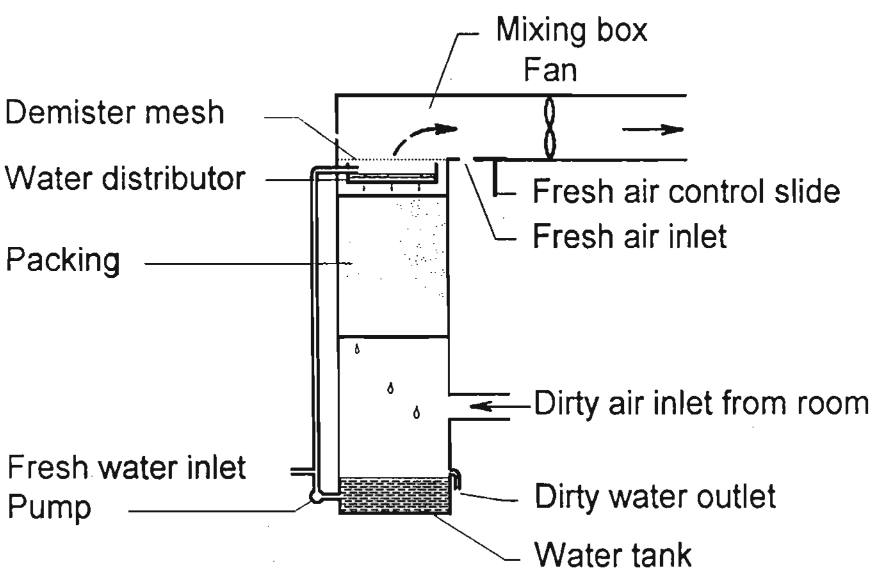

Figure 7.15 Wet scrubber

The scrubber capacity was 11% of the maximum required summer ventilation rate. The cleaned air was recirculated and mixed with the required amount of fresh air.
The concentration of total dust in the weaner house was 4.0 mg/m^3 which was reduced to 3.7 mg/m^3 by wet scrubbing. However, the concentration at the scrubber outlet was reduced to 0.7 mg/m^3, but because of the limited capacity of the scrubber, the dust concentration in the weaner house was reduced only slightly. It is assumed that the reduction can be improved by increasing the air capacity of the wet scrubber. By using the wet scrubber, the ammonia concentration was reduced by about one-third and the odour was also reduced at the scrubber outlet. Therefore, the wet scrubber can also be used for reducing odour emissions by cleaning the outgoing air. However, this is not considered to be cost effective for livestock buildings.

Purge ventilation

At the Centre for Rural Building, Scotland (Robertson, 1989), experiments were carried out on purge ventilation in pig buildings with either natural ventilation or mechanical ventilation. The effect of the purge cycle on the number of particles within the buildings was measured with a near-light scatter particle counter. The mean pre-purge total dust concentration was 12 mg/m^3. The purge produced a 60% reduction in estimated total dust concentration, but the dust concentration increased rapidly when the purge was complete. As a consequence of the purge, the inside temperature droped rapidly in the first two minutes of the purge cycle.

Deep litter

At Rosmalen in the Netherlands (Roelofs et al., 1993) experiments were carried out with deep litter wood-shavings in houses for fattening pigs (Ecopor-system and Finnfeeds-system). The buildings were insulated and mechanically ventilated. During day-time, the concentration of total dust was 1.1 mg/m^3, dropping to 0.8 mg/m^3 during night-time. These concentrations are approximately 50% of typical dust levels in pig buildings. The 24-hour average of respirable dust was 0.2 mg/m^3. At SjF in Denmark (Møller, 1992) an investigation of dust concentrations was carried out with fattening pigs on deep litter in an uninsulated house with natural ventilation. The results were compared to concentrations in traditional Danish houses for fattening pigs with totally or partially slatted floors and mechanical ventilation in insulated houses. The amount of total dust in the deep litter house was 0.55 mg/m^3. As an average for one year's measurements, the concentration of total dust was only 25% of the amount in the traditional houses, and the amount of respirable dust was only 40%. The low concentration of dust is probably due to the high air exchange rate in the house with deep litter, where the inside temperature was only a few degrees above the outside temperature.

Position of air inlets

In the Netherlands (Klooster, van 't, et al., 1993a) an investigation was carried out to minimise the exposure of the stockmen to dust in confinement buildings for pigs (Figure 7.16). The air inlets were located as near as possible to the stockmens' noses. The air outlet was located near the re-entrainment area underneath the slats. The dust concentration which increasED with the number of days after the start date, varied from less than 1.0 to 3.5 mg/m^3. In a direct comparison with an identical room the average inhalable dust levels, measured continuously over 24 hour periods at 1.6 m on the feed walk, were reduced by 40%. The average inhalable dust levels at 1.0 m above lying area were 50% lower in the room with the modified ventilation as compared to the standard room.

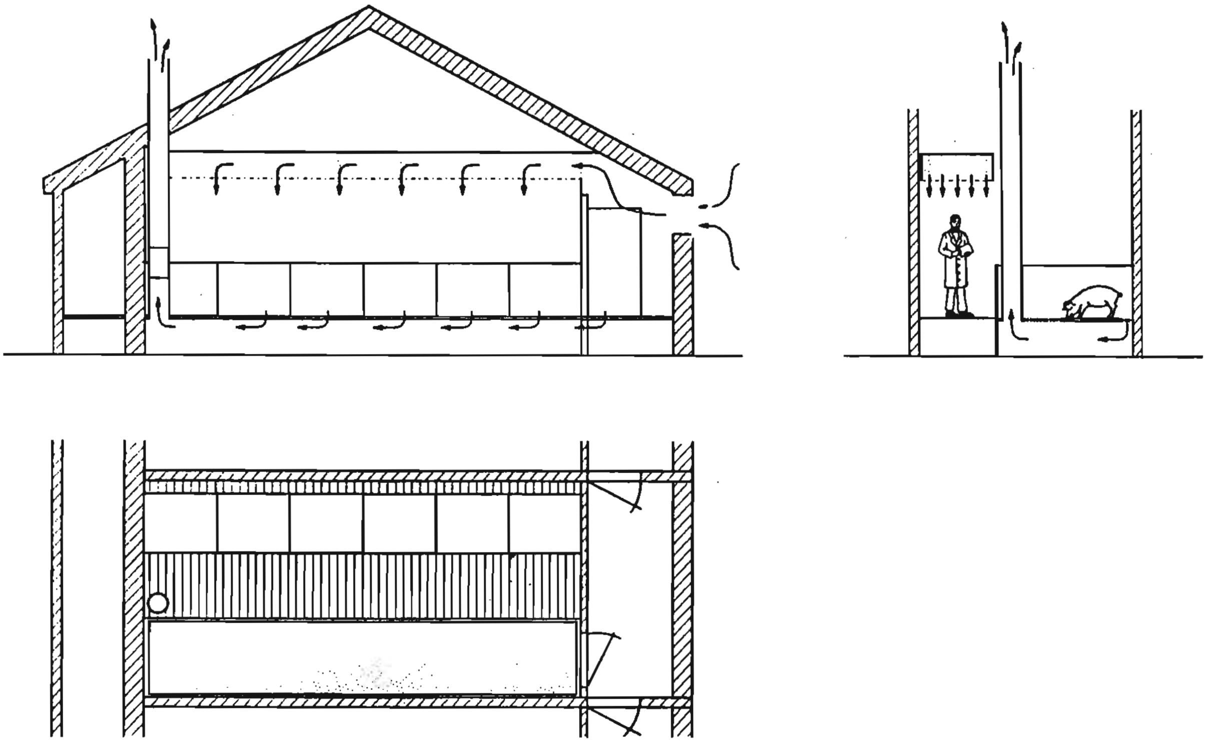

Figure 7.16 Position of air inlets

7.6 Comparison between different methods of reducing dust

The previous sections have shown results from different experiments with different methods of reducing airborne dust in livestock buildings. On the basis of this information and experience from others, the scale of reductions which can be expected in practice is shown in Figure 7.17. This shows that, currently, the highest reduction has been obtained by fogging with rape seed oil.

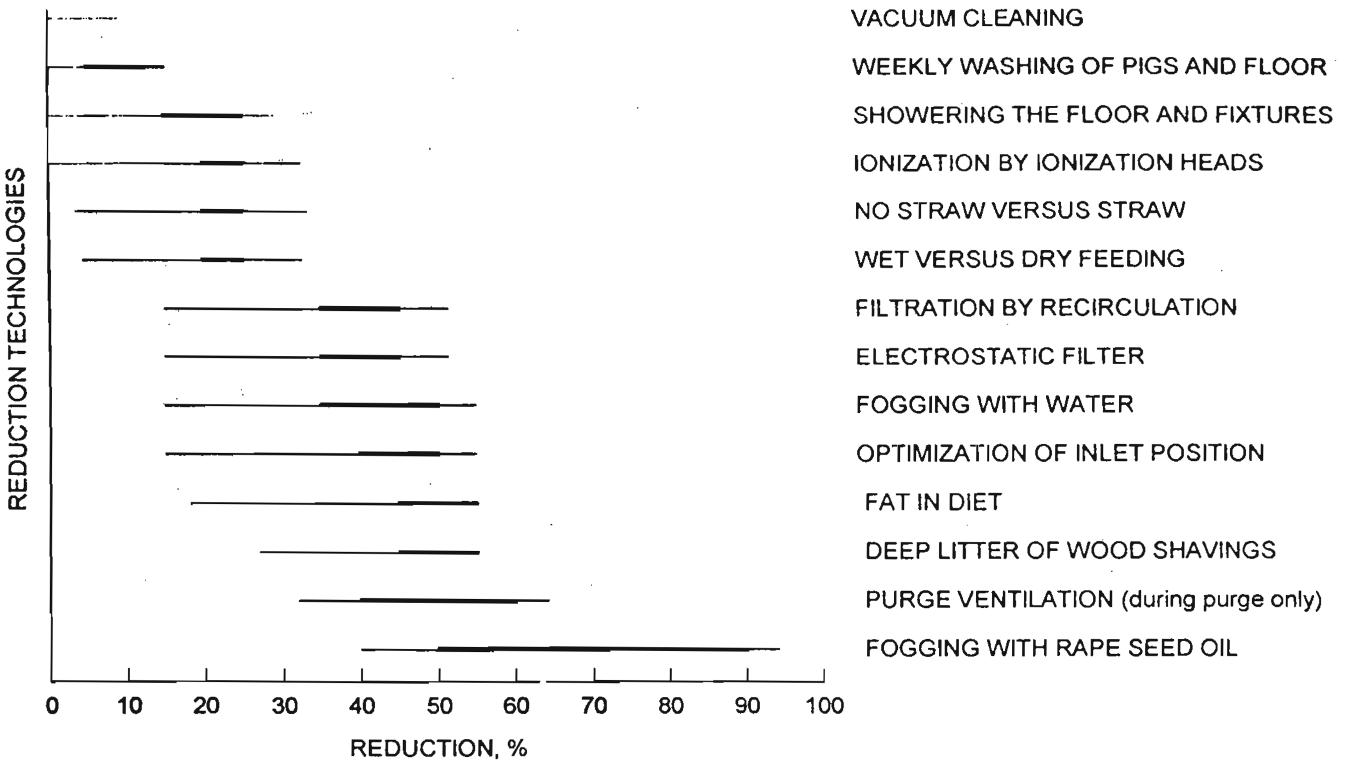

Figure 7.17 Expected reductions in airborne dust with different dust reduction technologies in livestock buildings

7.7 Legal requirements

Most European countries have limits, either recommended or enforceable, for the amount of airborne dust in livestock buildings and at the human workplace. Concerning this report, in the participating countries the limits for allowable airborne dust are:

Austria:	No recommendation for animals. In the work place the limits are 15 mg/m^3 for total dust and 6 mg/m^3 for respirable dust.
Belgium:	No recommendation for animals. In the work place the limits are 10 mg/m^3 for total dust and 5 mg/m^3 for respirable dust.
Denmark:	No recommendation for animals. Up to 1.7.1992 the maximum limit for 8 hour's exposure per day was 5 mg/m^3 of total organic dust. Because of obvious problems with the health of humans, the maximum limit of total dust was reduced to 3 mg/m^3 for 8 hour exposure. (At-anvisning, 1992)
Finland:	10 mg/m^3 for organic dust at 15 minutes' exposure and 5 mg/m^3 for 8 hours' exposure.
France:	10 mg/m^3 of total and 5 mg/m^3 for respirable dust for 8 hours.
Germany:	No recommendations for animals.
Great Britain:	No recommendation for animals. For humans 10 mg/m^3 of total and 5 mg/m^3 for respirable dust for 8 hours.
Netherlands:	10 mg/m^3 of total and 5 mg/m^3 for respirable dust.
Italy:	No recommendation for animals
Norway:	5 mg/m^3 of total dust for humans.
Sweden:	10 mg/m^3 of total dust for animals.

In the U.K. the recognition that grain dust can cause respiratory damage has been acknowledged by the creation of a "Maximum Exposure Limit" of 10 mg/m^3. The implication is that dust levels MUST be below this level, and that the airborne concentration must be reduced "as low as is reasonably practicable". Similar legislation does not exist for exposure of livestock to dust.

References

At-anvisning 1992. Grænseværdier for stoffer og materialer. (Limiting values of compounds and materials) Arbejdstilsynet (The Danish Labour Inspection Service), At-anvisning Nr. 3.1.0.2, January 1992.

Baekbo, P., 1989. Air quality and pig herd health (in Danish). Ph.D. Thesis, The Royal Veterinary and Agricultural University, Copenhagen.

Barber E.M., J.R. Dawson, V.A. Battams & R.A.C. Nicol, 1991. Spatial variability of airborne and settled dust in a piggery. Journal of Agricultural Engineering 50: 107-127

Brouwer R., 1987. Prevalence, control and prevention of non-specific lung disorders among pig farmers in the Netherlands. In "Environmental aspects of respiratory disease in intensive pig and poultry houses, including the implications for human health" (Eds. J.M. Bruce and M. Sommer), CEC, Luxembourg. Proc. EC meeting Oct. 1986, Aberdeen. EC Report EUR 10820. pp 191.

Bruce, J.M. & M. Sommer (Eds), 1987. Environmental aspects of respiratory disease in intensive pig and poultry houses, including the implications for human health. Proc. EC meeting Oct. 1986, Aberdeen. EC Report EUR 10820, 191 pp.

Carpenter, G.A., 1986. Dust in livestock buildings - review of some aspects. Journal of Agricultural Engineering Research 33: 227-241.

Carpenter, G.A. & J.T. Fryer, 1990. Air filtration in a piggery: filter design and dust mass balance. Journal of Agricultural Engineering Research 46 (3): 171-186.

Chiba L.I., E.R. Peo Jr., A.J. Lewis, M.C. Brumm, R.D. Fritschen & J.D. Crenshaw, 1985. Effect of dietary fat on pig performance and dust levels in modified open-front and environmentally regulated confinement buildings. J. Anim. Sci. 61: 763-781.

Chiba L.I., E.R. Peo Jr. & A.J. Lewis, 1987. Use of dietary fat to reduce dust, erial ammonia and bacterial colony forming particle concentrations in swine confinement buildings. Transactions of the ASAE, Vol 30(2), 464-468

Clarke, A., 1991. Air hygiene and equine respiratory disease, Equine Practice, 59-79.

Cox, C.S., 1987. The aerobiological pathway of microorganisms. John Wiley and Sons. pp 172-201.

Crook, B., P. Griffin, M.D. Topping & J. Lacy, 1988. An appraisal of methods for sampling aerosols implicated as causes of work-related respiratory symptoms. In: "Aerosols, their generation, behaviour and applications, 2nd Aerosol Society conference" Ed. W.D. Griffiths, p. 327-333.

Crook, B., J.F. Robertson, S.A. Travers Glass, E.M. Botheroyd, J. Lacey & M.D. Topping, 1991. Airborne dust, ammonia, microorganisms, and antigens in pig confinement houses and the respiratory health of exposed farm workers. Am. Ind. Hyg. Assoc. J. 52(7):271-279.

Danuser, C.W., 1991. Personal communication.

Dawson, J.R., 1990. Minimising dust in livestock buildings: possible alternatives to mechanical separation. Journal of Agricultural Engineering Research, 47(4):235-248.

doPico, G.A., 1986. Report on diseases. Am, J. Ind. Med. 10:261-265.

Donham K., 1986. Studies on environmental exposures, swine health engineering design in swine confinement buildings in southern Sweden. Institute of Agricultural Medicine and Occupational Health. The University of Iowa. Report No. 4/86. Ames. Iowa.

Donham, K.J. & K.E. Gustafson, 1982. Human occupational hazards from swine confinement. Ann. Am. Conf. Gov. Ind. Hyg., Vol 2:137-142.

Donham, K.J. & J.R. Leininger, 1984. Animal studies of potential lung disease of workers in swine confinement buildings. American Journal of Veterinary Research 45,(5):926-931.

Donham K.J., 1990. Health concerns from the air environment in intensive swine housing. In: "Making swine buildings a better place to work.", R.N. Goodwin (ed). National Pork Producers Council, Des Moines, Iowa, p. 9-20.

Feddes, J.J.R., J.J. Leonard & J.B. McQuitty, 1983. The influence of selected management practices on heat, moisture and air quality in swine housing. Canadian Agricultural Engineering, 25, 2, 175-179.

Feddes, J.J.R., B.S. Koberstein, F.E. Robinson & C. Riddell, 1992. Misting and ventilation rate effects on air quality, and heavy tom turkey performance and health. Canadian Agricultural Engineering 35(2): 177-181.

Ferguson, I.R., 1991. Leptospirosis update: the risk is small and may be reduced by simple precautions. British Medical Journal 302: 128-129.

Grant, I.W.B., W. Blyth, V.E. Wardrop, R.M. Gordon, J.C.G. Pearson & A. Mair, 1972. Prevalence of farmers lung in Scotland: a pilot survey. British Medical Journal 1:530-534.
Gregory, P.H. & E.L. Lacey, 1993. Mycological examination of dust from mouldy hay associated with farmer's lung disease. Journal of General Microbiology 30, 75-88.
Gustafsson, G., 1989. Mass balances of dust in swine houses. Proceedings: 11th. CIGR conference, 4-8 September 1989, Dublin, p. 1465-1469. A.A. Balkama, Rotterdam.
Gustafsson, G., 1993. Personal communication concerning fogging the air with water.
Gustafsson, G. & L. Mårtensson, 1990. Luftforureningar i djurstallar: Damm. (Air pollution in livestock houses: dust), Sveriges Lantbruksuniversitet, konsulentavdelningens raporter. 161, pp. 97-103. Uppsala.
Hage-Hamsten, M. van, E. Johansson, A. Wiren & S.G. Johansson, 1991. Allergy (Copenhagen) 46(2): 142-146.
Heber, A.J. and Martin, C.R., 1988. Effect of additives on aerodynamic segregation of dust from swine feed. Trans. ASAE, 31, 558-563.
Hartung, J., 1986. Dust in livestock buildings as a carrier of odours. Seminar proceedings "Odour prevention and control of organic sludge in livestock farming" NIAE, England, April 1985, pp 99-111.
Heber, A.J. & M. Stroik, 1988. Influence of environmental factors on dust characteristics in swine finishing houses. Procs. III Int. Liv. Env. Symp. ASAE, 1-88, 291-298.
Howarth, R.F.B., 1990. Grain dust: some of its effects on health. Research paper 28, Health and Safety Executive, Bootle, UK.
Jones, C.R. & A.J.F. Webster, 1981. Weather induced changes in airborne bacteria within a calf house. Veterinary Record 109, 493-494.
Klooster, C.E van 't, P.F.M.M. Roelofs & P.A.M. Gijsen, 1993a. Positioning air inlet and air outlet to reduce dust exposure in pig buildings. Fourth International Symposium, University of Warwick, England, p. 754-760.
Klooster, C.E. van 't, P.F.M.M. Roelofs & L.A. den Hartog, 1993b. Effects of filtration, vacuum cleaning and washing in pig houses on aerosol levels and pig performance. Livestock Production Science, 33 (1993) 171-182.
Larsson, K., 1983. Dust reducing methods when handling concentrates. Swedish Institute of Agricultural Engineering (JTI) Report No. 399.
Liao, C.M. & J.J.R. Feddes, 1989. Modelling and analysis of dynamic behaviour of airborne dust in ventilated airspace. ASAE Paper PNR 89-402. ASAE, St. Joseph, MI.
Lyngtveit T. & W. Eduard, 1992. Ioniseringsanlegg i hønehus (In Norwegian) (Ionization in houses for laying hens) Norges Landbrukshøgskole ITF Rapport 27/92.
MacVean, D.W., 1986. Field studies of environmental parameters associated with bovine pneumonia. Procs. of 4th Int. Symp. on Vet. Epidem. and Econ.Singapore, 18-22 Nov. 19985. 159-161.
Madelin, T.M. & C.M. Wathes, 1989. Air hygiene in a broiler house: a comparison of deep litter with raised netting floors. British Poultry Science 30: 23-37.
Mark D. & J.H. Vincent, 1986. A new personal sampler for airborne total dust in workplace. Ann. Occup. Hyg. 30: 89-102.
MDHS 14, 1986. Health and Safety Executive: Occupational Medicine and Hygiene Laboratory, England. MDHS 14. General methods for the gravimetric determination of respirable and total inhalable dust.
Morrison, W.D., L.A. Braithwaite, S. De Boer & J.H. Smith, 1990. Air quality effects of pig health and performance and an overview of problem control methods studied at the University of Guelph Symp. on "Making swine buildings a safer place to work", Iowa, US, 15.11.90.
Møller F. & H. Takai, 1991. Svinenes sundhedstilstand ved reduceret støvindhold (In danish). (The health condition of pigs at reduced dust content in piggeries), Information Sheet No. 76, SjF, Bygholm, Denmark.
Møller, F., 1991. Støvreduktion i stalde ved ionisering (In Danish). (Reduction of dust in animal houses by ionization). Information sheet No. 74, SjF, Bygholm, Denmark.
Møller, F., 1992. Slagtesvin på dybstrøelse (In Danish) (Fattening pigs on deep bedding) Report no. 50. SjF, Bygholm, Denmark.
Nilsson, C., 1982. Dust investigations in pig houses. Swedish University of Agric. Sc. Dpt. of Farm Buildings. Special report No. 149. Lund.
Nilsson, C. & G. Gustafsson, 1987. Damm i slaktsvins stallar (Dust in fattening houses) Swedish University of Agricultural Sciences Special Report 149.
Pearson, C.C., 1989. Air cleaning with wet scrubbers. Farm Buildings and Engineering (6) 2.

Pedersen, S., 1993. Time based variation in airborne dust in respect to animal activity. Fourth International Livestock Environment Symposium. Coventry, England.

Pritchard, D.G., Carpenter, C.A., Morzaria, S.P., Harkness, J.W., Richards, M.S. and Brewer, J.I., 1981. Veterinary Record 109, 5-9.

Qi, R., H.B. Manbeck & R.G. Maghirang, 1992. Dust net generation rate in a poultry layer house. Trans ASAE 35(5): 1639-1645

Ramwall, E., 1992. Damreducering med jonisering i stall för lösgaende höns (Swedish). Swedish University of Agricultural Sciences, Department of Farm Buildings. Thesis no 73, Uppsala.

Robertson, J.F., 1989. Effect of purge ventilation on the concentration of airborne dust in pig buildings. Proceedings of the Eleventh International Congress on Agricultural Engineering, Dublin,4-8 September.

Robertson, J.F., D. Wilson & W.J. Smith, 1990. Atrophic rhinitis: the influence of the aerial environment. Animal production 50: 173-182.

Robertson, J.F., 1992a. Dust exposure from cleaning using broom and vacuum cleaner. Farm Building Progress 108: 20-23.

Robertson, J.F., 1992b. The influence of the aerial environment on the severity of enzootic pneumonia in pigs. In "Environmental and energy aspects of livestock housing". Proc. Seminar of CIGR 2nd Technical Section, Polanica, Poland.

Roelofs, P.F.M.M., G.P. Binnendijk & H.J. Romein, 1993. Labour requirements and conditions in deep litter systems for fattening pigs (in Dutch). Report P 1.96, Institute for Pig Husbandery, Rosmalen, The Netherlands, 60 pp.

Rylander R. & Y. Peterson, 1988. Organic dusts and lung disease. Proc. of an Int. Workshop, held in Skokloster, Sweden, Oct. 24-17.

Ryhr-Andersson, E., 1990. Showering in houses for growing pigs - effects on dust concentration and animal health. Swedish University of Agricultural Sciences. Special Report 176.

Sorenson, W.G., J.P. Simpson, M.J. Peach III, T.D. Thedell & S.A. Olenchock, 1981. Aflatoxin in corn dust particles. J. Toxicology and Environmental Health 7, 3/4, 669-672.

Takai, H., J.O. Johnsen & P. Dahl, 1993. Gravimetric method for stationary measurement of airborne dust concentration in livestock buildings. EU-project PL 900703. SjF, Horsens, Denmark.

Test report 819, 1991. Reduction of airborne dust in pig buildings by use of electrostatic filter. Statens jordbrugstekniske Forsøg, Horsens, Denmark. Test Report no. 819.

Test report 883, 1993. Reduction of airborne dust in pig buildings by spraying rape seed-oil. Statens jordbrugstekniske Forsøg, Horsens, Denmark. Test Report no.883.

Virtanen, T., P. Kalliokoski, P. Vilhunen, A. Taivainen & R. Mantyjarvi, 1990. Concentrations of specific dusts in swineries and the humoral response of swinery workers. Allergy (Copenhagen) 45(5):354-362.

Wathes, C.M., C.D.R. Jones & A.J.F. Webster, 1983. Ventilation, air hygiene and animal health. Veterinary Record, 113: 554-559.

Wathes, C.M. & J.M. Randall, 1989. Aerosol sampling in animal houses. Proceedings of EC-sponsored workshop held at the University of Bristol, 26-28 July.

Webster, A.J. 1990. Housing on respiratory disease in farm animals. Outlook on Agriculture 19(1): 31-35.

Welford, R.A., J.J.R. Feddes & E.M. Barber, 1990. Reducing dust levels in a livestock barn by addition of canola oil to the feed. Canadian Society of Agricultural Engineering. Paper 90-123: 14 pp.

Whyte, R.T., P.A.M. Williamson & J. Lacey, 1993. Air pollutant burdens and respiratory impairment of poultry house stockmen. Procs. IVth Int. Symposium "Livestock Environment", University of Warwick, England. (Eds. E. Collins and C Boon) 709-717.

Summary

Since 1977 there has been a CIGR Working Group on "Climatization and Environment Problems in Animal Housing". This working group No 13 published its 1st Report in Budapest 1984 and the 2nd Report in Dublin 1989. This is the 3rd Report published and presented at the XII World Congress in Milan 1994. Members of the CIGR Working Group No 13 represent 11 European countries.

Purpose and scope of the Report

The purpose and the objective of the 3rd Report is to provide both scientific and advisory workers with information and basic facts about:

* Production and dispersion of airborne particles (dust and gases) inside livestock buildings.
* Emission of particles (pathogens excluded), gases and odour to the surroundings from livestock buildings (emissions from manure storage are excluded from the Report).
* Practical measurement methods for actual contaminants.
* Effects of contaminants on humans and animals.
* Methods to reduce indoor production, concentrations and emissions of contaminants.

The Report also aims to improve the awareness of environmental responsibility within the animal production industry. The working method of the Group has been to appoint the most qualified member for a specific area to take the responsibility for collecting material with aid from other group members and to be responsible for writing that chapter of the report. The Group as a whole has discussed the content of the different chapters during the annual meetings, so consequently the group as a whole has a "multifactorial" responsibility for the Report.

In the Report, aerial contaminants are divided into three groups and discussed in separate chapters: gases, particles and odour. The basic idea was to describe each contaminant under the headings: *Introduction; Production-origin; Dispersion-behaviour; Measurement methods; Effects on animals and humans; Reduction technology and References.* The Report contains the following chapters:

1. Preface
2. Summary of previous Reports 1 and 2
3. General effects of aerial contaminants
4. Air flow patterns, measurements and theory
5. Gases
6. Odour
7. Airborne particles

Summary

General effects of aerial contaminants

Emissions in and from animal buildings must be identified and analysed in respect of potential detrimental hazardous effects on the atmosphere, man, animals, buildings and environment. The problems must be viewed and solved from a system analysis approach which includes synergetic effects between different compounds, circulation and mass balances. When proposing measures to reduce the release of some emission, it is preferable to look for the best system solution and not merely convert one kind of emission to another. An important strategy is of course to minimise the primary sources of emissions e.g. feed composition and manure handling systems.

Since animal production is global and atmosphere knows no borders, the problems should be solved from an international perspective.

The effect on animals is multifactorial and a direct relationship between air quality factors and animal health can be difficult to measure. However, there is substantial evidence that some gases and particles have a negative effect on the health and productivity of animals. For humans the area factor will affect persons within the building and also those living nearby. Persons working in animal buildings can develop respiratory problems. The general strategy should aim at reducing exposure to aerial contaminants.

Air flow patterns - measurements and theory

Air flow patterns in livestock buildings are important because they influence the distribution of air velocities, temperature, gas concentrations, and release of gases from manure. When examining the release and distribution of gases, the air pattern must be made visible with smoke; methods and equipment are presented. Techniques to measure ventilation rates at the exhaust are examined. The air flow pattern outside livestock buildings is described with a plume model, which is discussed.

Gases

Gases covered in the report are *ammonia* NH_3, *carbon dioxide* CO_2, *methane* CH_4, *hydrogen sulphide* H_2S, *hydrogen cyanide* HCH and *carbon monoxide* CO. The basic chemical, enzymatic and microbial processes and principles which are involved in the production or forming of the gases are given. Expressions for the production of CO_2 and CH_4 are given. The behaviour and dispersion of gases within animal buildings and techniques to measure concentrations in, and emissions from, the buildings are presented. Gas distribution caused by density differences is outweighed by the air flow pattern.

Ammonia is given most attention because of tie relative high concentration in livestock buildings and because the emissions contribute to environmental damage both locally and globally. Vegetation, soil, surface and ground water are directly affected by ammonia emissions. 80% of ammonia in the atmosphere originates from agriculture, especially from animal production. High deposition of nitrogen oxides and ammonium contribute together with SO_2 and volatile organic compounds to an acidification of both soil and water, which can contribute to changes in the vegetation due to the increased availability of nitrogen (eurotrophication).

Chemical, enzymatic and microbial processes transforming nitrogen-containing compounds into ammonia are discussed and following conclusions drawn.
- Ammonium is readily produced from urea in urine from cattle and pigs and from urine acid from poultry. Production from faeces (organic matter is much slower.
- Separation of urine and faeces reduces ammonia volatilisation in cattle and pig manure.
- A pH below 6 would virtually eliminate ammonia emission from manure. Manure storage temperature below 10°C greatly reduces ammonia emissions, as does the absence of air movement above the manure surface.

Odour

Odour is characterised by a totally different behaviour as compared to gases and airborne particles. Conflicts between livestock producers and the public concerning dour are now being reflected in laws and regulations to protect the public from malodours generated by livestock units. Nowadays, therefore, there is an acute need for effective methods of odour control and reliable and efficient odour measurements. Odour is the effect of a gas mixture produced by bacterial actions. Only volatile compounds have been identified in piggery waste. Some of them will contribute more to the odour than others.

Since odour is a very complex and subjective phenomenon it cannot be easily expressed in ordinary figures. Odour measurement methods must use three complementary approaches: sensory (the response - odour perception by a panel), chemical (the dose analysed by gas chromatography or spectrometry) and sociological methods (the annovance level assessed by questionnaire). These methods are presented and also discussed critically from the perspective of emission and related annoyance. Empirical models fro distances necessary between livestock buildings and residential areas are reviewed.

Approaches to odour abatement can be made by destroying or inhibiting the bacterial and enzymes responsible for the production of odorous compounds by the use of chemicals, biological-mechanical treatment of the manure (aerobic treatment, separation of manure and urine, etc.), or treatment of the exhausted air. Examples are given of large collective biogas plants constructed as combined energy and environmental plants. Currently 10 large plants are operating in Denmark. Reduction techniques in the ventilation air could be applied using biofilters or scrubbers. Comparisons between methods are made. There is also a survey of the effects of odour control chemicals, stating that not all tested chemicals were effective in reducing odour. Some products may have side-effects on humans, animals and crops, and their use is questionable.

Airborne particles

The aerosol mixture in animal houses includes micro-organisms, gas, water vapour and other substances. Dusts are dispersed particles of solid matter in gases which are generated during mechanical processes. Inspirable aerosols are the fraction of airborne particles and droplets which enter the nose and mouth during breathing. Respirable aerosols are the fraction of airborne particles and droplets which, penetrates through the gas exchanges region of the lung, the alveoli. The chapter relates aerosols to dust particles. For intensive buildings the dust sources are: incoming air, feed, bedding, manure and animals. Dust is removed by ventilation air extraction or filtration, settling, and removal with manure.

The opportunity to reduce dust by manipulating ventilation rates is limited, but should not be ignored. However, a significant part of the dust will be removed by ventilation.

Sedimentation in still air follows Stokes Law and dust will deposit on the floor fixtures, etc. The settling velocity for a 2 μm diameter particle is 0.12 mm/sec. This explains why smaller particles follow the movement of air. The total amount of airborne dust in livestock buildings at any time is the equilibrium between all sources of dust "production" (included re-suspended settled dust) and the various removal mechanisms (sedimentation and ventilation).

Factors influencing dust production are primarily animal feed and animal activity. Increasing the moisture content of grain before grinding gives an 80% reduction in dust production. Adding fat to the feed can give an equivalent reduction. Airborne dust varies considerably depending on animal activity. Simultaneous measurements of pig activity and dust concentration show that variations in pig activity can explain most of the variation in dust concentration within a building.

The most interesting methods for measuring dust are presented and evaluated. The filter methods (total and respirable) give only average dust concentration and the particle counter gives only relative measurements.

Effects on animal and humans

The main diseases associated with agricultural work, allergic rhinitis and asthma, pneumonitis/alveolitis, organic dust toxic syndromes and bronchitis are described and examples are presented with references from different studies. The relevance of dust to livestock is twofold: most important is damage to the respiratory tract caused by dust particles the second concern involves micro-organisms which cause damage to the respiratory systems.

Some of the information available on the relationship between airborne particles and respiratory ailments remains contentious, although studies have demonstrated significant relationships between air quality factors and the severity of respiratory diseases when viable pathogens are also present. Examples of studies with references which relate to air quality factors and respiratory problems are given.

This report can be ordered from

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CEMAGREF Editions 1994 - ISBN 2-85362-377-7