Managing Emissions from Swine Facilities:  
Current situation in The Netherlands and Europe

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INTRODUCTION

Animal production has become highly specialized, industrialized and concentrated geographically in various parts of the world. In Europe swine production volumes strongly increased over the last decades. In Europe main swine producing areas can be found in the north (e.g. Denmark, the Netherlands, Belgium, Brittany in France, Niedersachen in Germany) and the south (Lombardy in Italy, Catalonia and Galicia in Spain; Figure 1). Expansion and specialization have enabled higher productivity level at the farms. New housing systems and improved feeding and manure management methods have been introduced to increase the efficiency and volume of animal production and labor productivity. This process of expansion and specialization has, without doubt, improved farmers' living standards in recent decades. However there are drawbacks in this process of intensification that are related to animal welfare and health issues and, especially where swine production has been concentrated in restricted areas (Figure 1), environmental pollution. Concern has been growing about the environmental effects of gases emitted from livestock production systems causing nuisance in surrounding residential areas and affecting natural ecosystems by eutrophication and acidification.

Odorous gases from livestock houses, manure storages and from manure during and after application on the field has received increasing attention from the 1970’s on. This is caused by the mentioned intensification of animal production on one hand and the strong urbanization in these areas on the other hand (Tamminga, 1992). In the densely populated Netherlands pig production is concentrated in the east and south, here reaching levels of over 2000 pigs per km². The main problem of odor is its nuisance for people in the vicinity of the farm. In the Netherlands, an odor regulatory system based on setback distances and odor source strength has been applied since 1972.

More recently, attention also has been focused on gases that are detrimental for the environment, e.g. ammonia (NH3) and greenhouse gases. A significant part of the N-input in pig production is emitted as ammonia, under European conditions estimated at 30% both from animal houses and from application of manure (IPPC, 2003). The regional deposition of N from this abundant alkaline gas eventually causes, in a chain of conversion processes, acidification and eutrophication in ecosystems (vanBreemen et al., 1982). In many parts of the east and south of the Netherlands, critical depositions loads in nature reserves are considerably exceeded. Similar problems play in other pig concentration areas in Europe. Besides atmospheric leaching of N to the environment in these concentration areas, the pressure of large manure volumes leads to high application levels of animal manure and consequently leaching of N (as nitrate) and P (as phosphate) to ground and surface water. Nitrate concentrations in groundwater in these areas,
like in the east of the Netherlands, exceed the 50 mg/l threshold that is set by the European Nitrate directive.

In this paper attention will be focused on how emissions from swine facilities can be managed by producers, and in narrow relationship with it, are regulated by authorities given the available management options and environmental targets. European approaches and research in new swine housing systems and management, and the regulatory approach on national and European level are highlighted, with special emphasis on the developments in the Netherlands. The next sections will deal first with an overview of the regulatory framework, followed by measurement methods for odor and ammonia that are used for assigning emission factors in regulations, options for reducing odor emissions in the production chain, and finally examples of new low-emitting swine housing systems and future perspectives in managing emissions in swine production.

Regulatory framework for emissions from intensive livestock facilities
In Europe a major and still increasing part of legislation is defined by European Union (EU) directives to which national legislations of the member states have to comply. Member states are in a continuous process of modifying their national legislation in compliance with new EU directives, each within their own legislative framework. In addition, states have their own local legislation that may differ considerably between each other. This section deals with the three most important EU directives for environmental protection in relation to intensive livestock production, followed by national regulations to prevent odor nuisance.

IPPC Directive
In 1996 the Integrated Pollution Prevention and Control (IPPC) Directive was set out by the EU Council. IPPC aims at controlling the effects of large swine facilities and a wide range of other industries on the environment. It does so by preventing, and if not economically possible, by reducing emissions to air, water and soil, and by making efficient use of resources. The IPPC Directive provides for a permitting system for categories of industries requiring both producers and regulators to take an integrated, overall look at the polluting potential and the water and energy use of the industry. The overall aim is to ensure a high level of protection for the environment as a whole. Central to this approach is that producers should take all appropriate preventative measures against pollution by the application of so called ‘best available techniques’ or BAT (IPPC, 2003).

For swine production, facilities that house more than 750 breeding sows or more than 2000 fattening pigs are subject to IPPC. In practice this means that the majority of pig farms in Europe are excluded, however in the concentration areas with specialized large scale pig facilities producers are or will be subject to a licensing system in compliance with IPPC. All sorts of emissions are covered by the rules: mineral emissions in manure application, dust, noise and ammonia and odor emissions as related to buildings and slurry storage and spreading. The IPPC requirements affect the whole of the production cycle, from feed intake up to the end products. The key issue for farmers to obtain a production permit is that they have to demonstrate the use of BAT, both in management practices and in the design and maintenance of buildings and equipment. The impact of IPPC on pig production and environmental protection is mainly determined by the definition of BAT. An EU Technical Working Group recently has completed the first reference document for poultry and pig production that describes the currently accepted
BAT’s, thus defining the European state of the art of management practices and housing systems that protect the environment and are economically viable (IPPC, 2003). This document will be regularly updated to incorporate newly developed techniques. The document can be accessed at http://eippcb.jrc.es.

Nitrate Directive
The EU member states adopted the Nitrate Directive in 1991 to protect waters against pollution caused by nitrates from agricultural sources. This directive requires member states to designate nitrate vulnerable zones and to establish action plans for the minimization of agricultural nitrate leaching in these zones. Pollution of surface- and groundwater by excess nutrients from agriculture is a major cause of concern in Europe. This input far exceeds the uptake by crops and vegetation and poses a threat to surface- and groundwater quality. The nitrogen surplus in 1997 ranged from 24 kg/ha in Portugal to 256 kg/ha in The Netherlands (Eurostat, 2001).

To address the above issue the Nitrate Directive defines actions related to agricultural nutrient management and application that are particularly relevant for nitrate leaching. These include measures such as periods of prohibition of fertilizer application, maximum yearly N-application per ha for animal manure, restrictions for application of manure on sloped or frozen soils, sufficient manure storage, crop rotation, buffer strips etc. The nitrate directive has a strong impact on swine production in concentration areas. For example in the Netherlands the directive has been implemented by the introduction of a minerals accounting system for farms. All livestock facilities have to keep record of their yearly input and output of N and P, and depending on the amount of own land have to register the mineral surpluses. Livestock producers with mineral surpluses have to transport animal manure to arable land of other farms or otherwise face levies on these surpluses. To enable farmers and authorities to keep track of the minerals on the farms, correct figures for the mineral contents of manures should be used. Therefore, samples from all manure transports originating from the particular farm have to be taken and analyzed.

NEC Directive
The 2001 Directive on National Emission Ceilings for certain atmospheric pollutants (the so-called NEC directive) requires member states of the EU to establish and report emission inventories and projections (up to 2010) for the four pollutants covered (sulphur dioxide (SO2), nitrogen oxides (NO2), volatile organic compounds (VOC) and ammonia (NH3)) and to report these data yearly to the European Council and the European Environmental Agency. Additionally, states are obliged to draw up national programs to show how they are going to meet the national emission ceiling by 2010 at the latest. For livestock production in the Netherlands the NEC is especially important with regard to the requirement that ammonia emission, where livestock production contributes more than 90%, has to be significantly reduced. The 2000 level of 157 kton ammonia has to be reduced to 100 kton in 2010. The main approach to reach this target is the obligatory implementation of low emission housing systems in case of building or renewing animal housings.
Odor regulations

Odor nuisance from agriculture is caused by two main sources: odor from application of manure on the field and odor from livestock buildings. Different approaches can be distinguished to regulate odors (Mahin, 2001):

1. The use of specified setback distances between new or expanding livestock operations and sensitive receptors which are based only on the number and type of animals and the type of receptor (such as single home versus residential development / urban area).
2. Similar as indicated for 1, but including additional factors that influence odor emissions and odor dispersion, such as manure handling system, local terrain type, type of feed, type of ventilation system, etc.
3. The use of ambient air limits for individual compounds, such as hydrogen sulphide as used in certain states in the US and Canada.
4. Off site limits based on levels predicted by dispersion modeling and using the dynamic olfactometry approach.
5. General regulatory schemes/statements that prohibit off-site nuisance or annoyance conditions as determined by field inspectors.

In the Netherlands the first approach has been chosen. Since 1972 a regulation is in force to control odor emission from livestock buildings. The basis of this regulation can be summarized as follows, (Klarenbeek and Harreveld, 1995):

- Odor emissions from all livestock farms are calculated on basis of a table with conversion values. Within this table the odor emission for all species and categories of livestock is converted to a standard emission per animal, expressed in a unit that corresponds to the odor emission of one fattening pig.
- A distance chart gives the minimum distance between the farm, with a certain odor emission, and an odor sensitive object (e.g. a house).
- A division in level of sensitivity of the different objects. For instance another farm has a lower sensitivity than a house. Four different sensitivity categories are distinguished.

At the moment the Dutch Government develops new approaches. Targets for odor regulation are to limit odor annoyance to a maximum of 12% annoyed locations at the short term and no annoyed locations in the long term. Within the table with conversion values additional values have been included, e.g. for systems that proved to give low ammonia emissions, also lower conversion values are given for odor emissions. Recently an odor measurement program that started in 1997 has been completed to validate and modify the conversion factors in this regulatory scheme ((Mol and Ogink, 2002; Ogink and Koerkamp, 2001).

In Germany and Austria the second approach is used. Setback guidelines are being used. The potential odor emission is first assessed by the number of animals. Step two in the assessment is the evaluation of the system used, e.g. manure handling, ventilation system, type of feed, the topography of the site etc. The separation distances are fixed by graphs.

In Belgium and the UK the fourth approach is in use. In Belgium ‘sniffing units’ are determined. The sniffing unit is defined as the maximum distance from the odor source at which the odor can be observed. The sniffing units of an odor source are determined by on site measurements. On basis of the determined sniffing units the emission rates from the source are determined by
dispersion modeling. In the UK maximum levels of OU/m³ of air are set, based on emission measurements at the odor source and dispersion modeling.

In Denmark and Norway approach 5 is used. In Denmark for new livestock facilities a minimum distance should be maintained from urban areas. There is also regulation on the way the manure should be applied into the soil. In Norway an environmental impact assessment is required for large livestock facilities.

**Measurement methods for odor and ammonia**

Odor can be measured or characterized in different ways:
- By human sensory evaluation;
- By chemical evaluation;
- By electronic sensor evaluation

**Sensory evaluation of odor**

Odors from livestock buildings are usually a complex mixture of individual odorous compounds. This makes quantification of odor a lot more difficult than measuring for instance ammonia concentration in the air. At the moment the human nose is still the most reliable instrument to measure odor. The sensory observation of odor can be expressed in terms of quantity (concentration) and quality (pleasantness of the odor). Odor concentration is determined by the amount of odor units per unit of volume. One odor unit is defined as the amount of odor causing gases that when diluted in 1 m³ of air just can be distinguished from clean air by 50% of the members of an odor panel. The definition of odor unit is rather complex, because it tries to quantify a physiological response on an odorous gas, in which different components can be present.

In Europe, odor measurements have been made for more than 20 years based on various methods, different panel selections, a variety of dilution systems (olfactometers) and different reference substances. A working group from the European Standardization Organization (CEN) has recently completed a new standard method EN 13725 to measure odor concentration by olfactometry (CEN, 2003). The quality criteria within this standard mainly address the following:
- Instrumental accuracy of the dilution equipment (dynamic olfactometer).
- Sensory accuracy of the selected panel.
- Overall quality criteria of the complete olfactometry system of each individual laboratory, i.e. regular testing of panels with reference substance n-butanol.

An odor sample is evaluated by a panel of at least 4 persons at 2 repetitions per person. Odor concentration in terms of odor units per m³ of air (OU/ m³) is determined as the geometric mean of the measured odor threshold values of the sample.

In recent years dynamic olfactometry is worldwide accepted as the standard method for determining odor concentrations in odor units. The main explanation for this is that dynamic olfactometry has the best potential for high accuracy and repeatability. The accuracy and repeatability of the measurements are improved by selecting panel members with similar odor sensitivity. For this selection a standard odorous gas, e.g. n-butanol, is used. In the new EN 13725 standard panel members are selected who have an odor detection threshold between 20 and 80 ppb. Standard errors in the determination of the odor concentration of a single odor
sample, according to the Dutch standard NVN 2820 that is almost similar to the new CEN standard, are in the range of 15 to 20% under repeatability conditions (Ogink and Klarenbeek, 1997).

Qualitative measurements of odor
Not only is the quantity of odor of importance with respect to nuisance, but the quality of the odor as well. Therefore methods have been developed to determine the (un)pleasantness of an odor as well. This is called the hedonic value of the odor. In Europe, the most accepted hedonic measuring system is based on the German VDI-guideline (VDI, 1994, 1992). Within this method odorous air is offered to a panel at increasing concentrations. All concentrations lie above the threshold value of the odor. Panel members have to characterize the odor at every concentration level on a scale between −4 (very unpleasant) to 4 (very pleasant). For unpleasant odors, generally, the unpleasantness increases at increasing concentration of the odor. Within the VDI method a linear relationship is assumed between the logarithm of the odor concentration and the hedonic value at that concentration. Little is known as yet about the accuracy and repeatability of the hedonic value measuring system. Further research and standardization within this area is needed and ongoing.

Chemical evaluation of odor
Odor from livestock production systems, generally, consists of a wide range of odorous compounds. This wide range of compounds is defined in this paper as the odor profile. This odor profile can be chemical and analytical characterized by determining which compounds are in this profile and at which concentrations. For chemical analysis of the odor profile three successive steps are essential: sampling and preconcentration of the odor, separation of components and identification of the separated components. The basic technique for separation of odorous compounds is gas chromatography. The best available technique for identification of volatile odorous compounds in combination with gas chromatography is mass spectrometry. This combination of separation and identification is also called GC-MS. With this method volatile compounds can not only be identified but quantified, as well. Until recently, high investment costs in combination with the complexity of the system and the experience needed to interpret the data have blocked a broad introduction of this system. During recent years, however, the costs of this system have been reduced. Modern systems have an extended build-in library of the different spectra of components. This makes interpretation of the data more easy and straightforward.

Electronic sensor evaluation
The concept of an electronic nose device originated from about two decades ago. The basic sensing elements are an array of non-specific chemosensors. Signal patterns from these sensors are related to the measured odors using a wide variety of methods. Electronic noses are attractive from the perspective that they enable continuous and in principle low-cost monitoring of odors. The main application area of commercial devices is quality control, especially in the food processing industry. Applications in livestock production have been explored on an experimental basis (Gallmann et al., 2003), but are far from implementation given the complex mixture of compounds in livestock odors.
Relationship between olfactometry and chemical-analytical methods
Olfactometry is a rather time-consuming method to determine odor concentration. Therefore, different research groups at different places in the world have tried to develop cheaper and more practical methods. Starting point of these alternative methods are that they should have a good relationship with olfactometry values. Until now the results are rather poor, mainly caused by the complex odor profile in livestock production. This odor profile is not easily characterized by just a few components. (Hobbs et al., 1995) distinguished 15 components in air from livestock buildings as the main components determining odor concentration. By determining these components in air samples taken from air above storage systems for pig manure, 75% of the variance between odor concentrations of these samples could be explained. New developments with regard to improved GC-MS techniques and the development of electronic noses may eventually link the analytical approach to sensory measurements.

Measuring methods for ammonia emissions from animal housings
In the Netherlands, ammonia emission factors expressed in kilogram’s ammonia per day and per animal are assigned to all existing animal housing systems in the different animal categories. Based on these factors the total ammonia emission per farm is calculated that should exceed levels that are defined in the environmental license for production. Accurate validated emission factors are important both for producers and regulators and are based on measurements taken on farm locations according to a standard protocol. From the early 1990’s on the ammonia emission of a broad range of housing systems have been measured.

Animal houses are in general, a well-defined source, the emission occurring from a confined space. But while in mechanically ventilated animal houses the inlets and outlets are normally well defined, this is not usually the case for naturally ventilated animal houses, because openings can act in some cases as inlet and in some other cases as outlet, depending on the weather conditions. The current protocol to measure ammonia emissions from animal houses is based on continuous measurements of the ventilation rate and the ammonia concentration in the outgoing air. The ammonia emission is then calculated as the product of the ventilation rate and the ammonia concentration leaving the animal house via the different outlets. For mechanically ventilated animal houses, the current protocol specifies the use of a NH3 to NO converter and a NOx analyzer to measure ammonia concentrations, and a fan wheel anemometer in the shaft to estimate the ventilation rate (Groenestein et al., 2001). For naturally ventilated animal houses, the determination of the ventilation rate is based on the mass balance approach (intern tracer gas ratio method): a tracer gas is introduced in the animal house at a constant rate (Qtracer), and the concentration of the tracer gas (Ctracer) is measured in the outgoing air (Mosquera et al., 2003).

The ratio between the (constant) tracer gas emission and the measured concentration is then used as an indicator of the ventilation rate in the animal house for the calculation of the ammonia emission (QNH3): 

\[ Q_{NH3} = \frac{Q_{tracer} \cdot C_{NH3}}{C_{tracer}} \]

Because the frequency of measurements of ammonia concentrations and ventilation rates is high, the results obtained following this approach (continuous measurements of ventilation rates and concentrations) are usually precise and reliable for the investigated site. One advantage of using
this method is that it is possible to follow the emission processes. However, care should be taken on:
- Periodic calibration of the equipment by specialized personnel
- Heating and isolation of the sampling line, to avoid condensation problems, because ammonia rapidly dissolves in water,
- The anemometer should cover the total exhaust area (for mechanically ventilated houses)

In addition, using the mass balance approach for ammonia and the tracer gas for naturally ventilated animal houses requires the following assumptions to be fulfilled:
- The tracer gas should be injected in a way that mimics the ammonia emission sources in the animal house (i.e. tracer gas injected close to ammonia sources)
- The dispersion of both ammonia and the tracer gas should be similar, which implies the assumption of good mixing of both gases in the animal house, and that the residence time for both gases is long enough to allow them to mix properly
- The tracer gas should be easy detectable with the used equipment

Factors that affect odor emission in livestock production
Different factors affect the forming and emission of odorous components in livestock production. In the scheme below the main influencing factors are shown. The main factors are discussed.

Feed and water intake
Feed is the source material for almost all odorous compounds in animal houses. Not much research has been done yet on the relationship between feed and odor emissions. In theory,
however, this seems a very promising route to tackle high odor emissions from animal houses. According to (Spoelstra, 1980) the inhibition of methanogenesis in wastes is an important cause of the accumulation of volatile odorous compounds in manure. When methanogenesis is not inhibited these odorous compounds will be broken down to CH4 and CO2. Inhibiting factors are according to the same author:
- low temperature of the manure;
- overloading of the system, causing high concentrations of inhibiting components like hydrogen and ammonia;
- toxic effects of heavy metals.
The last two inhibiting factors can be influenced by dietary manipulation, and this might be an option for future research on reducing odor emissions.

Hobbs et al. (1997b) have confirmed the hypothesis of reducing odors by reducing the dietary crude protein. However, they proved that also other components are of importance. In their study the home- grown cereal based diet caused higher odor emissions than the least cost formulated diet, based on fish meal and soya, at the same protein content of the diets.

Animal
Animal behavior in relation to odor emission is especially important for pigs. Pigs, generally, make a spatial separation between the lying and excreting locations. Different studies have shown that when this separation is not clear and the solid pen floor is fouled with feces urine, odor emission may increase considerably. Especially in the summer at high ambient temperatures pen fouling is difficult to prevent in partially slatted pens for fattening pigs (Aarnink et al., 2000).

Urine and feces
Some odorous compounds are formed by the fast process of enzymatic hydrolysis. Examples are the reduction of sulphate to hydrogen sulphide, the hydrolysis of glucuronides to phenols and the hydrolysis of hypuric acid to benzoic acid (Spoelstra, 1980). All these components are present in urine. The emission of components from urine is linearly related to the emitting area in animal houses as long as the source in urine is not limiting. For well soluble components in the manure, like ammonia, indeed a linear relationship was found (Aarnink, 1997). For badly soluble components this relationship is not valid. Then, the velocity of formation and diffusion to the surface mainly determines emission.

The emission of almost all odorous compounds is influenced by the pH. The pH determines the equilibrium between the ionized and non-ionized form of the component. When the equilibrium is shifted toward the non-ionized form the emission will increase. Within an alkaline environment, especially, the alkaline components will emit (e.g. ammonia), while in an acid environment, especially, the acid components will emit (e.g. volatile fatty acids).

Manure
With respect to the kind of manure it seems important whether the urine and feces are stored as slurry or whether they are stored separately. Quantitatively little is known yet about the effect of manure separation on odor emission. Pain and Bonazzi (1993) reported lower emissions from
straw manure than from slurry. Straw can bind odorous compounds and a thick layer of straw also reduces the air exchange between the manure and the air.

Most odorous compounds in animal houses are formed from anaerobic digestion of manure during storage. Especially, the breakdown of protein and crude fiber may produce odorous compounds (Pain and Bonazzi, 1993). According to Spoelstra (1980) odorous compounds are mainly formed when the different processes in this breakdown are not in balance. Within a balanced situation the volatile odorous compounds will be converted into methane and carbon dioxide. Research by Hobbs et al. (1997a) supports the hypothesis of Spoelstra. They found a negative relationship between methane and odor emissions.

For the emitting area and the pH the same is valid for manure as for urine and feces. Klarenbeek et al. (1982) found a positive relationship between the manure surface in the pig house and the odor emission. They also found a reduction in odor emission of 39% when the manure was regularly flushed from the pig house with aerated manure.

Ambient factors
Temperature of the manure seems to be a very significant factor for odor emissions. Klarenbeek et al. (1982) found lower odor emissions of 80% in the winter when compared to the summer. Also Verdoes and Ogink (1997) found higher odor emissions in the summer season than in the winter season for all categories of pigs. Donham et al. (1985) found significant lower odor emissions at temperatures below 18oC. Oldenburg (1989) found correlation coefficients varying from 0.40 – 0.84 between the seasonal temperature changes and odor emission. Different researchers also found positive correlations between air exchange rate and odor emission (Oldenburg, 1989; Ogink et al., 1997). A higher air exchange rate increases the concentration difference between the manure and the air, thereby increasing emissions. Also increased air velocities above the emitting surface will increase the release of volatile compounds.

About the effect of straw on odor emissions little is known yet. Straw may have different effects: (1) it increases the emitting area; (2) it absorbs volatile compounds; (3) it reduces the air exchange between the manure and the air. Depending on which factor has the strongest effect in a certain situation odor emission will decrease or increase when using straw.

Odor reducing measures and techniques
Some techniques are available at the moment to reduce odor emission from livestock production units. These techniques can be subdivided as follows:
- Techniques preventing the release of odor from the manure (manure treatment techniques).
- Techniques preventing odorous air being emitted from animal houses and manure stores (air treatment techniques).
- Preventing nuisance from odorous air by dilution.

Manure treatment techniques
Aeration of manure will oxidize volatile (odorous) components to especially carbon dioxide and water. In the 1980's in the Netherlands aerating systems were installed in manure storages outside animal houses. The aerated manure was used to flush the fresh manure from the animal
house as well, thereby reducing the emission from the building as well. Aerated manure has a low odor emission at surface application of the manure as well. Drawbacks are the high-energy costs and the loss of nitrogen (by nitrification and de-nitrification nitrogen is lost as N2). Because of the high costs this approach is not applied in livestock facilities in Europe.

Anaerobic digestion of manure converts most of the odorous compounds in methane and carbon dioxide, causing less odor emission (Jongebreur and Schaefer, 1980; Powers et al., 1995) main disadvantage is the production of ammonia and hydrogen sulphide. The digested manure, therefore, is less suitable for flushing the fresh manure from animal houses.

Adding chemical components to the manure may reduce odor emission. Changing the pH of the manure to levels below 4 or to levels above 9.5 will stop biological activity and thereby stop the production of odorous compounds. Other chemical methods to reduce odor emission is the binding, elimination or masking of odorous compounds (Ritter, 1989). Additives are not used in practice.

**Air treatment techniques**

It is known for a long time that biofilters consisting of materials like compost, peat, bark or mixtures of these materials can effectively clean the air from odorous compounds. These compounds are removed by a combination of adsorption, absorption and biological breakdown. Important parameters are the retention time of the air inside the filter and the humidity of the filter. In the Netherlands biofilters are normally not used in livestock production because of a lack of reliability of the filter (risks of leakage shortcuts), and the risk of high ammonia concentrations in the inlet air of the filter that eventually may lead to contamination of the filter and a breakdown of its microbial functioning.

The risk of contamination by ammonia is being eliminated in air scrubbers in which odorous air is intensively contacted with the washing liquid that is recycled. The recycling liquid is frequently discharged to remove the accumulated components and thus contamination is avoided.

Two types of air scrubbers can be distinguished: bio scrubbers and chemical scrubbers. The bio scrubber is characterized by the biological activity within the filter. Bacterial mass is developed on the filling material of the filter. These microorganisms are responsible for the breakdown of the organic compounds within the air. The filling material is important to reach a large area per unit of volume without increasing the flow resistance to undesirable levels (Hartung et al., 2001).

In a chemical scrubber compounds are bound chemically and by that way removed from the air. Because air from animal houses consists of a lot of different chemical compounds, chemical scrubbers are less suitable for reducing odor emissions. Ogink and Koerkamp (2001) reported a reduction of 29% when using an acid scrubber in a house for growing-finishing pigs. For bioscrubbers different filling materials are available. Most are made of plastic. The main function is that the area per unit of volume is increased without causing a large pressure fall across the filter. Odor reduction efficiencies of varying types of bioscrubbers at pig facilities in practical conditions ranged between 40 and 50% on average (Mol and Ogink, 2002). From other research under experimental conditions it is known that odor removal by bioscrubbers can be more efficient up to reduction percentages of 60-70%. However it has to be realized that bioscrubbers in the Netherlands are primarily dimensioned for the removal of ammonia and not for odor.
Dilution of odorous air
Odorous compounds are generally not directly detrimental for the environment. Therefore the odor problem is especially a concentration problem. Dilution of odorous air before it can cause nuisance for the people living in the vicinity of the farm is therefore an acceptable method to reduce the odor problem. High trees around the farm or high extended ventilation shafts for removal of the odorous air are effective methods to dilute the odorous air.

Low emitting swine housing systems
To abate ammonia deposition in the Netherlands, governmental policies and measures have been developed that are aimed at reduction of emission of ammonia, including:
- Covering of outside slurry storage (1985, mandatory)
- Restrictions to slurry application during autumn and winter, and the obligatory use of low emission techniques (injection) in application of manure (1990, mandatory)
- Promoting the introduction of low emitting animal housing, Green Label covenant (1995, voluntary)
- Transition towards low emitting swine and poultry houses (2002-2008, mandatory)

Key element in the ammonia abatement policy is the transition towards low housing systems. Maximum emission levels per animal have been defined for the main animal categories that have to be fulfilled by 2008. For swine producers this means that current emission levels of fattening pigs in conventional housings with partially slatted floors and slurry storage under slats have to be reduced from yearly 2.5 kg ammonia per pig to a maximum of 1.2 kg ammonia. Similar reductions have to be reached for sows and piglets.

From the 1990’s on a wide variety of new housing systems have been developed. The main principles used here are:
- Reduction of the emitting slurry surface by a specific configuration of the slurry pit (Figure 2);
- Cooling of the upper layer of stored slurry in the barn thus creating an air-boundary layer that minimizes conversion processes and air exchange between the boundary layer and air in the house (Figure 3);
- Implementation of air scrubbers (chemical scrubbers and bioscrubbers).

The minimum extra yearly costs for investments in low emitting systems compared to the conventional housings are estimated at 3-5 euro per pig place depending on the housing type. Currently, approximately 30% of the fattening pigs in the Netherlands are housed in these low-emitting systems.

Perspectives for managing emission in swine production in Europe
During the last decade growing public concern for the protection of the environment and the quality of life has led to new legislation by the European Union with clear targets and time schedules to reduce environmental pollution. For livestock production and swine production in particular the directives that aim to reduce the damaging effects of ammonia deposition (NEC directive), to improve the water quality (Nitrate directive), and the local environment around industries (IPPC directive) are of great importance. Especially in the regions with high animal
densities, like in the Netherlands (Figure 1), compliance to these directives is a challenge that requires a strict control of emissions to the air (ammonia, odor, greenhouse gases) and emissions to soils and water through manure application (N and P minerals, heavy metals). Over the last decade a number of technical measures have been developed to reduce these emissions. Significant progress has been made in developing direct injection methods for manure application and low emitting housing systems. So far farmers in these regions have managed to balance the extra investment costs by other factors like scale of operation, favorable logistics, efficient management, and product quality. Yet still considerable efforts have to be made to reach the environmental targets for 2010 and further. In the Netherlands experiences from the last years has demonstrated that these targets can be reached only if the following socio-economic and technical factors are considered by the involved parties:

- Understanding and agreement on the environmental impact (including nuisance) of emissions by both authorities and livestock producers are essential for an effective strategy based on well motivated parties.
- Improvements in both housing systems and management practices should be utilized. So far regulations have put main emphasis on housing systems as an easily verifiable element in licensing. However, monitoring of farm emissions with identical housing systems indicate large differences as a result of different management practices (feed composition, pen hygiene, ventilation management). These variations provide a basis for improving management. Means have to be developed that credit farmers for good management practices that can be monitored.
- On-farm monitoring of emissions through direct and indirect parameters enables producers to tune their management toward low emissions and utilize their innovative abilities. There is a need for low-cost monitoring devices to support management.
- Integrated approaches are required that consider both environmental, ecological, animal welfare and economic factors. Pilots of integrated approaches on farm level have been worked out that demonstrate the technical possibilities (Ogink et al., 2001; Willers et al., 2000) but that need further development for implementation in practice.
REFERENCES


Figure 1. Animal density in the European Union in number of livestock units (500 kg LW) per hectare of utilised area (IPPC, 2003)
Figure 2. Schematic depiction of the housing system with a reduced emitting surface in the manure pit underneath the slatted floor.

Figure 3. Schematic depiction of the housing system with cooling of the manure in the manure pit underneath the slatted floor.