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Development of new methods and strategies for monitoring operational performance of ammonia emission mitigation technology at livestock operations

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Abstract

The objective of this paper is to describe new methods and strategies for the on-farm verification of the proper functioning of ammonia mitigation technologies, that are based on routine farm monitoring of process and output parameters. The adoption of these strategies in the regulatory framework should result in a much wider and better utilization of available mitigation options. The paper describes the evolution and state of the art of current verification strategies in the Netherlands. Two alternative approaches are presented. Both approaches are based on intensive monitoring and continuous logging of the mitigation process. In the first approach data from key parameters that reflect the effectiveness of the mitigation process are logged in a secured database and made available at any time to interested parties, including regulators; in this approach no direct measurements of pollutant concentrations in the air are involved. The second approach is based on continuous direct measurementt and logging of air pollutant concentrations in the ventilation air of a low ammonia housing system using sensors. In conclusion we expect that the application of automated monitoring systems combined with secured databases opens up new perspectives for different types of mitigation technology, like air cleaners or feed additves. To utilize the benefits of output-oriented verification, reliable and robust gas ammonia sensors are required that are not available yet. It is expected that a direct verification of emission parameters is currently only feasible in mechanically ventilated buildings

Keywords: ammonia, odour, emission, mitigation, pig production, poultry production

Introduction

A wide variety of mitigation techniques has been developed for the abatement of gaseous emissions (ammonia, odour and fine dust) from livestock operations. In the Netherlands over the last fifteen years, an increasing number of low emitting housing systems and air cleaning techniques are applied at intensive livestock farms in order to comply with air quality regulations (Starmans and Van der Hoek, 2007). Initially the implementation of these mitigation techniques was stimulated under the so called Green Label framework, an agreement between agricultural industry and government to reduce ammonia emissions. Later on this framework was incorporated in a national regulatory system that makes use of a list of precisely defined low ammonia emitting housing systems and their emission factors (VROM, 2002). An important aspect of this system is the on farm verification by regulatory authorities of the true and effective application of mitigation techniques at livestock farms. In practice, mitigation options are admitted only to the regulatory list if the method allows an effective verification of its application and effective working on farm. Effective verification is mainly based on the principle of visual observation by regulators of installed technical hardware that is part of the applied mitigation technology. This verification prerequisite has determined to a large extent which categories of mitigation tools could be developed and implemented and which could not. As a result the potential of a number of effective mitigation tools, like those based on additives to feed and manure so far have not been utilized in practice because verification of use cannot sufficiently be linked to the installation of hardware. Another result is that the development of cost saving optimizations of air purification techniques by partial air cleaning with bypass is obstructed because the verification of proper use of the bypass is considered to be too complicated by regulators.

The objective of this paper is to describe new methods and strategies for the on farm verification of the proper working of ammonia mitigation technologies based on routine farm monitoring of process and output parameters. The adoption of these strategies in the regulatory framework should result in a much wider and better utilization of available mitigation options.

After describing the evolution and state of the art of current verification strategies in the Netherlands, the development of two alternative approaches will be presented in this paper and their potential use explored. Both approaches are based on intensive monitoring and continuous logging of the mitigation process. In the first approach data from key parameters that determine the effectiveness of the mitigation process are logged in a secured database and made available at any time to interested parties, including regulators; in this approach no direct measurements of pollutant concentrations in the air are involved. As an example, the paper describes the outline of newly developed monitoring and logging systems in air scrubbers. The second main approach is based on continuous monitoring and logging of air quality parameters in the outgoing ventilation air of a low ammonia housing system using sensors. The paper concludes with a discussion of factors and points of views of stakeholders in current verification strategies. It outlines which steps have to be taken to contribute to a better and more cost effective use of available mitigation technology.

Evolution and state of the art of current verification strategies

The verification of the effectiveness of mitigation systems for ammonia emissions on livestock operations in the Netherlands has been based since its introduction in the mid 1990's on four consecutive steps:

1. A standardized testing procedure of the system under practical farm conditions during which the ammonia emission is measured.
2. Description of the essential characteristics of the system on a leaflet, and assignment of a general ammonia emission factor for this system on a national regulatory list of the Ministry of Environment supported by advice of an independent technical committee.
3. Now that the system has been allowed for on-farm implementation, each and every newly implemented mitigation system is inspected at its completion by local regulators to verify the essential hardware characteristics, as described in the environmental permit for production.
4. Depending on the type of applied mitigation system, regular on-farm inspection and measurements related to the functioning of the system.

From this scheme it follows that the actual reduction performance of the system is tested on a limited scale before wide application as low ammonia emitting system in practice is allowed. This testing procedure for mitigation systems has recently gone through major changes, in which an intensive single farm measurement setup has been replaced by a multiple farm location test (Ogink *et al.*, 2008). Currently most low emission housing systems are based on modified pen and manure storage designs, and additional equipment like cooling devices for slurry surfaces in pig housings or drying equipment for litter in poultry barns. Regulators use for inspection the descriptions of the essential lay-out characteristics on the official leaflets that are available for each of the systems on the national regulatory list (InfoMil, 2009). For example, in case of a pig housing system with restricted manure surface area they visually check the design an verify that the dimensions of the pen are in line with the description on the leaflet.

The advantages of this approach are:

- Limiting costs of performance measurements. A general testing procedure in which emissions of a system are only measured once replaces direct verification of emissions on each farm where this mitigation system is installed. Costs of the required measurement protocols are not affordable for individual farmers.
- Standardized assessment procedure can be used in which mitigations systems are tested on basis of measurement protocols using scientifically sound and accepted methods that reflect the state of the art in this field.
- Relatively limited efforts required by local regulators to verify the application in practice as only the presence of hardware is checked.

However the current approach has a number of limitations that are becoming more apparent with the development of new mitigation methods:

- Effective and reliable verification is considered a key element by regulators. In the current scheme, verification is mainly based on the ability of systems to be easily visually inspected by available hardware elements. So far promising mitigation options that do not include clearly visible elements, like those based on feed additives and modified feed compositions or manure additives, are not included. Their verification requires a more comprehensive and complicated monitoring effort that exceeds farm level, and that is considered to be too costly and not reliable enough.
- At farm level there is no direct incentive to ensure that mitigation systems work effectively, except for the need to show that hardware elements are installed, and except for the individual farmers' feeling of responsibility towards environmental issues. In most cases proper management of the mitigation system is important to ensure optimal working performance. In an analysis of Mosquera and Ogink (2008) it was shown that ammonia emissions may substantially differ between farms that are equipped with the same low emitting housing system. They attribute an important part of these differences to management effects.
- In cases of more complicated mitigation options, like air cleaning systems, regulators find it difficult to verify the essential features and dimensions of the installation. Furthermore the verification of the actual use and proper operation of these techniques is, compared to straightforward pen and manure channel modifications, an extra challenge.

Development of electronically logged monitoring systems in air scrubbers

Over the last years, numbers of installed air scrubbers in pig barns in the Netherlands have increased sharply (Melse *et al.*, 2008). However, public concern has been raised because of examples of installations that do not operate properly, or are not operating at all. As the scale of implementation of air scrubbers increases, these concerns have become more and more serious. There is a general understanding among involved stakeholders that a strong improvement in monitoring the operational performance of scrubbers is essential to ensure and regain the confidence in this mitigation technology. In essence, it means that public acceptance of this type of mitigation is at stake if no drastic improvement in the verification of its functioning is realized.
The challenge of a proper verification of the effectiveness of air cleaning systems should be linked to the regular monitoring efforts of the proper functioning of the system after installation. In the current system monitoring by the local authorities is based on:

- On-site inspection of the installation, in practice once per one or two years.
- Sampling and analysis of the recirculation water of the installation by a certified laboratory, in practice once per one or two years, depending on the requirements specified in the environmental permit.

- Registration of the cumulative use of water pump, and registration of the cumulative volume of discharge water, normally carried out during sampling of the recirculation water.
- Measurement of the ammonia removal, once per one or two years if specified in the environmental permit; in most cases only demanded if there are clear indications of malfunctioning based on on-site visits.

Our observations in practice make clear that many municipalities have problems in meeting the demands of this monitoring setup. Site inspections are time consuming, and many municipalities lack sufficient capacity to meet the required frequency. If carried out, inspectors have to announce their visit days before the visit as unannounced visits are not allowed. They do not always have the expertise to verify the proper working of an installation. Sampling and analysis of recirculation water is not always carried out at prescribed intervals. Contacts with municipal inspectors show that they find it complicated to assess the analysis of recirculation water or the volume of registered discharge water. Inspectors often are not able to invest sufficient time in understanding the monitoring parameters. In short, the current monitoring scheme requires personnel capacity and expertise that is in many cases not available.

To overcome the described problems, an automated continuous logging system could provide a lot of benefits to all parties involved. In such a system, information of essential operational parameters of the scrubber are electronically logged in a secured database. This database can be accessed by farmer, manufacturer and inspectors for different reasons and purposes. It is commonly agreed among experts that the monitoring and continuous logging of a limited number of key parameters is sufficient to reliably assess the ammonia removal performance and stability over time, without actual measurement of ammonia or other pollutant concentrations in the air:

- pH of recirculation water in both acid scrubbers and biotrickling filters.
- Conductivity of recirculation water in biological trickling filters to monitor ammonium, nitrite and nitrate build up.
- Pressure drop over the filter.
- Operational hours of recirculation pump and energy consumption.
- Volume flows of discharge water.
- If applicable, air flow rates through bypasses of the system.

These parameters are measured by sensors and flow meters that are partly already in place for controlling the functioning of the system. The extra monitoring and automated logging requires a small extra investment compared to the total cost of the cleaning system.

A first example of this verification approach can be found in air cleaning systems that comply with the requirements of the Signum-test (Arends *et al.*, 2006). Here manufacturers have the option to demonstrate the working of a secured electronic database with monitored key parameters over long term prescribed periods, from which inspectors can derive data on a memory-stick.

In its most effective and extended form an approach based on at distance access (through telephone/internet connection) of the secured database would give the following opportunities and advantages:

- *Increased reliability of performance verification:* the combined information of several key parameters yields a clear and reliable picture of the level of functioning.
- *Improving operational stability:* operational problems can be much earlier noticed by farmer and manufacturer.
- *Clarification of the values of key parameters*: by programming threshold values and alarms in the database-software, the performance level can be described in terms of categories that vary between optimal and serious malfunctioning. This information is essential for both farmer and inspection authorities. In case of doubt, information can be easily transferred to air cleaning experts for advice. In practice less training and expertise is required from regulatory inspectors.

- *Cost efficiency in inspection*: verification on distance saves time for inspectors. Site-visits are only needed in case of serious problems. For farmers a monitoring scheme based on automated logging systems, is more cost efficient than a monitoring scheme in which farm visits by third parties are carried out for sampling, registering flow meters, and if required measurements.
- *Cost efficiency in energy use:* continuous monitoring of pressure drops over the air cleaning systems combined with alerts, indicates timely to farmers when to clean packing material, thus saving energy and costs.
- *Better and more efficient maintenance:* the continuous access to information on key parameters of the cleaning system to a manufacturer, enables a better and more efficient method of servicing the installation.

The setup of monitoring systems for key operational parameters can be organized in many different ways. This may vary from a continuation of the current verification routine by authorities that is supplemented with the results of the electronic logbook collected during farm visits, to an approach based on at distance verification only. The latter is depending on direct access to the secured database by farmer, regulatory inspector and manufacturer. A number of issues and potential pitfalls deserve extra attention:

- Legal issues with regard to rights of third parties to access electronic logbooks of farms and to base legal action on electronic logbooks.
- Robustness and reliability of sensor and registration systems.
- Risk of relying solely on electronic information and neglect of physical inspection.
- Over alertness at every single deviation from normal operation pattern.

During 2009 a pilot initiated by regional authorities in the Netherlands, will be carried in which different types of electronic logging and data extraction and use are investigated. The pilot will be carried out by a joint project team of regulatory authorities, manufacturers, farmers and researchers. The outcome will be used to facilitate the introduction of a new verification system for air cleaning systems based on electronic logging.

Towards a performance oriented verification strategy for mitigation control

Another potentially attractive, but technically challenging approach, could be to focus verification on output parameters, i.e. directly monitored emissions, instead of on-site inspection of the actual installation of hardware elements and verifying operational elements of the system, as described earlier. This second approach implies a fundamental change of perspective for both farmers and regulatory authorities as it will allow much more flexibility for farmers in how to comply with air quality standards, whereas for regulators they only have to focus on emission levels itself and not on mitigation technology. The technical outlooks and current feasibility of such direct air quality monitoring systems will be briefly discussed.

When considering the feasibility of routine monitoring of the actual emissions from animal housings and mitigation technologies, it is important to distinguish between mechanically and naturally ventilated buildings because they represent fundamentally different challenges.

In mechanically ventilated buildings, information on both ventilation rates and concentrations in outlet air is required to monitor emissions. In barns where ventilation control is based on fan wheel anemometers, total ventilation rate can be estimated directly from the readings of these measuring wings. If not, estimates could be based on rotational frequency and power use, but this is less reliable. A variety of options is available for continuous measurement of ammonia concentration, but most of them will be too complicated and too expensive to apply at a routine level. During the last decade some progress has been made in developing ammonia sensors that are suitable for application in livestock housings. However, a robust ammonia sensor that is reliable in the required 1-50 ppm range is still not available for continuous use under practical conditions (high dust and humidity levels). Alternatively, use could be made of specialized measurement firms that carry out routine measurement on a large scale, thus scaling down the costs of expensive equipment. Especially for farms with central ventilation ducts, as seen in large pig barns, sampling of concentrations could be relatively simply organized. This would imply that emission measurements for monitoring are carried out during a limited number of days throughout the year. Such information could be combined with emission models that include the most important farm and meteorological variables to make year round predictions for individual farms.

For naturally ventilated buildings challenges to monitor emissions on a routine basis are much larger. Ventilation rates are notoriously difficult to measure in research on emissions from open livestock buildings (Mosquera, 2007). Methods based on tracer gas injection can be used only in housings that allow a proper mixing of tracer and compounds from emitting surfaces. No reliable methods are available for open naturally ventilated housings where these mixing conditions are not met. De facto, this means that a verification strategy based on direct monitoring is and will not be available in the next couple of years.

Alternatively an output-based verification approach could also be based on measuring parameters that are known to be strongly correlated with emissions. A well known example is the relationship between ammonia emissions from dairy housings and the urea concentration in milk. From studies that aimed to decrease ammonia emissions in dairy cattle by diet modification it could be demonstrated that a positive correlation existed between the mean urea concentration in milk and barn emission (Duinkerken, 2003). This relationship was used as a key indicator in an collective agreement between dairy producers and national government to lower ammonia emissions from dairy barns (VROM, 2003). This relationship is known to be valid only on a general sector level, and cannot be used to monitor single farms. Further research including extra parameters is needed to develop this relationship for single farm use.

Discussion and conclusions

Perspectives for improvement of verification methods for mitigation technology in the livestock sector can be best understood from cost-benefit considerations of involved stakeholders. Investment in mitigation by farmers is mainly motivated by the need to maintain an adequate scale of operation. There has been a drastic increase in what is considered an economically viable scale during the last decades in the Netherlands. In this investment process mitigation technology is experienced by many farmers as an inevitable cost only, without visible rewards in terms of direct improvement in production efficiency or output. Regulatory authorities take this perception as a starting point in their verification methods. This attitude is dominated by concern that mitigation techniques are not sufficiently implemented and maintained, and the concern that this will lead to public nuisance and environmental complaints. Reliable verification is therefore a key factor that defines and restricts which mitigation techniques are accepted and which not.

In this paper we discussed two types of verification methods, the most widely used approach which is based on inspection of prescribed hardware elements and process parameters, and an alternative approach based on verification of output parameters, i.e. direct measurement of the emission of the pollutant involved. We believe that improvements with mutual rewards for both sides can be developed in both approaches. For farmers this could mean a better balance between mitigation costs and environmental performance, for regulatory authorities this would imply higher reliability at affordable costs.

The first approach can be improved by better utilizing the potentials of automated logging and access to key parameters. In this paper we described this approach for air cleaning technology, but it might also be applied to other mitigation options. For example at a mitigation system based on feed additives in pig and poultry facilities, one could think of feed sampling and detection systems that automatically stores composition parameters of offered feeds in a secured database. The advantage for farmers of adopting such logging systems would be that more low cost mitigation options with high performance levels would become available on the market, whereas for authorities the reliability of verification is ensured and verification efforts can be minimized. The potential of this approach is promising and so far has only been utilized in a few directions.

Verification strategies based on output parameters offer the advantage of making available any type of mitigation technology as long as its output can be reliably verified. As such it utilizes the inventiveness and management skills of farmers and industry to reach threshold targets with combinations of techniques, and it motivates them to keep up performance to ensure their production license on the long term. As discussed before the perspective that automated monitoring systems for direct parameters like ammonia concentration and ventilation rates can be successfully applied in future is currently only to be expected for mechanically ventilated housings with central ventilation outlets. There is a strong need for reliable and robust gas sensors that can measure accurately in the relatively low ammonia concentration ranges that are typical for animal housings. For naturally ventilated buildings on the short and medium term it will not be possible to follow this approach, given the complexity of measuring air flow rates. A promising alternative would be to focus on indirect parameters that show strong correlations with emissions. As mentioned before urea in milk is an example for this approach, although it needs stronger scientific basis to apply it on a single farm scale. In case of air cleaners one could think of monitoring the amount of ammonium sulfate in the discharge water as a measure for the removal performance. We believe that the potential of indirect output parameters has not been fully utilized yet.

In conclusion we expect that the application of automated monitoring systems combined with secured databases opens up new perspectives for different types of mitigation technology. The potential of this approach is promising and deserves more attention. To utilize the benefits of output-oriented verification, reliable and robust gas ammonia sensors are required that are not available yet. It is expected that a direct verification of emission parameters is currently only feasible in mechanically ventilated buildings.

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