STANDARDIZED TESTING AND REPORTING FOR MITIGATION TECHNOLOGIES

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INTRODUCTION

Airborne emissions of gases and particulate matter from livestock production facilities are a critical issue facing the livestock industry from both an environmental and regulatory perspective. Additionally, odor emissions are a concern for both the farmers and nearby neighbors. An array of projects have and are attempting to quantify air emissions from buildings, open lots, and manure storage systems through both short- and long-term monitoring using a variety of equipment and measurement protocols. Recent projects funded through producer organizations, the CSREES-NRI and the USEPA have resulted in a lengthy set of Standard Operating Protocols (SOPs) that must be followed to quantify actual ammonia and hydrogen sulfide emissions. Although quantifying actual emissions is essential, there is also a critical need to quickly, accurately, and inexpensively quantify the effectiveness of emission mitigation technologies. Although a less expensive and quicker means of quantifying emissions or emissions reductions may be slightly less accurate (absolute), a reasonable trade off seems very beneficial to all of the parties involved.

Currently, systems for reducing emissions of air pollutants are being developed by research universities/institutes and private industry. However, the lack of standard protocols for quantifying and documenting the effectiveness of these mitigation systems is slowing the adoption and development of these technologies. In addition, the lack of standard quantification and reporting methods for air emission mitigation technologies makes it difficult for the regulatory community (local, state and federal) to confidently assign Best Management Practice (BMP) status to these technologies and for the agricultural community to confidently invest in these technologies. This lack of quantitative information on mitigation technology effectiveness is limiting the development and implementation of these technologies in Minnesota and other states and thus hindering the development of the animal agriculture industry in the USA.

This paper presents a draft mitigation technology testing protocol developed in Minnesota and funded by the Minnesota State Legislature through the Minnesota Department of Agriculture (2007). It is intended that this draft be used as a starting point for discussing the critical issues in development of a national standard for mitigation technology testing. Note that this protocol is focused on quantifying emission reductions for a mitigation technology (compared to a control) rather than assessing the absolute flux rate from an emission source. Reported results using this protocol will be in terms of percent reductions expected along with some measure of statistical confidence for these reported reductions.

Three key components are involved in this testing protocol and described in more detail below. Initially some assessment of the technology should be made to determine the scientific merit of the technology and the likelihood that further testing has some potential to show reasonable results. Secondly, a experimental design specific for the technology must be developed. Finally, a summary of the test data should be reported in a standard way that allows for comparisons between different mitigation methods. A preliminary discussion of all of these steps is provided in the Minnesota Draft Protocol as reported below.

MINNESOTA DRAFT PROTOCOL (SUMMARY)

INITIAL SCREENING

To increase the likelihood of a successful evaluation, it is important that some baseline parameters are met prior to testing. This initial screening includes a description of the technology along with some estimates of emission reductions to be expected and a description of the farms or production units that will be used as test sites.

Technology Description

Descriptions of the treatment technology and treatment principles are required prior to any testing. Trade secrets do not need to be revealed but some general description related to the general principles governing the technology need to be stated. This section should also include factors that may affect treatment performance (e.g. ventilation rate, moisture content, feedstock).

Preliminary Reduction Estimates

Estimated or claimed reductions for all gas emission reduction claims (e.g. hydrogen sulfide, ammonia, odor, VOC's) must be included in the report to help guide the validation protocol. Claims must be substantiated by a preliminary investigation showing a minimum of 20% reduction, literature citations of similar technologies, or overwhelming anecdotal evidence. Reductions of less than 20% are difficult to validate because of the variability of the systems and measurement methods and maybe not worth the producers efforts to implement. The use of gas detection or diffusion tubes, or other similar inexpensive methods, are acceptable for these preliminary reduction estimates.

Test Sites

Provide detailed information on two or more farms where the technology is currently in place and where testing will likely be conducted. Note that the technology must be in operation six months prior to testing unless justification is made for shorter or longer acclimation times. For instance, justification for testing a microbial treatment technology may be that evidence shows that microbial environmental parameters typically stabilize (moisture, pH, DO, etc.) within a shorter period of time. In any case, it is important that all waste manure?? streams being treated have stabilized and masking smells from air treatment technologies have been normalized (e.g. specific smells from wood chips) prior to testing This time period would vary depending on the treatment technology.

Include information that is critical to the technology performance such as: type of source (manure storage, building, etc.), size of building or volume and size of manure storage basin, size of building or volume and size of manure storage basin, amount of manure treatment per day (loading rate of manure and dosing frequency), ventilation rate of building or fan performance information, description of any pretreatment technologies in place that are critical to the performance of the technology (e.g. solid liquid separation), addition of other organic material to the system (e.g. byproducts or other waste), and the potential impact of those additions on the technology performance.

EXPERIMENTAL DESIGN GUIDANCE

Testing protocols must be based on sound statistical methods for the determination of the number of installations tested, the number of samples taken and the type of measurements taken. General protocols are outlined below but specific sampling and protocols may be technology specific and should be addressed and accepted by the Research University or third party responsible for the testing. In general, however the following conditions must be met.

1. The technology must be in place and acclimated appropriately.
2. Measurements must be made at the range of standard operating conditions for the technology – which likely will include seasonal differences.
3. After each set of measurements, the data should be evaluated to determine if the testing protocol is correct and if the technology provider wishes to continue the evaluation. (For instance, if technology is not showing any reduction the funding supplier (company or granting agencies) of the testing may decide to discontinue the testing.)
4. Protocols must be developed specifically for each technology evaluation. Sections below provide some guidance on protocols for evaluating manure treatment technologies (e.g. additives, anaerobic digestion) or air treatment technologies (e.g. biofilters, wet scrubbers).

In all of the protocols, it is critical to note the type of analyzer used for quantification and adhere to the calibration and operating protocols for the equipment. This may include calibration schedule, operating temperatures, and maintenance items. The following is a list of acceptable equipment that can be used in the testing protocol.

Table 1. Proposed acceptable equipment for monitoring (Minnesota Draft).

Equipment Type	***Gas measured***	***Measurement Error (SD)***
Hydrogen Sulfide Analyzer, Model 45C, Thermal Environmental Instruments, Franklin, MA	H_2S	
Hydrogen Sulfide Single Point Monitor, Zellweger Analytical Lincolnshire, IL	H_2S	
Jerome Meter Model, Arizona Instruments, Phoenix, AZ	*Reduced Sulfur*	
Ammonia Analyzer, Model 17C, Thermal Environmental Instruments, Franklin, MA	NH_3, *NOx*	
Anova Ammonia Analyzer	NH_3	
Gas Detector Tubes, Gastec Corporation.	NH_3, H_2S	
Tapered Element Oscillating Microbalance (TEOM), Model 1400a, Rupprecht and Patashnick, Albany, NY.	PM_{10}, $PM_{2.5}$	
MiniVol portable air sampler, Airmetrics, Eugene, OR	PM_{10}	
[1]*ACCENT® International Olfactometer, St. Croix Sensory, Inc. Stillwater, MN*	*Odor*	
GS/MS	*VOC*	
Open Path FTIR	*VOC*	

[1]*Odor collection and evaluation done according to CEN 13725.*

Manure Treatment Experimental Design Protocols

Treatment technologies such as additives, anaerobic digestion and aeration have been used to reduce odor and gas emissions from buildings, manure storages, and land application. Quantification of emission reductions from manure is challenging for a variety of reasons that must be addressed in the validation protocol. For example, the following issues may have an impact on measurements and should be addressed in the experimental design.

1. Crusting of the manure surface can interfere with measurement and often may be a more dominant factor in reducing emissions than the specified technology. For instance, anaerobic digestion may result in less odorous emissions but if there is no solid separation after digestion a crust will likely form on the manure storage structure. This crust will limit emissions from this structure despite the effectiveness of the anaerobic treatment.

2. Finding a site to use as a “control” for comparing treatment effectiveness is challenging. Management, diet, genetics, and other factors often result in different emissions from similarly designed manure handling systems.

3. Diurnal and seasonal variation in temperatures, humidity, wind, etc. will result in microbial changes in the manure which in turn impact emissions. This must be considered in the protocol by repeated measurements in different seasons.

4. Manure treatment such as pit additives may be shown to reduce emissions from a manure storage but that same reduction may not apply in evaluating emission reductions for an entire deep pitted facility because emissions are also likely from the flooring, animal, feeders, etc.. This fact must be made clear in the technology claims and in the testing protocol.

Micro-meteorological methods, flux chambers, wind tunnels, and a new method using a micro-tunnel could be used for validating reductions from manure treatment technologies. These methodologies must clearly be defined in the protocol.

Laboratory quantification (laboratory simulation of manure treatment in small vessels) may provide a controlled environment for documenting emission reductions; however, laboratory conditions likely do not reflect field conditions. As such, reductions determined using laboratory methods may not be acceptable.

Manure chemistry, predicting emissions based on concentrations of specific chemicals in manure and the physical and chemical processes governing emissions, has not been validated (mass transfer models are adequate for dilute aqueous solutions but may not be valid for concentrated wastewater such as manure storage basins). As such, such methods cannot be used for reduction quantification or verification of manure treatment.

Air Treatment Experimental Design Protocols

Biofiltration and wet-scrubbers are examples of two air treatment technologies. For these types of technologies sampling methods are a critical factor in the technology assessment. to As such, any sampling protocol must include provisions for sampling the entire exhaust air stream or the fraction of air that has been sampled should be documented. For instance, biofiltration on pit fans can be tested by evaluating samples pre- and post- biofilter. However, this same emission reduction can only be applied to the entire building if the entire exhaust air stream goes through the biofilter. Similarly, a technology that captures only a fraction of air being exhausted (some air bypassing the filter) must be tested with a protocol that quantifies this bypass air. Note that quantification of absolute ventilation rates is not necessary for air treatment technology validation when sampling occurs pre- and post-treatment and the samples are taken at the same ventilation rate (and same time). Some estimate of ventilation rate during the sampling time, based on fan performance curves should be included in the report as it is likely the treatment effectiveness will be somewhat dependent on flow rate.

Two methods are acceptable for evaluating emission reductions.

1. Exhaust air can be measured semi-continuously or continuously for a minimum of 24 hours per sampling event. The semi-continuous measurements must switch from pre-treatment and post-treatment samples at intervals less than 30 minutes. If the technology claims to treat air at various flow rates, the protocol must include measurements at the minimum and maximum flow rates. Real-time gas analyzers are needed if conducting continuous monitoring. The experimental design must include a minimum number of samples at different times of the year (assuming that the technology's performance may vary seasonally). It is assumed that, at a minimum, testing will be done in three different seasons.
2. Comparing pre- and post-treatment grab samples are also a valid means of a technology evaluation. Grab samples can often be collected pre- and post- treatment simultaneously resulting in data that may be very reflective of actual performance. As with continuous measurement, samples should be taken in the typical range of ventilation rates to quantify reductions at these different flow rates. Grab samples can be collected in Tedlar bags or similar but should be evaluated within a time frame appropriate to the chemical being evaluated. Sample collection in Tedlar bags are not recommended for VOC quantification. Instantaneous analyzers that generate a snapshot for the concentration of gas or dust is typically used in these cases although analyzers that use a time-weighted average method such as a gravimetric device for measuring PM can still be used over relatively short periods of time.

Dust sampling (PM_{10}, $PM_{2.5}$, Total Dust, Respirable Dust, etc.) of exhaust air is challenging. Most of the equipment is not designed for sampling in exhaust streams with high air velocities. As such, care must be taken to insure the flow rates across these samplers are appropriate.

Technologies installed on naturally ventilated barns will not be accepted protocols due to the difficulty in obtaining representative samples pre- and post- treatment.

Statistical Evaluation

A Student t-test run at the 90% confidence interval is required for determining % reductions. For systems where there testing is done on independent samples (vs paired samples), an independent t-test should be used. For example, testing of a manure additive cannot be a "pre-" and "post-" type of test. In this situation, emissions from the barn with the additive would be compared to other similar barns where no additive is used. In this case either a set of "control" barns could be evaluated for mean and standard deviation and compared to the treated barns mean and standard deviation using an independent t-test.

The t-test for this independent sampling uses the following equations.

Test parameters: μ_1 *= average emission value for control sites*
μ_2 *= average emission value for treated sites*
$\mu_1 - \mu_2$ *= the difference in average emissions*

To determine the probability of a specific reduction in emissions the following would be the null hypothesis.

$$H_0 \Rightarrow (\mu_1 \cdot (1 - \frac{\%red}{100})) \leq \mu_2$$

The test statistic is

$$z = \frac{x_1\left(1 - \frac{\%red}{100}\right) - x_2}{\sqrt{\frac{s_1^{\,2}}{n_1} + \frac{s_2^{\,2}}{n_2}}}$$

Where

z = probability
red=the anticipated emission reduction
x = mean of data set
s = sample standard deviation
n = number of samples

Using level of significance of 0.1, the upper tailed critical value is 1.28. The null hypothesis would be rejected if z<1.28. (To be 90% confident that the anticipated reduction has been achieved the value of z must be greater than 1.28.)

Example: 10 samples were taken from several similar dairy manure storages. The samples had a mean hydrogen sulfide emissions of 69 (SD=50). Six samples were taken from a manure storage that was treated. The mean of these samples was 30 (SD=25). If we would like to claim a 20% reduction with 90% confidence interval the following calculation would be made.

$$z = \frac{69 \times \left(1 - \frac{20\%}{100}\right) - 30}{\sqrt{\frac{50^2}{10} + \frac{25^2}{6}}}$$

$$z = 1.33$$

Because z is greater than 1.28 we can be confident that there is a 20% reduction with this technology. Note that the mean reduction for this example is 57% (1-30/69) but due to sample size and variability, the paired t-test is showing that only a 20% reduction can actually be achieved.

Reporting Requirements

Reporting requirements for the testing must include the following information.

1) A brief technology description and summary of testing protocols and results. Also included in this section must be a listing and description of the farm sites used in the testing. Photographs may be included to help visualize the technology.
2) A summary of the experimental must be submitted with the final testing report. This section must include specific information regarding the actual data taken such as the number and dates of all site visits, the number of samples taken at each visit. In addition,
3) Finally, for each sampling event all critical site specific data such as ambient temperatures or specific management issues during the time of sampling must be noted. All of the raw site data must be reported in table format. A statistical analysis of the data and summary must be presented with any deviations from the original experimental design protocol explained.

1) Preliminary Information
Company, Technology Name, Primary Contact, Address, Phone/fax/email, Testing Application Date

Item	***Description***
Technology Description	
Reduction Estimate and Basis for Estimate *:*	
Test Site 1*: Farm name, primary contact, address, phone, email, summary of operation, specific information on source where technology is installed.*	
Test Site 2*: Farm name, primary contact, address, phone, email, summary of operation, specific information on source where technology is installed.*	
Test Site 3*: Farm name, primary contact, address, phone, email, summary of operation, specific information on source where technology is installed.*	

2) Written Protocol

Item	*Description*
Type of Testing (Manure or Air)	
Number and names of of sites being tested. *(e.g. samples will be collected at the Johnson, Smith and Wilson site as listed in preliminary assessment forms)*	
Number and timing of site visits *(e.g Samples collected in May-June, July-August, Sept-October at each of three sites.*	
Number of samples taken per site visit. *(e.g. 24 hour sampling or grab samples)*	
Sample collection method and description *(e.g. continuous measurement equipment on site. switching sampling lines from control to treatment every 30 minutes over a 24 hour sampling period. Ventilation rate held constant throughout sampling period.)*	
Type of Measurements Made and Specific Equipment Used *(use reference numbers from Table 1)*	
Description of baseline or "control" measurement including sampling location and sample collection method. Include farm names. *(e.g. Johnson farm, east pit fans, sampling line inserted on suction side of fan)*	
Description of "Treatment" Measurement including location and sample collection method. Include farm names. *(e.g. Johnson farm, east pit fans. Samples taken in exhaust stream of shroud constructed to capture all exhaust gases from treatment system.)*	

General Information for Sampling Events for Farm #1 (add additional tables for additional farm sites tested)

General Information	*Sampling Event 1*	*Sampling Event 2*	*Sampling Event 3*
Date and time of sample collection			
Current status of source – number of animals, weight of animals, etc.			
Notation of any system changes, breakdowns or modifications within previous 30 day period.			
Most recent operation or maintenance of the system noted (e.g. filter replacement)			
Ambient temperature at sampling			
Exhaust temperature at sampling (if air sampling)			
Other meteorological conditions that might impact sampling results.			
Samples Taken and IDs			

Data Reporting Form

Farm ID	***Date***	***Time***	***Pre or Post***	***Grab or Cont.***	***H_2S (ppb)***	***NH_3 (ppm)***	***Odor (DT)***	***PM10 (µg/m3)***

Note that this form can be modified for the specific technology and sampling protocol.

STATISTICAL ANALYSIS

A complete statistical analysis as outlined in the original protocol (t-test or other). Additional statistical analysis and summary should also be included if deemed necessary. If possible, photos should be included to show the testing methodology.

SUMMARY

This paper was written as a means of initiating a discussion regarding the need to develop quick and inexpensive standardized procedures for evaluating air emissions from livestock and poultry facilities. A draft protocol of such a method was presented as a means of communicating the types of information that might be included in such a standard protocol. Note that the emphasis for this protocol is NOT to determine absolute emissions but rather determine, with some degree of confidence, anticipated reductions in these emissions that would result from the implementation of mitigation technologies that have been tested using a standard set of procedures.

There are a variety of items that could be included in such a protocol development. Most importantly, it is critical for such a protocol to have widespread adoption by both the industry and the regulatory community. This would likely come about through a large national project with advisors representing all interested parties. However, once developed, such a protocol would vastly improve the development and implementation of new mitigation technologies. Currently the development of such standard protocols is occurring in the Netherlands (Mosquera and Ogink, 2006) related to ammonia emissions and for odor measurements in Germany (Both, personal communication, 2008).

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REFERENCES

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