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Analysis of Sampling Protocols for the EPA Animal Feeding Operations Consent Agreement

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Abstract. *In January of 2005, the United States Environmental Protection Agency (EPA) released the notice of the Animal Feeding Operations Consent Agreement and Final Order, offering animal feeding operations (AFOs) the opportunity to participate and help fund a nationwide emissions monitoring study that will be used to develop methodologies for estimating emissions from AFOs. As part of the Consent Agreement, ammonia and particulate matter emissions will be measured from swine, poultry, and dairy operations. This paper addresses the proposed protocol for measuring ammonia and particulate matter emissions as part of the EPA Consent Agreement.*

Keywords. Consent Agreement, ammonia, TSP, PM10, PM2.5, emissions, samplers

Introduction

In January of 2005, the United States Environmental Protection Agency (EPA) released the notice of the Animal Feeding Operations Consent Agreement and Final Order (Federal Register, 2005). The Consent Agreement offers animal feeding operations (AFOs) the opportunity to participate and help fund a nationwide emissions monitoring study that will be used to develop methodologies for estimating emissions from AFOs. The data will also be used to determine the compliance of AFOs with the Clean Air Act (CAA), the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and the Emergency Planning and Community Right-To-Know Act (EPCRA). All participating AFOs will be required to demonstrate compliance with applicable CAA, CERCLA, and EPCRA regulations at the conclusion of the agreement.

Several facilities at AFOs, including animal housing facilities, manure storage areas, and manure/slurry application sites, are sources of various air pollutants, including particulate matter (PM), ammonia (NH_3), hydrogen sulfide (H_2S), and volatile organic compounds (VOCs). Because NH_3 and H_2S are considered hazardous substances under CERCLA and EPCRA, facilities releasing reportable quantities of these substances (100 pounds per day for NH3 and H2S) may be required to report emissions. However, facilities whose emissions are "of a naturally occurring substance in its unaltered form, or altered solely through naturally occurring processes or phenomena, from a location where it is naturally found" are exempt from CERCLA and EPCRA reporting requirements (42 U.S.C. §9604(a)(3)(A)). Senate Report No. 99-11 (1985) specifically stated that this exception includes animal waste, indicating that AFOs are exempt from CERCLA and EPCRA reporting requirements. PM and some VOCs are regulated under the CAA.

The Consent Agreement is available to egg, broiler, chicken, turkey, dairy, and swine AFOs that meet the definition of an AFO under the Clean Water Act. Emissions from animal housing structures and livestock waste storage and treatment units such as lagoons will be monitored under the agreement. Participating AFOs pay a civil penalty of $200 to $1000 per AFO depending on the number of animals housed. The total penalty is capped between $10,000 for a participant having ten or fewer farms and $100,000 for a participant having over 200 farms. Additionally, participating AFOs, with the exception of certain contract growers, will pay $2,500 per farm into a fund to conduct the emissions study and will make their facilities available for emissions testing under the two-year study. The data collected during the course of the study will be used to develop emissions factors for AFOs across the country.

Participating AFOs will also receive a "limited release and covenant not to sue" based on certain past and ongoing CAA, CERCLA, and EPCRA violations. However, this covenant does not protect participating AFOs from private lawsuits that may be lodged against them. The covenant not to sue will extend only until appropriate CAA permits are acquired. Furthermore, AFOs that install waste-to-energy systems to derive electricity from animal manure will receive an extra 180 days to apply for permits and report emissions based on CERCLA and EPCRA reporting requirements (Federal Register, 2005).

An overview of the protocol to be used for measuring emissions of the aforementioned pollutants has been specified by the EPA in Attachment B of the Consent Agreement (Federal Register, 2005). The pollutants to be measured are shown in Table 1 by animal type and source.

Table 1. Pollutants Monitored as Part of the AFO Consent Agreement.

Animal	Source	Pollutants to be Monitored
Swine	Mechanically Ventilated Barns	NH_3, H_2S, CO_2, TSP[a], $PM_{2.5}$[b], PM_{10}[c], VOC[d]
	Lagoons	NH_3, H_2S, VOC
Laying Hens	Mechanically Ventilated Barns	NH_3, H_2S, CO_2, TSP, $PM_{2.5}$, PM_{10}, VOC
Meat Birds	Mechanically Ventilated Barns	NH_3, H_2S, CO_2, TSP, $PM_{2.5}$, PM_{10}, VOC
	Open Manure Piles	NH_3, H_2S
Dairy	Naturally Ventilated Buildings	NH_3, H_2S, CO_2, TSP, $PM_{2.5}$, PM_{10}, VOC
	Manure Storage Systems	NH_3, H_2S, VOC
	Mechanically Ventilated Buildings	NH_3, H_2S, CO_2, TSP, $PM_{2.5}$, PM_{10}, VOC

a. TSP = Total Suspended Particulates

b. $PM_{2.5}$ = Particulate matter (PM) with an aerodynamic equivalent diameter (AED) ≤ 2.5µm

c. PM_{10} = PM with an AED ≤ 10µm

d. VOC = Volatile Organic Compound

The purpose of this paper is to analyze the proposed protocols of the Consent Agreement for measuring ammonia and PM emissions from AFOs so that participants, investigators, and those who might use data collected as part of the Consent Agreement will be aware of potential sources of error, bias and/or uncertainty in the data and resulting emission factors. It is critical that the data and results of any emissions monitoring study, including the Consent Agreement, be understood and applied in light of the strengths and shortcomings of the methods used to obtain the data. The methods to be used for determining the emissions of ammonia and PM as part of the Consent Agreement will be detailed below:

Ammonia Emissions from Mechanically Ventilated Swine, Poultry, and Dairy Barns

Ammonia emissions from mechanically ventilated swine, poultry, and dairy barns will be determined by multiplying the average concentration of ammonia inside the barn by the airflow rate through the exhaust system. Ammonia concentrations will be measured using chemiluminescence or photoacoustic infrared technology. Airflow from mechanically ventilated barns will be estimated by "continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers" (Federal Register, 2005).

Chemiluminescence

Chemiluminescence samplers determine the concentration of ammonia in an air sample by oxidizing the ammonia to form nitric oxide (NO). The NO is further oxidized within the instrument, using ozone, to make nitrogen dioxide (NO_2) in an excited state. The NO_2 releases electromagnetic radiation with a wavelength around 1200 nm as it is reduced to a lower energy state. The instrument measures the amount of radiation released to determine the concentration of ammonia (Phillips et al, 2001). A background measurement of NO and NO_x is conducted automatically by some chemiluminescence samplers to improve the accuracy of the data (Mennen et al, 1996). The Consent Agreement does not state whether a background measurement of NO and NO_x will be conducted.

Chemiluminescence ammonia samplers are able to measure a wide range of ammonia concentrations, from 1 ppb up to 500 ppm in extended range mode (TEI, 2002). However, when using the samplers in extended range mode, adjustments may need to be made to the photomultiplier tube voltage and the converter temperature (Capareda et al, 2004). Phillips et al

(2001) reported that chemiluminescence samplers have a precision of ±0.3 ppb and can be highly accurate but only if they are carefully and frequently calibrated.

Users of chemiluminescence analyzers should be aware of several potentially large sources of error associated with this sampling method. First, this method assumes that the conversion from NH_3 to NO and then to NO_2 in the instrument is 100 percent efficient, which is rarely the case. Using chemiluminescence ammonia monitors, Mennen et al (1996) reported that "the residence time of the aerosol in the converter is probably too small, preventing complete conversion. Indeed, after each experiment some of the aerosol was found on the walls of the tubes inside the instrument." Further confounding the ammonia concentration measurements is the fact that other compounds besides ammonia may be converted to NO during the conversion process, including organic nitrogen containing compounds, nitric acid (HNO_3), nitrogen dioxide (NO_2), and ammonium (NH_4OH) containing aerosols. Therefore, background concentrations of these compounds must be measured and conversion efficiencies assumed in order to accurately calculate the concentration of ammonia in the air samples taken.

Additionally, neither chemiluminescence nor photoacoustic infrared systems (discussed below) can process samples containing PM, or dust. Therefore, before a sample of air can enter the converter of the chemiluminescence analyzer, dust must be filtered from the sample. It has been proven that ammonia will adsorb on the surface of dust particles (Neftel et al, 1998; Moller and Schieferdecker, 1989; Asman and Jansen, 1987). Therefore, filtering the dust out of a sample will effectively reduce the measured concentration of ammonia, thus leading to artificially low emission rates.

Photoacoustic Infrared

Photoacoustic infrared analyzers measure the concentrations of specified gases by measuring the amount of radiation in the infrared (IR) spectrum (2.5-25µm) absorbed by the gases in a sample. Gases such as CO_2, H_2O, CO, SO_2, NO, N_2O, HCN, and NH_3 each absorb radiation in a different band of the IR spectrum. Ammonia is characterized by IR absorption at 10.4 and 10.8 µm wavelengths (Phillips et al, 2001). To obtain accurate measurements, temperature and pressure corrections must be used as well as compensation for water vapor and carbon dioxide.

The selectivity and sensitivity of these monitors for ammonia can be enhanced by the use of narrow band optical filters, optical interference filters, gas-filled filter cells, and light modulations. Using these measurement aids, photoacoustic IR analyzers have a detection range down to 20 ppb, but they, like the chemiluminescence monitors, require very careful calibration (Phillips et al, 2001). Even with these improvements, the sensitivity of the instrument is not isolated to ammonia. For example, these instruments are almost as sensitive to volatile fatty acids, which may be abundant at animal feeding operations, as they are to ammonia (Hollander, 1993a). Furthermore, as indicated above, because photoacoustic infrared systems cannot analyze samples containing PM, adsorbed ammonia will not be accounted for, artificially lowering the reported emission rates.

Airflow

Due to variability in ventilation system installation and maintenance and wind effects, measuring ventilation rates is not a straightforward process. As stated above, the airflow from mechanically ventilated barns will be measured by "continuously measuring fan operational status and building static pressure" (Federal Register, 2005). While not specifically mentioned in the protocol, it is believed that the Fan Assessment Numeration System (FANS) will be used to conduct in situ airflow measurements. The alternative to the FANS system includes using the Bernoulli's equation. In order to use Bernoulli's equation based on building static pressure, "the

discharge coefficient for the type of opening being considered must also be known. [Unfortunately, these are normally only available for airflows perpendicular to the plane of the opening (Pearson & Owen, 1994), whereas in reality oblique flows are common]" (Phillips et al, 2001). Confounding this issue is the impact of wind on static pressure measurements. Depending on the wind direction relative to building orientation, the static pressure will vary depending on where it is measured. Furthermore, changes in fan performance as the static pressure changes due to switching fans on and off must be accounted for (Xin et al, 2003) as well as changes in fan performance with use (Bottcher et al, 1996).

The FANS system was developed through the collaboration of USDA-ARS Southern Poultry Research Laboratory and the University of Kentucky. The system uses an array of anemometers to perform an equal area traverse in order to measure fan air flow capacity in the field (Wheeler et al, 2002). Measuring the actual flow rate of fans in the field is important because the addition of supplementary equipment such as shrouds and shutters decrease the amount of airflow relative to the manufacturers' fan curve, which are developed under ideal conditions. Wheeler et al (2002) found that "manufacturer data was 2 to 13 percent higher than actual field performance." Data must also be taken for each fan at several different static pressures so that an accurate in situ fan curve can be developed.

Unless the in situ performance of each fan is measured, the uncertainty of ventilation airflow estimates will be substantial, thus leading to significant uncertainties in emission estimates developed using the data collected under the Consent Agreement. However, according to Wheeler et al (2002), a complete evaluation of each fan requires approximately 70 minutes, requiring a substantial amount of time for large production facilities, which may have 50 or more fans per barn. Furthermore, fan evaluation cannot be conducted while a building is inhabited by livestock without altering the comfort level and emissions of the animals inside. Indeed, measurement of the ventilation rate from the buildings in each study will likely require a substantial amount of time and/or be a major contributor to uncertainty in the final emission factors developed under the Consent Agreement.

Ammonia Emissions from Manure Storage and Naturally Ventilated Dairy Barns

Ammonia emissions from lagoons, open manure piles, and naturally ventilated dairy barns will be measured using optical remote sensing (ORS). Fourier infrared spectroscopy (FTIR) will be used to measure ammonia, carbon dioxide, and, in some cases, hydrogen sulfide emissions from naturally ventilated dairy barns. Ammonia concentrations 10 m upwind and downwind of lagoons and open manure piles at heights of 1m, 6m, and 12m will be measured using FTIR and collocated open path ultraviolet differential optical absorption spectroscopy (UV-DOAS) systems. Three dimensional wind velocity measurements will be taken at heights of 2m and 12m. Emissions will then be determined from differences in upwind and downwind ammonia concentrations using both a Eularian-Gaussian and a Lagrangian Stochastic based dispersion model.

In general, ORS systems are advantageous because they average the ammonia concentration across a plume, which is required in several flux measurement techniques. However, there is the potential for large values of uncertainty associated with the emission rates reported under the Consent Agreement since ammonia fluxes will be measured at only three heights and wind profiles measured at two heights. The small number of measurement locations leaves a significant potential for uncertainty associated with the spatial variability of the ammonia plume. Furthermore, according to Zhao et al (2002), "in situ [ammonia] measurements cannot obtain 3D NH_3 distributions in continuous operation mode. Lidar is the only remote sensing instrument

that can measure one- to three-dimensional ammonia concentration distributions for air quality studies with much needed temporal and spatial resolution."

Fourier Infrared Spectroscopy (FTIR)

FTIR uses similar principles to the photoacoustic infrared system described above, but the recorded absorption peaks, resulting from different concentrations of absorptive gases in the light path, are deciphered using Fourier transforms. These transforms allow the isolation of the species of interest from other interfering gases, such as water vapor, allowing a good measurement of ammonia concentration (Krahl et al, 1996). Biermann et al (1998) reported a detection limit of 1.5 ppb using FTIR. However, FTIR systems require very frequent and careful re-calibration using costly standard gas mixtures as well as an experienced operator (Phillips et al, 2001).

Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS)

UV-DOAS systems work by emitting UV (200-700nm) radiation from a high-pressure xenon lamp focused on a receiver, which is connected to a fast scanning spectrometer. Like the infrared systems, UV-DOAS systems detect the amount of light absorbed by different gases. Ammonia absorbs light between 190-230 nm (Phillips et al, 2001). The radiation spectrum detected by the receiver is interpreted by comparing the sampled differential absorption spectra to a database of calibrated absorption spectra gases. Spellicy et al (1991) strongly recommends that the calibrated spectra should be produced on the same instrument used for measurement. Absorption spectra of interfering gases, such as water vapor and volatile fatty acids (VFAs), can be used for correction if available (Hollander, 1993b). Given the narrow beams of light used by the UV-DOAS system, the process of aligning the transmitter and receiver for field experiments should be automated (Phillips et al, 2001).

Multiple papers have been written regarding the effectiveness of UV-DOAS, with mixed reviews of the system. In laboratory test chamber and field experiments, Mennen et al (1996) determined that the detection limit of the UV-DOAS system is a function of the length of light path and the averaging time of the measurement, with the lower detection limit being approximately 1 ppm. With the understanding that increased distance between the emitter and receiver diminishes sensitivity, measurements with the UV-DOAS system can be conducted over distances from 0.1m up to several kilometers. Klarenbeek et al (1993) compared several ammonia measurement methods, including UV-DOAS, and determined that agreement between all of the methods was good, with a maximum difference between reported values of 25 percent.

Phillips et al (2001) reported that "energy loss in the atmosphere limits the application to a light path of approximately 200m." Sommer et al (1995) showed differences between the ammonia concentrations found using an acid bubbler method and those from a UV-DOAS system, with the UV-DOAS system averaging around 60 ppb lower than the bubbler one day and 110 ppb higher than the bubbler the next, calling to question the reliability of the output of UV-DOAS system. The results of a study by Neftel et al (1990) were verified by Mennen et al (1996), concluding that "the noise level of the UV-DOAS system appeared to be too high, at 2μg-m^{-3} (3 ppb), for hourly concentrations." Phillips et al (2001) determined that "at present, the UV-DOAS system does not seem to be a 'ready to use' system for ammonia measurements in the low μg-m^{-3} (ppb) range." Given the conflicting reviews the system has received, the reliability of results found using this system seem questionable, and the heavy reliance on the UV-DOAS system for determining emission rates from AFOs as part of the Consent Agreement is troubling.

Modeling

Mathematical models can be useful tools for analyzing the dispersion of pollutants from point or area sources. Both Eularian Gaussian and Lagrangian Stochastic models will be used to determine emission rates from AFOs based on ammonia concentrations measured upwind and downwind of the source. Gaussian-based models assume that "the concentration of a pollutant in both the vertical and horizontal plane, at a given downwind distance from a source, can be represented by a normal, or Gaussian, distribution" (Fritz et al, 2005). Lagrangian Stochastic models, also known as random-flight models, attempt to simulate turbulent dispersion by determining particle trajectories. The Lagrangian Stochastic model predicts the path followed by each particle to a receptor (Seinfeld and Pandis, 1998).

Industrial Source Complex Short-Term Version 3 (ISCST3), a Gaussian-based model, is the model currently used by most state air pollution regulatory agencies for low-level point sources and large industrial sources. The general form of the Gaussian equation is shown in equation 1:

$$C_{10} = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right)\left[\exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right)\right] \tag{1}$$

where

C_{10} = steady-state 10-minute concentration at a point (x,y,z) ($\mu g/m^3$)

Q = emission rate ($\mu g/s$)

σ_y = horizontal dispersion coefficient (m)

σ_z = vertical dispersion coefficient (m)

u = wind speed at stack height (m/s)

y = horizontal distance from plume centerline (m)

z = height of receptor with respect to ground (m)

H = effective stack height (m)

The Gaussian equation is simply the ratio of emission rate over wind speed multiplied by a normal density function for the horizontal direction and another normal density function for the vertical direction. Assuming that the receptor location, wind speed, and dispersion coefficient (which is based on atmospheric stability) are known, a measured downwind concentration can easily be back-calculated into an emission rate.

However, the accuracy of Gaussian-based dispersion models has long been debated (Beychok, 1996). The Gaussian model assumes constant diffusion coefficients and is limited to idealized meteorological conditions. Furthermore, problems with artificial diffusion and closure associated with parameterization of relatively small sources plague Gaussian-based models (Lee and Naslund, 1998).

Lagrangian Stochastic models are often used as viable alternatives to Gaussian models for simulating dispersion and transport. "In a Lagrangian simulation, dispersion and concentration statistics are calculated by following the advection and diffusion of marker particles within a mean velocity field. While the trajectories of the particles due to advection are determined from the specified velocity field, the diffusion portion of the particle motion can be computed by either deterministic or statistical formulations" (Lee and Naslund, 1998). Furthermore, the Lagrangian Stochastic approach is touted as "offering flexibility in plot design and requiring a minimum number of samplers" (Misselbrook, 2005). The Lagrangian Stochastic approach is complex

and, therefore, is not detailed here. A discussion of this approach may be found in Flesch et al (2004).

Price et al (2004) demonstrated that if emission rates derived for a source using WindTrax (a backward Lagrangian Stochastic model) were used in ISCST3 (a Gaussian model), the resulting predicted downwind concentration was approximately 10 times that which was measured. Given the different approaches used by Gaussian and Lagrangian Stochastic models to predict downwind pollutant concentrations from a source, it is expected that the models will yield differing results. Conversely, when measured downwind concentrations are used to determine the emission rate of a pollutant from a source, the calculated emission rates will be different. Caution should be exercised, then, when publishing and/or utilizing emission rates to specify the model for which this emission rate applies.

Particulate Matter (PM) Emissions

An accurate measurement of PM from AFOs is an important part of the Consent Agreement because PM_{10} and $PM_{2.5}$ is regulated by the National Ambient Air Quality Standards (NAAQS). Three "categories" of PM will be measured as part of the Agreement, including total suspended particulates (TSP), PM_{10}, and $PM_{2.5}$. PM_{10} and $PM_{2.5}$ is particulate matter with an aerodynamic equivalent diameter less than or equal to 10 and 2.5 µm, respectively. Like the ammonia measurements, the concentration of PM inside the building will be determined and combined with airflow data to determine emissions.

The Consent Agreement only specifies that PM from dairies will be measured using "particle samplers located with a sampling height of 5m." While the lack of detail is disconcerting, because no detail is given on the methods used to measure PM from dairies, little further analysis will be given for these facilities. However, it is noteworthy that the sampler bias of PM_{10} and $PM_{2.5}$ pre-collectors discussed below are as equally applicable to emissions from dairy facilities as to swine and poultry facilities. The remainder of the discussion on PM sampling protocol applies to mechanically ventilated swine and poultry facilities.

TSP Emissions

TSP is to be measured from swine and poultry facilities using isokinetic multipoint gravimetric samplers. If filters with low background counts (such as Teflon) are used for TSP sampling, subsequent particle size distribution analysis may be conducted, yielding PM_{10} and $PM_{2.5}$ concentrations with which to compare the results of the samples collected using Federal Reference Method (FRM) samplers (Buser, 2004). However, no indication is given in the Consent Agreement that such an action will be taken.

PM_{10} Emissions

According to the Consent Agreement, PM_{10} concentrations will measured using tapered element oscillating microbalances (TEOMs) equipped with FRM PM_{10} pre-collectors. The TEOM continuous PM monitor is an EPA PM_{10} equivalent method (EPA, 1990). Using the default setting, the TEOM operates by drawing air into the sampling train at 16.71 L/min. The air sample passes through a flow splitter from which 3.1 L/min passes through a 16 mm diameter filter connected to the top of a narrow vibrating hollow tapered glass tube. As particles are deposited on the filter, the frequency of the vibration of the tube decreases proportionally to the mass of PM on the filter. The inlet of the sampler is kept at 50°C to eliminate the effect of condensation on the measurements. A microprocessor converts the vibration frequency of the filter to mass concentrations, which are updated every 13 s" (Soutar et al, 1999). Although not

specified in the sampling protocol, because TEOMs cannot be setup for isokinetic sampling, PM_{10} emissions must be estimated by multiplying the indoor concentration by the building ventilation rate. Therefore, the same issues with measuring airflow rates described above will also apply to PM_{10} emissions estimates.

The TEOM is a convenient tool for conducting continuous measurements, but problems with the reported concentrations are widely acknowledged (e.g. Green et al, 2001; Cyrys et al, 2001; Pang et al, 2002; Anderson et al, 2002). Using TEOM systems to measure PM_{10}, Vega et al (2003) reported that "mass comparison showed significant differences between [TEOMs and gravimetric samplers] that exceeded the expected uncertainties. In general, the TEOM measured higher and more variable PM_{10} than [gravimetric samplers]." They then concluded that "TEOM and filter-based PM_{10} cannot be used interchangeably." Some of the discrepancy in mass measurement is a result of the volatilization of ammonium nitrate and some semi-volatile organic compounds in the sample as the sample is heated to 50°C (Pang et al, 2002). However, it is unlikely that this volatilization accounts for all of the difference in concentration measurements, given the large differences between measured concentrations. TEOM measurements as high as two to four times that measured by gravimetric sampling have been reported (Vega et al, 2003).

Attempts have been made to correct TEOM measurements to correspond better with gravimetric measurements. While the Consent Agreement does not indicate that any correction of TEOM readings will be conducted, it is worth mentioning the results of such studies. In a previous continuous monitoring study conducted in the United Kingdom, the Airborne Particles Expert Group (APEG) recognized the sampling bias of the TEOMs and suggested the use of a correction factor (APEG, 1999). However, because of the high variability in TEOM measurements, the influence of humidity, and spatial-temporal differences in concentrations of semi-volatiles, the use of simple correction factors has been unsatisfactory (Allen et al, 1997; Green et al, 2001; Price et al, 2003; Rizzo et al, 2003; Soutar et al, 1999). Gehrig et al (2005) proposed a promising method for correcting TEOM data using manual gravimetric PM_{10} measurements taken every fourth day to compare with the TEOM data. However, the Consent Agreement makes no provision for such manual PM_{10} sampling or use of a correction factor for PM_{10} data collected using TEOMs.

Confounding the biases associated with use of TEOMs for PM_{10} measurements is the bias of the PM_{10} pre-collectors when sampling aerosols with mass median diameters (MMDs) greater than 10μm, as is characteristic of agricultural PM emissions. Buser et al (2001) reported on the inherent biases associated with PM_{10} samplers with a cut point of 10 μm as a result of the interaction of particle size and sampler design using a theoretical analysis. For a "typical" agricultural dust, Buser reported over sampling of 3.2 times the actual PM_{10} concentration. Additionally, using an empirical approach, Pargmann et al (2001) and Wang et al (2003) documented shifts in PM_{10} pre-collector cut points when exposed to PM larger than the sampler's design cut point leading to further over sampling biases.

Given the widely acknowledged bias associated with the use of TEOM samplers for measuring PM_{10} concentrations, confounded with the over sampling bias of the PM_{10} pre-collector in agricultural environments and uncertainties associated with airflow measurements, extreme caution should be used when utilizing PM_{10} emission rates determined under the Consent Agreement.

$PM_{2.5}$ Emissions

$PM_{2.5}$ emissions from sites monitored under the Consent Agreement will be "measured gravimetrically with a Federal Reference Method for $PM_{2.5}$ at least one month per site." Given

that the method to be used for $PM_{2.5}$ measurement is not specified, only a limited analysis of the sampling protocol can be conducted. However, it should be noted that the biases associated with PM_{10} pre-collectors described above are multiplied for $PM_{2.5}$ pre-collectors in the presence of agricultural dusts. For a "typical" agricultural dust, Buser (2001) reported over sampling of 14.0 times the actual $PM_{2.5}$ concentration if no shift in cut point occurs.

The limited amount of time allotted for $PM_{2.5}$ sampling is also of concern. If sampling is only conducted for a one month "snapshot," holistic $PM_{2.5}$ emission rates may not be determined due to changes in emissions with stage of production. For example, Lacey et al (2003) reported on PM emissions from broiler production houses, which have an average grow-out period of seven weeks, during which time there is a substantial increase in bird weight. Lacey et al found a significant ($\alpha = 0.05$) correlation between PM_{10} emissions and bird weight. Were $PM_{2.5}$ emissions to be monitored for such a facility for only one month, the resulting emission rate would be too low (if measured at the beginning of the production cycle, when the birds are lightest) or too high (if measured at the end of the production cycle, when the birds are heaviest). Furthermore, the emission rate may not reflect the two week period between production cycles when no birds are present in the barn.

Again, given the inherent biases associated with the use of $PM_{2.5}$ pre-collectors in the presence of agricultural dusts and the limited time frame in which $PM_{2.5}$ concentrations will be monitored, extreme caution should be used when utilizing $PM_{2.5}$ emission rates determined under the Consent Agreement.

Conclusion

The Animal Feeding Operations Consent Agreement and Final Order, promulgated by the EPA in January of 2005, proposes protocols to measure emissions of several pollutants, including ammonia and particulate matter, from certain participating AFOs. However, the proposed protocol raises grave concerns regarding the accuracy of emission rates that will be determined from data collected as part of the agreement. While the preceding analysis only addressed the protocol for ammonia and PM, there are additional concerns regarding the protocol for measuring emissions of H_2S, CO_2, and VOCs as well. Amendments should be made to the sampling protocol to address the concerns outlined above. Additionally, care should be taken by those using the data and conclusions of the Consent Agreement to be aware of the short comings of the processes used to collect and analyze the data.

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