Development of VOC Emissions Estimating Methodologies for Animal Feeding Operations

Draft

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GLOSSARY / ACRONYMS

AFO	animal feeding operation
bLS	backward Lagrangian stochastic
CFI	call for information
CH_4	methane
EEM	emission estimation method
EPA	Environmental Protection Agency
EtOH	ethanol
FID	flame ion detection
FRM	federal reference method
GC-FID	gas chromatography with flame ion detection
GC-MS	gas chromatography-mass spectrometry
GSS	gas sampling system
H_2S	hydrogen sulfide
MeOH	methanol
mL/min	milliliters per minute
N H_2SO_4	normalized sulfuric acid
NAEMS	National Air Emissions Monitoring Study
NH_3	ammonia
NH_4^+	ammonium
NMHC	nonmethane hydrocarbon
NMVOC	nonmethane volatile organic compounds
PAS	photoacoustic spectroscopy
PIC	path integrated concentration
PM	particulate matter
QAPP	quality assurance project plan
RPM	radial plume mapping
S-OPS	synthetic open-path system
THC	total hydrocarbon
TO	toxic organic
USDA	U.S. Department of Agriculture
VFAs	volatile fatty acids
VOCs	volatile organic compounds

1 INTRODUCTION

With respect to the definitions of criteria air pollutants, the Environmental Protection Agency (EPA) defines volatile organic compounds (VOCs) as any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions (40 CFR 51.100). The vast array of organic chemical compounds that are classified as VOCs evaporate easily at room temperature and can contribute to the odor issues associated with animal feeding operations (AFOs), along with ammonia (NH_3) and hydrogen sulfide (H_2S). As the science has advanced, the list of VOCs associated with AFOs has grown to more than 500 compounds (Schiffman et al., 2001; Ni 2015). Many of these detected compounds occur at very low concentrations, which makes their measurement difficult and expensive (Janni, 2020). Among the VOCs found at AFOs that contribute to odor are volatile fatty acids (VFAs), alcohols, aldehydes, amides, amines, aromatics, esters, ethers, fixed gases, halogenated hydrocarbons, hydrocarbons, ketones, nitriles, other nitrogen-containing compounds, phenols, sulfur-containing compounds, steroids, and other compounds (Janni, 2020). Since these compounds are closely associated with odor issues, many studies only report VOC concentration in odor units, or correlate concentrations with odor concentrations (Ni, 2015).

VOCs are emitted by several sources on AFOs, including animal eructation and exhalation, animal waste in animal pens, flushing lanes, lagoons, silage storage piles and silos, and feed mixtures in feed lanes and bunks (Alanis et al., 2008; Chung et al., 2010). Recent studies at dairies found that VOC concentrations were higher near silage and piles of animal feed (Alanis et al., 2008; Chung et al., 2010; Malkina et al., 2011; Yuan et al., 2017). Yuan et al. (2017) found the percent contribution of the various farm sources (e.g., silage, and animal waste) to VOC emissions could vary by compound and animal type. The complexity of VOC emissions from AFOs make it a topic of continued study.

This report outlines the methods used to monitor VOC emissions during the National Air Emissions Monitoring Study (NAEMS), as well as a summary of the data collected, and the limitations of that data. Finally, the report concludes by outlining options for moving forward for initial informal comment by stakeholders.

2 VOC MEASUREMENT AND DATA COLLECTION

As noted in the process overview report, the 2005 Air Compliance Agreement (Agreement) included a monitoring protocol outlining the pollutants and measurement methodologies to be used in the NAEMS. The monitoring protocol was developed by a broad array of stakeholders that included representatives from the AFO industry; university, United States Department of Agriculture (USDA) and EPA scientists; state and local air quality agencies, and environmental organizations. The monitoring protocol identified a comprehensive list of parameters that were to be monitored to provide a greater understanding and accurate characterization of emissions from AFOs. By monitoring these parameters, the stakeholders believed that the EPA would have the necessary information to develop emission estimation methods (EEMs) for uncontrolled emissions of particulate matter (PM), NH_3, H_2S, and VOCs from AFOs.

The monitoring protocol provided guidance on the number, type and geographical locations of confinement houses and open sources (lagoons and basins) that should be monitored in the NAEMS. The farms that were monitored were selected by the study's Science Advisor, Dr. Al Heber, and approved by the EPA. Table 1-1 provides a summary of the sites by animal and structure type monitored. The monitoring protocol also identified specific methodologies for measuring emissions from confinement houses and open sources. Confinement houses were to be monitored for PM, NH_3, H_2S and VOC emissions, while open sources were to be monitored for NH_3, H_2S and VOC emissions.

Table 1-1. NAEMS sites by process group

Animal - Process	Structure type	Sites
Swine - Breeding Gestation	Gestation barn	IA4B, NC4B, OK4B
Swine - Breeding Gestation	Farrowing room	IA4B, NC4B, OK4B
Swine - Breeding Gestation	Open source	IN4A, NC4A, OK4A
Swine - Grow-Finish	Finishing barn	IN3B, NC3B
Swine - Grow-Finish	Open source	IA3B, NC3A, OK3A
Poultry - Broiler	House	CA1B, KY1B-1, KY1B-2
Poultry - Egg layer	Manure belt house	IN2B
Poultry - Egg layer	Manure Shed	IN2B
Poultry - Egg Layer	High rise house	CA2B, IN2H, NC2B
Dairy	Mechanically ventilated barn	IN5B, NY5B, WI5B
Dairy	Milking center	IN5B, NY5B, WI5B
Dairy	Naturally ventilated barn	CA5B, WA5B
Dairy	Open source	IN5A, TX5A, WA5A, WI5A

2.1 NAEMS Monitoring Protocol

The Agreement's monitoring protocol (70 FR 4957, Attachment B) specified that an initial VOC characterization study was to be conducted on a barn for each animal sector participating in the NAEMS. The characterization study was to be conducted on a day during the first month at the first monitored site for an animal sector. Along with building airflow rate, total non-methane hydrocarbons (NMHC) were to be continuously monitored using a dual-channel flame ionization detector (FID) analyzer (EPA Federal Reference Method (FRM) 25A). VOCs were to be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (modified EPA FRM 26). Each VOC sample was to be evaluated using concurrent gas chromatography-mass spectrometry (GC–MS) and gas chromatography with flame ion detection (GC-FID) for toxic organic (TO) compounds (EPA Method TO-15) and other FID-responding compounds. VOC mass was to be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass were to be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass was to be chosen for the remainder of the study.

The monitoring protocol specified that after the initial VOC characterization study, the selected VOC sampling method would be used to collect quarterly VOC samples at all sites, along with continuous FRM 25A monitoring at a single site for each animal sector. The FRM 25A measurements were to be corrected from an ''as carbon'' basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC–MS evaluations during applicable intervals of time.

For open sources, the monitoring protocol specified that samples of the lagoon/basin liquid were to be collected and analyzed for VOC, and the EPA model WATER9 was to be used to estimate emissions based on measured VOC values. The monitoring protocol did not specify either sampling frequency or analytical methodology.

2.2 NAEMS Initial VOC Characterization Study

The confinement source quality assurance project plan (QAPP) (Heber et al., 2008) further specified the collections methods of the characterization study to note VOCs were sampled from one site per species at the barn's primary representative exhaust fan using three different methods: sorbent tubes, canisters, and all glass impingers. The methods were elaborated

on in the "Initial VOC Characterization Study for the NAEMS", which was provided on April 27, 2009 (available in Appendix A) and is summarized in the following sections.

2.2.1 Methods

Sorbent tube samples were collected through the gas sampling system exhaust/odor port using a method that allowed the incoming airstream to be split into two roughly equal substreams. Each of these substreams flowed through two pairs of sorbent tubes connected in series. The second tube in the series served as a "breakthrough" tube for the first tube. Additional studies were conducted to determine the optimal length of time for sampling to avoid ice formation in the sample inlet due to excessive water in the tubes. These studies showed that 30 min of sampling time provided an additional margin of safety, while still yielding quantifiable levels of VOCs.

Canister sampling was conducted for 24 hours, with 6-liter TO-Can Canisters (Restek Corp, Bellefonte, PA. The flow controllers on the canisters were pre-set in the lab to deliver a flow of approximately 3 milliliters per minute (mL/min). The impinger sampling was conducted using midget (30 mL) all-glass impingers (Ace Glass, Vineland, NJ), with four impingers connected in series. The first two impingers contained 15 mL of 0.1 N H_2SO_4 for sample collection. The third impinger was a blank to avoid spillover of trapping solution into the fourth impinger, which contained a moisture trap. The impingers collected samples over a two-hour period.

The samples were collected at four NAEMS sites, one for each animal species included in NAEMS. Table 2-1 summarizes the sites monitored for the characterization study, and the measurements taken at each. The characterization study did not include any open sources (i.e., lagoons, basins, or corrals).

Table 2-2. Characterization report sites and measurements

Animal - Process	Structure type	Sites	Measurements
Swine - Grow-Finish	Finishing barn	IN3B	10/23/08 Canisters, sorbent tubes
Poultry - Broiler	House	CA1B	11/18/08 Canisters, sorbent tubes, impingers 12/2/08 Sorbent tubes
Poultry - Egg Layer	High rise house	IN2H	11/5/08 Canisters, sorbent tubes, impingers 11/13/08 Sorbent tubes
Dairy	Mechanically ventilated barn	IN5B	10/15/08 Canisters, sorbent tubes, impingers 10/29/08 Sorbent tubes, impingers

2.2.2 Results and Conclusions

The impinger sampling detected no significant peaks, other than ammonium (NH_4^+), and were not considered for further sampling. The primary focus of the characterization study analysis were the canister and sorbent tube samples.

The characterization study found the canisters were typically more effective at capturing compounds than sorbent tubes across the sites, especially for the compounds in the 90% mass groups for CA1B and IN5B, and for the single most-dominant compound (isopropyl alcohol) at IN2H. The exception was IN3B, where better performance of tubes relative to canisters was seen. This was attributed to one tube sample containing significantly elevated levels of most analytes relative to the others, thus inflating the average tube-sample yield.

The characterization study did note there were several problems encountered with tube sampling, including several samples with sufficient moisture that either could not be analyzed (due to freezing of the GC inlet), or gave extremely distorted chromatograms. The study also saw breakthrough tubes with non-negligible levels of some analytes, which indicates trapping by the primary tube was incomplete.

The Science Advisor selected canister sampling over sorbent tubes due to better performance in measuring target compounds and being less challenging to operate.

2.3 NAEMS Monitoring

2.3.1 Confinement Sites

The confinement source QAPP (Heber et al., 2008) noted quarterly VOC samples using the selected VOC sampling method from the characterization study were to occur at all sites. Continuous monitoring for total non-methane VOC (NMVOC), and methanol (MeOH)and/or ethanol (EtOH), was planned to be conducted at a minimum of one site per species for the duration of the study.

For the continuous measurements, the QAPP (Heber et al., 2008) indicates that concentrations of total NMHC were to be measured using either the INNOVA Model 1412 or a TEI Model 55C. The TEI Model 55C were scheduled to be used at one swine site (IN3B), two dairy sites (CA5B and IN5B), and one layer site (IN2B) as a check on the performance of the INNOVA.

NAEMS confinement sites followed the QAPP and used the INNOVA analyzed NMHC concentrations by measuring total hydrocarbon (THC) and subtracting EtOH and methane. (CH_4) The THC data was questionable, however, due to irreconcilable interferences by water vapor and other gases. Therefore, the VOC-related gas emissions measured by the INNOVA were not included in the final reports or data deliveries to EPA. The Science Advisor also found that continuous NMHC concentrations obtained using the TEI 55C were biased low due to its inability to detect oxygenated VOC. This low bias would have been present in both inlet and exhaust air concentrations. Total nonmethane hydrocarbon (TNMHC) data from IN3B and IN5B were provided in the final reports. This left VOC data obtained using the canisters and analyzed with the GC-MS as the only VOC data provided by the NAEMS effort.

The canister sampling frequency specified in the QAPP resulted in only seven sampling events per site. Between January 1, 2009, and October 7, 2010, approximately 7 canisters samples (24-hour sampling period) taken at each NAEMS barn site. Table 22 summarizes the number of valid emissions values. There are between 7 and 39 samples for any structure type monitored under NAEMS. As a comparison, the next small pollutant data set was $PM_{2.5}$, which also had a limited collection schedule that resulted in a dataset that ranged from 30 (layer manure shed) to 683 (broiler) daily observations for each structure type. However, unlike VOCs, $PM_{2.5}$ has an advantage in that decisions about parameters affecting $PM_{2.5}$ emission could be drawn from the more plentiful PM_{10} data, since $PM_{2.5}$ is a subset of $PM_{10.}$ The emissions estimates derived from the canister samples are provided in Appendix B.

Table 2-3. VOC samples by process group

Animal - Process	Structure type	Number of Samples
Swine - Breeding Gestation	Gestation barn	30
Swine - Breeding Gestation	Farrowing room	12
Swine - Grow-Finish	Finishing barn	39
Poultry - Broiler	House	13
Poultry - Egg layer	Manure belt house	14
Poultry - Egg Layer	High rise house	34
Poultry - Egg Layer	Pit of high rise house	7
Dairy	Mechanically ventilated barn	32
Dairy	Milking center	8
Dairy	Naturally ventilated barn	15

The Science Advisor allocated four canisters for each sampling event, which were used to obtain measurements of exhaust air only. There were no inlet air or background concentrations obtained with the canisters, except at CA5B. This means the estimates of VOC emissions provided were gross emissions, where the emissions reported assume zero VOC in the inlet air and thus are a worst-case scenario (i.e., assumes all VOCs monitored are from the source). Inlet sampling at CA5B suggested net emissions were only a small fraction of gross emissions (on average, 22%). It is possible that the particularly low contribution of the CA5B barn might be atypical, as there might have been interference in the measurements from an upwind dairy exercise yard in combination with the additional challenges associated with upwind and downwind sampling at naturally ventilated barns. In light of this, it is hard to conclude all monitored structures would have a similar small contribution to gross emissions.

2.3.2 NAEMS Open Source Site

Due to the nature of the open-source emission methodology, the same VOC sampling method could not be used to determine VOC emissions as was used for confinement sources (i.e., 24-hour sampling collection). As noted in Section 2.1, the Agreement's monitoring protocol specified that to estimate VOC emissions from lagoons, samples of the lagoon liquid would be collected and analyzed for VOC, and the WATER9 model would be used to estimate emissions based on measured VOC concentrations, pH, and other factors. However, the open source QAPP (Grant, 2008) proposed a revised method due to difficulties in validating the WATER9 model. The QAPP proposed that emissions of VOCs would be estimated based on synthetic open-path sampling (S-OPS) in conjunction with a gas sampling system (GSS), photoacoustic spectroscopy (PAS), and one to three 3D wind velocity measurements near the surface. The choice of the photoacoustic multi-gas analyzer for the VOC measurements was chosen based on the ability to make continuous accurate measurements of multiple VOCs in combination with NH_3. Specifically, the QAPP noted the measurements of CH_4, EtOH, MeOH, and residual VOC concentration (as well as NH_3 and water vapor concentration and barometric pressure) would be made using PAS, following the Standard Operating Procedure for the Operation of the INNOVA 1412 Photoacoustic multi-gas analyzer (SOP G7).

The concentration measurements would be combined with modeling, either inverse dispersion analysis using a backward Lagrangian stochastic method (bLS) or Radial Plume Mapping (RPM), to estimate the VOC emissions. Emissions of CH_4, THC, MeOH and EtOH

were to be calculated using the bLS method or the ratio of VOC measured by PAS from air sampled by the S-OPS to the nearest equivalent NH_3 path integrated concertation (PIC) multiplied by RPM calculated emissions of NH_3. NMHC emissions were to be calculated by adding the MeOH and EtOH emissions to the THC emissions.

Ultimately, no VOC, CH_4, THC, MeOH, EtOH, or NMHC values for open-source sites were reported to EPA. Initial efforts with the INNOVA 1412 had interferences by water vapor and other gases, similar to the barn measurement attempts. An email from the Science Advisor did note that an attempt was made to use a TEI Model 55C, in lieu of the INNOVA 1412, at IN5A for the Fall and Winter of 2009-2010. However, no flux estimates of NMHC were made.

2.3.3 KY Sites

As described in the process overview report, two additional broiler sites in KY from a Tyson Foods study were included in NAEMS, as the study was developed to be consistent with NAEMS QAPP and provided to EPA for review. Unlike the other NAEMS sites, the QAPP for the KY sites (Moody et al., 2008) specified that THC, CH_4, and NMVOC component emissions from the confinement houses would be measured continuously by both an INNOVA 1412 Photoacoustic Multi-gas Monitor and a VIG Industries, Inc. Model-200 total hydrocarbon gas analyzer. According to the QAPP, the INNOVA 1412 was initially intended to be used to measure NH_3 and carbon dioxide emissions. However, the VIG Model-200 was unable to achieve the 75% data completeness criteria during the first two months of the study. To address the VOC data completeness issue, the INNOVA 1412 was fitted with additional filters that enabled it to measure CH_4 and NMHC in addition to NH_3 and carbon dioxide.

At the KY sites, an initial characterization study to characterize the speciation of NMHC emitted from the facilities was performed. Stainless steel canisters (Entech Instruments, Inc., Simi Valley, CA) were used to collect the air samples from the two broiler houses (Burns et al., 2009). A GC-MS method was used to speciate the NMHC compounds. A solid sorbent method (TO-17) was used simultaneously to collect the air samples on glass sorbent tubes containing Carbopack X and Carbopack C (2:1 packing volume) custom-made by Supelco, Inc. (Bellafonte, PA) with a GS 301 gas sampler (Gerstel, Inc., Baltimore, MD). Two collection and speciation trials were conducted on April 19, 2006, at Tyson 3-3 (empty house) and Feb 6, 2007, at Tyson 1-5 (with birds in house). The air samples were collected from nine different locations

throughout the whole house, including each air sampling location. The top 25 compounds were speciated with the TO-15 & TO- 17 methods.

During the study, ambient background was not sampled for NMHC (Burns et al., 2009). The researchers assumed that background ambient air consisted of the same NMHC compounds emitted from the houses. They also assumed that the empty house and occupied house had similar chemical profiles for detectable compounds, but the concentrations would change between the empty or occupied house (Burns et al., 2009). As detailed in the QAPP, the confinement house VOC emissions were measured continuously by the INNOVA 1412 and VIG Model-200. However, the data collected by the INNOVA was not reported in the final report because the researchers determined that water vapor caused interference problems with the INNOVA. All the NMHC data presented in the Tyson Foods final report was collected using the VIG Model-200. Despite initial completeness issues with the VIG Model-200, the Tyson study provided NMHC estimates for most of the days on site (Table 2-3). These data are provided in Appendix C. As Section 2.4.2 will detail these continuous NMHC measurements had issues measuring the oxygenated hydrocarbon component of the total VOC.

Table 2-4. Summary of NMHC daily average from KY broiler sites

site	house	Days on Site	Number of daily averages
KY1B-1	H5	394	280
KY1B-2	H3	379	227

2.4 Limitations of NAEMS data

The limited quantity of VOC and NMHC samples for the NAEMS sites is problematic for EEM development. In addition, there are quality issues associated with the emission estimates submitted to EPA. The following sections summarize the quality issues with the data collected.

2.4.1 NAEMS Confinement Canister Samples

Canisters work well for many non-polar compounds but can have low recoveries of certain compounds including polar compounds such as phenols, indoles, and VFAs (Wang and Austin, 2006). Sorbent tubes can collect a wide range of VOCs including polar VOCs; however, sorbent tubes are more challenging to use due to water sorption in humid environments and artifact formation, as seen during the NAEMS characterization study. The difficulty in collection

with sorbent tubes contributed to the decision to solely use canisters for VOC collection for the study.

A lingering question from NAEMS was whether the canister alone sufficiently captured VOC concentration at the farms. Shortly after the conclusion of NAEMS, USDA Agricultural Research Service (ARS) scientists published a study (Trabue et al., 2010), which examined the type of VOCs emitted from a broiler house using canisters and sorbent tubes simultaneously. Trabue et al. (2010) concluded that neither sorbent tubes nor canisters were only able to capture more than 55% of VOCs present in the house, when considered separately. The implication is that the collection of VOCs by canister during the NAEMS could underpredict total VOC concentration. This coupled with the lack of an inlet measurement, which can contribute a significant portion of VOCs, adds to the uncertainty of the VOC emission estimates generated during NAEMS.

2.4.2 NMHC samples

As noted in section 2.3, three sites (CA1B, IN2H and IN3B) analyzed NMHCs using the INNOVA instrument by measuring THC and subtracting EtOH and CH_4. Following the NAEMS, the science advisor noted the emissions are inaccurate due to the inaccurate measurement of oxygenated hydrocarbons due to irreconcilable interferences by water vapor and other gases. Similarly, the continuous NMHC measurements from the KY sites measured with the VIG-200 instrument also inaccurately measures the oxygenated hydrocarbon component. The KY measurements were also reported in units of propane, which is different from the NAEMS and add a further challenge to integrate the data.

After the NAEMS, a study led by USDA-ARS scientists (Trabue et al., 2013) examined three different commercial NMHC analyzers methods to determine their ability to measure VOCs. Included in the methods studied were the GC/FID model 55C and PA-IR model 1412 (INNOVA model 1412), which were used by NAEMS. The study concluded that NMHC analyzers under-report total VOC concentrations when the compound profiles have significant levels of polar compounds, like at AFOs. The implication is that any NAEMS measurements, including the KY sites, would be an underestimation of NMHC and VOCs for the sites.

3 CALLS FOR INFORMATION

As part of the NAEMS effort, EPA issued two calls for information (CFI) to collect any additional data that should be considered in developing the NAEMS based EEMs. The first CFI issued in January of 2011, (https://www.regulations.gov/docket/EPA-HQ-OAR-2010-0960) was a broad call for quality-assured emissions and process data relevant to developing EEMs for any pollutant. The second CFI in issued in September of 2019 focused on VOC data for EEM development. Both CFIs yielded several peer reviewed journal articles that contained aggregated VOC emission rates. Under the second CFI, a commentor provided data from the South Lakes Dairy VOC Emission Characterization Report, which was conducted for the Center on Race, Poverty, and the Environment for use in the Association of Irritated Residents v. Fred Schakel Dairy lawsuit. The study was conducted over a two-day period, October 18-19, 2007, with emissions collected via flux chambers, sorbent tubes, and GC-MS. Results from the study were provided as speciated emission rates and factors for various components of the farm. No additional VOC data sets that could be used in an EEM development process like other pollutant collected during NAMES were offered under either of the CFIs.

4 DATA FROM LITERATURE

As noted in the introduction, VOC is a complex pollutant as it is the combination of several hundred compounds that can vary depending on the source (animal type and location on the farm) as well as farm conditions, such as meteorological conditions and feed type. Most research on VOC from AFOs is focused on odor or odor mitigation/abatement. As such, results provided in literature are typically in concentration (ppb, etc.) or odor units (OU). Obtaining an accurate estimate of airflow, or ventilation rate, further complicates the ability of researchers to report emissions of VOCs from various farm sources. In a critical review of swine VOC literature, Ni (2012)found only 8% of articles reported VOCs in terms of an emission rate for the farm. This lack of reported VOC emission rate complicates the ability to use information from peer reviewed journal articles to develop emission estimation methods.

Additionally, studies often focus on the most odorous, prevalent, or reactive compounds founds at AFOs, instead of total VOC. While not providing a complete picture of VOCs at AFOs, these studies do provide insight into the compounds of key interest to public health and ozone formation.

Appendix D contains an initial list of information collected from literature to utilize in method development, both total VOC estimates and estimates for individual compounds found on AFOs.

5 PROPOSED ACTION

NAEMS is one of the most comprehensive AFO monitoring studies to date. However, the NAEMS VOC data lack the quality and quantity to develop a total VOC EEMs using a similar statistical modeling process utilized for the other pollutants. At this time, EPA is continuing to search literature for data, both total VOC and individual compounds, that can be used to develop an emission estimation method based on subsequent studies that built off the lessons learned in NAEMS. This report summarizes our initial data findings as a progress report for the study. EPA continues to review additional data sources and is working toward providing an estimation method for AFOs to use in evaluating whether they trigger Clean Air Act thresholds. EPA plans on releasing an updated draft with this estimation method in by summer 2023.

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Appendix A: Initial VOC Characterization Study

Initial VOC Characterization Study
for the
National Air Emissions Monitoring Study
Albert J. Heber, Bill Bogan and Changhe Xiao
April 27, 2009

Methodology

As specified in the QAPP, VOC's were sampled from one site per species at the barn's primary representative exhaust fan using sorbent tubes (SOP V1), canisters (SOP V2) and all glass impingers (SOP V3).

Following several pilot tests of sorbent tubes, the type selected was the 6 mm x 7″ TDS tube (Carbotrap 300, Gerstel Inc, Linthicum, MD). Sorbent tube samples were collected through the GSS exhaust/odor port using a sampling box that allowed the incoming airstream to be split into two roughly-equal substreams. Each of these substreams flowed through two pairs of sorbent tubes connected in series such that the second tube served as a "breakthrough" tube for the first tube. Target flow rate was 50 mL/min for each substream. All tubing and fixtures upstream of (and between) the two sorbent tubes were Teflon. Studies were conducted to determine the optimal length of time for sorbent tube sampling to avoid ice blockage of the GC/MS sample inlet due to excessive water in the tubes. These studies showed that sampling from sites IN3B and IN2H should have maximum sampling times of 40-45 min to avoid excessive water, and that 30 min of sampling time provided an additional margin of safety, while still yielding quantifiable levels of VOCs. Simultaneously, based on recommended levels of water that could be introduced without freezing the inlet, psychrometric calculations based on measured sample RH and T (from AirDAC) were used on-site to ensure that excess water would not be trapped.

Canister sampling was conducted with 6-L TO-Can Canisters (Restek Corp, Bellefonte, PA), equipped with 1/4″ Swagelok SS4H Bellows Valves and 30-psig vacuum pressure gauges. Sampling trains contained Veriflo 423XL flow controllers with 2- to 4-sccm critical orifices and 7-µm in-line stainless steel filters. Flow controllers were pre-set in the lab to deliver approximately 3 mL/min. Canister sampling was conducted for 24 h, and the pressure of the canister was recorded at the beginning and end of the sample period for calculation of total sampled volume.

Impinger sampling was conducted using midget (30 mL) all-glass impingers (Ace Glass, Vineland, NJ). For each sample collected, four impingers were connected in series, with the first two each containing 15 mL of 0.1 N H_2SO_4. The third impinger was a blank to avoid spillover of trapping solution into the fourth impinger, which contained a moisture trap (approximately 20 g of dried silica gel). The inlet of the first impinger was connected to a Teflon filter holder containing a 47-mm PTFE filter membrane (1.0-µm pore size), and the outlet of the last impinger was connected first to a 0-5 L/min rotameter, and then to a sampling pump. All connections upstream of the last impinger were Teflon. The sampling pump was set to pull 2 L/min through the impinger train; this flow rate was checked several times during each two-hour sampling period to ensure that it was maintained.

Sites sampled, dates, and methods used are as follows:

IN2H	11/5	Canisters, sorbent tubes, impingers
	11/13	Sorbent tubes
IN3B	10/23	Canisters, sorbent tubes
IN5B	10/15	Canisters, sorbent tubes, impingers
	10/29	Sorbent tubes, impingers
CA1B	11/18	Canisters, sorbent tubes, impingers
	12/2	Sorbent tubes

All the sorbent tube and canister samples were analyzed (SOPs V4 & V6) on an Agilent Model 6890N GC coupled with a Model 5795 MS equipped with a Gerstel TDS-G sample inlet and manual sample introduction. The Electronic Impact mode was utilized. A temperature gradient from 34°C to 250°C was used to separate the compounds. The analytical results were analyzed by ChemStation, and all integrations were manually checked. This method used an external standard compound for instrumental monitoring, instead of an internal standard. This was necessary to avoid losses of low-molecular-weight analytes, which would occur in the purging of any solvent used to introduce the internal standard(s).

Emissions calculations for tube samples were conducted. The mass concentration was determined by dividing the mass of a compound detected on the sorbent tube by sampled volume (flow through tube series in mL/min times sampling duration in min). The daily emitted mass was the mass concentration multiplied by barn airflow for the sampling period. The annual emission rate was estimated by multiplying the daily emitted mass by the number of days of sampling (1440/sampling duration in minutes) and by 365.

Canister sample analyte concentrations (corrected for dilution necessary to pressurize the canister for sample transfer to the GC) were multiplied by barn airflow for the 24-hour sampling period to yield a daily emission rate, which was then multiplied by 365 to give the annual emission rate.

Impinger samples were analyzed (SOP V5) on a Dionex Ion Chromatograph (IC) which consists of a GP50 solvent delivery system, a CD25 conductivity detector, and an autosampler. The IC was equipped with a CS18 cation column and CSRS –II suppressor. The gradient elution ran from 0.5 mM methylsulfonic acid (MSA) to 30 mM at 0.3 mL/min. The suppressor current was set at 80 mA. The injection volume was 10 μL. No compounds other than ammonia were detected in any of the impinger samples.

Results

Broilers (CA1B)

Of the samples collected, three sorbent tube samples from Barn 12 (two on 12/2 and one on 11/18) gave quantifiable results, along with all four canisters 11/18. Emissions rates based on these samples are reported in Table 1.

A total of 26 compounds were each detected in at least one exhaust sample. Canister samples yielded greater annual emission rates for 24 of the 26 compounds. The only exceptions were two low-level compounds (dimethyl sulfone and indole) that were undetected in the canisters. By contrast, 17 of the compounds were undetected in any of the sorbent tubes. Fourteen of the 26 compounds contributed to the 90% cumulative mass, led by dimethyl sulfide (21.9%), isopropyl alcohol (17.9%), and acetic acid (15.7%). Isopropyl alcohol was undetected in all sorbent tubes.

Dimethyl disulfide, the predominant compound identified at site CA1B, has been reported as a main constituent of broiler emissions detected in previous field studies with canisters (Summers 2005), under laboratory conditions with sorbent tubes (Chang and Chen 2003), and in analysis of headspace above broiler litter in closed chambers (Hobbs et al 1995). Several of the predominant compounds in the CA1B samples were also among the most prevalent in sorbent tube samples collected at several locations in a commercial broiler facility (Trabue et al 2008); these authors generally found acetic acid, butanoic acid and propanoic acid to be the dominant species. Their list of target compounds did not include isopropyl alcohol (which, based on our results, may not have been successfully trapped by tubes anyway) or dimethyl sulfide.

Table 1. VOC emission rates calculated for broiler site CA1B from characterization study.

	# samples with detects		Tube/canister	Percent of Total Mass	
Compounds	**Tubes**	**Canisters**	**Emitted Mass Ratio**	**Analyte**	**Cumulative Sum**
Dimethyl disulfide	3/3	4/4	0.219	21.9%	21.9%
Isopropyl alcohol	0/3	4/4	0.000	17.9%	39.8%
Acetic acid	2/3	4/4	1.083	15.7%	55.5%
Butanoic acid	0/3	1/4	0.000	5.5%	61.0%
Propanoic acid	0/3	1/4	0.000	5.4%	66.4%
Methanol	0/3	2/4	0.000	4.8%	71.2%
Hexane	2/3	4/4	0.215	3.0%	74.3%
Nonanal	3/3	4/4	0.984	3.0%	77.2%
Hexanal	1/3	4/4	0.449	2.6%	79.8%
Phenol	2/3	4/4	1.523	2.4%	82.2%
n-Propanol	1/3	3/4	0.514	2.2%	84.4%
Heptanal	0/3	4/4	0.000	2.1%	86.5%
Octanal	0/3	3/4	0.000	1.9%	88.4%
4-Methyl phenol	1/3	4/4	0.603	1.7%	90.1%
Benzaldehyde	3/3	3/4	1.771	1.60%	91.7%
Pentanal	0/3	3/4	0.000	1.5%	93.2%
Dimethyl sulfone	2/3	0/4	-	1.5%	94.6%
Ethanol	0/3	4/4	0.000	1.0%	95.7%
Tridecane	2/3	2/4	4.323	0.94%	96.6%
Undecane	2/3	4/4	2.739	0.92%	97.5%
Toluene	3/3	4/4	0.428	0.88%	98.4%
Benzene	2/3	4/4	0.201	0.61%	99.0%
Acetone	0/3	1/4	0.000	0.49%	99.5%
Dodecane	0/3	2/4	0.000	0.20%	99.7%
Indole	2/3	0/4	-	0.16%	99.9%
Pentadecane	0/3	1/4	0.000	0.14%	100.0%

Layers (IN2H)

Valid results were obtained from a total of five sorbent tubes taken from exhaust air. Three of these samples (two from Barn 6 and one from Barn 7) were collected on 11/5, while the remaining two (both from Barn 7) were collected on 11/13. Valid data were obtained from all four canisters sampled on 11/5. Table 2 below summarizes annual emission rates calculated from these nine samples.

Although a total of 27 compounds were detected in at least one tube or canister, isopropyl alcohol alone was responsible for over 85% of the total emitted mass from the IN2H barns. Isopropyl alcohol was successfully trapped by canisters only, and was undetected in any of the sorbent tubes. The combination of isopropyl alcohol, acetic acid and butanoic acid was sufficient to reach 90% of the cumulative mass. In contrast to CA1B, acetic acid, butanoic acid and several minor compounds were trapped better with sorbent tubes than with canisters. These included eight minor compounds that were present in at least one tube sample, but none of the canister samples. However, the failure of tubes to trap isopropyl alcohol clearly rules out their use for this site.

An earlier study of organic acids in egg layer houses (Mårtensson et al 1999) observed that acetic acid was the dominant species, followed by butanoic (butyric) and propanoic (propionic) acids. The relative ratios of these three compounds in IN2H samples (acetic acid was approximately 4 times as abundant as each of the other two compounds) were very similar to those reported by these authors in one of the two houses they studied.

Swine (IN3B)

All four sorbent tubes and all four canisters from the 10/23 sampling event provided valid emission data (Table 3).

Each of 36 individual VOCs were identified in at least one IN3B sample and nine compounds contributed to 90% of the mass. Except for 4-methyl phenol, all nine compounds were organic acids, led by acetic, butanoic and propanoic acids. Unlike any of the other sites, several of the highest-concentration analytes appear to show better trapping by sorbent tubes than by canisters. However, this is mainly due to the presence of one very high-concentration tube sample, which contained approximately eight times more of most analytes than the other three tubes. Had this sample contained analyte levels more commensurate with the others, the tube/canister ratio for most compounds would have been similar to those seen at other sites.

An SPME study of indoor air at two Czech swine farms (Ciganek and Neca 2008) reported acetic acid, butanoic acid, *p*-cresol, propanoic acid, pentanoic acid, phenol and hexanal as the primary compounds. Thus, four of the top five compounds from the Czech study match exactly with the top five VOCs identified from IN3B, although *p*-cresol was not detected in the IN3B samples. Phenol and hexanal were also detected from IN3B, albeit not in the list of compounds contributing to the 90% total mass.

Table 2. VOC emission rates calculated for layer site IN2H from characterization study.

	# samples with detects		Tube/canister	Percent of Total Mass	
Compounds	Tubes	Canisters	Emitted Mass Ratio	Analyte	Cumulative Sum
Isopropyl alcohol	0/5	4/4	0.000	85.3%	85.3%
Acetic acid	4/5	4/4	3.245	4.5%	89.8%
Butanoic acid	4/5	3/4	1.938	1.7%	91.5%
Acetone	0/5	3/4	0.000	1.6%	93.2%
Propanoic acid	3/5	3/4	1.465	1.3%	94.5%
Hexanal	5/5	4/4	0.851	0.9%	95.5%
Hexane	5/5	4/4	2.466	0.86%	96.3%
Nonanal	5/5	3/4	1.380	0.70%	97.0%
Heptanal	3/5	4/4	0.321	0.36%	97.4%
Benzaldehyde	4/5	4/4	1.653	0.33%	97.7%
Dimethyl disulfide	5/5	4/4	1.526	0.28%	98.0%
3-Methyl butanoic acid	2/5	0/4	-	0.27%	98.3%
n-Propanol	2/5	4/4	0.854	0.25%	98.5%
Octanal	0/5	3/4	0.000	0.23%	98.8%
Pentanal	1/5	4/4	0.046	0.17%	98.9%
Phenol	1/5	4/4	0.500	0.15%	99.1%
4-Methyl phenol	2/5	4/4	0.483	0.15%	99.2%
2-Methyl propanoic acid	1/5	0/4	-	0.14%	99.4%
2-Methyl butanoic acid	1/5	0/4	-	0.14%	99.5%
Dimethyl sulfone	2/5	0/4	-	0.11%	99.6%
Ethanol	4/5	4/4	0.289	0.11%	99.7%
Undecane	2/5	0/4	-	0.08%	99.8%
Toluene	5/5	3/4	2.274	0.06%	99.9%
Benzene	4/5	3/4	2.545	0.06%	99.9%
Tridecane	1/5	0/4	-	0.03%	100.0%
4-Ethyl phenol	1/5	0/4	-	0.02%	100.0%
Propyl butyrate	1/5	0/4	-	0.01%	100.0%

As with IN2H, the IN3B organic acid results agreed quite well with a finishing house study by Mårtensson et al. (1999), who observed that acetic acid was about twice as abundant as either butanoic or propanoic acids, with other acids (valeric, isovaleric, lactic), none of which was detected at IN3B, present at much lower concentrations. Essentially the same results were reported in a study of *in vitro* incubation of swine manure (Miller and Varel 2003). Our results also closely parallel those of a recent sorbent tube study in a finisher house (Trabue et al 2008), which observed acetic acid, butanoic acid, propanoic acid, 4-methyl phenol and 2-methyl propanoic acid, in that order, to be the most abundant VOCs.

Dairy (IN5B)

All sorbent tube data from the 10/15 sampling event were invalid. Upon reducing the sampling period from 60 to 30 minutes, all four tubes on 10/29 provided good data. All four of the canister samples from 10/15 were usable.

Emissions from site IN5B contained a total of 34 identifiable compounds. Of these, 14 contributed to the 90% mass total. Canisters performed better than tubes for 31 of the 34

Table 3. VOC emission rates calculated for swine site IN3B from characterization study.

	# samples with detects		Tube/canister	Percent of Total Mass	
Compounds	Tubes	Canisters	Emitted Mass Ratio	Analyte	Cumulative Sum
Acetic acid	3/4	4/4	4.618	35.9%	35.9%
Butanoic acid	4/4	4/4	4.579	18.1%	54.0%
Propanoic acid	4/4	4/4	3.631	16.4%	70.4%
Pentanoic acid	4/4	4/4	3.117	5.5%	75.8%
3-Methyl butanoic acid	4/4	2/4	4.680	4.0%	79.9%
2-Methyl butanoic acid	4/4	3/4	3.199	3.8%	83.7%
2-Methyl propanoic acid	3/4	4/4	1.350	2.7%	86.4%
Hexanoic acid	2/4	0/4	-	2.1%	88.5%
4-Methyl phenol	3/4	4/4	1.022	2.0%	90.5%
n-Propanol	3/4	4/4	0.589	1.1%	91.7%
1-Butanol	1/4	3/4	0.245	1.1%	92.8%
Phenol	3/4	4/4	0.589	1.0%	93.8%
2-Methyl hexanoic acid	1/4	0/4	-	1.0%	94.8%
Ethanol	0/4	3/4	0.000	1.0%	95.7%
Methanol	0/4	2/4	0.000	0.79%	96.5%
Hexanal	1/4	4/4	0.229	0.35%	96.8%
Ethanol	4/4	0/4	-	0.34%	97.2%
2-Butanol	0/4	4/4	0.000	0.30%	97.5%
Nonanal	2/4	4/4	0.755	0.29%	97.8%
4-Ethyl phenol	2/4	4/4	1.000	0.27%	98.0%
Dimethyl disulfide	1/4	4/4	0.337	0.27%	98.3%
Benzaldehyde	3/4	4/4	1.187	0.26%	98.6%
Heptanal	0/4	4/4	0.000	0.22%	98.8%
Dimethyl sulfone	1/4	4/4	0.515	0.20%	99.0%
Isopropyl alcohol	0/4	1/4	0.000	0.13%	99.1%
Hexane	1/4	3/4	1.023	0.13%	99.2%
n-Propyl acetate	0/4	2/4	0.000	0.12%	99.4%
Dodecane	0/4	3/4	0.000	0.11%	99.5%
Toluene	4/4	4/4	2.000	0.12%	99.6%
Undecane	0/4	4/4	0.000	0.09%	99.7%
Tridecane	0/4	4/4	0.000	0.09%	99.8%
Benzene	4/4	3/4	0.556	0.08%	99.9%
Hexadecane	0/4	2/4	0.000	0.05%	99.9%
Indole	2/4	3/4	1.600	0.05%	100.0%
Pentadecane	0/4	1/4	0.000	0.03%	100.0%
Hexane	0/4	1/4	0.000	0.02%	100.0%

compounds, including 23 compounds that were undetected in any of the tubes. The remaining three analytes (ethyl acetate, ethanol and propyl propanoate), each of which was included in the 90% mass cutoff, were trapped equally well by canisters and tubes. Two alcohols (n-propanol and isopropyl alcohol) were the dominant VOCs; ethyl acetate was the only other compound that accounted for >10% of the total emitted mass.

Analyses of indoor air from Czech dairies (Ciganek and Neca 2008) showed acetic acid, butanoic acid, propanoic acid, *p*-cresol and phenol as the predominant compounds. All three of these acids were present in the 90% mass group for the IN5B samples, although they were surpassed by n-propanol, isopropyl alcohol and ethyl acetate. These three compounds either were undetected or were not analyzed for in the Czech study. Mårtensson et al (1999) identified acetic

acid as the primary acid in indoor dairy air samples, although, in their study, it was followed closely by lactic acid, which was undetected in the IN5B samples. Filipy et al (2006) reported ethanol to be the only VOC emitted in significant levels from a WA experimental dairy. Of the five compounds present at higher levels at IN5B, these authors did not detect n-propanol, and do not appear to have targeted isopropyl alcohol, acetic acid, or ethyl acetate. Lastly, several of the most prevalent compounds in the IN5B samples (e.g. acetic acid, propanol, ethanol) were among those measured at the highest levels at a California dairy (Rabaud et al 2003), although several other compounds found at medium-to-high levels (e.g. methyl isobutyrate, butylamine, pyridine, dimethyl sulfoxide, ethyl ether) were not observed at IN5B.

Table 4. VOC emission rates calculated for dairy site IN5B from characterization study.

	# samples with detects		Tube/canister	Percent of Total Mass	
Compounds	**Tubes**	**Canisters**	**Emitted Mass Ratio**	**Analyte**	**Cumulative Sum**
n-Propanol	4/4	4/4	0.63	31.8%	31.8%
Isopropyl alcohol	2/4	4/4	0.09	12.6%	44.4%
Ethyl acetate	4/4	4/4	1.13	10.7%	55.1%
Acetic acid	2/4	4/4	0.67	8.2%	63.3%
Ethanol	4/4	4/4	1.07	6.6%	69.9%
n-Propyl acetate	4/4	4/4	0.84	5.8%	75.6%
2-Methyl propanoic acid	0/4	3/4	0.00	4.6%	80.3%
Butanoic acid	0/4	2/4	0.00	2.7%	83.0%
2-Methyl hexanoic acid	0/4	1/4	0.00	1.5%	84.5%
Propanoic acid	0/4	1/4	0.00	1.5%	85.9%
2-Butanol	2/4	4/4	0.37	1.5%	87.4%
Propyl propanonate	4/4	3/4	1.06	1.1%	88.5%
4-Methyl phenol	0/4	4/4	0.00	1.0%	89.5%
Pentanal	0/4	4/4	0.00	1.0%	90.5%
Hexanal	1/4	4/4	0.08	0.99%	91.5%
Heptanal	0/4	4/4	0.00	0.96%	92.4%
Octanal	0/4	3/4	0.00	0.85%	93.3%
Phenol	0/4	4/4	0.00	0.85%	94.1%
4-Ethyl phenol	0/4	4/4	0.00	0.80%	94.9%
Nonanal	0/4	3/4	0.00	0.79%	95.7%
Hexane	0/4	4/4	0.00	0.71%	96.4%
Benzyl alcohol	0/4	3/4	0.00	0.60%	97.0%
Dimethyl disulfide	0/4	4/4	0.00	0.57%	97.6%
Benzaldehyde	0/4	4/4	0.00	0.52%	98.1%
Propyl butyrate	0/4	2/4	0.00	0.35%	98.5%
Toluene	4/4	4/4	0.89	0.27%	98.8%
Dodecane	0/4	3/4	0.00	0.22%	99.0%
Undecane	0/4	4/4	0.00	0.21%	99.2%
Dimethyl sulfone	0/4	1/4	0.00	0.18%	99.4%
Propyl hexanoate	0/4	1/4	0.00	0.17%	99.5%
1-Butanol	0/4	1/4	0.00	0.15%	99.7%
Propyl pentanoate	0/4	1/4	0.00	0.13%	99.8%
n-Butanol	0/4	1/4	0.00	0.11%	99.9%
Benzene	4/4	2/4	0.98	0.08%	100.0%

Overview of Results

Identifications of predominant VOCs, in general, agreed well with existing literature for all four species. Based on the 90% mass cutoffs for each species, the target analyte list for the sampling phase of the NAEMS will consist of 26 compounds (Table 5).

Table 5. Target analytes for VOC sampling as determined by the initial characterization study.

Compound	Present in 90% mass cutoff for:			
	Broilers	Layers	Swine	Dairy
Acetic acid	+	+	+	+
Butanoic acid	+	+	+	+
2-Butanol				+
Dimethyl disulfide	+			
Ethanol				+
Ethyl acetate				+
Heptanal	+			
Hexanal	+			
Hexane	+			
Hexanoic acid			+	
Isopropyl alcohol	+	+		+
Methanol	+			
2-Methyl butanoic acid			+	
3-Methyl butanoic acid			+	
2-Methyl hexanoic acid				+
4-Methyl phenol	+		+	+
2-Methyl propanoic acid			+	+
Nonanal	+			
Octanal	+			
Pentanal				+
Pentanoic acid			+	
Phenol	+			
Propanoic acid	+		+	+
n-Propanol	+			+
n-Propyl acetate				+
Propyl propanoate				+

Analyte trapping was usually better with canisters than sorbent tubes, especially for the compounds in the 90% mass groups for CA1B and IN5B, and for the single most-dominant compound (isopropyl alcohol) at IN2H. The apparent better performance of tubes relative to canisters at IN3B was apparently due to one tube sample containing significantly elevated levels of most analytes relative to the others, thus inflating the average tube-sample yield.

Several problems were also encountered with tube sampling. Despite the precautions detailed above, a high percentage of the tube samples collected from the CA1B (5/8) and IN2H (3/8) sites contained sufficient moisture that they either could not be analyzed (due to freezing of the GC inlet), or gave extremely distorted chromatograms. The latter is an expected consequence of

tubes trapping too much moisture (Trabue et al 2008). Furthermore, breakthrough tubes collected at some sites (e.g. CA1B) did show non-negligible levels of some analytes (data not shown), indicating that trapping by the primary tube was incomplete. Finally, the 30-min tube sampling period introduces considerably more opportunity for sampling bias, as compared with the 24-hour canister sampling, which will represent a full day of site operations, along with all the diurnal variations that might be missed by employing a shorter sampling period.

Based on these results, canister sampling will be used exclusively for the ongoing VOC sampling effort. No significant peaks (apart from NH_4^+) were observed in any of the impinger samples; thus, amine sampling via this method will not be conducted for the remainder of the NAEMS.

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Appendix B: VOC Data Summary

Table B-1. Dairy VOC sample data

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
IN5B	B1	Dairy	Mechanically ventilated barn	6/1/2009	1	6.92	259	155
IN5B	B1	Dairy	Mechanically ventilated barn	6/15/2009	2	2.53	269	58.8
IN5B	B1	Dairy	Mechanically ventilated barn	8/17/2009	2	3.5	260	78
IN5B	B1	Dairy	Mechanically ventilated barn	1/19/2010	2	2.95	121	31
IN5B	B1	Dairy	Mechanically ventilated barn	2/3/2010	2	3.53	121	37
IN5B	B1	Dairy	Mechanically ventilated barn	2/17/2010	2	2.72	113	26.6
IN5B	B1	Dairy	Mechanically ventilated barn	3/10/2010	2	1.45	273	34.2
IN5B	B2	Dairy	Mechanically ventilated barn	6/1/2009	1	5.71	258	127
IN5B	B2	Dairy	Mechanically ventilated barn	6/15/2009	2	3.89	262	88.1
IN5B	B2	Dairy	Mechanically ventilated barn	8/17/2009	2	3.76	260	84.2
IN5B	B2	Dairy	Mechanically ventilated barn	1/19/2010	2	2.35	95.9	19.5
IN5B	B2	Dairy	Mechanically ventilated barn	2/3/2010	2	3.22	98.3	27.3
IN5B	B2	Dairy	Mechanically ventilated barn	2/17/2010	2	2.61	99.5	22.4
IN5B	B2	Dairy	Mechanically ventilated barn	3/10/2010	2	1.03	245	21.8
NY5B	B1	Dairy	Mechanically ventilated barn	4/24/2009	1	1.87	240	38.7
NY5B	B1	Dairy	Mechanically ventilated barn	4/27/2009	1	4.44	207	79.5
NY5B	B1	Dairy	Mechanically ventilated barn	5/27/2009	1	6.24	288	155
NY5B	B1	Dairy	Mechanically ventilated barn	7/15/2009	2	6.99	305	184
NY5B	B1	Dairy	Mechanically ventilated barn	9/14/2009	2	5.07	307	134
NY5B	B1	Dairy	Mechanically ventilated barn	10/26/2009	2	7.68	118	78
NY5B	B1	Dairy	Mechanically ventilated barn	11/10/2009	2	3.77	113	36.7
NY5B	B1	Dairy	Mechanically ventilated barn	12/2/2009	1	16.8	22.3	32.2
WI5B	B1	Dairy	Mechanically ventilated barn	4/6/2009	2	2.39	75.3	15.5
WI5B	B1	Dairy	Mechanically ventilated barn	6/15/2009	2	1.18	158	16.1
WI5B	B1	Dairy	Mechanically ventilated barn	7/20/2009	2	0.85	279	20.4
WI5B	B1	Dairy	Mechanically ventilated barn	8/24/2009	2	0.49	291	12.2
WI5B	B1	Dairy	Mechanically ventilated barn	9/7/2009	2	0.73	229	14.4
WI5B	B2	Dairy	Mechanically ventilated barn	4/6/2009	2	2.41	68.8	14.3
WI5B	B2	Dairy	Mechanically ventilated barn	6/15/2009	2	1.1	210	20.1
WI5B	B2	Dairy	Mechanically ventilated barn	7/20/2009	2	2.27	329	64.4
WI5B	B2	Dairy	Mechanically ventilated barn	8/24/2009	2	1.05	343	31.1
WI5B	B2	Dairy	Mechanically ventilated barn	9/7/2009	2	0.71	288	17.6
WI5B	B2	Dairy	Mechanically ventilated barn	11/9/2009	2	1.98	N/A	N/A

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
WI5B	B2	Dairy	Mechanically ventilated barn	12/7/2009	2	5.97	N/A	N/A
NY5B	MC	Dairy	Milking center	4/24/2009	1	1.69	43.5	6.37
NY5B	MC	Dairy	Milking center	4/27/2009	1	0.13	63.2	0.74
NY5B	MC	Dairy	Milking center	5/27/2009	2	2.7	72.2	16.8
NY5B	MC	Dairy	Milking center	7/15/2009	2	2.43	75.1	15.8
NY5B	MC	Dairy	Milking center	9/14/2009	2	1.3	82.7	9.26
NY5B	MC	Dairy	Milking center	10/26/2009	2	1.19	68.3	7.04
NY5B	MC	Dairy	Milking center	11/10/2009	1	0.9	40.8	3.17
NY5B	MC	Dairy	Milking center	12/2/2009	2	5.89	21.8	11.1
CA5B	B2	Dairy	Naturally ventilated barn	12/18/2009	4	0.292	768	-7.1
CA5B	B2	Dairy	Naturally ventilated barn	1/8/2010	4	0.924	628	32.3
CA5B	B2	Dairy	Naturally ventilated barn	1/23/2010	4	1.115	135	9.8
CA5B	B2	Dairy	Naturally ventilated barn	1/29/2010	4	0.234	1483	5.4
CA5B	B2	Dairy	Naturally ventilated barn	2/11/2010	4	0.4	2571	10.6
CA5B	B2	Dairy	Naturally ventilated barn	2/18/2010	4	0.826	1138	-33.4
CA5B	B2	Dairy	Naturally ventilated barn	2/22/2010	4	0.37	1605	32.2
WA5B	B2	Dairy	Naturally ventilated barn	5/6/2009	2	0.17	2125	30.9
WA5B	B2	Dairy	Naturally ventilated barn	6/24/2009	2	0.4	1577	54.1
WA5B	B2	Dairy	Naturally ventilated barn	9/23/2009	2	0.51	473	20.8
WA5B	B2	Dairy	Naturally ventilated barn	9/29/2009	2	1.03	1151	102.4
WA5B	B4	Dairy	Naturally ventilated barn	5/6/2009	1	0.6	1241	64.6
WA5B	B4	Dairy	Naturally ventilated barn	6/24/2009	2	0.63	1661	89.8
WA5B	B4	Dairy	Naturally ventilated barn	9/23/2009	2	1.82	359	56.5
WA5B	B4	Dairy	Naturally ventilated barn	9/29/2009	2	1.83	1256	198.1

Table B-2. Poultry VOC sample data

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
CA1B	H10	Poultry - Broiler	House	7/14/2010	2	0.78	58.8	3.94
CA1B	H10	Poultry - Broiler	House	8/3/2010	2	0.91	4.5	0.35
CA1B	H10	Poultry - Broiler	House	8/16/2010	2	0.74	18.9	1.21
CA1B	H10	Poultry - Broiler	House	8/26/2010	2	0.96	30.4	2.53
CA1B	H10	Poultry - Broiler	House	9/3/2010	2	0.39	56.3	1.89
CA1B	H10	Poultry - Broiler	House	9/12/2010	2	0.39	51.2	1.72
CA1B	H10	Poultry - Broiler	House	10/7/2010	2	1.42	5.12	0.63
CA1B	H12	Poultry - Broiler	House	7/14/2010	2	1.1	59.7	5.7
CA1B	H12	Poultry - Broiler	House	8/3/2010	2	0.75	4.41	0.29
CA1B	H12	Poultry - Broiler	House	8/16/2010	2	0.76	18.8	1.24
CA1B	H12	Poultry - Broiler	House	8/26/2010	2	1.36	29.4	3.45
CA1B	H12	Poultry - Broiler	House	9/3/2010	2	0.43	55.4	2.06
CA1B	H12	Poultry - Broiler	House	10/7/2010	2	1.8	4.73	0.73
CA2B	H5	Poultry - Egg Layer	High rise house	6/9/2009	2	0.55	56.5	2.7
CA2B	H5	Poultry - Egg Layer	High rise house	6/18/2009	2	1.13	86.2	8.4
CA2B	H5	Poultry - Egg Layer	High rise house	7/29/2009	2	0.64	78.5	4.34
CA2B	H5	Poultry - Egg Layer	High rise house	10/2/2009	2	9.58	60	49.7
CA2B	H5	Poultry - Egg Layer	High rise house	10/12/2009	2	0.38	38.7	1.26
CA2B	H5	Poultry - Egg Layer	High rise house	10/15/2009	2	0.28	64.4	1.55
CA2B	H5	Poultry - Egg Layer	High rise house	11/18/2009	2	1	19	1.64
CA2B	H6	Poultry - Egg Layer	High rise house	6/9/2009	2	0.56	54.5	2.66
CA2B	H6	Poultry - Egg Layer	High rise house	7/29/2009	2	0.45	72	2.78
CA2B	H6	Poultry - Egg Layer	High rise house	10/2/2009	2	11.4	55.8	54.9
CA2B	H6	Poultry - Egg Layer	High rise house	10/12/2009	2	0.41	34.6	1.24
CA2B	H6	Poultry - Egg Layer	High rise house	10/15/2009	2	0.35	53.9	1.62
CA2B	H6	Poultry - Egg Layer	High rise house	11/18/2009	2	0.81	33.7	2.35
IN2H	H6	Poultry - Egg Layer	High rise house	1/9/2009	2	23.5	38.9	78.9
IN2H	H6	Poultry - Egg Layer	High rise house	3/12/2009	2	1.18	37.3	3.8
IN2H	H6	Poultry - Egg Layer	High rise house	4/30/2009	2	0.63	55.9	3.05
IN2H	H6	Poultry - Egg Layer	High rise house	5/9/2009	2	0.6	59.4	3.07
IN2H	H6	Poultry - Egg Layer	High rise house	5/13/2009	2	1.09	57.3	5.39
IN2H	H6	Poultry - Egg Layer	High rise house	5/27/2009	2	2.68	58.1	13.5
IN2H	H6	Poultry - Egg Layer	High rise house	6/23/2009	2	0.52	49.7	2.25

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
IN2H	H7	Poultry - Egg Layer	High rise house	1/9/2009	2	4.67	37.7	15.2
IN2H	H7	Poultry - Egg Layer	High rise house	3/12/2009	1	1.18	38	3.86
IN2H	H7	Poultry - Egg Layer	High rise house	4/30/2009	2	0.72	46.2	2.88
IN2H	H7	Poultry - Egg Layer	High rise house	5/9/2009	2	0.73	46.6	2.96
IN2H	H7	Poultry - Egg Layer	High rise house	5/13/2009	2	4.91	35.2	14.9
IN2H	H7	Poultry - Egg Layer	High rise house	5/27/2009	2	0.81	36.7	2.56
IN2H	H7	Poultry - Egg Layer	High rise house	6/23/2009	2	1.26	19.4	2.11
NC2B	H4	Poultry - Egg Layer	High rise house	4/12/2009	2	0.45	17.7	0.69
NC2B	H4	Poultry - Egg Layer	High rise house	4/27/2009	2	0.42	127	4.65
NC2B	H4	Poultry - Egg Layer	High rise house	5/20/2009	2	0.54	43.4	2.03
NC2B	H4	Poultry - Egg Layer	High rise house	7/2/2009	2	0.44	178	6.81
NC2B	H4	Poultry - Egg Layer	High rise house	8/26/2009	2	0.46	220	8.7
NC2B	H4	Poultry - Egg Layer	High rise house	9/9/2009	2	0.24	130	2.66
NC2B	H4	Poultry - Egg Layer	High rise house	9/18/2009	2	0.29	80	2.03
NC2B	H4 pit	Poultry - Egg Layer	High rise house	4/12/2009	2	0.54	17.7	0.83
NC2B	H4 pit	Poultry - Egg Layer	High rise house	4/27/2009	2	0.41	128	4.52
NC2B	H4 pit	Poultry - Egg Layer	High rise house	5/20/2009	2	0.62	43.4	2.31
NC2B	H4 pit	Poultry - Egg Layer	High rise house	7/2/2009	2	0.51	178	7.9
NC2B	H4 pit	Poultry - Egg Layer	High rise house	8/26/2009	2	0.29	220	5.51
NC2B	H4 pit	Poultry - Egg Layer	High rise house	9/9/2009	2	0.26	130	2.94
NC2B	H4 pit	Poultry - Egg Layer	High rise house	9/18/2009	2	0.41	80.4	2.83
IN2B	B8	Poultry - Egg layer	Manure belt house	9/24/2009	2	0.62	90.6	4.88
IN2B	B8	Poultry - Egg layer	Manure belt house	10/1/2009	2	0.88	74.6	5.7
IN2B	B8	Poultry - Egg layer	Manure belt house	10/7/2009	2	4.37	73.5	27.7
IN2B	B8	Poultry - Egg layer	Manure belt house	10/19/2009	2	1.66	67.5	9.7
IN2B	B8	Poultry - Egg layer	Manure belt house	11/4/2009	2	1.4	67.1	8.1
IN2B	B8	Poultry - Egg layer	Manure belt house	11/18/2009	2	1.35	66.9	7.8
IN2B	B8	Poultry - Egg layer	Manure belt house	12/9/2009	2	2.42	57.3	12
IN2B	B9	Poultry - Egg layer	Manure belt house	9/24/2009	2	0.67	88.1	5.12
IN2B	B9	Poultry - Egg layer	Manure belt house	10/1/2009	2	0.78	30.5	2.06
IN2B	B9	Poultry - Egg layer	Manure belt house	10/7/2009	2	6.92	34	20.3
IN2B	B9	Poultry - Egg layer	Manure belt house	10/19/2009	2	3.14	73.8	20
IN2B	B9	Poultry - Egg layer	Manure belt house	11/4/2009	2	1.3	14.4	1.62
IN2B	B9	Poultry - Egg layer	Manure belt house	11/18/2009	2	1.39	29.4	3.53

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
IN2B	B9	Poultry - Egg layer	Manure belt house	12/9/2009	2	0.96	10.5	0.87

Table B-3. Swine VOC sample data

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
IA4B	Far9	Swine - Breeding Gestation	Farrowing room	2/19/2009	1	5.67	0.36	0.18
IA4B	Far9	Swine - Breeding Gestation	Farrowing room	3/5/2009	1	23.6	0.47	0.96
IA4B	Far9	Swine - Breeding Gestation	Farrowing room	5/27/2010	2	1.89	0.59	0.1
IA4B	Far9	Swine - Breeding Gestation	Farrowing room	7/1/2010	2	1.16	1.8	0.18
IA4B	Far9	Swine - Breeding Gestation	Farrowing room	7/29/2010	2	0.52	1.47	0.07
IA4B	Far9	Swine - Breeding Gestation	Farrowing room	8/6/2010	2	0.67	2.45	0.14
IA4B	Far9	Swine - Breeding Gestation	Farrowing room	8/12/2009	2	0.43	3.41	0.13
NC4B	Far	Swine - Breeding Gestation	Farrowing room	4/21/2009	1	1.12	2.14	0.21
NC4B	Far	Swine - Breeding Gestation	Farrowing room	5/12/2009	2	0.78	1.86	0.12
NC4B	Far	Swine - Breeding Gestation	Farrowing room	7/4/2009	2	0.23	3.96	0.08
NC4B	Far	Swine - Breeding Gestation	Farrowing room	7/11/2009	2	0.27	4.32	0.1
NC4B	Far	Swine - Breeding Gestation	Farrowing room	8/4/2009	2	1.3	4.89	0.55
IA4B	B1	Swine - Breeding Gestation	Gestation barn	2/19/2009	1	3.72	10	3.22
IA4B	B1	Swine - Breeding Gestation	Gestation barn	3/5/2009	1	15	21.3	27.6
IA4B	B1	Swine - Breeding Gestation	Gestation barn	5/27/2010	2	0.69	27.4	1.64
IA4B	B1	Swine - Breeding Gestation	Gestation barn	7/1/2010	2	0.29	51.9	1.29
IA4B	B1	Swine - Breeding Gestation	Gestation barn	8/6/2010	2	0.45	60.1	2.31
IA4B	B2	Swine - Breeding Gestation	Gestation barn	2/19/2009	1	1.31	9.53	1.08
IA4B	B2	Swine - Breeding Gestation	Gestation barn	5/27/2010	2	1.46	36	4.56
NC4B	B1	Swine - Breeding Gestation	Gestation barn	4/21/2009	1	1.19	32.1	3.31
NC4B	B1	Swine - Breeding Gestation	Gestation barn	5/12/2009	2	0.81	26.5	1.85
NC4B	B1	Swine - Breeding Gestation	Gestation barn	6/25/2009	2	0.54	84.1	3.9
NC4B	B1	Swine - Breeding Gestation	Gestation barn	7/4/2009	2	0.19	70.9	1.14
NC4B	B1	Swine - Breeding Gestation	Gestation barn	8/4/2009	2	1.91	78.4	12.9
NC4B	B1	Swine - Breeding Gestation	Gestation barn	12/7/2009	2	0.62	7.9	0.42
NC4B	B2	Swine - Breeding Gestation	Gestation barn	4/21/2009	1	0.68	23.7	1.4
NC4B	B2	Swine - Breeding Gestation	Gestation barn	5/12/2009	2	1.67	18.8	2.71

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
NC4B	B2	Swine - Breeding Gestation	Gestation barn	6/25/2009	2	0.43	54.3	2.02
NC4B	B2	Swine - Breeding Gestation	Gestation barn	7/11/2009	2	0.45	46.6	1.83
NC4B	B2	Swine - Breeding Gestation	Gestation barn	12/7/2009	2	0.62	7.26	0.39
OK4B	B1	Swine - Breeding Gestation	Gestation barn	4/8/2009	2	0.48	39.2	1.63
OK4B	B1	Swine - Breeding Gestation	Gestation barn	5/18/2009	2	0.16	44.6	0.62
OK4B	B1	Swine - Breeding Gestation	Gestation barn	6/9/2009	2	0.45	55.2	2.15
OK4B	B1	Swine - Breeding Gestation	Gestation barn	7/16/2009	2	0.32	58.5	1.6
OK4B	B2	Swine - Breeding Gestation	Gestation barn	4/8/2009	2	1.03	35.4	3.14
OK4B	B2	Swine - Breeding Gestation	Gestation barn	5/18/2009	2	0.77	44.6	2.98
OK4B	B2	Swine - Breeding Gestation	Gestation barn	6/9/2009	2	0.37	52.9	1.71
OK4B	B2	Swine - Breeding Gestation	Gestation barn	6/25/2009	2	0.53	69.6	3.17
OK4B	B3	Swine - Breeding Gestation	Gestation barn	5/18/2009	2	0.3	3.35	0.09
OK4B	B3	Swine - Breeding Gestation	Gestation barn	6/9/2009	2	0.45	5.14	0.2
OK4B	B3	Swine - Breeding Gestation	Gestation barn	6/25/2009	2	0.59	6.61	0.34
OK4B	B3	Swine - Breeding Gestation	Gestation barn	7/16/2009	1	0.42	6.74	0.25
IN3B	R5	Swine - Grow-Finish	Finishing barn	6/1/2009	1	1	0.66	34.5
IN3B	R5	Swine - Grow-Finish	Finishing barn	6/8/2009	1	1	0.81	41.7
IN3B	R5	Swine - Grow-Finish	Finishing barn	6/24/2009	1	1	0.81	48.8
IN3B	R5	Swine - Grow-Finish	Finishing barn	7/13/2009	1	1	0.29	26.6
IN3B	R5	Swine - Grow-Finish	Finishing barn	7/22/2009	1	1	1.23	20.9
IN3B	R5	Swine - Grow-Finish	Finishing barn	7/23/2009	1	1	0.8	26.3
IN3B	R6	Swine - Grow-Finish	Finishing barn	6/1/2009	1	1	0.95	32.4
IN3B	R6	Swine - Grow-Finish	Finishing barn	6/8/2009	1	1	4.06	47.7
IN3B	R6	Swine - Grow-Finish	Finishing barn	6/24/2009	1	1	0.88	48.4
IN3B	R6	Swine - Grow-Finish	Finishing barn	7/13/2009	1	1	0.79	35.8
IN3B	R6	Swine - Grow-Finish	Finishing barn	7/22/2009	1	1	1.49	26
IN3B	R6	Swine - Grow-Finish	Finishing barn	7/23/2009	1	1	0.83	36.2
IN3B	R7	Swine - Grow-Finish	Finishing barn	6/1/2009	1	1	0.95	32.2
IN3B	R7	Swine - Grow-Finish	Finishing barn	6/8/2009	1	1	1.03	42.2
IN3B	R7	Swine - Grow-Finish	Finishing barn	6/24/2009	1	1	0.44	50.5
IN3B	R7	Swine - Grow-Finish	Finishing barn	7/13/2009	1	1	1.12	42.6
IN3B	R7	Swine - Grow-Finish	Finishing barn	7/22/2009	1	1	0.62	26.8
IN3B	R7	Swine - Grow-Finish	Finishing barn	7/23/2009	1	1	0.46	33.8
IN3B	R8	Swine - Grow-Finish	Finishing barn	6/1/2009	1	1	1.01	32.8

Site	House	Animal – Process	Structure type	Date	# canisters	Concentration, mg m-3	Airflow, $m^3 s^{-1}$	Emission, $kg d^{-1}$
IN3B	R8	Swine - Grow-Finish	Finishing barn	6/8/2009	1	1	0.58	41.2
IN3B	R8	Swine - Grow-Finish	Finishing barn	6/24/2009	1	1	0.52	46.7
IN3B	R8	Swine - Grow-Finish	Finishing barn	7/13/2009	1	1	1.48	33.6
IN3B	R8	Swine - Grow-Finish	Finishing barn	7/22/2009	1	1	0.46	32.9
IN3B	R8	Swine - Grow-Finish	Finishing barn	7/23/2009	1	1	0.81	30.9
NC3B	B1	Swine - Grow-Finish	Finishing barn	4/24/2009	1	0.37	23.4	0.74
NC3B	B1	Swine - Grow-Finish	Finishing barn	7/11/2009	2	0.21	22	0.39
NC3B	B1	Swine - Grow-Finish	Finishing barn	8/3/2009	2	0.49	21.2	0.89
NC3B	B1	Swine - Grow-Finish	Finishing barn	12/2/2009	2	1.01	7.36	0.64
NC3B	B1	Swine - Grow-Finish	Finishing barn	12/18/2009	2	0.91	1.43	0.11
NC3B	B1	Swine - Grow-Finish	Finishing barn	12/26/2009	2	0.78	3.31	0.22
NC3B	B2	Swine - Grow-Finish	Finishing barn	4/24/2009	1	0.72	29.3	1.81
NC3B	B2	Swine - Grow-Finish	Finishing barn	7/11/2009	2	0.38	21.9	0.72
NC3B	B2	Swine - Grow-Finish	Finishing barn	12/11/2009	2	1.06	1.93	0.18
NC3B	B2	Swine - Grow-Finish	Finishing barn	12/18/2009	2	0.85	2.52	0.19
NC3B	B3	Swine - Grow-Finish	Finishing barn	4/24/2009	1	0.67	23	1.33
NC3B	B3	Swine - Grow-Finish	Finishing barn	8/3/2009	2	0.42	21.3	0.78
NC3B	B3	Swine - Grow-Finish	Finishing barn	12/2/2009	2	1.07	6.81	0.63
NC3B	B3	Swine - Grow-Finish	Finishing barn	12/11/2009	2	0.7	1.53	0.09
NC3B	B3	Swine - Grow-Finish	Finishing barn	12/26/2009	2	0.97	3.74	0.31

Appendix C: Tyson NMHC data

Table C-4. Kentucky NMHC sample data

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
14-Feb-06	25,830					
15-Feb-06	25,711	0.80	0.00003			
16-Feb-06	25,667					
17-Feb-06	25,641					
18-Feb-06	25,621					
19-Feb-06	25,605					
20-Feb-06	25,585			25,515	0.67	0.00003
21-Feb-06	25,572			25,486	1.36	0.00005
22-Feb-06	25,551			25,460	1.39	0.00005
23-Feb-06	25,536			25,424		
24-Feb-06	25,525	1.30	0.00005	25,342		
25-Feb-06	25,510	1.49	0.00006	25,286		
26-Feb-06	25,493	1.77	0.00007	25,265		
27-Feb-06	25,475	1.97	0.00008	25,264		
28-Feb-06	25,460	1.47	0.00006	25,239		
1-Mar-06	25,449	1.23	0.00005	25,222		
2-Mar-06	25,440	1.35	0.00005	25,202		
3-Mar-06	25,430	1.89	0.00007	25,180	2.30	0.00009
4-Mar-06	25,419	1.74	0.00007	25,157	1.47	0.00006
5-Mar-06	25,400	1.43	0.00006	25,141		
6-Mar-06	25,397	1.11	0.00004	25,120		
7-Mar-06	25,389	1.62	0.00006	25,100	1.72	0.00007
8-Mar-06	25,382	1.73	0.00007	25,072	1.09	0.00004
9-Mar-06	25,376	1.21	0.00005	25,058		
10-Mar-06	25,371	1.24	0.00005	25,044		
11-Mar-06	25,365			25,037		
12-Mar-06	25,358			25,029		
13-Mar-06	25,350			25,023		
14-Mar-06	25,346			25,012		
15-Mar-06	25,338	1.62	0.00006	25,008	1.17	0.00005
16-Mar-06	25,332	2.46	0.00010	24,991	1.11	0.00004
17-Mar-06	25,322	1.84	0.00007	24,980	1.53	0.00006
18-Mar-06	25,315	1.77	0.00007	24,963	2.11	0.00008
19-Mar-06	25,307	1.36	0.00005	24,953	1.49	0.00006
20-Mar-06	25,302	1.89	0.00007	24,941		
21-Mar-06	25,288	1.68	0.00007	24,928		
22-Mar-06	25,282	2.07	0.00008	24,907	1.26	0.00005
23-Mar-06	25,275	2.56	0.00010	24,891	1.75	0.00007
24-Mar-06	25,267	2.27	0.00009	24,880	1.68	0.00007
25-Mar-06	25,257	2.40	0.00010	24,872	1.52	0.00006
26-Mar-06	25,246	1.80	0.00007	24,856	1.66	0.00007
27-Mar-06	25,237	1.94	0.00008	24,825	1.06	0.00004
28-Mar-06	25,222			24,780	1.17	0.00005
29-Mar-06	25,212			24,759	2.45	0.00010
30-Mar-06	25,177			24,728	1.85	0.00008
31-Mar-06	25,158			24,709	1.73	0.00007

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
1-Apr-06	25,158			24,698	1.42	0.00006
2-Apr-06	25,158			24,677		
3-Apr-06	25,158			24,643		
4-Apr-06	25,158			24,619	3.14	0.00013
5-Apr-06				24,598		
6-Apr-06				24,579		
7-Apr-06				24,486		
8-Apr-06				24,284		
9-Apr-06				24,167	0.74	0.00003
10-Apr-06				24,167	0.77	0.00003
11-Apr-06					0.78	
12-Apr-06					1.08	
13-Apr-06					0.83	
14-Apr-06		0.13			0.64	
15-Apr-06		0.00			0.43	
16-Apr-06		0.30			0.03	
17-Apr-06		0.18			0.05	
18-Apr-06						
19-Apr-06						
20-Apr-06		0.88				
21-Apr-06	22995	0.29	0.00001			
22-Apr-06	22840	0.31	0.00001			
23-Apr-06	22748	0.37	0.00002			
24-Apr-06	22690	0.41	0.00002			
25-Apr-06	22625	0.46	0.00002			
26-Apr-06	22578					
27-Apr-06	22517				0.03	
28-Apr-06	22462	1.01	0.00004		0.06	
29-Apr-06	22437	0.93	0.00004		0.01	
30-Apr-06	22418	1.07	0.00005		0.00	
1-May-06	22408	1.19	0.00005		0.00	
2-May-06	22394	1.25	0.00006		0.00	
3-May-06	22382	2.56	0.00011		0.00	
4-May-06	22365	2.55	0.00011		0.00	
5-May-06	22347	1.89	0.00008		0.00	
6-May-06	22333	2.10	0.00009		0.00	
7-May-06	22321	2.10	0.00009		0.00	
8-May-06	22312	1.93	0.00009		0.03	
9-May-06	22290	1.46	0.00007		0.00	
10-May-06	22278	0.78	0.00004		0.00	
11-May-06	22256	0.79	0.00004		0.00	
12-May-06	22245	0.92	0.00004		0.00	
13-May-06	22235	0.94	0.00004		0.00	
14-May-06	22227	0.88	0.00004		0.00	
15-May-06	22220	0.72	0.00003		0.11	
16-May-06	22214	0.60	0.00003		0.04	
17-May-06	22210	0.82	0.00004		0.06	

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
18-May-06	22203				0.00	
19-May-06	22193	0.80	0.00004		0.00	
20-May-06	22178	0.84	0.00004		0.00	
21-May-06	22168	0.75	0.00003		0.11	
22-May-06	22160	0.88	0.00004	24,450	0.50	0.00002
23-May-06	22147			24,439	0.45	0.00002
24-May-06	22136	0.88	0.00004	24,421	0.46	0.00002
25-May-06	22126	1.62	0.00007	24,394	0.90	0.00004
26-May-06	22086	1.31	0.00006	24,377	0.73	0.00003
27-May-06	22074	2.83	0.00013	24,356	0.78	0.00003
28-May-06	22064	2.74	0.00012	24,338	1.08	0.00004
29-May-06	22051	2.87	0.00013	24,311	0.76	0.00003
30-May-06	22021	1.95	0.00009	24,292	0.92	0.00004
31-May-06	22001			24,274	1.04	0.00004
1-Jun-06	21983			24,246	1.10	0.00005
2-Jun-06	21964			24,229	0.64	0.00003
3-Jun-06	21889	1.89	0.00009	24,214	0.75	0.00003
4-Jun-06	21854			24,199	0.65	0.00003
5-Jun-06	21788			24,179	0.79	0.00003
6-Jun-06	21762	2.82	0.00013	24,168	0.79	0.00003
7-Jun-06	21708	4.05	0.00019	24,153	0.81	0.00003
8-Jun-06	21634	3.86	0.00018	24,142	0.98	0.00004
9-Jun-06	21634	3.00	0.00014	24,133	0.71	0.00003
10-Jun-06		3.60		24,123	0.88	0.00004
11-Jun-06		2.18		24,115	0.64	0.00003
12-Jun-06		1.30		24,108		
13-Jun-06		1.43		24,102	1.01	0.00004
14-Jun-06				24,092	1.45	0.00006
15-Jun-06		0.84		24,083	1.33	0.00006
16-Jun-06		1.81		24,075	1.12	0.00005
17-Jun-06		0.85		24,067	1.40	0.00006
18-Jun-06		0.14		24,061	1.07	0.00004
19-Jun-06		0.38		24,059		
20-Jun-06		0.63		24,056		
21-Jun-06		1.04		24,052	2.20	0.00009
22-Jun-06	24465	0.75	0.00003	24,049	0.72	0.00003
23-Jun-06	24396	0.41	0.00002	24,041	0.83	0.00003
24-Jun-06	24355	0.68	0.00003	24,031		
25-Jun-06	24324	0.45	0.00002	24,024		
26-Jun-06	24291			24,012		
27-Jun-06	24262			24,004		
28-Jun-06	24240			23,991		
29-Jun-06	24211			23,981		
30-Jun-06	24199			23,968	1.12	0.00005
1-Jul-06	24189			23,948	1.96	0.00008
2-Jul-06	24182			23,940	2.99	0.00013
3-Jul-06	24168			23,919		

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
4-Jul-06	24156			23,902		
5-Jul-06	24151			23,873		
6-Jul-06	24147			23,848		
7-Jul-06	24142			23,818		
8-Jul-06	24135			23,768		
9-Jul-06	24129			23,718		
10-Jul-06	24123			23,718		
11-Jul-06	24108			23,718		
12-Jul-06	24100					
13-Jul-06	24086					
14-Jul-06	24066					
15-Jul-06	24060					
16-Jul-06	24053					
17-Jul-06	24034					
18-Jul-06	24025					
19-Jul-06	24019					
20-Jul-06	24014					
21-Jul-06	24006					
22-Jul-06	24000	0.83	0.00003			
23-Jul-06	23993	1.22	0.00005		0.00	
24-Jul-06	23982	1.07	0.00004			
25-Jul-06	23972	1.29	0.00005			
26-Jul-06	23965	1.72	0.00007			
27-Jul-06	23941	1.74	0.00007			
28-Jul-06	23933			24,380		
29-Jul-06	23924			24,341		
30-Jul-06	23918			24,309		
31-Jul-06	23896			24,281	0.55	0.00002
1-Aug-06	23885			24,264		
2-Aug-06	23870			24,231		
3-Aug-06	23861			24,209		
4-Aug-06	23843	4.28	0.00018	24,198	0.41	0.00002
5-Aug-06	23808	3.28	0.00014	24,188	0.63	0.00003
6-Aug-06	23795	3.99	0.00017	24,174	0.40	0.00002
7-Aug-06	23752	4.82	0.00020	24,163	0.63	0.00003
8-Aug-06	23752	4.78	0.00020	24,150	0.68	0.00003
9-Aug-06	23752	4.09	0.00017	24,139	0.62	0.00003
10-Aug-06	23752	4.35	0.00018	24,130		
11-Aug-06		2.72		24,123		
12-Aug-06				24,111		
13-Aug-06				24,103		
14-Aug-06				24,098		
15-Aug-06		0.77		24,090	0.79	0.00003
16-Aug-06		0.00		24,085	0.84	0.00003
17-Aug-06		0.26		24,078		
18-Aug-06		1.26		24,072		
19-Aug-06		2.31		24,067		

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
20-Aug-06		1.74		24,064		
21-Aug-06		1.75		24,062		
22-Aug-06				24,058		
23-Aug-06				24,052	1.16	0.00005
24-Aug-06		1.04		24,047	0.65	0.00003
25-Aug-06		**0.23**		24,044	0.97	0.00004
26-Aug-06		0.03		24,040	0.99	0.00004
27-Aug-06		0.01		24,038	0.56	0.00002
28-Aug-06		0.03		24,037	0.68	0.00003
29-Aug-06		0.31		24,034	1.13	0.00005
30-Aug-06		0.12		24,029	1.16	0.00005
31-Aug-06		0.15		24,021	1.23	0.00005
1-Sep-06				24,018	1.74	0.00007
2-Sep-06				24,011	1.35	0.00006
3-Sep-06				23,996	1.38	0.00006
4-Sep-06		0.06		23,980	1.73	0.00007
5-Sep-06	25695	0.19	0.00001	23,976	2.05	0.00009
6-Sep-06	25680	0.24	0.00001	23,968	2.15	0.00009
7-Sep-06	25665	0.35	0.00001	23,948	2.03	0.00008
8-Sep-06	25646	0.24	0.00001	23,937		
9-Sep-06	25635	0.59	0.00002	23,927		
10-Sep-06	25622	0.58	0.00002	23,914		
11-Sep-06	25610	0.52	0.00002	23,892		
12-Sep-06	25596	0.67	0.00003	23,875		
13-Sep-06	25587	0.70	0.00003	23,863		
14-Sep-06	25578	1.23	0.00005	23,848	2.76	0.00012
15-Sep-06	25561	1.63	0.00006	23,833	3.24	0.00014
16-Sep-06	25550	1.13	0.00004	23,809	3.13	0.00013
17-Sep-06	25540	0.98	0.00004	23,809	2.63	0.00011
18-Sep-06	25523	0.76	0.00003	23,809	0.00	0.00000
19-Sep-06	25509	0.84	0.00003	23,809	2.30	0.00010
20-Sep-06	25499	0.82	0.00003		0.38	
21-Sep-06	25486	0.97	0.00004			
22-Sep-06	25472	0.76	0.00003			
23-Sep-06	25449	0.99	0.00004			
24-Sep-06	25433	1.05	0.00004		1.37	
25-Sep-06	25417	1.02	0.00004		0.64	
26-Sep-06	25389	1.10	0.00004		1.03	
27-Sep-06	25374	1.56	0.00006		0.78	
28-Sep-06	25356	1.12	0.00004		0.02	
29-Sep-06	25347	1.15	0.00005		0.12	
30-Sep-06	25335	1.16	0.00005		0.21	
1-Oct-06	25325	1.73	0.00007		0.00	
2-Oct-06	25312	1.18	0.00005		0.00	
3-Oct-06	25300	0.95	0.00004		0.06	
4-Oct-06	25286	1.24	0.00005		0.22	
5-Oct-06	25267	0.86	0.00003	25,778		

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
6-Oct-06	25257	1.07	0.00004	25,734	0.65	0.00003
7-Oct-06	25243	1.14	0.00005	25,704	0.63	0.00002
8-Oct-06	25173	1.06	0.00004	25,659	0.67	0.00003
9-Oct-06	25121	1.10	0.00004	25,631	0.47	0.00002
10-Oct-06	25100	1.08	0.00004	25,601	0.50	0.00002
11-Oct-06	25027			25,576		
12-Oct-06	24994			25,552	1.18	0.00005
13-Oct-06	24824	1.79	0.00007	25,538	1.24	0.00005
14-Oct-06	24782	1.47	0.00006	25,528	1.04	0.00004
15-Oct-06	24485	1.35	0.00006	25,522	1.32	0.00005
16-Oct-06	24402	1.95	0.00008	25,487	0.80	0.00003
17-Oct-06	24340	2.54	0.00010	25,410	0.98	0.00004
18-Oct-06	24296	2.34	0.00010	25,405	1.17	0.00005
19-Oct-06	24278	2.11	0.00009	25,398	1.40	0.00006
20-Oct-06	24231	3.05	0.00013	25,393	1.73	0.00007
21-Oct-06	24183	3.27	0.00014	25,386	0.93	0.00004
22-Oct-06	24165	3.21	0.00013	25,381	1.43	0.00006
23-Oct-06	24046	2.95	0.00012	25,376	0.95	0.00004
24-Oct-06	24046	3.22	0.00013	25,367	1.92	0.00008
25-Oct-06	24046	4.14	0.00017	25,364	1.41	0.00006
26-Oct-06		1.97		25,360	1.02	0.00004
27-Oct-06		0.78		25,357	1.00	0.00004
28-Oct-06		0.85		25,353	0.99	0.00004
29-Oct-06		0.40		25,347	1.03	0.00004
30-Oct-06		0.00		25,334	0.94	0.00004
31-Oct-06		0.00		25,328	1.30	0.00005
1-Nov-06		0.04		25,326	1.49	0.00006
2-Nov-06				25,323	1.57	0.00006
3-Nov-06		0.59		25,319	1.76	0.00007
4-Nov-06		0.08		25,316	1.96	0.00008
5-Nov-06		0.00		25,314	1.86	0.00007
6-Nov-06		0.62		25,311	1.58	0.00006
7-Nov-06				25,307	1.90	0.00008
8-Nov-06		0.28		25,300	2.08	0.00008
9-Nov-06		0.44		25,294	2.29	0.00009
10-Nov-06		1.04		25,289		
11-Nov-06		0.30		25,286		
12-Nov-06		0.22		25,279		
13-Nov-06		0.01		25,262		
14-Nov-06		0.05		25,256		
15-Nov-06		0.02		25,246		
16-Nov-06		0.55		25,229		
17-Nov-06	25080	0.46	0.00002	25,213		
18-Nov-06	25000			25,199		
19-Nov-06	24396			25,176		
20-Nov-06	23358	0.94	0.00004	25,148		
21-Nov-06	22248	1.35	0.00006	25,113		

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
22-Nov-06	21048	1.19	0.00006	25,113		
23-Nov-06	20276	1.13	0.00006	25,113		
24-Nov-06	19626	0.98	0.00005	25,113		
25-Nov-06	19201	0.89	0.00005	25,113		
26-Nov-06	19051	0.89	0.00005	25,113		
27-Nov-06	18328	0.64	0.00003	25,113		
28-Nov-06	18039	0.68	0.00004			
29-Nov-06	17790	0.67	0.00004			
30-Nov-06	17305	0.38	0.00002			
1-Dec-06	17191				0.00	
2-Dec-06	17003					
3-Dec-06	16913				0.00	
4-Dec-06	16528				0.96	
5-Dec-06	16420	0.85	0.00005		0.74	
6-Dec-06	16301	1.29	0.00008		0.29	
7-Dec-06	16231	2.08	0.00013		0.09	
8-Dec-06	16171	2.50	0.00015		0.07	
9-Dec-06	16127	2.20	0.00014		0.00	
10-Dec-06	16102	2.10	0.00013		0.07	
11-Dec-06	16064	2.12	0.00013		0.27	
12-Dec-06	16022					
13-Dec-06	15966					
14-Dec-06	15932	2.37	0.00015	24,970		
15-Dec-06	15862	2.63	0.00017	24,917		
16-Dec-06	15820	2.52	0.00016	24,872	0.79	0.00003
17-Dec-06	15800	1.96	0.00012	24,806		
18-Dec-06	15774	2.50	0.00016	24,762		
19-Dec-06	15718	3.19	0.00020	24,730		
20-Dec-06	15690	4.17	0.00027	24,706		
21-Dec-06	15649	1.34	0.00009	24,690		
22-Dec-06	15624	1.70	0.00011	24,676		
23-Dec-06	15556	2.67	0.00017	24,664	0.51	0.00002
24-Dec-06	15466	3.12	0.00020	24,652	0.46	0.00002
25-Dec-06	15379	2.75	0.00018	24,634	0.42	0.00002
26-Dec-06	15149	3.41	0.00022	24,623	0.40	0.00002
27-Dec-06	14919	2.13	0.00014	24,612		
28-Dec-06	14675	1.87	0.00013	24,603		
29-Dec-06	14571	2.14	0.00015	24,594		
30-Dec-06	14316	1.39	0.00010	24,591		
31-Dec-06	14248	1.48	0.00010	24,586		
1-Jan-07	14061	2.52	0.00018	24,583		
2-Jan-07	13946	2.19	0.00016	24,577		
3-Jan-07	13876	2.12	0.00015	24,570	0.80	0.00003
4-Jan-07	13876	1.69	0.00012	24,562	0.68	0.00003
5-Jan-07	13876	1.65	0.00012	24,559		
6-Jan-07	13876	1.45	0.00010	24,551	0.90	0.00004
7-Jan-07	13876	1.48	0.00011	24,541	0.98	0.00004

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
8-Jan-07	13876	1.73	0.00012	24,538	1.14	0.00005
9-Jan-07	13876	1.52	0.00011	24,532	1.18	0.00005
10-Jan-07		0.23		24,519	1.26	0.00005
11-Jan-07		0.04		24,506	1.30	0.00005
12-Jan-07		1.68		24,499	1.47	0.00006
13-Jan-07		0.42		24,490	1.19	0.00005
14-Jan-07		0.20		24,482	1.25	0.00005
15-Jan-07		0.55		24,464	1.23	0.00005
16-Jan-07		1.36		24,452	1.44	0.00006
17-Jan-07		1.00		24,430	1.33	0.00005
18-Jan-07		0.19		24,401	1.46	0.00006
19-Jan-07		0.26		24,381	1.49	0.00006
20-Jan-07		0.00		24,362	1.88	0.00008
21-Jan-07				24,344	2.27	0.00009
22-Jan-07	26600			24,320	1.96	0.00008
23-Jan-07	26500			24,299	2.19	0.00009
24-Jan-07	26465			24,275	2.92	0.00012
25-Jan-07	26427			24,241	2.68	0.00011
26-Jan-07	26404			24,206	2.90	0.00012
27-Jan-07	26374			24,171	2.79	0.00012
28-Jan-07	26323			24,133	3.10	0.00013
29-Jan-07	26307			24,103		
30-Jan-07	26290			24,050		
31-Jan-07	26272			24,050		
1-Feb-07	26260			24,050	3.84	0.00016
2-Feb-07	26244			24,050	1.73	0.00007
3-Feb-07	26234				0.26	
4-Feb-07	26228				0.73	
5-Feb-07	26220				0.49	
6-Feb-07	26199					
7-Feb-07	26167				0.06	
8-Feb-07	26142				0.05	
9-Feb-07	26055	2.72	0.00010			
10-Feb-07	26030	1.81	0.00007			
11-Feb-07	25981	1.12	0.00004			
12-Feb-07	25884	0.87	0.00003	26,013	0.22	0.00001
13-Feb-07	25861	1.23	0.00005	25,992	0.24	0.00001
14-Feb-07	25846	1.72	0.00007	25,958	0.23	0.00001
15-Feb-07	25808	2.64	0.00010	25,926	0.32	0.00001
16-Feb-07	25790	2.75	0.00011	25,887	0.35	0.00001
17-Feb-07	25784	1.85	0.00007	25,852	0.41	0.00002
18-Feb-07	25764	2.37	0.00009	25,821	0.46	0.00002
19-Feb-07	25751	1.80	0.00007	25,802	0.47	0.00002
20-Feb-07	25720	2.12	0.00008	25,772	0.53	0.00002
21-Feb-07	25701	1.75	0.00007	25,748	0.83	0.00003
22-Feb-07	25690	2.05	0.00008	25,730		
23-Feb-07	25677	2.11	0.00008	25,714		

Date	KY1B-1			KY1B-2		
	Bird #	NMHC,lbs	NMHC, lbs/hd	Bird #	NMHC, lbs	NMHC, lbs/hd
24-Feb-07	25660	1.64	0.00006	25,697		
25-Feb-07	25634	0.96	0.00004	25,681		
26-Feb-07	25609	1.92	0.00008	25,672		
27-Feb-07	25580	4.47	0.00017	25,664		
28-Feb-07	25497	4.62	0.00018	25,656		
1-Mar-07	25345	4.02	0.00016	25,648		
2-Mar-07	25269	3.86	0.00015	25,648		
3-Mar-07	25159	4.04	0.00016	25,648		
4-Mar-07	25052	3.97	0.00016	25,648		
5-Mar-07	24948	3.36	0.00013	25,648		
6-Mar-07	24670	4.76	0.00019			
7-Mar-07	24655	4.44	0.00018			
8-Mar-07	24633	4.65	0.00019			
9-Mar-07	24604					
10-Mar-07	24575	5.24	0.00021			
11-Mar-07	24546	4.49	0.00018			
12-Mar-07	24546	4.96	0.00020			
13-Mar-07	24546	4.84	0.00020			
14-Mar-07	24546	2.68	0.00011			

Appendix D: Emission Factors from Literature

Table C-51. Total VOC Emissions Factors from literature

Farm Type	Structure Type	Emission Factor	Unit of Emission Factor	Reference
Dairy, (≥ 1,000 milk cows)	Enteric Emissions from Cows	4.10	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Milking Parlor(s)	0.03	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Freestall Barns	1.80	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Corrals/Pens	6.60	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Liquid Manure Handling (lagoons, storage ponds, basins)	1.30	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Liquid manure land application	1.40	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Solid manure land application	0.33	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Separated solids piles	0.06	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (≥ 1,000 milk cows)	Solid manure storage	0.15	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Enteric Emissions from Cows	4.30	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Milking Parlor(s)	0.04	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Freestall Barns	1.90	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Corrals/Pens	10.00	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Liquid Manure Handling (lagoons, storage ponds, basins)	1.50	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Liquid manure land application	1.60	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Solid manure land application	0.39	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Separated solids piles	0.06	lb/hd-yr	Sheraz and Norman, 2012
Dairy, (< 1,000 milk cows)	Solid manure storage	0.16	lb/hd-yr	Sheraz and Norman, 2012
Dairy	Milking cows	12.800	lb/hd-yr	AQMD, 2016
Dairy	Dry Cows	8.700	lb/hd-yr	AQMD, 2016
Dairy	Heifer (4-24 months)	6.100	lb/hd-yr	AQMD, 2016
Dairy	Heifer (4-24 months), with flush lanes that are flushed with water to a holding pond	4.700	lb/hd-yr	AQMD, 2016
Dairy	Calf (under 3 months)	4.500	lb/hd-yr	AQMD, 2016

Farm Type	Structure Type	Emission Factor	Unit of Emission Factor	Reference
Layers	Manure from Laying hens and associated birds	0.026	lb/hd-yr	AQMD, 2016
Broilers	Manure from Broiler chickens and associated birds	0.026	lb/hd-yr	AQMD, 2016
Dairy	Lagoon	4.500	lb/yr-AU	EPA, 2001
Swine	Lagoon	2.400	lb/yr-AU	EPA, 2001
Layer	Lagoon	4.000	lb/yr-AU	EPA, 2001
Swine	Finishing pig	30.300	mg d-1 kg hd	Feilberg, et al., 2010
Swine	Finishing pig, shallow pit	4.99	mg d-1 kg hd	Heber et al, 2004
Dairy	Stable	11.10	kg/yr/hd	Kammer et al. 2020

Table C-2. VOC Emissions Factors from literature

Farm Type	Structure Type	VOC	Emission Factor	Unit of Emission Factor	Reference
Dairy	Freestall Barns (cows and feed)	Methanol	1.780	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Ethanol	2.010	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Propionic Acid	0.080	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Isobutyric Acid	0.080	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Butyric Acid	0.010	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Isovaleric acid	0.010	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Valeric Acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Hexanoic Acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Phenol	0.000	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	P-Cresol	0.020	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	4-Ethylphenol	0.000	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	2-Amino-actophenone	0.000	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Undole	0.000	lb/TAU/yr	Parker, 2008
Dairy	Freestall Barns (cows and feed)	Skatole	0.000	lb/TAU/yr	Parker, 2008

Farm Type	Structure Type	VOC	Emission Factor	Unit of Emission Factor	Reference
Dairy	Openlot (manure and feed)	Methanol	4.900	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Ethanol	11.650	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Propionic Acid	3.630	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Isobutyric Acid	0.750	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Butyric Acid	0.090	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Isovaleric acid	0.090	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Valeric Acid	0.110	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Hexanoic Acid	0.340	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Phenol	0.010	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	P-Cresol	0.020	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	4-Ethylphenol	0.000	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	2-Amino-actophenone	0.000	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Undole	0.000	lb/TAU/yr	Parker, 2008
Dairy	Openlot (manure and feed)	Skatole	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Methanol	0.010	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Ethanol	0.040	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Propionic Acid	0.140	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Isobutyric Acid	0.020	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Butyric Acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Isovaleric acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Valeric Acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Hexanoic Acid	0.000	lb/TAU/yr	Parker, 2008

Farm Type	Structure Type	VOC	Emission Factor	Unit of Emission Factor	Reference
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Phenol	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	P-Cresol	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	4-Ethylphenol	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	2-Amino-actophenone	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Undole	0.000	lb/TAU/yr	Parker, 2008
Dairy	Liquid Manure Handling (lagoons, storage ponds, basins)	Skatole	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Methanol	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Ethanol	0.070	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Propionic Acid	0.090	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Isobutyric Acid	0.070	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Butyric Acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Isovaleric acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Valeric Acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Hexanoic Acid	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Phenol	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	P-Cresol	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	4-Ethylphenol	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	2-Amino-actophenone	0.000	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Undole	0.010	lb/TAU/yr	Parker, 2008
Dairy	solid manure handling	Skatole	0.000	lb/TAU/yr	Parker, 2008
Swine	Lagoon	Acetaldehyde	0.660	$\mu g\ m^{-2}\ min^{-1}$	Rumsey et al 2012
Swine	Lagoon	Acetone	2.110	$\mu g\ m^{-2}\ min^{-1}$	Rumsey et al 2012
Swine	Lagoon	Ethanol	0.590	$\mu g\ m^{-2}\ min^{-1}$	Rumsey et al 2012

Farm Type	Structure Type	VOC	Emission Factor	Unit of Emission Factor	Reference
Swine	Lagoon	2-ethyl-1-hexanol	0.180	$\mu g\ m^{-2}\ min^{-1}$	Rumsey et al 2012
Swine	Lagoon	Methanol	1.190	$\mu g\ m^{-2}\ min^{-1}$	Rumsey et al 2012
Swine	Lagoon	MEK	0.560	$\mu g\ m^{-2}\ min^{-1}$	Rumsey et al 2012
Swine	Shallow pit Barn	Acetaldehyde	0.100	g/d	Rumsey et al 2012
Swine	Shallow pit Barn	Acetone	0.240	g/d	Rumsey et al 2012
Swine	Shallow pit Barn	2,3-butanedione	0.190	g/d	Rumsey et al 2012
Swine	Shallow pit Barn	Ethanol	0.450	g/d	Rumsey et al 2012
Swine	Shallow pit Barn	Methanol	0.270	g/d	Rumsey et al 2012
Swine	Shallow pit Barn	4-methylphenol	0.160	g/d	Rumsey et al 2012

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