CHARACTERIZATION OF AMMONIA EMISSIONS FROM GROUND LEVEL AREA SOURCES AT CENTRAL TEXAS DAIRIES

A Dissertation

by

ATILLA MUTLU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2007

Major Subject: Biological & Agricultural Engineering

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Approved by:

Chair of Committee,	Saqib Mukhtar
Committee Members,	Ronald E. Lacey
	John W. Nielsen-Gammon
	Calvin B. Parnell, Jr.
Head of Department,	Gerald L. Riskowski

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ABSTRACT

Characterization of Ammonia Emissions from Ground Level Area Sources at Central Texas Dairies. (December 2007)

Atilla Mutlu, B.S.; M.S., Cukurova University

Chair of Advisory Committee: Dr. Saqib Mukhtar

There is a need for a robust and accurate technique to measure ammonia (NH_3) emissions from animal feeding operations (AFOs) to obtain emission inventories and to develop abatement strategies. Seasonal studies were conducted to measure NH_3 emissions from open-lot and free-stall dairies in central Texas since summer of 2003. Ammonia emission flux (EFl) was measured using an isolation flux chambers (FC) protocol from ground level area sources (GLAS) and converted to emission factor (EF) to potentially develop source specific NH_3 emission control strategies. The GLAS including open-lots, free-stall barns, separated solids, primary and secondary lagoons and milking parlor were sampled to estimate NH_3 emissions.

In the first study, assessment of summer and winter data from the open-lot dairy indicated that overall NH_3 EFs were 11.6 ±7.1 kg NH_3 $year^{-1}$ $head^{-1}$ for the summer and 6.2 ±3.7 kg NH_3 $year^{-1}$ $head^{-1}$ for the winter season. The estimated annual NH_3 EF was 9.4 ±5.7 kg NH_3 $year^{-1}$ $head^{-1}$ for this open-lot dairy. The estimated NH_3 emission factor for winter was nearly 47% lower than summer EF. Open-lot corrals (~63%) in summer

and (~95%) in winter were the highest contributors to NH_3 emissions for the open-lot dairy.

In the second study, the EFs for the free-stall dairy were determined to be 11.1 ±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for summer season and 4.7± 4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for winter season. The estimated annual NH_3 EF was 8.4 ±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for this free-stall dairy. In winter, composted manure and free-stalls contributed nearly 73% to the total NH_3 emissions for the dairy. However in summer, approximately 65% of overall NH_3 emissions were contributed by two lagoons at the dairy.

The overall differences between winter and summer NH_3 emissions from the dairies were due to ambient temperature variations and loading rates of manure on GLAS. There was spatial variation of NH_3 emissions from the open-lot earthen corrals due to variable animal density within different divisions of the open-lot. This spatial variability was attributed to dispirit manure loading within these areas.

DEDICATION

This dissertation is dedicated to my beloved family:

my son, Arda Kaan

and

my lovely wife, Muge.

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I am thankful to God for letting me have this opportunity and complete my graduate study program to pursue my Ph.D. degree.

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My parents, Cennet and Mustafa Mutlu, and my brother Atalay Mutlu. It did not really matter how far apart we were but, I always felt your warm support in my heart. I cannot thank you enough for your endless support and valuable sharing.

And final words go to my beloved family. There were only two people under the roof when I began my PhD program. Now, there are three people under the same roof. Arda Kaan, my little angel, you brought me something that I have never experienced before. And my best friend and wife Muge, my only source of inspiration, you showed me the way where I have never been. I love both of you so much more, than anything.

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CHAPTER I

INTRODUCTION

Recently, agricultural ammonia (NH_3) emissions into the atmosphere have been recognized as an important air quality issue. Animal feeding operations (AFOs) are known to be the most significant contributors to overall agricultural NH_3 emissions and cattle, including dairy cows, are the major livestock sources to emit NH_3. In both Europe and the United States, agricultural NH_3 emissions from AFOs and fertilizer applications are estimated to be up to 80% of the total NH_3 emissions (Battye et al., 1994; DEFRA, 2002).

Ammonia is released to the atmosphere due to the biological decomposition of dairy manure. Animal feeding operations would classify as a pollutant source if manure, which is generated in AFOs or used for fertilizer application, is considered a "hazardous substance". The US lawmakers are currently debating whether animal waste should be termed as a "toxic pollutant" (Sadler, 2007).

Currently, NH_3 emissions from animal agriculture are not regulated under the Clean Air Act (CAA). Ammonia emissions are only subject to be reported to federal, state, or local agencies if the emission exceeds reportable quantity (RQ). Two federal acts were designated to manage this reporting process.

This thesis follows the style of *Transactions of the ASABE*.

The RQ set by Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and Emergency Planning and Community Right-to-Know Act (EPCRA) for NH_3 is 45.4 kg per day (100 pounds per day).

The potential for federal air quality regulations accelerates the need for better estimates and effective management practices for reducing NH_3 emissions. It is important to obtain real-time, direct estimates of emissions from different NH_3 emission sources at AFOs. There is also need for a better technique to measure NH_3 emissions from AFOs to obtain emission inventories and to develop abatement strategies.

The quantification of NH_3 emissions from ground level area sources (GLAS) in a dairy operation is needed to understand which sources contribute the most to the overall NH_3 emissions during winter and summer seasons. Information on seasonal NH_3 emission variations at GLAS from dairy operations will assist with the evaluation and selection of best management practices to control and reduce NH_3 emissions. The estimated real-time and direct NH_3 emission factors from central Texas dairies will help to develop farm-scale NH_3 inventories.

The isolation flux chamber (FC) is one of the direct measuring techniques for surface gas emissions, such as NH_3. This measurement technique is also applicable to quiescent liquid surfaces such as lagoons where surface runoff and waste water are stored and treated under anaerobic conditions.

Ammonia EFs for dairies have been reported generally based on the nitrogen mass balance method. Ammonia EFs for dairy facilities were estimated to be anywhere

from 1.5 kg-NH_3 $year^{-1}$ $head^{-1}$ to 55.5 kg-NH_3 $year^{-1}head^{-1}$ in both Europe and the US. These EFs were generally estimated from the nitrogen content in excreted manure or from a mass balance of nitrogen inputs and outputs at dairy operations. None of these studies conducted real time, direct NH_3 emissions and flux measurements from individual waste storage and treatment sources (GLAS) of a dairy operation.

Flux chambers have been used to measure gaseous emissions, especially NH_3, from the GLAS. At an AFO, these sources may include lagoons, compost piles, manure storage, open lots, animal buildings, and milking parlors. In this study, using a flux chamber protocol, NH_3 emission fluxes (EFl) were measured from GLAS and converted to emission factor (EF) for free-stall and open-lot dairies during winter and summer seasons.

An ammonia emissions measurement study at open-lot and free-stall dairies was conducted to test the following hypotheses:

- Ammonia emissions such as ERs and EFs can be determined from each individual GLAS of dairy facilities using a direct measurement system,
- Treatment lagoons in the summer and open-lots in the winter are the largest emitters of NH_3 at a dairy feeding operation,
- Ammonia emissions from open-lot surfaces are highly spatially variable,

These hypotheses above will be accepted or rejected using appropriate statistical analysis of collected real-time and on-site data. Data collection process to test these hypotheses and statistical analyses are described in the next chapter.

CHAPTER II

A LITERATURE REVIEW FOR CHARACTERIZING AMMONIA EMISSIONS FROM ANIMAL FEEDING OPERATIONS

2.1. Introduction

Increasing public concerns over air quality impacts from animal feeding operations (AFOs) in the United States have led the USEPA to begin establishing an air-monitoring study to obtain reliable emission inventory for livestock and poultry facilities.

Ammonia (NH_3) emissions are considered an important environmental issue. Agricultural NH_3 emissions from AFOs and fertilizer applications are considered as major contributors (up to 80%) to the total NH_3 emissions (Battye et al., 1994; DEFRA, 2002).

Mansell (2005) indicated in the final report of Western Regional Air Partnership (WRAP) visibility modeling that there were large uncertainties in the variation of emitted concentrations, seasonal variation, and spatial distribution of NH_3 emissions. Those uncertainties may hinder obtaining accurate NH_3 emissions estimates.

Source-specific ambient NH_3 concentrations should be measured in order to determine NH_3 emission flux (EFl), rates (ER) and factors (EF). Accurately determined EFs will help to develop a reliable emission inventory (EI) for AFOs.

2.2. Properties of Ammonia

Ammonia is generally known as a gas with a characteristic sharp odor. It is colorless and lighter than air. Physical properties of gases are important parameters to determine behavior of gases in known conditions. Gas behaviors can be accurately predicted using the ideal gas law. According to Cooper and Alley (2002), we need to separate between gas and vapor phases. The main reason for making a distinction is due to different control techniques that can be applied to gas and vapor. Pollutants such as sulfur dioxide (SO_2), carbon monoxide (CO), or nitric oxide (NO) are considered gases and most volatile organic compounds (VOCs) are considered as vapors (Cooper and Alley, 2002).

In gas phase, in this case NH_3, internal energy of the molecules plays an important role. Critical temperature is defined as the highest temperature value for the condensation (liquefied form), critical pressure is the value when the gas liquefied at the critical temperature. Critical volume is also an important parameter to determine gas behaviors, and it is defined as a volume of constant mass of gas at critical temperature and pressure.

Steward et al. (1986) and Appl (1999) described thermodynamic properties of NH_3. Thermodynamic properties are important parameters for understanding and managing gas behaviors under different environmental conditions. These properties for NH_3 gas are presented in Table 2.1.

Table 2.1 Properties of NH_3 gas.

Molecular weight	17.0312
Molecular volume (at 0°C, 1 atm)	22.08 L mol^{-1}
Critical temperature point	132.4 °C
Critical pressure point	112 atm
Critical volume	4.225 cm^3 g^{-1}
Critical density	0.2350 g cm^{-3}
R (ideal gas law constant)	4.8180 atm $cm^3 g^{-1}$ K^{-1}
Density (at 0°C, 1 atm.)	0.7714 g L^{-1}
Melting point	-77.71 °C
Boiling point (at 1 atm.)	- 33.43 °C
Vapor pressure	6.077 kPa
Enthalpy (Standart gas at 25 °C)	-46.22 kJ mol^{-1}
Heating value	18.577 kJ g^{-1}
NH_3 - O_2 mixture (at 20°C, 101.3 kPA)	15-79 vol% NH_3
NH_3 - Air mixture (at 0°C, 101.3 kPA)	16-27 vol% NH_3
NH_3 - Air mixture (at 100°C, 101.3 kPA)	15.5-27 vol% NH_3

Ammonia has a pyramid-shaped molecular geometry and is very similar to the configuration of water (Appl, 1999). Therefore, liquid NH_3 has the ability to dissolve many substances. Anhydrous (water-free) NH_3 gas is easily converted to liquid form under pressure (at 20°C liquid ammonia has a vapor pressure of about 8.16 atm).

2.3. Ammonia Production at AFOs

Biological decomposition of manure from AFOs results in emission of NH_3 and other gases. Ammonia is released into the atmosphere due to microbial decomposition of manure. Manure and urine that are excreted by livestock are the most significant sources of NH_3 emissions. Dairy cows consume a significant amount of nitrogen (N) containing substances in their feed. Ammonia is produced by conversion of N in manure to total ammoniacal N (TAN=NH_4^+-N + NH_3-N). This conversion occurs in different biochemical degradation processes such as hydrolysis of urea and volatilization. Hydrolysis of urea can be simplified by following equation:

Hydrolysis of Urea: $CO(NH_2)_2 + H_2O \rightarrow CO_2 + 2NH_3$

Urea plays an important role as the main source of ammonia in the urine of cattle, cows, pigs, and other mammals. Urease is an enzyme and mostly found in animal manure and soil. Urease is used for the converting of urea to TAN (DEFRA, 2002). Ammonia volatilization process is explained with details in following topic.

2.3.1. Ammonia Volatilization and Deposition

In general, atmospheric gases in the atmosphere tend to move from higher levels of concentration to lower levels of concentration by diffusion. Similarly, NH_3 volatilizes from high concentration zones, such as urine and excreta accumulated in a corral, to lower concentration zones such as the atmosphere. In other words, NH_3 is released from the liquid or semi-solid zone as gas phase (DEFRA, 2002). Manure is considered the

main source of NH_3 volatilization in AFOs. Ammonia is released from the source as total ammoniacal N (TAN). The volatilization of NH_3 is variable and depends upon several factors: including surface and ambient temperature, air velocity, moisture content, pH level, and TAN concentration of the of the emitting source (Arogo et al., 2001 and Becker and Graves, 2004).

Ammonia emissions may change seasonally during the year. High temperatures increase NH_3 volatilization. High wind speed may increase NH_3 emission if manure is stored in open areas. The population of animals at AFO may vary during a year. Animal density may also effect NH_3 emissions from the AFO. These factors cause NH_3 emissions to vary in terms of season and region (USEPA, 2002).

The pH value of stored solid manure may range from 7.5 to 8.5, but manure stored as liquid or semi-liquid may have lower pH. Therefore, livestock manure may be stored as liquid or semi-liquid to reduce NH_3 emissions from the livestock facility (USEPA, 2002).

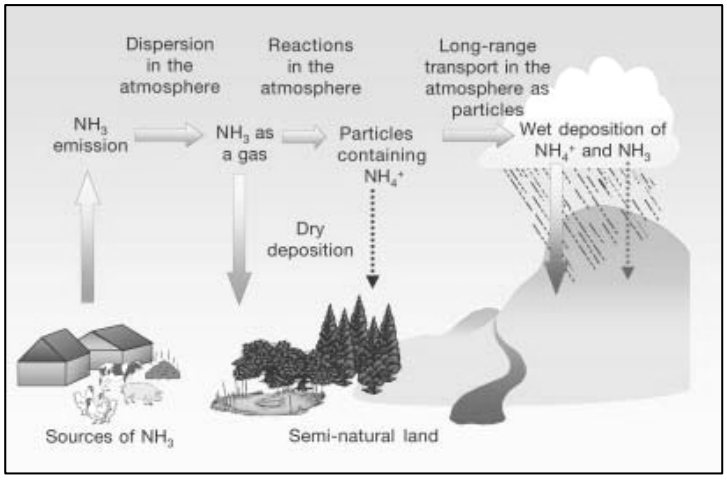

Figure 2.1. Ammonia paths in the atmosphere. (Source: DEFRA, 2002)

Ammonia in the atmosphere is deposited back to the earth's surface as "dry" (most common) or "wet" (Figure 1). In dry deposition, fine particles containing (ammonium) NH_4^+ and NH_3 are absorbed by soil and water surfaces. Dry deposition is decreased by increasing distance from the emitting surface. Dry deposition generally occurs in locally and local deposition can be seen in the first 500 m from the emitting source (Fowler et al., 1998). In another study by Fangmeier et al., 1994 reports that the NH_3 concentration was reduced by 50-70 % at the distance of 600 m and 4 km from the source, respectively. In wet deposition, NH_4^+ and NH_3 can be deposited to the surface by rainfalls. Wet deposition occurs in long distances from the emitting sources (DEFRA, 2002).

Increasing ambient NH_3 concentration and atmospheric deposition of N are related to increasing NH_3 emissions from AFOs (DEFRA, 2002) and Fowler et al., (1998) reported that NH_3 dry deposition is decreased by increasing the distance from the

source. Ammonia may be removed in the atmosphere to the earth's surface in the form of reduced ammonia (NH_x) ($NH_x = NH_3 + NH_4^+$) by depositions. High concentration of NH_x at the earth's surface may cause acidification of soils due to nitrification; eutrophication of water sources result in a decline or loss of species and damaged forest systems (Asman et al., 1987; Phillips et al., 2000; Aneja et al., 2003).

2.4. Environmental Impacts of Ammonia Emissions

In the atmosphere, NH_3 neutralizes acidic aerosols such as nitrogen oxides NO_x (combination of NO and NO_2) and sulfur dioxides (SO_2). This chemical process is considered to be a major source of atmospheric acidification (Aneja et al., 2003 and Asman and Janssen, 1987; Arogo et al., 2001).

Asman and Janssen (1987), Brost et al. (1988) and Arogo et al. (2001) described N-based aerosols as combinations of NH_3 with acidic compounds. Ammonia reacts with nitric acid (HNO_3) , hydrochloric acid (HCl), and sulfuric acid (H_2SO_4) to form ammonium nitrate (NH_4NO_3), ammonium chloride (NH_4Cl), and ammonium sulfate ($(NH_4)_2SO_4$), respectively.

Potential environmental effects of these N-based aerosols may include the following (Arogo et al., 2001):

- High concentrations of particulate aerosols may cause respiratory diseases in the vicinity,
- Nitrate contamination may increase in drinking water,

- Eutrophication, as a result of nutrient pollution, may increase N and phosphorus levels in natural waters and impair water quality,
- Higher concentration of N may cause direct damage to vegetation,
- Increasing nitrous oxide (N_2O), which is considered a strong greenhouse gas, when associated with higher N concentration may effect climatic changes (global warming), and
- Nitrogen levels of forest soils and soil acidification may increase during high N concentration in the ecosystem.

There is a large uncertainty associated with determining NH_3 emissions from the source and NH_3 deposition from the atmosphere. There is a need for real time and source specific measurements and models to minimize this uncertainty. Models are important tools that may predict sufficient details about changes in NH_3 emission when field measurements are not available.

2.5. Ammonia Emissions and Current Regulatory Processes

Currently, NH_3 emissions from animal agriculture are not regulated. Ammonia emissions are only subject to be reported to federal, state, or local agencies if the emission exceeds reportable quantity (RQ). Currently, two major programs are designated to manage this reporting process.

The first program was enacted in 1980 and called the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as "Superfund". This program was intended to clean up abandoned sites or locations that may have contained hazardous substances (HS). This program was first applied concerning toxic waste dumps to Love Canal and Times Beach in the 1970's. The CERCLA gives USEPA several legal authorities to protect public health and the environment (USEPA, 2007).

The second program, Emergency Planning and Community Right-to-Know Act (EPCRA), was enacted in 1986. This program contains an extremely hazardous substances (EHS) list and intends to protect the public and environment from releasing of EHS.

The primary purpose of reporting HS emissions in CERCLA and EPCRA is defined by USEPA (1998) as "to notify various levels of government of potential hazards so that the necessary response actions can be taken in a timely fashion to ensure maximum protection of human health and the environment". Section 103 of CERCLA states that release notifications help EPA determine the sites that could have potential threat to public health.

In general, CERCLA provides release reports on a federal scale by submitting to National Response Center (NRC) while EPCRA reports are submitted to state emergency response centers (SERCs) and local emergency response centers (LERCs).

Ammonia is not considered a hazardous air pollutant; therefore, it is not listed in EPA's hazardous air pollutant (HAP) list (USEPA, 2007a). However, NH_3 is listed (CAS# 7664-41-7) as one of the hazardous substances by CERCLA.

In addition, more than 300 hazardous substances, including NH_3, were listed (CAS# 7664-41-7) as extremely hazardous substances (EHS) under section 302 of EPCRA and its reportable quantity (RQ) was set at 45.4 kg per day (100 pounds per day). EPCRA requires a report if RQ of NH_3 is released from an animal feeding facility in a 24 hour period (USEPA, 2007b).

If EPCRA is applied to a dairy facility, according to definition of "facility", the barns, open-lot corrals, lagoons and manure storage structures would be subjected to a combined (overall) RQ analysis. This analysis must be site-specific and should not compare with any other management practices.

2.6. Ammonia Measurement Methods

Several measuring methods have been developed in the last 20 years. Some techniques are available for direct NH_3 measurement (Ni and Heber, 2001; Phillips et al., 2001). Several sensors are also available to measure NH_3 concentrations from AFOs.

Ammonia sampling methods and appropriate monitoring instrument/device play an important role to quantify NH_3 emissions from AFOs. It is essential in a research study to obtain high quality data using a suitable method and measurement system (Ni and Heber, 2001).

Ammonia concentrations are measured using a flux enclosure, nitrogen mass balance, and micrometeorological methods.

2.6.1. Flux Enclosure Method

Enclosure methods are used to determine direct NH_3 flux from a source. Enclosure methods involve simple, portable devices that can be used on different surfaces or at multiple spots on the same surface (Harper, 2005).

Isolation flux chambers (IFC) and wind tunnels are common devices for the flux enclosure method. Isolation flux chambers have been previously used by Aneja et al. (2000), Mukhtar et al. (2003) and Capareda et al. (2005) to measure NH_3 fluxes from different emitting surfaces (i.e. open-lot corrals, lagoon surfaces, and composted manure surfaces). The IFC is equipped with several ports; the major ports include inlet and outlet ports. The inlet port is used to pull pollutant-free air into the chamber. The outlet port is used to measure well-mixed polluted air. Another port is left open to the atmosphere to stabilize internal atmospheric pressure. Pollutant-free air, called "zero grade sweep air", is applied at a known flow rate to provide enough air exchanges in order to have well-mixed air sampling inside of the chamber. Once NH_3 concentrations are measured with an analyzer, flux emissions are determined using the following equation:

$$EFl_{NH_3} = \frac{C_{mass} \times V_{fc}}{A_{fc}} \qquad \text{(eq.2.1)}$$

where:

EFl_{NH_3} = NH_3 gas emission flux (μg m^{-2} sec^{-1}),

C_{mass} = mass concentration, (μg m^{-3}),

V_{fc} = volumetric flow through the flux chamber (m^3 sec^{-1}),

A_{fc} = area of flux chamber ("footprint", m^2).

Surface emission flux (μg m^{-2} sec^{-1}) is determined as the product of measured concentration in mass (μg m^{-3}) and volumetric sweep air flow rate (m^3 sec^{-1}) divided by the enclosed surface area "footprint" (m^2). The IFC method allows comparing one measurement with another one when using the same chamber under the same conditions (Arogo et al., 2006).

Wind tunnels are another type of enclosure that has one side open to the atmosphere. Polluted air is pulled from the inlet side by a fan and is drawn to the opposite end (exhaust) of the tunnel. Ammonia flux can be determined as following when wind tunnels are used (Shah et al., 2006):

$$EFl_{NH_3} = (C_{out} - C_{in})\frac{V}{A} \qquad \text{(eq.2.2)}$$

where:

EFl_{NH_3} = NH_3 gas emission flux (μg m^{-2} sec^{-1}),

C_{out} = Measured NH_3 concentration at outlet, (μg m^{-3}),

C_{in} = Measured NH_3 concentration at inlet, (μg m^{-3}),

V = volumetric flow rate through the wind tunnel (m^3 sec^{-1}),

A_{fc} = area of treated surface ("footprint", m^2).

There are some concerns regarding the wind tunnel systems. Condensation on the inner surface and rainfall, which can reduce NH_3 emission, must be avoided when the wind tunnel is used. There are several problems that may occur when enclosures are used due to strong effects of environmental conditions and gas behaviors. Since NH_3 is considered as highly reactive and is soluble in water, absorbance may occur inside of the enclosure or tubing walls which may negatively affect the accuracy of measurements due to possible condensation (Harper, 2005). However, enclosures are a suitable method to compare replicated measurements on the emission surface (Shah, 2006; Harper, 2005).

According to Shah et al. (2006), the closed-dynamic chamber may be the most preferred method for measuring NH_3 fluxes for real-time data on the soil surface and short crops. There are also some limitations of the flux chamber method. The first limitation could be accurately supplying sweep air flow rate, which plays an important role to determine gas emissions. If the sweep air flow rate can not be supplied accurately, different dilution ratios occur inside of the chamber and provide non-constant emission values from the flux chamber that has fixed a volume. Disturbing gas emitting surfaces may increase gas emission. Solar radiation may increase temperature and relative humidity levels inside of the chamber. Insulation should be used to avoid any environmental disturbance inside of the chamber. Wind tunnels are also applicable for directly measuring gas emissions from the quiescent and turbulent surfaces. Wind tunnels could be the best method for NH_3 volatilization if it is used at variable fan

speeds. Harper (2005) indicated that the wind tunnel system can be suitable for obtaining relative comparisons from the gas-emitting sources.

2.6.2. Nitrogen Balance Method

The nitrogen mass balance (NMB) approach is a rough estimate of NH_3 emissions for the AFOs. There are two assumptions made by researchers regarding N balance. The first assumption, more realistically, is that the N balance process is an indicator of NH_3 losses. The second assumption is that all of the N loss is in the NH_3 form (Shah et al., 2006). The NMB method consists of two parts: N inputs into the AFO, and N outputs from the AFO (Arogo et al., 2006).

All potential N sources are considered as input parameters such as animal feed, bedding materials, N from fertilizer applications and from the ambient air. N outputs from an AFO are described as the sale of animals, animal product (e.g. milk, meat), harvested crop, mortalities, surface runoff from applied manure to surface, manure storages, and emitted gas emissions. Ammonia emissions are determined as the net difference between inputs and outputs in a N budget at AFOs (Arogo et al., 2006).

There are some limitations of this method. The NMB methods do not include any direct measurements of NH_3 emissions so that this method provides rough and higher emission estimates. It is not easy to determine all the parameters in N budget as inputs and outputs. More samples are needed to characterize all model inputs and outputs.

However, the NMB methods are preferable to some investigators due to lower cost and simplicity related to the direct measurement methods.

2.6.3. Micrometeorological Method

Micrometeorological methods (MMs) are suitable for monitoring flux emissions at large spatial sources (Shah et al., 2006). Ammonia concentration and meteorological parameters, such as wind speed and temperature, are the main inputs to the MMs. The meteorological data is collected at different heights above the experiment surface (Arogo et al., 2006).

The MMs do not agitate the pollutant source and ambient conditions which may affect NH_3 release. They also provide continuous measurements and average emissions within the source area. These advantages minimize possible sampling problems during the experiment. The MMs are applicable for large scale areas that usually emit low emissions. They also require sensitive equipment and operation knowledge to apply protocol steps (Harper, 2005).

Several types of MMs have been used: Eddy correlation and Eddy accumulation (Zhu et al., 2000), Gradient and aerodynamic techniques which use energy and momentum balance (Harper et al., 2000; Sutton et al., 2000), and energy mass balance (Denmead et al., 1998).

In all, the gradient and eddy correlation methods require more than 100 meter fetch length with uniform distribution. Energy mass balance method is robust and

simple. Energy mass balance may be the most preferable method for determining NH_3 flux from animal waste stockpiles and is also applicable for the liquid surfaces (Shah et al., 2006).

2.6.4. Dispersion Models

Dispersion modeling (DM) is one of the most commonly used air quality modeling and recommended models such as AERMOD (the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee's Dispersion Model) are described in the EPA's Guideline on Air Quality Models, 40 CFR Part 51 (USEPA, 2006a). Dispersion models can be used to determine gas emissions where direct measurements are not suitable or feasible due to physical limitations (e.g. site characteristics, topography) (Arogo et al., 2006).

Dispersion models can be employed for small scale (from a few meters to a few kilometers) or large scale sources (region, counties, state) (Arogo et al., 2006).

Dispersion models are mathematical methods and run based on the Gaussian distribution theory. Flux emissions and meteorological parameters (wind speed, wind direction, ambient air temperature, and solar radiation) are the main inputs and must be known for use in the model in order to predict downwind pollutant concentration at specified receptor points (USEPA, 2006a). Variations on the wind speeds and directions are the main factors to define atmospheric stability. Some assumptions are made to

simplify the model, which could include uniform flux and homogenous turbulence (Seinfeld and Pandis, 1998).

Dispersion models are important tools that help understanding the transport of gases and particles through the atmosphere. It is essential that dispersion models need to be validated with measured values at the source (Arogo et al., 2006). Dispersion modeling and MMs are similar. Concentrations of pollutants are measured downwind from fugitive sources and the models are used to back-calculate emission rates (ERs).

Dispersion models, even if simplified by several assumptions, are still complex and do not take into account all meteorological conditions into the model. Dispersion models reduce sampling costs and time on the field, but require experience and knowledge to process data and analyze the model output.

2.7. Ammonia Measurement Devices

There are several types of devices that have been used to measure NH_3 emissions in parallel of technologic developments. Most of the devices measure direct and time-averaged NH_3 concentrations during sampling. Ammonia emissions may exist as gaseous $NH_{3(g)}$ and particulate NH_4^+ forms in the atmosphere. There are some techniques available to measure only gaseous $NH_{3(g)}$ or particulate NH_4^+ . Different measurement devices/systems are described in following topics.

2.7.1. Denuders

The denuder device is designed to exclude particulates from the collection area. The air is forced into the denuder tubes at a known and constant flow rate. Ammonia gas is captured by creating an absorbing surface (collection surface) inside of the denuders. The absorbing surface is usually coated with acidic solution such as citric acid, oxalic acid, and phosphoric acid (Perrino and Gherardi,1998; McCulloch et al., 1998).

Air molecules move more quickly than particles in the atmosphere, which causes a different diffusion velocity between air molecules and particles (Harper, 2005). Gas phase NH_3 is absorbed by the denuder walls while the particulates pass through with drawn air and are collected on a filter due to difference in diffusion velocity of NH_3 gas and NH_4^+ particles (Arogo et al,. 2006).

The other type of denuder is commonly called filter packs. The filter packs are active NH_3 samplers containing Teflon filters treated with acid (i.e. citric acid, oxalic acid). Polluted air is vacuumed through the filters using a pump. Acid reacts with NH_3 during the sampling process to form solids. The first stage filter is used to remove larger particulates from polluted air. After large particulates are removed, second and third stage filters are analyzed in the laboratory. The second and third stage denuder filters are typically extracted with a known amount of distilled water. The extracted solution is then reacted with the Nessler's Reagent and absorbance of solution is read on a spectrophotometer at 425 nm (Fitz et al. 2003). The calculations of actual NH_3 concentration in the samples are done using a calibration curve based on NH_4-N standard solutions of different concentrations treated the same way as the denuder extracts. By

knowing the volume of the air sampled, NH_3 concentration can be calculated in μgNH_3 m^{-3}.

Upwind/downwind ambient NH_3 concentrations can be measured by using an active denuder system. Active denuder methods are used to determine the dry deposition of gaseous concentrations and to monitor gas concentrations at known multiple heights using a tower system. Denuder towers are located at several heights above the surface. Asman (1998) indicated that 60% of the NH_3 emitted from sources were up to 3 m in height. Asman (1998) also pointed out that local deposition shows variations with vegetation cover, atmospheric stability, surface roughness and source height. This method has been used in several studies by Harrison et al.(1990), Wiebe et al. (1990), Andersen et al. (1994), Aneja et al. (1998), Horvath and Sutton (1998), Fitz et al. (2003), Huang et al. (2004), and Cassel et al. (2005).

The major problem associated with the denuder system is to control flow rate during the sampling. Total volume of air is considered a dominant parameter when precision of the denuder is determined. Therefore a little error in volumetric air flow rate will cause a high error in the concentration. Flow rates should be regulated and frequently recorded with appropriate flow meters that have high precision.

2.7.2. High-tech Sensors

High-tech sensors have been widely used to detect real-time and direct NH_3 concentration from emitting sources. High-tech sensors are applicable to both solid and

liquid surfaces. Chemiluminescence, photo-acoustic analyzers and open-path laser sensors have been widely used in air quality research recently.

The chemiluminescence analyzer works based on the reaction of nitric oxide (NO) with ozone (O_3). An air sample is drawn into the analyzer by an external vacuum pump. This air sample is mixed with O_3 which is generated by an internal ozone creator in a reaction chamber of the analyzer. The sensor measures nitrogen oxides (NO_x), and total nitrogen N_t (N_t= NO+ NO_2+ NH_3), sequentially. Nitrogen oxide is converted to NO in a molybdenum converter at 325°C. The NO_2 concentration is determined by subtracting the NO_x concentration from the NO concentration. Ammonia concentrations are determined by subtracting NO_x signals from the N_t signal in either parts per million (ppm) or parts per billion (ppb). Previous studies (Mukhtar et al., 2003 and Capareda et al., 2005) have provided details of the principle of chemiluminescence to measure NH_3 concentrations.

Photo-acoustic sensors are infrared detectors that detect light absorption at a fixed wavelength range. Webber et al. (2001) describe that the sampling environment consists of ambient temperature, varies typically between 0 °C and 40 °C, atmospheric pressure and activities of water vapor in the air. Laser wavelength levels can be adjusted to level where CO_2 absorption and water vapor are minimal. This adjusted wavelength level is the best for measuring NH_3 concentration. The performance of photo-acoustic sensors depends on CO_2 and water vapor concentrations in the polluted air (Shah et al., 2006). The accuracy of the photo acoustic sensor is reliable at high concentrations,

however, it is not stable and sensitive at low concentrations (<3 ppm) when compared with chemiluminescence analyzers (Arogo et al., 2006).

The open-path sensors are used to measure mean concentration of polluted gas on an open path. Open-path tunable diode lasers and open-path Fourier transform infrared devices are common types of the optical sensors. The optical sensors are generally used to combine meteorological measurement and dispersion model methods to determine NH_3 emissions. Tunable diode sensors can be adjusted to specific wavelength levels which generate individual absorption lines and each absorption line is used for a specific gas measurement. The sensor is tuned to a single absorption line to measure gas concentration. Fourier sensors have a single absorption line which passes a single beam of light to the atmosphere. Absorbance is detected by Least Square fitting method (Harper, 2005).

High-tech gas sensors and analyzers are very expensive and need frequent calibrations to increase accuracy. Some of the calibrations can be done by users but others need to be calibrated by manufacturer which will add more cost to sampling procedure. In addition, high maintenance costs may be other disadvantages for these sensors. Respond time, user friendly operating steps, portable design and easy to carry in the field are the advantages of high-tech analyzers.

2.8. Ammonia Emission Factors

In 2005, the USEPA offered a "consent agreement" to individual AFOs who will participate as volunteers and allow conducting a source specific study to monitor air emissions from their AFOs. This "Consent Agreement" protects participating AFOs from enforcement while monitoring study is being conducted at their sites (USEPA, 2006).

The National Air Emission Monitoring Study (NAEMS) was established in 2006 by the Consent Agreement. Various gases including NH_3 and airborne pollutants emitted from livestock and poultry operations will be monitored across the nation.

The USEPA defines emission factor as "a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant" (USEPA, 1995).

Having a reliable NH_3 inventory is essential to determine how much NH_3 is emitted into the atmosphere (emission factors) and possible affects to the environment. An inventory is a list that shows all quantities of estimated gas emissions from all known sources. We can identify the major source of emissions and determine the most contributing source to overall NH_3 emission. According to Pain et al. (1998), Total NH_3 emissions in a cattle farm come from housing for cattle production (28%), manure storage buildings (17%) and land spreading (50%). The USEPA (2002) reported that total N loss occurred in lagoons as 43% and open-lots as 15% and flush barns as 22% in dairy farm.

Therefore, emission factors and emission inventories are important tools for air quality management. Emission factors are important for developing emission control strategies. Reliable EFs will determine the highest contributor to overall emission inventory. Control strategies may be applied to those most contributing sources in order to reduce overall EF for the AFOs. Emission factors will guide us to determine applicability of control programs and selecting appropriate mitigation strategies.

Ammonia EFs for dairies have been reported generally based on the nitrogen mass balance and measurement-based method. In Europe and the US EFs for dairy facilities were estimated to be anywhere from 1.5 kg-NH_3 $year^{-1}$ $head^{-1}$ to 55.5 kg-NH_3 $year^{-1}$ $head^{-1}$. Ammonia air emissions from dairy operations were reported as 38.1 kg-NH_3 $year^{-1}$ $head^{-1}$ in the year 2002 National Emissions Inventory (NEI) by USEPA.

The EFs were generally estimated from the nitrogen content in excreted manure or from a mass balance of nitrogen inputs and outputs at dairy operations. Some of these studies were conducted as direct NH_3 emissions and flux measurements from individual waste management sources, ground level area sources (GLAS), of a dairy operation. Additionally, differences in climate, housing, feed and waste management practices between European dairy operations and dairies in the southwestern US contributed to the differences among reported EFs.

Ammonia ERs and EFs can also be determined as a function of management practices and environmental conditions (Cassel et al., 2005). Estimated emission factors vary by different type of management practices, sampling methods and sampling seasons.

CHAPTER III

SEASONAL AND SPATIAL VARIATIONS OF AMMONIA EMISSIONS FROM AN OPEN-LOT DAIRY OPERATION

3.1. Introduction

Studies show that agricultural and animal feeding operations contribute considerable amount of NH_3 to the atmosphere (Battye et al., 1994; Aneja et al., 2003 and Arogo et al., 2001). Cattle, including dairy cows, are the largest animal sources contributing to NH_3 emissions. Atmospheric NH_3 is considered to be a precursor to $PM_{2.5}$ (particulate matter with aerodynamic diameter less than 2.5 μm) (Battye et al., 1994; Gupta et al., 2003 and Aneja et al., 2001) and PM ($PM_{2.5}$ and PM_{10}) is one of the six criteria pollutants for which National Ambient Air Quality Standards (NAAQS) were developed by the USEPA. Since NH_3 is highly correlated with $PM_{2.5,}$ it is anticipated that NH_3 emissions from AFOs in the US may be regulated in the near future.

Real time and continuous NH_3 measurements from GLAS are necessary to estimate ERs and EFs for a livestock facility. Ammonia EFs can be determined as a function of management practices and environmental conditions (Cassel et al., 2005).

Ammonia EFs for dairies have been reported generally based on the nitrogen mass balance method. In Europe and the US, EFs for dairy facilities were estimated to be anywhere from 1.5 to 55.5 kg-NH_3 $year^{-1}$ $head^{-1}$ using nitrogen analysis and mass

balance method. Some EFs reported using real time measurements varied from 1.8 to 40 kg-NH_3 $year^{-1}$ $head^{-1}$ in Europe and the US. However, NH_3 emission measurements were limited to naturally or ventilated dairy barns and milking parlor areas only. Ammonia emissions from dairy operations were reported as 38.1 kg-NH_3 $year^{-1}$ $head^{-1}$ in the year 2002 National Emissions Inventory (NEI) by USEPA (USEPA,2002).

The isolated flux chamber (FC) is one of the direct measuring techniques for emissions of surface gas such as NH_3. The USEPA has published a protocol using this method for GLAS gaseous emissions (Gholson et al., 1989). This measurement technique is also applicable to quiescent liquid surfaces such as lagoons where surface runoff and waste water are stored and treated under anaerobic conditions.

In our study, this protocol was used to determine NH_3 emission factors from different GLAS at an open-lot dairy in central Texas.

The objectives of our study were:

- to estimate seasonal ammonia EFs from an open-lot dairy using a real-time measurement system,
- to evaluate seasonal variations of EFs during two consecutive seasons,
- to determine spatial variations of NH_3 emissions in open-lot corrals due to different surface characteristics and animal activity during summer and winter.

Information on seasonal NH_3 emission variations at GLAS from dairy operations will assist the evaluation and selection of best management practices to control and abate such emissions.

3.2. Materials and Methods

An open-lot dairy (Fig. 3.1) in central Texas was selected to estimate NH_3 emissions using a USEPA approved FC measurement protocol. An open-lot corral was randomly selected to represent the entire lot area. In addition, GLAS including primary and secondary lagoons, milking parlor facility (winter only), and separated solids were sampled for NH_3 emissions during summer and winter conditions.

Figure 3.1. Sampled open-lot dairy.

Ammonia EFs were calculated using real time NH_3 concentration data. These NH_3 concentrations were measured from GLAS for five days each during summer and winter sampling. Due to the highly spatially variable emissions of NH_3 from the open-lot

corral, a total of 94 measurements in summer and 96 measurements in winter were made continuously from the same corral. Additionally, 30 and 31 manure samples during summer and winter respectively were collected from open-lot corral surfaces for total nitrogen (N), pH and moisture content analyses in the laboratory.

A total of 115 and 109 NH_3 concentration measurements were made from the open-lot dairy GLAS in summer and winter seasons, respectively.

3.3. Sampling Site: Open-lot Dairy

Approximately 2,000 lactating cows were housed at the open-lot dairy during this study in the summer and winter of 2005. This dairy included 12 earthen corrals which were centralized feeding and watering areas with free standing shelters for relief from severe weather conditions. Each corral was an un-paved, confined area with access to feed bunkers and water tanks**.** Although most of the manure (feces and urine) was deposited on the open-lot corral**,** a fraction of manure and process generated waste water was conveyed from the crowding area (the area where cows are held temporarily awaiting milking) and milking parlor to the primary lagoon. The secondary lagoon was used to store treated effluent from the primary lagoon and to irrigate crop and pasture land.

Accumulated manure in the concrete alley on the feeding side of corrals was removed by scraping using tractor mounted blades once a day. The scraped manure was

stockpiled on-site between lagoons and the corrals. Manure stockpiles were hauled frequently from the dairy using commercial trucks.

In both studies, one corral was randomly chosen to represent all open lots at the dairy. Based upon animal activity, the middle section (30.5m x 67m) of this corral was divided in to five sub-divisions namely dry division, transition from dry to shaded division (trans-ds), shaded division, transition from shaded to feeding division (trans-sf) and feeding division. Corral divisions and their dimensions are illustrated in Figure 3.2.

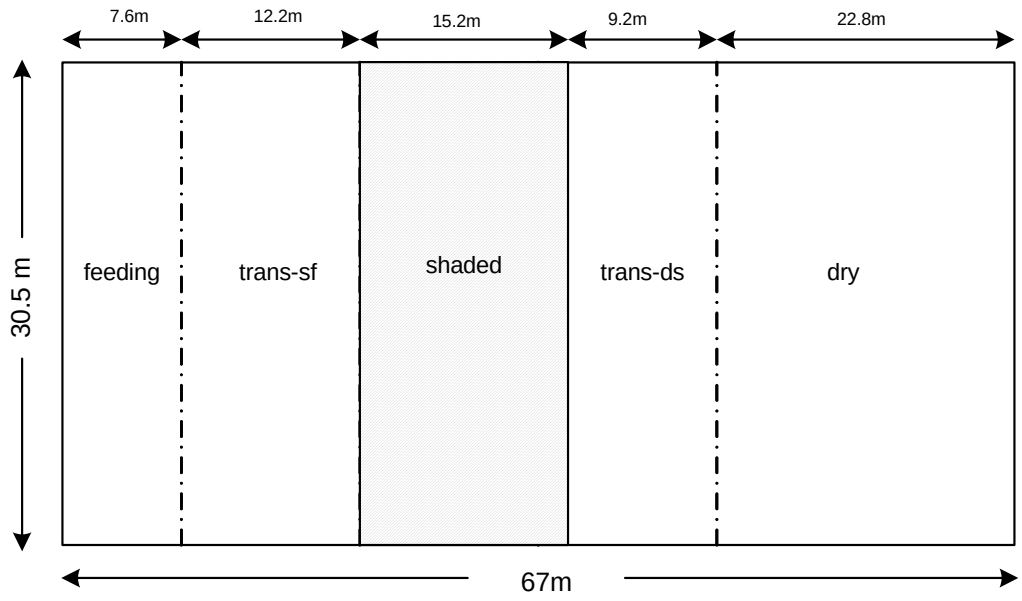

Figure 3.2. Schematic of sampled open-lot corral divisions.

Approximately 170 milking cows were fed in the sampled corral. Each corral had a similar total area of 8,585 m².

3.4. Sampling Equipment

Isolation FCs have been used to measure emission fluxes of volatile organic compounds (VOCs) and inorganic gaseous pollutants from a wide variety of sources (Eklund, 1992). The basic design of the FC includes a hemispherical top (dome) and a cylindrical skirt. Odotech Incorporated supplied the hemispherical top for use in this research (Odotech Inc. Montreal, Canada). A custom-fabricated stainless steel skirt and the dome were joined by a set of wing nuts and sealed using a rubber gasket (Figure 3.3).

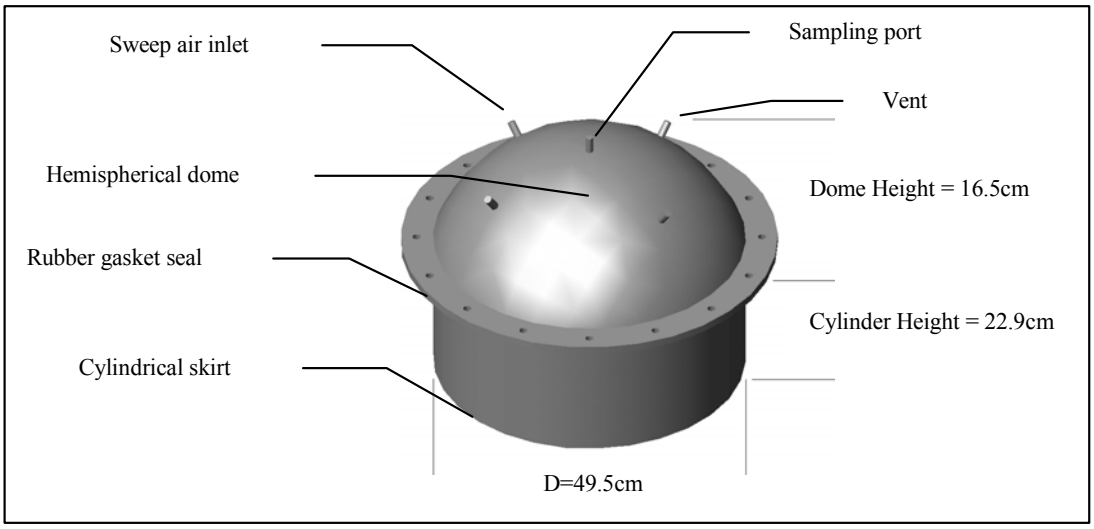

Figure 3.3. Schematic of isolation flux chamber.

The dome contained four symmetrical holes with stainless steel fittings. A tubing inlet located at one of the stainless steel fittings allowed for the flow of sweep air into the chamber. Sweep air is NH_3 free purified air and is generated from a zero-air

generator (Model 737-12, AADCO Instruments, Village of Cleaves OH). A fitting on the top of the dome allowed for the pollutant stream to be conveyed to a measurement device. Two of these holes were used to connect the FC to Teflon® and low density polyethylene (LDPE) tubing used to move the sweep air (contaminant free zero grade air) and sampling air (polluted air from FC) to and from the FC for purging and sampling, respectively (Mukhtar, et al., 2003).

On-site measurements for these studies were conducted by using a mobile laboratory. The mobile laboratory included NH_3 analyzers, air flow mixing devices, a multiplexer system including mass flow controllers (MFC) (Aalborg, Inc. Orangeburg, New York), a zero air generator, certified gas cylinders (Praxair, Inc., Danbury, CT) and power generators for electricity. This sampling set-up is illustrated in Figure 3.4.

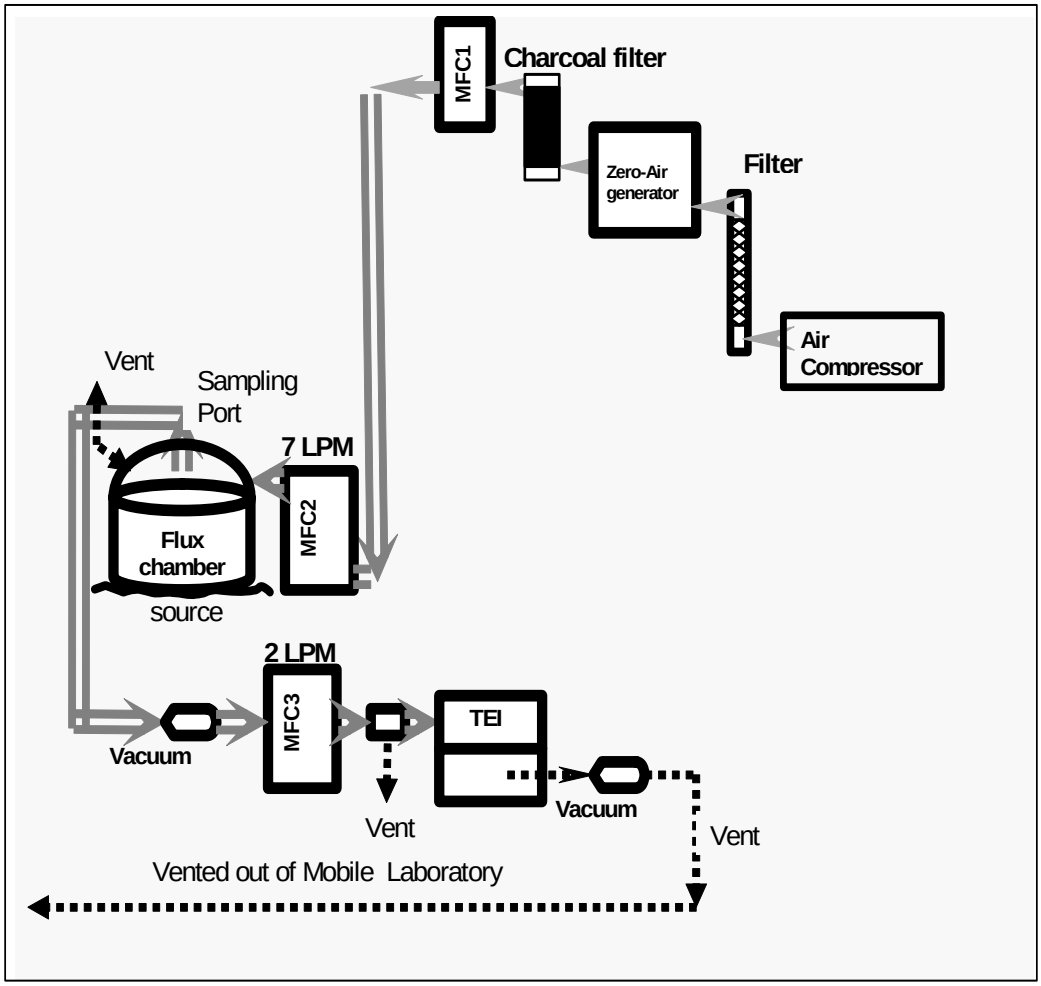

Figure 3.4. Sampling schematic.

The ambient air temperatures was collected from an on-site weather station and GLAS surface (temperature probe buried 1-2 cm below the surface) and chamber (probe hanging inside the chamber) temperatures were measured and recorded using HOBO data loggers mounted on the flux chambers (Onset Computer Corporation, Pocasset, MA).

3.5. Sampling Method

The sampled corral area was divided in to 25 equal grids, 5 rows and 5 columns. Each grid was approximately 6 m x 13.4 m. All sampling points in each grid were randomly distributed. Randomly chosen sampling points for this study are illustrated in Appendix B.1 and B.2 for summer and winter season, respectively. A minimum of three random samples were taken from each grid.

The EPA protocol requires 3 to 4 volumetric air exchanges in the FC during the sampling process. The FC dimensions in Figure 3.3 and an NH_3-free sweep air flow rate of 7 L min^{-1} provided 3.5 air exchanges for 30 minutes of NH_3 sampling.

A chemiluminescence analyzer (Model 17C, Thermo Environmental Instruments, TEI, Massachusetts.) was used to measure NH_3 for real time and continuous sampling. Previous studies (Mukhtar, et al., 2003; Capareda et al., 2005 and Boriack et al., 2004). have provided details of the principle of chemiluminescence to measure NH_3 concentrations. .

Using the ideal gas law, measured volumetric NH_3 concentrations (parts per million-PPM) were converted into mass concentration ($C_{mass,}$ $\mu g.m^{-3}$) and equations (3.1), (3.2), and (3.3) were used to calculate NH_3 EFls, ERs and EFs, respectively:

$$EFl_{NH_3} = \frac{C_{mass} \times V_{fc}}{A_{fc}} \qquad \text{(eq. 3.1)}$$

Where:

EFl_{NH3} = NH_3 gas emission flux ($\mu g\ m^{-2}\ sec^{-1}$),

V_{fc} = volumetric flow through the flux chamber (m^3 sec^{-1}),

A_{fc} = area of flux chamber ("footprint", m^2).

$$ER = EFl_{NH_3} \times A_{sc} \qquad \text{(eq. 3. 2)}$$

where:

ER = Emission rate, kg day^{-1},

A_{sc} = Area of source (GLAS), m^2.

$$EF = (\frac{ER}{TNA}) \times 365 \qquad \text{(eq. 3.3)}$$

where:

EF = Emission factor, kg-NH_3 $year^{-1}$ $head^{-1}$,

TNA = Total number of animal.

3.6. Calibration

The TEI analyzers were calibrated using known concentrations of NH_3, NO_2 and NO, certified high purity standard gases guaranteed by the manufacturer to be within ± 2% accuracy (Praxair, Inc., Danbury, CT). The analyzers were calibrated by using 50 ppm and 100 ppm NH_3, NO_2 and NO. Each cylinder was connected to a MFC. All MFCs were annually calibrated by the manufacturer. A Teflon static mixing tube was used to obtain a well mixed diluted gas which was conveyed to the analyzer at the rate of

2 L min^{-1}. The analyzed air mixture was vented to the atmosphere. Calibration set-up is illustrated in Figure 3.5.

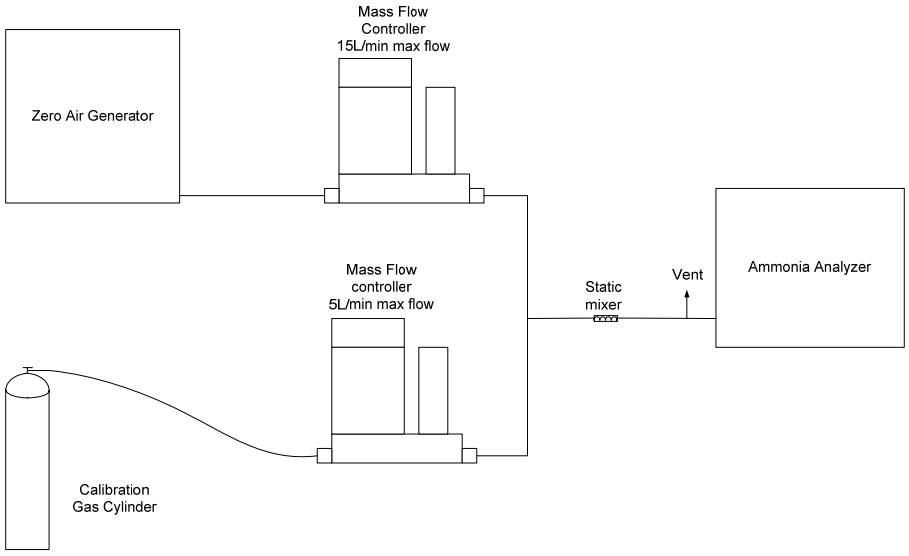

Figure 3.5. Calibration illustration for NH_3 analyzer. (Source: Boriack, 2005)

Calibration of the NH_3 analyzer is performed in 4 steps and details are presented in Figure 3.6.

1. Zero- The instrument is set up for zeroing by attaching zero air generator for 12 hours prior to calibration.
2. NO- The chemiluminescent detector is calibrated with NO.
3. NO_2- The NO_x converter efficiency is calibrated with NO_2.
4. NH_3- The N_t coverter efficiency is calibrated with NH_3.

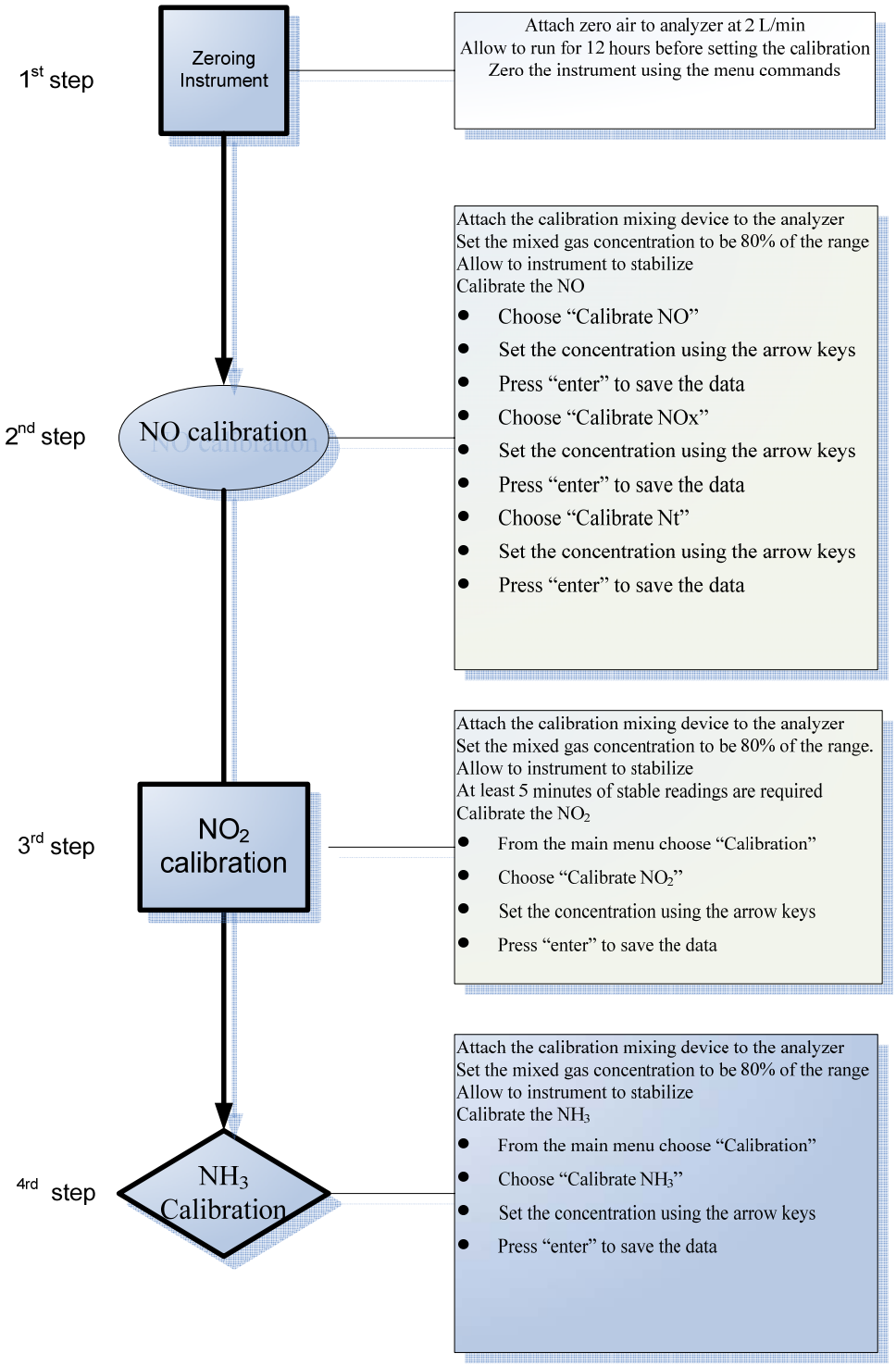

Figure 3.6. Calibration steps for NH_3 analyzer (Boriack, 2005).

Calibration process was completed by saving background and coefficient values for each used gas. The analyzers were calibrated before starting the field experiment and calibration checks were performed after each field experiment to determine stabilization of the instrument.

3.7. Adsorption and Uncertainty Analysis

Adsorption studies were conducted earlier to determine losses from the sampling tube (Teflon) and the FC system (Mukhtar, et al., 2003; Capareda et al., 2005). Results indicated that an adsorption loss of NH_3 on Teflon tubing was negligible (Mukhtar, et al., 2003) and NH_3 adsorption losses were approximately 8% for flux chamber (Capareda et al., 2005). Ammonia concentrations from the analyzer were corrected based upon adsorption losses.

Uncertainty analysis was performed on NH_3 sampling process (Boriack et al., 2004). The first order Taylor series technique was used to calculate uncertainty of this sampling procedure.

The uncertainty analysis was performed for the NH_3 sampling system including the analyzer, calibration gases, and the MFC. The overall uncertainty was found to be in the range of 8 to 10% for this NH_3 sampling set-up.

3.8. Results and Discussion

3.8.1. Seasonal Variations of Ammonia Emissions at the Open-lot Dairy

In this study, a total of 110 NH_3 concentration measurements were made from the open-lot dairy GLAS in summer and winter seasons. Each corral had a similar total area of 8570 m². In both studies, one corral was randomly chosen to represent all open lots at the dairy. Preliminary assessment of summer and winter data (Tables 3.1 and 3.2) indicated that overall NH_3 emission rates (ERs) were 66.2 ±22.2 kg day^{-1} for the summer and 35.9 ±10 kg day^{-1} for the winter season for the 2000-head dairy. The estimated NH_3 emission rate for winter was nearly one half (~54%) of that from summer. Open-lots (~60%) and lagoons (~40%) in summer and open-lot corrals (~97%) in winter were the highest contributors to NH_3 emission for the open-lot dairy.

Table 3.1. Summary of summer NH_3 Emissions (2000-head dairy).

GLAS	# of Samples	GLAS Area	Measured[1] Concentration	Mass Concentration[2]	Source Flux[3]	Emission Rates
		(m^2)	(ppb)	($\mu g\ m^{-3}$)	($\mu g\ m^{-2}\ s^{-1}$)	($kgNH_3\ day^{-1}$)
Open Lots	94	103000	10700[a]	7453	4.5	40.0
			(4783)[b]	(3332)	(2.0)	(17.8)
Lagoon-1	6	6275	22999[a]	16019	9.2	5.0
			(11428)	(7960)	(4.6)	(2.5)
Lagoon-2	6	46094	12701[a]	8847	5.3	21.2
			(1323)	(921)	(0.5)	(1.9)
Solid Separator	4	50	15[a]	10	0.0*	0.0*
			(43)	(30)	(0.0)	(0.0)
Statistic	110[c]					66.2[c]
						22.2[c,b]

[a] Average
[b] 95% confidence interval (CI)
[c] Summation
[1] Flux chamber measurement at 7 L min^{-1} sweep air flow rate and 30 minutes sampling period.
[2] at standard conditions.
[3] Source Flux from footprint of the flux chamber (0.192 m^2)
*Source Flux and Emission Rates < 0.005

Table 3.2. Summary of winter NH_3 Emissions (2000-head dairy).

GLAS	# of Samples	GLAS Area	Measured[1] Concentration	Mass Concentration[2]	Source Flux[3]	Emission Rates
		(m^2)	(ppb)	($\mu g\ m^{-3}$)	($\mu g\ m^{-2}\ s^{-1}$)	($kgNH_3\ day^{-1}$)
Open Lots	96	103000	9240[a]	6436	3.9	34.7
			(2582)[b]	(1798)	(1.1)	(9.4)
Lagoon-1	5	6275	1530 [a]	1066	0.6	0.3
			(1163)	(810)	(0.4)	(0.2)
Lagoon-2	3	22800	1072 [a]	746	0.5	0.9
			(477)	(332)	(0.2)	(0.4)
Solid Separator	3	500	821 [a]	572	0.3	0.0*
			(157)	(110)	(0.1)	(0.0)
Milking Parlor	3	500	131 [a]	91	0.1	0.0*
			(6)	(4)	(0.0)	(0.0)
Statistic	110[c]					35.9[c]
						10[c,b]

[a] Average
[b] 95% confidence interval (CI)
[c] Summation
[1] Flux chamber measurement at 7 L min^{-1} sweep air flow rate and 30 minutes sampling period.
[2] at standard conditions.
[3] Source Flux from footprint of the flux chamber (0.192 m^2)
*Emission Rates < 0.005

Assessment of summer and winter data in Table 3.3 indicated that overall NH_3 EFs were 11.6 ±7.1 kg NH_3 $year^{-1}$ $head^{-1}$ for the summer and 6.2 ±3.7 kg NH_3 $year^{-1}$ $head^{-1}$ for the winter season for a 2,000-head dairy. The long-term (1963-2007) average ambient air temperature data from a weather station located about 11 km from the dairy was downloaded from the National Climatic Data Center (NCDC) web site (NCDC, 2007). Five months, with average temperatures below 16 °C, were considered winter months and seven months, with average temperature above 16 °C, were considered summer months. Based upon this assumption, the annualized NH_3 EF for this dairy was estimated to be 9.4 ±5.7 kg NH_3 $year^{-1}$ $head^{-1}$ for this 2000-head dairy. The estimated NH_3 emission factor for winter was nearly 47% lower than summer EF. In addition, nitrogen mass balance method for the open-lot dairy was performed and NH_3 emission factor was calculated as 27.9 kg NH_3 $year^{-1}$ $head^{-1}$ for this dairy facility. Details are given in Appendix-A. In comparison, the EFs calculated in this study using mass balance method are within the same range (18.2 to 39.7 kg NH_3 $year^{-1}$ $head^{-1}$) with previously reported (Table 3.5) dairy NH_3 EFs using the same method in Europe and the US. However, there is a significant difference between our determined EFs from mass balance and directly measured flux data. Typically, EF (27.9 kg NH_3 $year^{-1}$ $head^{-1}$) from the mass balance method was in the range of 2-5 times higher than directly measured EF (11.5 to 6.2 kg NH_3 $year^{-1}$ $head^{-1}$) values. In N-mass balance method, it is assumed that all N losses in the air are in NH_3 form. This assumption does not reflect the real conditions in which all N losses can be estimated in the form of N_2 and N_2O (Arogo et al., 2006). Additionally, leaching losses of N are not taken into consideration.

Table 3.3. Seasonal ammonia EFs for GLAS of the open-lot dairy.

GLAS	GLAS Area	Summer EFs*	Winter EFs	Annual EFs
Open Lots	103000	7.3[a] (±6.6)[b]	5.9[a] (±3.6)[b]	6.8[c] (±5.4)[b]
Lagoon-1	6275	0.8[a] (±0.4)	0.1[c] (±0.0)	0.5[c] (±0.2)
Lagoon-2	46094	3.5[a] (±0.1)	0.2[c] (±0.1)	2.1[c] (±0.1)
Statistic		11.6[d] (±7.1)[d]	6.2[d] (±3.7)[d]	9.4[d] (±5.7)[d]

GLAS: Ground Level Area Source
* kg NH_3 $year^{-1}$ $head^{-1}$
[a]: average
[b]: CI (95%)
[c]: time weighted average
[d]: summation

Figure 3.7 shows that open-lot corrals were the highest contributor as nearly 63% of the total NH_3 EF in summer and 95% of the total NH_3 EF in winter. Primary and secondary lagoons contributed nearly 37% in summer and 5% in winter to NH_3 emissions for the open-lot dairy. Open-lot corrals and lagoons were the major contributors to the overall NH_3 EF in summer season while only open-lot corrals were the highest contributors to the overall NH_3 EF in winter season.

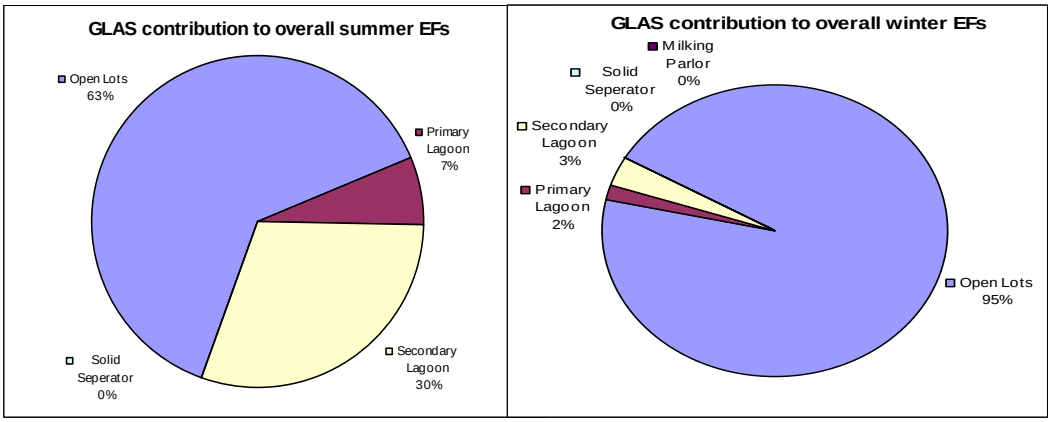

Figure 3.7 Seasonal GLAS contribution to overall EFs at the open-lot dairy.

The EFs from primary and secondary lagoons in summer were 0.8 ± 0.4 kg NH_3 $year^{-1}$ $head^{-1}$ and 3.5 ±0.1 kg NH_3 $year^{-1}$ $head^{-1}$ while winter season's EFs were 0.1 ±0 kg NH_3 $year^{-1}$ $head^{-1}$ and 0.2 ±0.1 kg NH_3 $year^{-1}$ $head^{-1}$, respectively. These differences in NH_3 emission from both lagoons were greater than 93% between summer and winter. As shown in Table 3.3, the summer and winter EFs for separated solids and the milking parlor were negligible (less then 0.005 kg NH_3 $year^{-1}$ $head^{-1}$).

Summer and winter EFs from the open-lot divisions and the area of each division (Table 3.3) were used to calculate the overall summer and winter ammonia EF to represent the entire open-lot corral. Table 3.4 shows that similar overall NH_3 EF from the open-lot corral were calculated during summer (7.3 ± 6.6 kg NH_3 $year^{-1}$ $head^{-1}$) and winter (5.9 ± 3.6 kg NH_3 $year^{-1}$ $head^{-1}$), but dispirit animal activity and manure loading on dry and shaded divisions of the corral resulted in different within season NH_3 emissions from these divisions.

Table 3.4. Summer and winter estimated NH_3 EFs from the open-lot divisions.

Sampled Corral Divisions	Area m²	Statistics	Seasonal EFs (kg NH_3 $year^{-1}$ $head^{-1}$)	
			Summer	Winter
Feeding	11704	n	12	12
		Mean	1.5[a] (±1.5)[a]	1.6 (±1.1)
Trans-sf	18727	n	18	20
		Mean	1.2 (±0.7)	1.1 (±0.8)
Shaded	23409	n	21	19
		Mean	2.3 (±2.8)	0.7 (±0.5)
Trans-ds	14045	n	12	14
		Mean	1.2 (±0.7)	0.9 (±0.7)
Dry	35113	n	31	31
		Mean	1.1 (±0.8)	1.6 (±0.6)
		Σn	94	96
		EF	7.3 [b] (±6.6)[a]	5.9 [b] (±3.6)[a]

n: number of samples.

[a] CI (95%)

[b] Summation

Trans-sf: transition area between shaded and feeding divisions.

Table 3.4 shows NH_3 EFs from each open-lot corral division. While summer and winter contributions of NH_3 emissions from feeding, Trans-sf and Trans-ds divisions were similar, shaded division in the summer contributed nearly three times greater NH_3 to the overall summer corral emissions as compared to its contribution of NH_3 to the overall winter corral emissions. This was due to little or no animal activity and manure accumulation in the shaded division during winter. The dry division during winter contributed nearly 30% more NH_3 to the overall winter corral emissions as compared to

its contribution of NH_3 to the overall summer corral emissions. This was caused by greater animal activity and higher loading of manure in the dry division during winter.

In comparison, previously reported (Table 3.5) dairy NH_3 EFs in Europe and US were higher than the seasonal EFs calculated in this study.

Table 3.5. Developed and reported NH_3 EFs.

Reported by	**Emission Factors (kg NH_3 $year^{-1}$ $head^{-1}$)**	**Method**
Buijsman et al. (1987)	12.2	Nitrogen Analyses
Möller and Schieferdecker (1989)	18.2	Mass Balance
Asman (1992)	39.7	Mass Balance
Van Der Hoek (1998)	28.5	Nitrogen Analyses
Pinder et al. (2004)	13.1-55.5	Farm Emission Model Based on manure management
Phillips, (1998)	1.5(± 0.4) (summer) 2.7(± 0.5) (winter)	Ferm tubes
Groot Koerkamp, (1998)	2.75- 17.5	Chemiluminescence
Misselbrook, (2001)	1.8- 5.7 (collecting yard) 8-12.6 (feeding yard)	Equilibrium Concentration Method
Cassel et al. (2005)	6.9 - 52.2	Passive Filter Pack
Misselbrook, (2006)	11.1(± 4.5) (collecting yard) 6.9 (± 3.0) (feeding yard)	Equilibrium Concentration Method
Rumburg, (2007)	40	Tracer ratio method for flux, optical absorption spectroscopy for ambient measurements

The EFs presented in Table 3.5 were generally estimated from the nitrogen content in excreted manure or from a mass balance of nitrogen inputs and outputs at dairy operations. A few NH_3 EFs presented in Table 3.5 were also estimated using direct

measurement methods rather than the nitrogen analysis. Phillips et al. (1998) estimated seasonal ammonia EFs from a naturally-ventilated dairy house in UK using Ferm tubes (passive NH_3 flux samplers) for measuring NH_3 emissions in summer and winter. Estimated EFs in summer and winter were 1.5 (± 0.4) and 2.7 (± 0.5) kg NH_3 $year^{-1}$ $head^{-1}$, respectively. The seasonal difference in emissions was due to cows spending much lesser time (4 h) in the building during summer than winter. Groot Koerkamp et al. (1998) reported EFs from mechanically ventilated cubicle dairy buildings and litter (bedding material) in several European countries using the chemiluminescence analyzer. Estimates of EFs varied from 2.75 to 17.5 kg NH_3 $year^{-1}$ $head^{-1}$. Ammonia EFs were also reported by Misselbrook et al. (2001 and 2006) in Europe. Ammonia EFs from dairy feed yard and collecting yard where cows crowd to enter the milking parlor ranged from 8-12.6 kg NH_3 $year^{-1}$ $head^{-1}$ and 1.8-6.9 kg NH_3 $year^{-1}$ $head^{-1}$, respectively. A recent study conducted by Rumburg et al. (2007) in the US shows an EF estimate of 40 kg NH_3 $year^{-1}$ $head^{-1}$ using a tracer ratio method for flux and optical absorption spectroscopy for ambient NH_3 measurement at the edge of the dairy building.

It is important to note that most studies involving a direct measurement method of NH_3 flux or concentration in Europe and US did not measure emissions from all of the potentially significant ground level area sources (GLAS) of NH_3 emission at a dairy operation. Additionally, southwestern US dairy management practices and climate are different than northern and Midwestern US and European dairy farms. For example, open-lot dairies in southwestern US include much larger corral area per cow and liquid waste storage and treatment structures such as two or three-stage lagoons. Reported

ammonia EFs from Europe and the US using nitrogen analysis were generally higher than EFs calculated in this study and using direct measuring methods were generally in the same range with EFs calculated in this study however the EFs reported by Rumburg et al. (2007) was higher than the EFs determined in this study. In general, differences in climate, housing, feed and waste management practices contributed to the differences between reported EFs in Table 3.5 and those determined in this study.

The meteorological data from on-site weather station and temperature sensors mounted on the flux chambers are presented in Table 3.6. The temperature data is the mean value and its 95% confidence level during sampling time of each individual GLAS (emitting source) NH_3 measurements.

Table 3.6. Seasonal GLAS and ambient weather data.

Sampling Sites	**Barometric Pressure**	**GLAS Temp.**	**Chamber Temp.**	**Ambient Temp.**
	(kPa)	**(°C)**	**(°C)**	**(°C)**
Summer, 2005				
Open-lot	95[a] (±1)[b]	29[a](27.6[c]-30.3[d])	29 [a] (27.8-31.1)	27 [a] (25.8-27.3)
Primary lagoon	95.9(±0.1)	34.3(32.4-36.2)	34.6(33.8-35.5)	33.7(33.3-34)
Secondary lagoon	95.7(±0.1)	30.7(21.2-40.2)	31.4(29.3-33.5)	32.4(31.1-33.7)
Winter, 2005				
Open Lots	97[a] (±1.9)[b]	6.1 (5.4[c]-6.7[d])	6.2 (5.6-6.9)	6 (5.6-6.4)
Primary lagoon	96.8(±0.1)	9.6(5.7-16.4)	11.2(5.9-16.4)	11.5(8.1-14.9)
Secondary lagoon	96.6(±1)	NA	NA	10.4

[a] Mean
[b] 95% confidence interval (CI)
[c] 95% CI for lower bound
[d] 95% CI for upper bound

The results showed that there was a significant difference between summer and winter GLAS (emitting source), inside of chamber and ambient air temperatures. Within a given season, ambient, chamber and GLAS temperatures were similar to one another for each sampling site. Ammonia emissions within a season (summer or winter) showed little or no dependence on source temperature or moisture. For instance in summer season, measured NH_3 emission from open-lot corral showed little positive dependence on corral surface temperature (r^2=0.08) and on ambient air temperature (r^2=0.11). Misselbrook et al. (2006) also indicated that there was a weak correlation between ambient air temperature and NH_3 emission rates (r^2=0.22).

3.8.2. Spatial Variability of Ammonia Emissions at the Open-lot Corral

The collected NH_3 samples from the open-lot corral surfaces had skewed distributions in summer and winters seasons as shown in Figures 3.8 and 3.9.

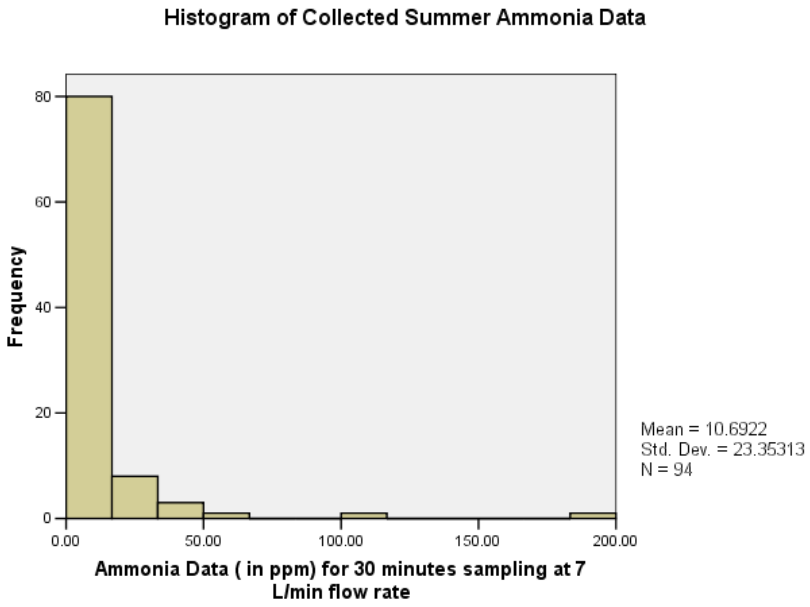

Figure 3.8. Histogram of collected ammonia open-lot samples in summer.

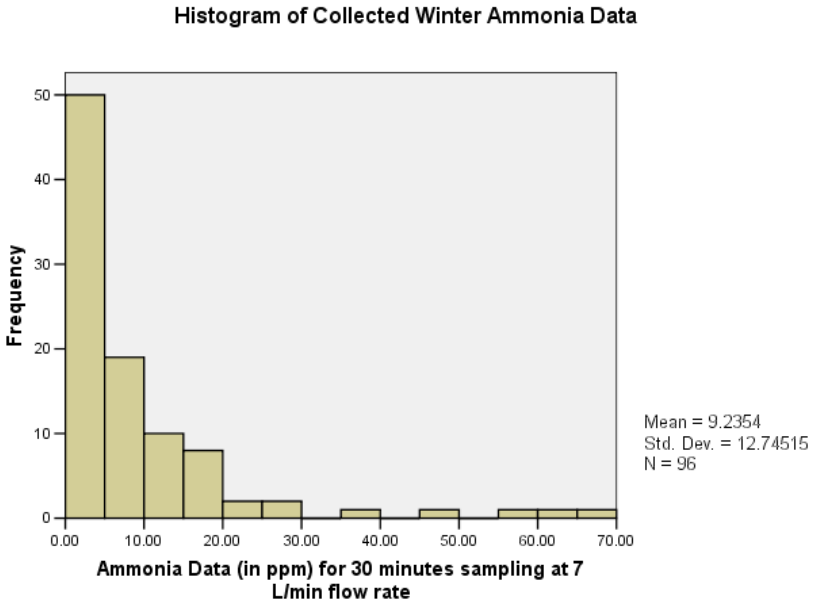

Figure 3.9. Histogram of collected ammonia open-lot samples in winter.

Ammonia emissions varied among dry, shaded, feeding and transition divisions of the corral. A One-way ANOVA test was run (SPPS, 2004) to determine any significant NH_3 emission differences among these divisions of the corral (Table 3.7). It was determined that summer NH_3 emissions and total N content of manure (mostly dry and aged manure) sampled from the dry division were significantly lower than all other divisions. During summer, animal activity was usually limited to feeding, and shaded divisions of the corral resulting in greater manure loading and higher NH_3 emissions in those divisions as compared to the rest of the corral divisions with little or no manure. Also in summer, no significant differences among corral divisions' temperature and moisture content were observed (Table 3.7).

In winter, NH_3 emissions from the feeding division were significantly higher than shaded and dry divisions and the shaded division had the lowest emissions of all divisions.

Table 3.7 Ammonia EF comparison of open-lot divisions.

	Summer, 2005	Winter, 2005	Summer vs. Winter
NH_3 EFs (kg NH_3 $year^{-1}$ $head^{-1}$**)**	Dry division was significantly lower than all other divisions (p =0.012(feeding), p=0.015 (trans-sf), p= 0.009 (shaded) and p= 0.006 (trans-ds) < 0.05) **Range: 1.1 - 2.3 kg NH_3 $year^{-1}$ $head^{-1}$**	Feeding division was significantly higher than shaded and dry divisions (p =0.011, and 0.04 < 0.05, respectively) **Range: 0.7 -1.5 kg NH_3 $year^{-1}$ $head^{-1}$**	No significant difference was observed between summer and winter seasons
Total N (%)	Dry division was significantly lower than feeding, shaded, trans-sf and trans-ds divisions (p=0.023, 0.006, 0.000, 0.025 < 0.05, respectively) and Trans-sf division was significantly higher than dry, feeding, shaded, trans-ds divisions (p =0.000, 0.036, 0.007, 0.001< 0.05, respectively) **Range: 0.56 - 2.18 %**	No significant differences among divisions were observed **Range: 0.44 - 2.60 %**	No significant difference was observed
Moisture Content (%)	No significant differences among divisions were observed **Range: 4 - 73 %**	Trans-ds division was significantly lower than feeding and trans-sf. (p =0.036, 0.036 < 0.05, respectively) Trans-sf division was significantly higher than shaded and trans-sd. (p =0.024, 0.036 < 0.05, respectively), Shaded division was significantly lower than feeding division. (p =0.035 < 0.05) **Range: 15.6 - 80.5 %**	MC was significantly higher in winter time (43.1%) than the summer time (27.3%) (p=0.002)
Source Temp. (°C)	No significant differences among divisions were observed. **Rang: 18 - 45 °C**	No significant differences among divisions were observed **Range: 0.3 - 11°C**	Source temperature was significantly higher in summer time (29.9°C) than the winter time (8.3°C) (p=0.00)
trans-ds: transition from dry to shaded area **trans-sf**: transition from shaded to feeding area			

This is due to the fact that during winter, shaded division was the least used area by animals and therefore, manure loading of this area was lower than the rest of the corral. Winter moisture content for all corral divisions varied considerably. Shaded division and transition between dry and shaded division had significantly lower moisture contents than all other divisions. No significant differences were found among corral divisions' temperatures in winter.

Spatial variations of NH_3 emissions (PPM) in the open-lot corral for both summer and winter season are also illustrated with 3-D surface maps (Surfer, 2002) in Figures 3.10and 3.11, respectively. A comparison of the two maps shows that summer NH_3 emissions were highly spatially variable and skewed to the feeding and shaded divisions of the corral with higher animal activity and greater manure loading. In contrast, winter NH_3 emissions varied spatially throughout the corral area due to relatively more uniform distribution of animal activity and manure loading.

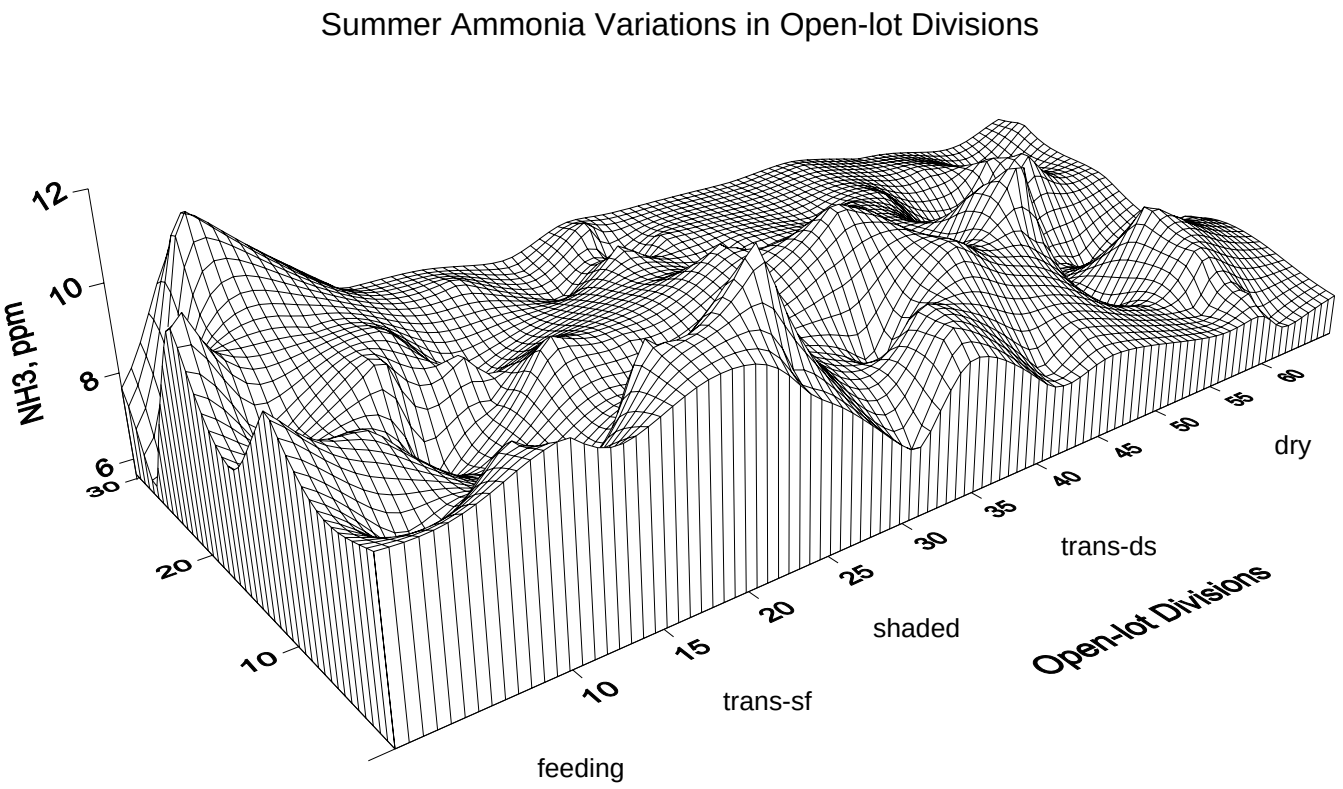

Figure 3.10. Spatial variations of summer ammonia concentrations in open-lot divisions.

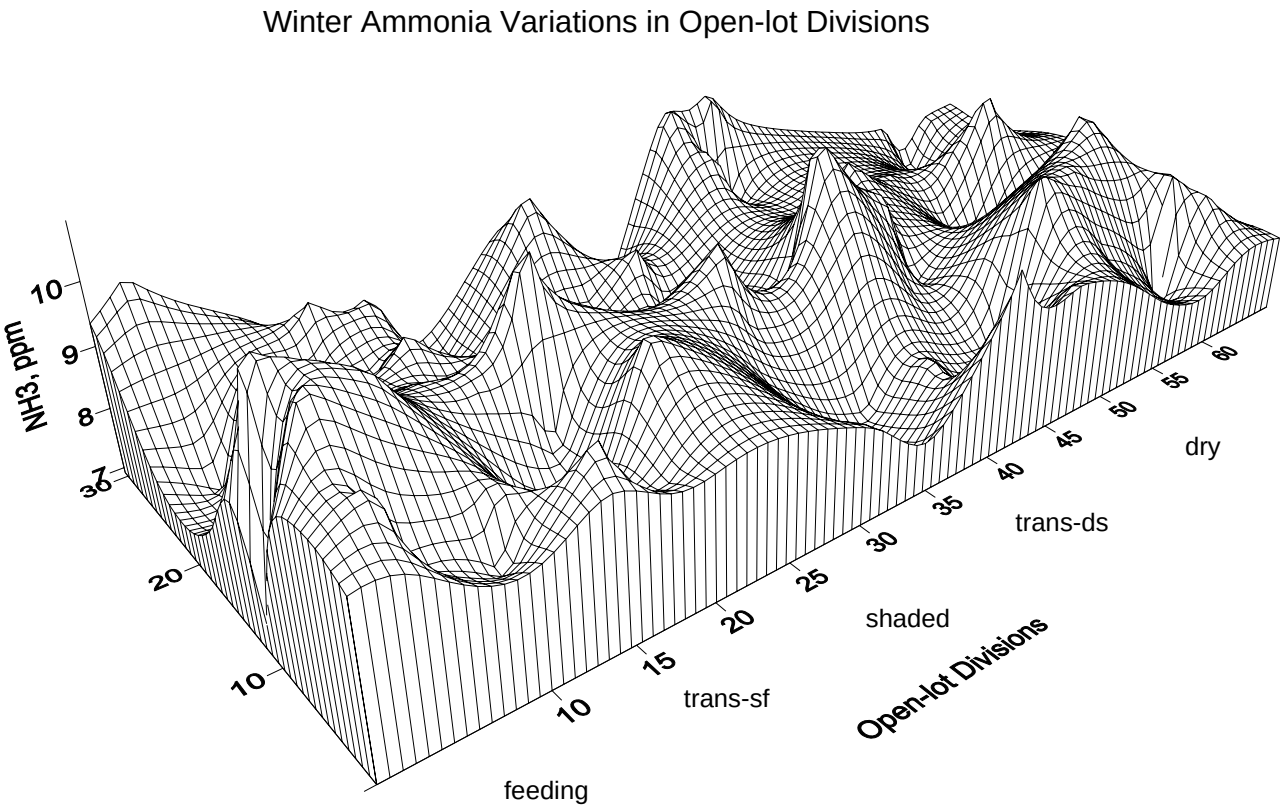

Figure 3.11. Spatial variations of winter ammonia concentrations in open-lot divisions.

3.9. Conclusions

The quantification of specific NH_3 emission rates (ERs) and factors (EFs) from ground level area sources (GLAS) in a dairy is needed to understand which sources contribute most to the overall NH_3 emissions during winter and summer conditions. Therefore, summer and winter NH_3 emission factors were estimated from an open-lot dairy.

Ammonia emission variations among GLAS occurred due to seasonal changes in ambient and source temperatures, and spatial variations of NH_3 within a given season occurred in the open-lot corrals due to varying cow density and the resulting dispirit manure loading in feeding, dry, shaded and transition divisions and the transition areas between these divisions. Within the open-lot corral, summer NH_3 emissions from the dry area were significantly lower than those from all other areas. In winter, NH_3 emissions from feeding division were significantly higher than shaded and dry divisions at the open-lot corral. Overall, summer NH_3 EFs were nearly two times those of winter EFs. Hence, it is necessary to consider both management practices and climate conditions to implement technologies to mitigate NH_3 emissions from the animal feeding operations.

Previously reported dairy NH_3 EFs in Europe and colder regions of the US were generally greater than those estimated in this study. Ammonia EFs vary due to differences in climate, housing, feed, and waste management practices between European/northern and Midwestern US dairy operations and open-lot dairies in the

southwestern US. It is important to note that studies involving a direct measurement method of NH_3 flux or concentration in Europe and the US did not measure emissions from all possible ground level area sources (GLAS) of NH_3 emission at a dairy operation.

CHAPTER IV

SEASONAL AMMONIA EMISSIONS FROM A FREE-STALL DAIRY IN CENTRAL TEXAS

4.1. Introduction

Ammonia is released to the atmosphere due to the biological decomposition of dairy manure. In both Europe and the United States, agricultural NH_3 emissions from animal feeding operations (AFOs) and fertilizer applications are considered as major contributors (up to 80%) to the total NH_3 emissions (Battye et al., 1994; DEFRA, 2002).

Animal feeding operations (AFOs) would classify as a complex if manure which is generated in AFOs or used for fertilizer application is considered a “hazardous substance”. Nowadays, the US lawmakers are debating whether animal waste should be termed as a “toxic pollutant” (Sadler, 2007).

Currently, NH_3 emissions from animal agriculture are not regulated. Ammonia emissions are only subject to being reported to federal, state or local agencies if the emission exceeds reportable quantity (RQ). Currently, two major laws are designated to manage this reporting process.

The first law was enacted in 1980 and was called the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as “Superfund”. This law was intended to clean up abandoned sites that may contain

hazardous substances (HS). This program was first applied to toxic waste dumps such as Love Canal and Times Beach in the 1970s. (USEPA, 2007).

The second law, Emergency Planning and Community Right-to-Know Act (EPCRA), was enacted in 1986. This program contains an extremely hazardous substances (EHS) list and intends to protect the public and environment from the releasing of EHS.

The primary purpose of releasing notifications in CERCLA and EPCRA is defined by the USEPA (1998) as "to notify various levels of government of potential hazards so that the necessary response actions can be taken in a timely fashion to ensure maximum protection of human health and the environment".

In general, CERCLA provides release reports on a federal scale by submitting to National Response Center (NRC) while EPCRA reports are submitted to state emergency response centers (SERCs) and local emergency response centers (LERCs).

EPCRA requires a person or facility owner to report to state and local agencies if RQ of substance is met by the facility. Recently, some livestock facilities (*Sierra Club vs. Seaboard Farms Inc.*, *Sierra Club vs. Tyson Food Inc.*) have been involved in major lawsuits regarding EPCRA (Karvosky, 2005).

Ammonia is not considered a hazardous air pollutant in the Clean Air Act (CAA); therefore, it was not listed in EPA's hazardous air pollutant (HAP) list (USEPA, 2007a). However, NH_3 is listed (CAS# 7664-41-7) as a hazardous substances (HS) by CERCLA.

CERCLA includes a national priority list (NPL) of the important HSs that may pose a serious threat to public health. NPL is reported on a 2-year basis using annual information. The NPL is generated based on 3 factors: frequency of appearance at NPL, level of toxicity and potential risk for human health (ATSDR, 2006).

In addition, more than 300 substances including NH_3 were listed (CAS# 7664-41-7) as extremely hazardous substances (EHS) under section 302 of EPCRA and set its reportable quantity (RQ) as 45 kg per day (100 pounds per day). EPCRA requires a report if RQ of NH_3 is released from an animal feeding facility in a 24 hour period (USEPA, 2007b).

If EPCRA is applied to a dairy facility, according to definition of "facility", the barns, open-lot corrals, lagoons and manure storage structures would be subject to a combined (overall) RQ analysis.

Increasing public concerns over air quality impacts from AFOs in the United States has led the USEPA to begin establishing an air monitoring study to obtain reliable emission inventory for livestock and poultry facilities.

In 2005, the USEPA offered a "consent agreement" to individual AFOs who will participate as volunteers. This agreement allows conducting a source specific study to monitor air emissions from AFOs. This "Consent Agreement" protects AFOs from enforcement while monitoring study is being conducted at their sites (USEPA, 2006). The National Air Emission Monitoring Study (NAEMS) was established in 2006 by the

Consent Agreement. Various gases including NH_3 and airborne pollutants emitted from livestock and poultry operations will be monitored across the nation.

The potential for federal air quality regulations accelerates the need for better estimates and effective management practices for reducing NH_3 emissions. It is important to obtain real-time, direct estimates of emissions from different NH_3 emission sources at AFOs. There is a need for an accurate technique to measure NH_3 emissions from AFOs to obtain emission inventories and to develop abatement strategies. A protocol to measure surface gas emission from GLAS using isolation flux chamber (FC) has been published by the EPA (Gholson et al., 1989). This measurement technique applies to quiescent liquid surfaces such as lagoons where surface runoff and process generated waste water from AFOs are stored and treated under anaerobic conditions.

In our study, this protocol was used to determine NH_3 emission factors from different GLAS at a free-stall dairy in central Texas.

The objectives of our study were:

- to estimate seasonal ammonia EFs from a free-stall dairy using a real-time measurement system; and
- to evaluate seasonal variations of EFs during two consecutive seasons.

4.2. Materials and Methods

4.2.1. Sampling Site: Free-stall Dairy

Free-stalls and open-lot dairies are the most common dairy systems in southern and western part of US. A free-stall dairy in central Texas was chosen to determine NH_3 emissions from different GLAS. An aerial photo of the site showing source of NH_3 emissions at the dairy is presented in Figure 4.1 (TGIC, 1998). Approximately 2,100 lactating and dry cows were housed at the dairy. The open-lots at this free-stall diary were provided for dry or low milk producing cows and included centralized feeding and watering areas and free standing shelters for relief from severe weather conditions.

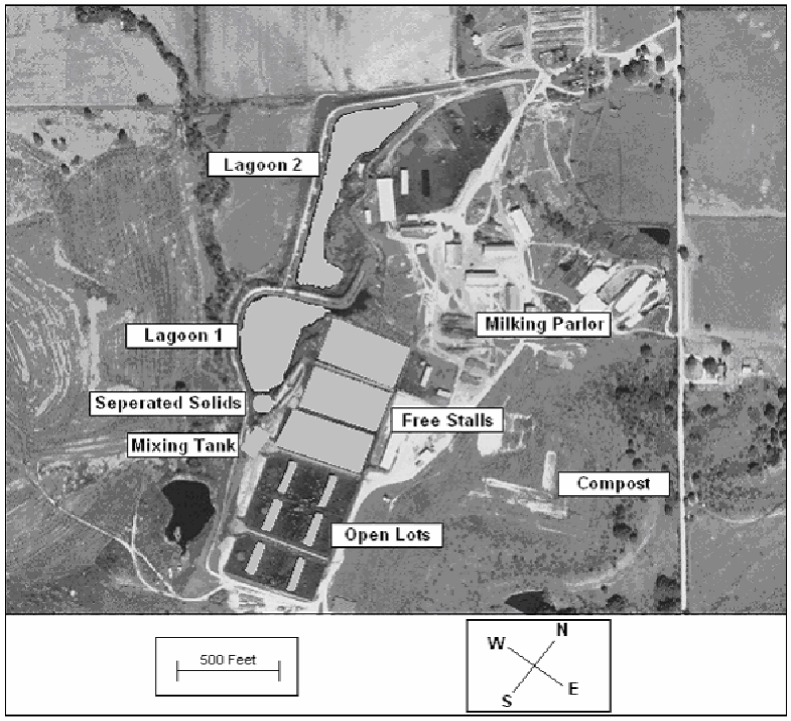

Figure 4.1. An aerial view of the sampled dairy (TGIC, 1998).

Manure accumulated in the free-stall barns was removed by flushing four times a day (7am, 1pm, 7pm, 1am). There were three free-stall barns located on this dairy and each free-stall was flushed in series from north to south. The slurry was then transported into a solids separator system for liquid-solid separation. Screened solids were composted on-site and used as bedding for the free-stall barns. The separated liquid portion was transported to the first cell of the anaerobic lagoon (lagoon 1). The effluent from primary lagoon was conveyed to the second cell (lagoon 2) with a pipe outlet. Lagoon 2 also accepted runoff from two other open-lots. Each open-lot was an un-paved, confined area with access to feed bunkers and water tanks. Manure produced in the open-lot was removed by scraping using tractor mounted blades. The rate of manure production was generally higher near feed bunkers and water tanks. The scraped manure was stockpiled and either land applied or composted on-site.

4.2.2. Sampling Equipment

Isolation FCs were used to measure real-time NH_3 concentrations from GLAS of the free-stall dairy. The basic design of the FC includes a hemispherical top (dome) and a cylindrical skirt (Figure 4.2). The dome contained four symmetrical holes with stainless steel fittings. A tubing inlet located at one of the stainless steel fittings allowed for the flow of sweep air into the chamber (Eklund, 1992).

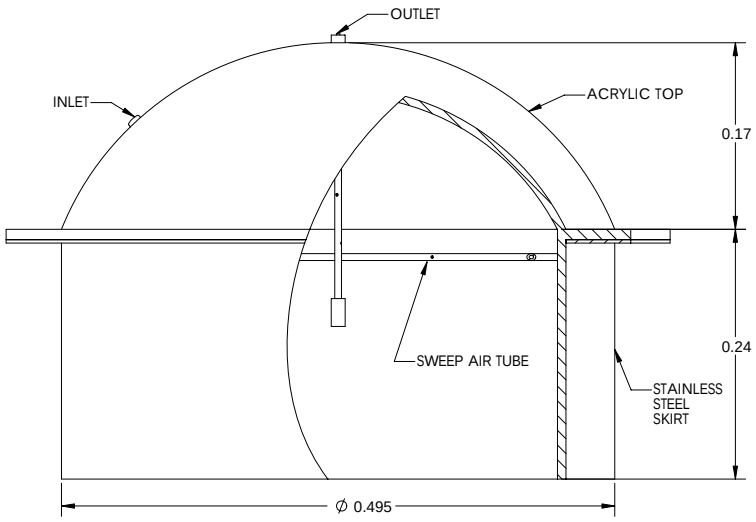

Figure 4.2. Schematic of the flux chamber (Source: Boriack, 2005).

The sweep air was NH_3 free purified air generated from a zero-air generator (Model 737-12, AADCO Instruments, Village of Cleaves OH). A fitting on the top of the dome allowed for the pollutant stream to be conveyed to a measurement device. Two of these holes were used to connect the FC to a low density polyethylene (LDPE) tubing to convey the contaminant free zero grade air to sweep and purge the chamber and a Teflon® tubing to convey a sample of the polluted air from the chamber to NH_3.gas analyzer. During summer sampling at the dairy, flux chambers were covered with cylindrical covers on the sides and on top (Figure 4.3) to minimize potential over heating of the chamber when exposed to direct sun light. This insulation kept inside temperature of the chamber similar to the ambient temperature

Figure 4.3. Isolation flux chambers in a free-stall barn.

Previous studies (Rose, 2003; Mukhtar et al., 2003, Boriack, 2005 and Capareda et al., 2005) have provided details of sampling NH_3 using flux chambers.

4.2.3. Sampling Method

The EPA protocol requires 3 to 4 volumetric air exchanges in the FC during the sampling process. Ammonia-free sweep air flow rate of 5 $L.min^{-1}$ was used during winter sampling and 7 $L.min^{-1}$ was used during summer sampling. Use of a larger capacity zero air generator allowed this increase in flow rate during summer sampling. Given the FC dimensions in Figure 2, these flow rates provided the needed air exchanges in a 30 min. period. The sampling process began when the FC was placed on a GLAS. Initially, the sweep air from the generator was pumped into the FC and it was purged for

a period of 30-min. After purging the FC, actual sampling of polluted air was initiated by conveying the Polluted air from FC to a TEI chemiluminescence analyzer (Model 17C, Thermo Environmental Instruments, TEI, Massachusetts.) to measure NH_3 for an additional period of 30 minutes.

The TEI analyzer was calibrated using known concentrations of NH_3 and NO, certified high purity standard gases guaranteed by the manufacturer to be within ± 2% accuracy (Praxair, Inc., Danbury, CT). Details of the principle of chemiluminescence to measure NH_3 have been provided in previous studies (Rose, 2003; Mukhtar et al., 2003, Boriack, 2005 and Capareda et al., 2005).

Adsorption studies were conducted earlier to determine losses from the sampling tube (Teflon) and the FC system. Results indicated that an adsorption loss of NH_3 on Teflon tubing was negligible (Mukhtar et. al., 2003) and NH_3 adsorption losses were approximately 8% for flux chamber (Capareda et. al., 2005). Ammonia concentrations from the analyzer were corrected based upon adsorption losses.

Uncertainty analysis was performed on NH_3 sampling process (Boriack, 2005). The overall uncertainty was found to be in the range of 8 to 10% for this NH_3 sampling set-up.

Using the ideal gas law, measured volumetric NH_3 concentrations (parts per million-PPM) were converted into mass concentration ($C_{mass,}$ μg m^{-3}) and equations (4.1), (4.2), and (4.3) were used to calculate NH_3 EFls, ERs and EFs, respectively:

$$EFl_{NH_3} = \frac{C_{mass} \times V_{fc}}{A_{fc}} \qquad \text{(eq. 4.1.)}$$

Where:

EFl_{NH3} = NH_3 gas emission flux (μg m^{-2} sec^{-1}),

V_{fc} = volumetric flow through the flux chamber (m^3 sec^{-1}),

A_{fc} = area of flux chamber ("footprint", m^2).

$$ER = EFl_{NH_3} \times A_{sc} \qquad \text{(eq. 4. 2.)}$$

where:

ER = Emission rate, kg day^{-1},

A_{sc} = Area of source (GLAS), m².

$$EF = (\frac{ER}{TNA}) \times 365 \qquad \text{(eq. 4.3)}$$

where:

EF = Emission factor, kg NH_3 $year^{-1}$ $head^{-1}$,

TNA = Total number of animal.

4.3. Results and Discussions

Two consecutive seasonal studies were conducted at the same free-stall dairy. First study was conducted in the winter season. Twenty-nine samples were collected to determine the ERs and EFs of ammonia from different GLAS of the dairy. The second study was conducted in following summer season and fifty-five samples were collected.

Assessment of winter and summer data (Tables 4.1 and 4.2) indicated that overall NH_3 emission rates (ERs) were 62.4 ±31 kg day^{-1} for the summer and 26.8 ± 27.9 kg day^{-1} for the winter season for 2100-head dairy. Manure composting area (~35 %) and free-stall barn (~35%) in winter and primary and secondary lagoons (~63%) in summer were the highest contributors to NH_3 emission for the free-stall dairy.

Table 4.1. Summary of winter NH_3 emissions.

GLAS	Number of Samples	Area (m^2)	Measured Concentration[1] (ppm)	Mass Concentration[2] ($\mu g\ m^{-3}$)	Source Flux[3] ($\mu g\ m^{-2}\ s^{-1}$)	ER ($kg\ day^{-1}$)
Compost	3	21000	17.4 ±23.5[b]	12120±16400	5.3 ±7.1[b]	9.5 ±12.9
Free Stall	5	10000	36.4 ±23.3	25354±16230	11.0 ±7.0	9.5 ±6.1
Dry Open Lot	3	36100	6.5 ±8.8	4527±6130	2±2.7	6.1 ±8.3
Wet Open Lot	4	1900	14.1 ±5.4	9821±3800	4.3±1.6	0.7 ±0.3
Separated Solids	2	110	9.3 ±7.9	6478±5500	2.8 ±2.4	0.03 ±0.02
Lagoon 1	6	14000	2.0 ±0.5	1393±350	0.6 ±0.2	0.7 ±0.2
Lagoon 2	6	16000	0.4 ±0.3	279±2210	0.1 ±0.1	0.2 ±0.1
Statistic	29[a]	88300[a]				26.8[a] ±27.9[b]

[a] Summation
[b] 95% confidence interval (CI)
[c] Average
[1] Flux chamber measurement at 7 L min^{-1} sweep air flow rate and 30 minutes sampling period.
[2] at standard conditions.
[3] Source Flux from footprint of the flux chamber (0.192 m²)

Table 4.2. Summary of summer NH_3 emissions.

GLAS	Number of Samples	Area (m^2)	Measured Concentration[1] (ppm)	Mass Concentration[2] ($\mu g\ m^{-3}$)	Source Flux[3] ($\mu g\ m^{-2}\ s^{-1}$)	ER ($kg\ day^{-1}$)
Compost	11	16600	1.8 ±1.5[b]	1337±1080	0.8 ±0.7[b]	1.2 ±1.0[b]
Freestall	14	9790				
Non-feed	5	2700	57.0 ±50.3	39727±35034	24.5 ±22	5.7 ±5.0
Feed	5	3090	73.2 ±71.7	51017±49945	31.4 ±31	8.4 ±8.2
Bedding	2	3800	2.4 ±22.2[1]	1716±15406	1.1 ±9.5	0.3 ±3.1
Water Area	2	200	20.9 ±79.7	14600±55541	9.0 ±34.2	0.2 ±0.6
Open Lot	8	38000	4.7 ±3.8	3295±2645	2.0 ±1.6	6.7 ±5.4
Crowding Area	4	925	9.4 ±7.9	6574±5514	4.0 ±3.3	0.3 ±0.3
Separated Solids	4	109	3.7 ±7.0	2580±4877	1.6 ±3.0	0.01 ±0.03
Lagoon 1	8	19200	31.8 ±7.2	22152±4998	13.1 ±3.1	22.6 ±5.1
Lagoon 2	6	17000	27.0 ±2.8	18826±1959	11.6 ±1.2	17.0 ±1.8
Statistic	55[a]	101625[a]	-	-	-	62.4[a] ±31

[a] Summation
[b] 95% confidence interval (CI)
[c] Average
[1] Flux chamber measurement at 7 L min^{-1} sweep air flow rate and 30 minutes sampling period.
[2] at standard conditions.
[3] Source Flux from footprint of the flux chamber (0.192 m²)

Winter NH_3 EFs, area of each GLAS, ambient and GLAS temperatures are presented in Table 4.1. During winter sampling, the total area of the composting windrows was nearly 27% greater (Table 4.3) than that during summer sampling (Table 4. 4). Conversely, areas of both lagoons, measured at the waterline, were lesser in winter (Table 4.1) than summer (Table 4.2) by nearly 37% and 6% for lagoon 1 and lagoon 2, respectively.

Table 4.3. Ammonia EFs from different GLAS of the dairy in winter season.

GLAS	**GLAS Area (m^2)**	**Winter EFs***	**Ambient Temp. (°C)**	**GLAS Temp. (°C)**
Compost	21,000	1.7[a] (±2.2)[b]	8.5	30.1
Free-stall	10,000	1.7 (±1.1)	6.3	6.4
Dry Open Lots	36,100	1.1 (±1.4)	-1.0	-1.1
Wet Open Lots	1,900	0.1 (±0.05)	-1.0	-1.1
Solid Separator	110	0.0 (±0.0)	3.7	3.6
Primary Lagoon	14,000	0.1 (±0.03)	16.7	8.7
Secondary Lagoon	16,000	0.0 (±0.02)	13.0	9.5
Statistic	99,110[c]	4.7[c] (±4.9)	6.6[a]	8.0[a]

GLAS: Ground Level Area Source
*: kg-NH_3.$year^{-1}$.$head^{-1}$
[a]: average
[b]: CI (95%)
[c]: summation

The highest ammonia EFs were from composting area and free-stall barns as 1.7±2.2 kg NH_3 $year^{-1}$ $head^{-1}$ and 1.7±1.1 kg NH_3 $year^{-1}$ $head^{-1}$, respectively. The

lowest EFs were from open lots and the primary lagoon (lagoon 1). Each source emitted 0.1 kg NH_3 $year^{-1}$ $head^{-1}$. The highly diluted secondary lagoon (lagoon 2) and small foot print of the separated solids site contributed little to the overall EFs. The compost and the free-stall areas contributed nearly 72% to the total ammonia EF for this facility while the dry open-lot contributed an additional nearly 23%. The overall calculated ammonia EF was 4.7± 4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for this free-stall dairy. The average ambient temperature during winter sampling was 6.6 °C.

At the same source and ambient temperature (Table 4.3), the wet areas of open-lots had higher NH_3 concentrations (Table 4.1) than the dry areas but due to a much smaller "foot print", EF from wet open-lots was lesser than dry open-lots. The area of free-stalls was less than one half of that of the open-lots, but much greater ammonia emissions measured from free-stalls resulted in higher EF than open-lots. This was due to the higher density of cows in the free-stall barn resulting in greater amounts of manure accumulation. Additionally, relatively higher free-stall barn temperatures as compared to open-lot also contributed to higher NH_3 emission from waste. High temperature of actively composting piles resulted in increased NH_3 emissions and higher emission rates resulted from the compost site representing the second largest area at the dairy.

The second study at the same free-stall dairy was conducted during summer season. Fifty-five samples were collected to determine NH_3 emissions from the same sources plus the crowding area (adjacent to the milking parlor) of the dairy. Additionally, for a better understanding of NH_3 emissions from the free-stall barn, NH_3

was measured from the feed and non–feed sides and from bedding and watering areas of the barn. Ambient air, GLAS and chamber temperatures were measured simultaneously with NH_3 emission measurements (Table 4.4).

Results of ammonia EFs from each individual GLAS are shown in Table4.4 Ammonia EFs ranged from nearly zero to 4.1±0.9 kg NH_3 $year^{-1}$ $head^{-1}$. Both primary (lagoon1) and secondary (lagoon 2) lagoons were the highest contributor to the overall ammonia EF in the summer season.

Table 4.4. Ammonia EFs from different GLAS of the dairy in summer season.

GLAS	GLAS Area (m^2)	Summer EFs*	GLAS Temp. °C	Chamber Temp. °C	Ambient Temp. °C
Compost	16,600	0.2[a] (±0.2)[b]	43.2[a] (±7.1)[b]	39.1 (±1.8)	33.3 (±1.6)
Free-stall Areas					
Non-feed	2,700	0.8 (±0.9)	25.8 (±3.2)	30.1 (±2.0)	33.4 (±1.3)
Feed	3,090	1.5 (±1.4)	33.9 (±56.1)	33.2 (±5.4)	34.6 (±0.2)
Bedding	3,800	0.1 (±0.0)	27.0 (±2.8)	31.1 (±2.5)	33.3 (±3.1)
Watering	200	0.0 (±0.1)	23.8(±2.1)	31.5 (±4.4)	34.5 (±2.7)
Open -lots	38, 000	1.2 (±1.0)	30.6 (±3.5)	35.3 (±3.1)	33.3 (±1.4)
Crowding area	925	0.1 (±0.0)	21.5 (±1.0)	24.2 (±1.0)	25.6 (±1.0)
Solids separator	110	0.0 (±0.0)	34.0 (±5.2)	32.7 (±4.7)	N/A
Lagoon 1	19,200	4.1 (±0.9)	29.5 (±1.2)	29.7 (±1.8)	29.6 (±2.3)
Lagoon 2	17,000	3.1 (±0.3)	28.4 (±0.7)	27.7 (±2)	26.7 (±1.9)
Statistic	101,625[c]	11.1 [c] (±4.9)			

GLAS: Ground Level Area Source
*: kg NH_3 $year^{-1}$ $head^{-1}$
[a]: average
[b]: CI (95%)
[c]: summation

Difference in NH_3 emissions occurred due to temperature variations, dispirit waste loading rates and biological activity. For instance, EFs from both lagoons were not significant contributors to the overall EF in the winter season in Figure 4.1. But, summer ammonia EFs were 4.1±0.9 kg NH_3 $year^{-1}$ $head^{-1}$ from the lagoon 1 and 3.1±0.3 kg NH_3 $year^{-1}$ $head^{-1}$ from lagoon 2 (Figure 4.4).

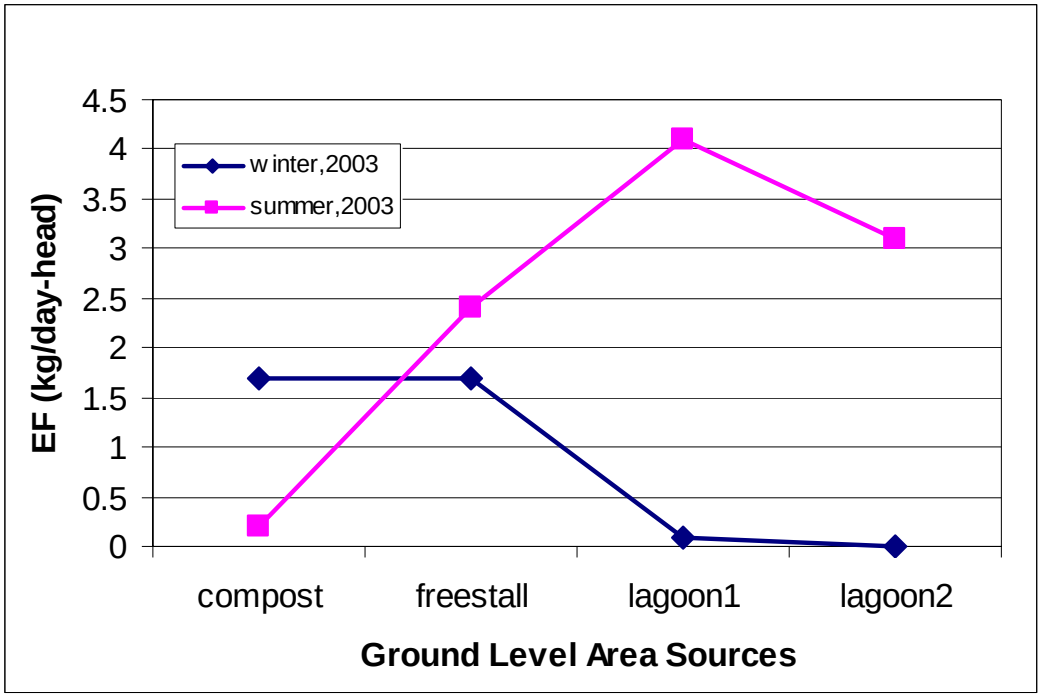

Figure 4.4. Seasonal variations of GLAS in free-stall dairy.

This increase in NH_3 emissions from both lagoons was attributed to increased volatilization of NH_3 due to much higher lagoon temperatures in summer than in the

winter. Also, greater lagoon surface areas in the summer resulted in greater estimates for summer lagoon EFs. Despite the higher compost pile surface temperature in summer than the winter season, NH_3 emissions from compost were lower in summer than those in winter (Table 4.1). At the time of summer NH_3 measurements, compost piles had already gone through an active heating cycle (the differences between pile and ambient temperatures were only 9.8 °C during summer sampling as compared to 21.6 °C during winter sampling) and microbial activity of piles was reduced, resulting in lower NH_3 volatilization. Additionally, lesser surface area of compost windrows also contributed to lower summer EF from the compost site. Total free-stall ammonia EF in summer (2.4±2.4 kg NH_3 $year^{-1}$ $head^{-1}$) was higher than that from winter (1.7±1.1 kg NH_3 $year^{-1}$ $head^{-1}$) due to higher summer temperatures.

During summer, feed area of free-stall had the highest NH_3 concentration followed by the non-feed side, water area and bedding (Table 4.2). The feed side of the barn had the most amount of waste accumulation resulting in the highest NH_3 emissions. Waste around the water tanks was diluted due to water spillage by cows in the vicinity, which resulted in lower NH_3 emissions than those from feed and non-feed sides. The free-stall bedding was composted separated solids with most nitrogen tied up in organic matter and had very little NH_3 volatilization, hence minimal NH_3 emissions were measured from the bedding area.

The overall calculated summer ammonia EF was 11.1±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for this facility. It is noticeable that nearly 65% of overall ammonia EFs were

contributed by two lagoons during the summer sampling. The free-stalls contributed an additional about 22% to the overall ammonia EFs.

Compared to the average ambient winter temperature of 6.6 °C (Table 4.1), the average ambient summer temperature was 31.5 °C (Table 4.2).

4.4. Conclusions

Ammonia is released to the atmosphere due to biological decomposition of dairy manure. At a dairy operation, free-stalls (cows in the barn), open -lots (cows on earthen corrals), manure composting area, separated solids from flushed manure, primary and secondary lagoons and milking parlor are all ground level area sources (GLAS) of NH_3.

Two consecutive seasonal studies were conducted to determine ammonia EFs at a free-stall dairy in Central Texas. The EFs were 11.1±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for the summer and 4.7±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for the winter season. The estimated annual NH_3 EF was 8.4 ±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for this free-stall dairy. In winter, composted manure and free-stalls contributed nearly 73% to the total NH_3 emissions at the dairy. However in summer, approximately 65% of overall NH_3 emissions were contributed by two lagoons at the dairy.

Overall, summer NH_3 emissions were nearly three times those of winter emissions. This seasonal difference was due to temperature, loading rates of dairy waste, and microbial activity of NH_3 emission sources at the dairy. Measuring NH_3 emissions and estimating EFs for individual sources of emissions at a free-stall dairy during the

winters and the summers provide better assessment of the seasonal differences in overall EF from a dairy operation. This approach also assists with the implementation of best management practices (BMP) to reduce NH_3 emissions from individual waste management components of the dairy for winter and summer seasons. For example, covering or chemically treating lagoons, solely for the purpose of controlling ammonia emissions to the atmosphere, may not be an effective BMP in the winter when little or no NH_3 volatilization occurs from lagoons due to low temperatures and microbial activity. On the other hand, reducing the size of composting operation on-site or moving it off-site will reduce dairy operations ammonia emissions throughout the year.

CHAPTER V

CONCLUSIONS AND FUTURE RESEARCH

This study focused on characterization of ammonia (NH_3) emissions from open-lot and free-stall dairies in central Texas. We have evaluated and determined seasonal and spatial variations of NH_3 emissions on these dairy facilities. The quantification of NH_3 emissions from ground level area sources (GLAS) in a dairy operation is needed to understand which sources contribute the highest to the overall NH_3 emissions during winter and summer seasons. Information on seasonal NH_3 emission variations at GLAS from dairy operations will assist with the evaluation and selection of best management practices (BMPs) to control and reduce NH_3 emissions.

The main purpose of this study was to determine a science-based NH_3 emissions from each individual GLAS within the dairy and developed farm-scale emission rates (ERs) and factors (EFs) for open-lot and free-stall dairies. Source-specific and directly-measured NH_3 emissions can provide better estimates for dairy EFs in the US and they may be used to apply NH_3 emission-reducing technologies for better environmental quality.

Ammonia emission variations among GLAS occurred due to seasonal changes in ambient and source temperatures, and spatial variations of NH_3 within a given season occurred in the open-lot corrals due to the varying cow density and the resulting dispirit manure loading in the feeding, dry, shaded, and transition divisions. Within the open-lot

corral, summer NH_3 emissions from the dry area were significantly lower than those from all other areas. In winter, NH_3 emissions from feeding division were significantly higher than shaded and dry divisions at the open-lot corral. Overall, summer NH_3 emissions were nearly four times those of winter emissions.

Currently, NH_3 emissions from animal agriculture are not regulated. Ammonia emissions are only subject to be reported to federal, state or local agencies under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and Emergency Planning and Community Right-to-Know Act (EPCRA) programs if the emission exceeds reportable quantity (RQ). The RQ set by CERCLA, and EPCRA for NH_3 is 45.4 kg per day (100 pounds per day).

The potential for federal air quality regulations accelerates the need for better estimates and effective management practices for reducing NH_3 emissions. It is important to obtain real-time, direct estimates of emissions from different NH_3 emission sources at AFOs. There is also the need for a better technique to measure NH_3 emissions from AFOs to obtain emission inventories and to develop abatement strategies.

Seasonal studies were conducted to measure NH_3 emissions from open-lot and free-stall dairies in central Texas since summer of 2003. Ammonia emission flux (EFl) was measured using an isolation flux chambers (FC) protocol from ground level area sources (GLAS) and was converted to emission factor (EF) to potentially develop source specific NH_3 emission control strategies. The GLAS including open-lots, free-stall barns, separated solids, primary and secondary lagoons, and milking parlor were sampled to estimate NH_3 emissions.

In the first study, assessment of summer and winter data from the open-lot dairy indicated that overall NH_3 EFs were 11.6 ±7.1 kg NH_3 $year^{-1}$ $head^{-1}$ for the summer and 6.2 ±3.7 kg NH_3 $year^{-1}$ $head^{-1}$ for the winter season. The estimated annual NH_3 EF was 9.4 ±5.7 kg NH_3 $year^{-1}$ $head^{-1}$ for this open-lot dairy. The estimated EFs for winter were approximately47% lower than summer EF. The open-lot corrals were the highest contributor as nearly 63% of the total NH_3 EF in summer and approximately 95% of the total NH_3 EF in winter. Primary and secondary lagoons contributed nearly 37% in summer and nearly 5% in winter to NH_3 emissions for the open-lot dairy. Open-lot corrals and lagoons were the major contributors to the overall NH_3 EF in summer season while only open-lot corrals were the highest contributors to the overall NH_3 EF in winter season.

In the second study, the EFs for the free-stall dairy were determined to be 11.1 ±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for summer season and 4.7± 4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for winter season. The estimated annual NH_3 EF was 8.4 ±4.9 kg NH_3 $year^{-1}$ $head^{-1}$ for this free-stall dairy. In winter, composted manure and free-stalls contributed nearly 73% to the total NH_3 emissions for the dairy. However in summer, approximately 65% of overall NH_3 emissions were contributed by two lagoons at the dairy.

The difference between the overall winter and summer NH_3 emissions from the dairies was due to ambient temperature variations and loading rates of manure on GLAS. There was spatial variation of NH_3 emission from the open-lot earthen corrals due to variable animal density within different divisions of the open-lot. This spatial variability was attributed to dispirit manure loading within these areas.

The difference in annual NH_3 EFs between the open-lot and free-stall dairy was due to different management practices at each dairy. On the free-stall dairy composted manure was one of the highest contributors to the overall EF in winter season, while no manure composting was conducted at the open-lot dairy. The primary lagoon was the highest contributor to overall EF in free-stall dairy in the summer season. This was attributed to large fraction of the in the free-stalls being flushed in to the primary lagoon. In contrast, the primary lagoon of the open-lot dairy collected only waste water that was conveyed from the crowding area (the area where cows are held temporarily awaiting milking) and milking parlor. This waste water was highly diluted resulting in lower NH_3 emissions from the primary lagoon of the open-lot dairy. Therefore, the primary lagoon had less overall NH_3 contributions to the EF in summer and winter time as compared to the corresponding primary lagoon at the free-stall dairy.

Dispersion modeling may be an alternative method to evaluate NH_3 flux measured from the chamber at a GLAS by back-calculating the NH_3 flux for the same GLAS by using NH_3 concentration at the property line of the dairy facility. Some concerns may be associated with this process. First, different dispersion models could give different results. Second, measuring NH_3 concentrations at the property line will not be precise if the NH_3 emissions are not high enough from the emitting source (GLAS).

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APPENDIX A

A.1 TOTAL NITROGEN MASS BALANCE FOR OPEN-LOT DAIRY OPERATIONS (NRC METHOD)

$$N_{Excreted} = N_{Feed} - N_{Milk} - N_{Culled} - N_{Leaving} + N_{Heifer}$$

where:

$N_{Excreted}$ = Amount of nitrogen excreted from dairy cows
N_{Feed} = Amount of nitrogen input in feed
N_{Milk} = Amount of milk produced by herd
N_{Culled} = Nitrogen content in culled cows
$N_{Leaving}$ = Nitrogen content of calves leaving farm
$N_{Heiffer}$ = Nitrogen content of replacement heifers entering farm

$$N_{Feed} = C_{LR}.M_{LR}.N_{LC} + C_{DR}.M_{DR}.N_{DC}$$

where:

C_{LR}	:	Concentration of nitrogen in lactating cow ration[1]	=	31280	mg.N/KgFeed (as drybasis)
M_{LR}	:	Mass of lactating cow ration[2]	=	21.77	Kg/cow-day
N_{LC}	:	Number of lactating cows[2]	=	2000	cows
C_{DR}	:	Concentration of nitrogen in dry cow ration[1]	=	31280	mg.N/KgFeed (as dry basis)
M_{DR}	:	Mass of dry cow ration[2]	=	12.7	Kg/cow-day
N_{DC}	:	Number of dry cows[2]	=	300	cows

[3]N in Feed=%Protein / 6.25
N= 19.55 (averaged % protein) / 6.25= 3.128 % dry basis x 10000 = 31280 mgN/kg Feed dry basis.

$$N_{Feed} = \left[31280 \frac{mgN}{kgFeed} \times 21.77 \frac{kg}{cow.day} \times 2000 lactatingcows + 31280 \frac{mgN}{kgFeed} \times 12.7 \frac{kg}{cow.day} \times 300 drygcows \right]$$

$$x365 \frac{days}{year} x \frac{1ton}{10^9 mg}$$

N_{Feed}=540.6 tonsN_{Feed}/year

$$N_{Milk} = M_M . C_M$$

where:

M_M	:	Mass of milk produced per day[2]	=	29.03	kg/cow-day
C_M	:	Concentration of nitrogen in milk by weight[3] (%)	=	0.005	

$$N_{Milk} = \left[29.03 \frac{kg}{cow - day} \times 2000 cows \times 0.005 \frac{1 ton}{10^3 kg} \times 365 \frac{days}{year} \right]$$

N_{Milk}= 106 tons N_{Milk}/year

$$N_X = C_X . M_X . N_X$$

where:

C	:	Concentration of nitrogen in body reserves[4]
M	:	Mass of animal[5]
N	:	Number of animal[2]
X	:	Type of nitrogen (from culled, leaving farm and entering farm)

$N_{Heiffer}$	$C_{heiffer}$[4]	=	26000	mg/kg
	$M_{heiffer}$ = Mass of heiffer[5]	=	437	kg/head
	$N_{heiffer}$ = Number of heiffer[2]	=	350	head

$$N_{Heiffer} = \left[26000 \frac{mg}{kg} x 437 \frac{kg}{head} x 350 \frac{head}{year} \right] x 1 \frac{ton}{10^9 mg}$$

$N_{Heiffer}$ =4.0 tons/year

N_{Culled}	C_{culled}[4]	=	29000	mg/kg
	M_{culled} = Mass of culled[5]	=	624	kg/head
	N_{culled} = Number of culled[2]	=	600	head

$$N_{Culled} = \left[29000 \frac{mg}{kg} x 624 \frac{kg}{head} x 600 \frac{head}{year} \right] x 1 \frac{ton}{10^9 mg}$$

N_{Culled} **=10.9 tons/year**

$N_{Leaving}$	$C_{leaving}$[4]	=	29000	mg/kg
	$M_{leaving}$ = Mass of leaving[5]	=	60	kg/head
	$N_{leaving}$ = Number of leaving[2]	=	600	head

$$N_{Leaving} = \left[29000 \frac{mg}{kg} x60 \frac{kg}{head} x600 \frac{head}{year} \right] x61 days^{a} x \frac{1 year}{365 days} x1 \frac{ton}{10^{9} mg}$$

[a] Leaving animals stay in dairy for 61 days during a year.

$N_{Leaving}$ **=0.2 tons/year**

$$N_{Excreted} = N_{Feed} - N_{Milk} - N_{Culled} - N_{Leaving} + N_{Heifer}$$

$N_{Excreted}$ = 540.6 -106 -10.9 -0.2 + 4.0

$N_{Excreted}$ = 427.5 ≈ 428 tons N excreted per year.

$N_{Excreted}$ = 186 kgN/head-year

$N_{Excreted}$ = 0.51 kgN/head-day

(Estimated N production from typical dairy manure: 0.45 kgN/head-day for lactating cow and 0.23 kgN/head-day for dry cow (ASAE Standard, D384.2, March 2005)

Buijsman (1987) reported that NH_3 volatilizations result in a range of 10-20% of total nitrogen becomes ammonia. Average estimation of 15% is used for following conversion.

$$NH_3 = 186 kgN / head - year \times \left(\frac{15 kgNH_3}{100 kgN} \right) = 27.9 \text{ kgNH}_3\text{/head-year}$$

Cited Studies:

(1) Results of feed and manure sample analysis.

(2) Dairy producer.

(3) Manure characteristics. Midwest Plan Service Publications. MWPS-18 Section 1.

(4) National Research Council.2002. Nutrient Requirements of Dairy Cattle.7th Edition. Washington,DC. National Academy Press.

(5) ASAE Standards. Averaged live weight for dairy cows., D384.2, March 2005

APPENDIX B

B.1. RANDOM AMMONIA SAMPLING POINTS IN OPEN-LOT CORRAL IN SUMMER

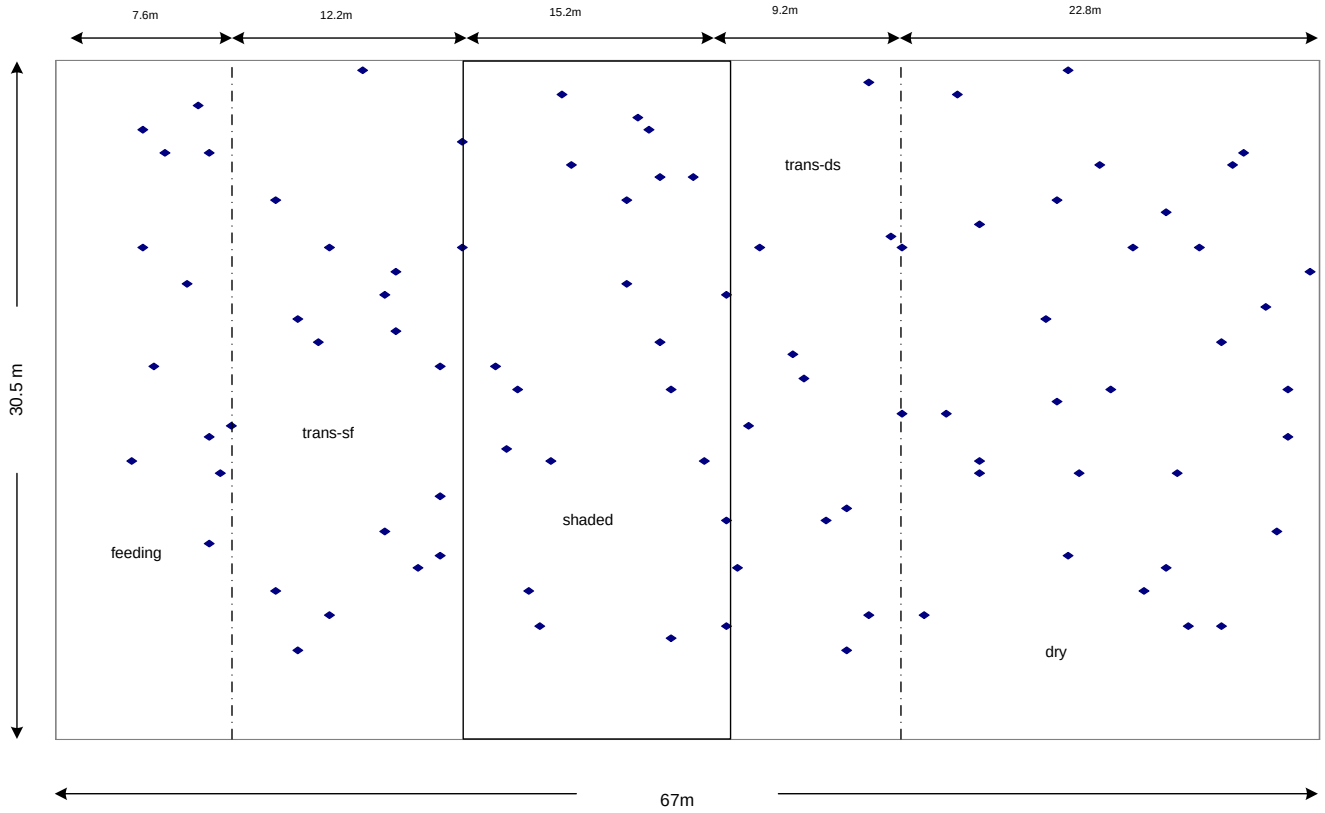

Figure B.1. Randomly selected flux sampling points on open-lot corral divisions in summer.

B.2. RANDOM AMMONIA SAMPLING POINTS IN OPEN-LOT CORRAL IN WINTER

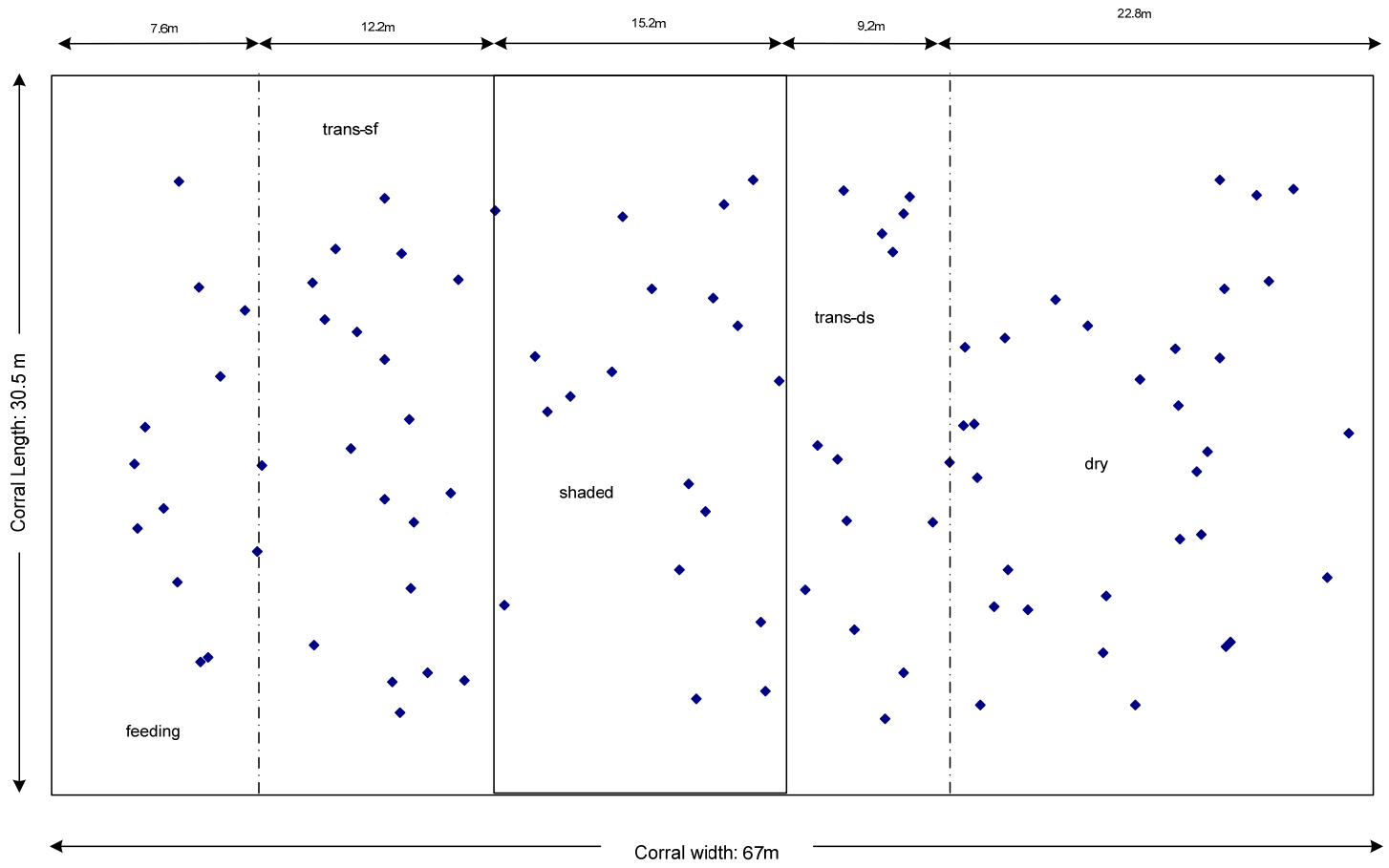

Figure B.2. Randomly selected flux sampling points on open-lot corral divisions in winter.

B.3. AMMONIA EMISSION DATA

Table 5.1 Summer NH_3 emissions from the open-lots at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station,
TX

$$\%NH_3 = -2.44x\ln(NH_3, ppb) + 27.68 \text{ (adsorption loses)}$$

Client: Dairy XXX
Comanche county, TX

Date: 6/13/2005
Source: Open Lots
Area of Source: 8570 m^2 103000 m^2 Entire Lot Area
Number of Head: 2000 Dairy

Original NH_3 Emissions from Open Lots

	Zero air Flowrate	NH3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	kPa	(°C)	(°C)	(°C)	(%)	(%)
OL5 1	7.1	2827.6	3062.0	2132.8	1.3	11.7	2.1	95.4	25.7	24.2	23.3	0.0%	83.8
OL5 2	7.1	1970.0	2150.7	1498.0	0.9	8.2	1.5	95.4	24.1	24.4	23.8	0.0%	82.5
OL5 3	7.1	3376.2	3641.4	2536.4	1.6	13.8	2.5	95.4	28.8	29.2	25.7	0.0%	77.8
OL5 4	1.1	5492.4	5858.7	4080.7	0.4	3.4	0.6	95.4	26.9	30.3	26.7	0.0%	75.4
OL5 5	7.1	6589.0	6999.2	4875.1	3.0	26.6	4.9	95.4	24.9	24.3	24.4	0.0%	80.8
OL5 6	7.0	216.3	247.8	172.6	0.1	0.9	0.2	95.4	26.2	27.3	25.0	0.0%	79.0
OL5 7	7.0	212.8	243.9	169.9	0.1	0.9	0.2	95.4	26.0	25.7	23.9	0.0%	82.2
OL5 8	7.1	294.1	334.7	233.1	0.1	1.3	0.2	95.4	25.1	24.4	23.4	0.0%	83.7
OL5 9	7.0	1054.0	1166.8	812.7	0.5	4.4	0.8	95.4	27.6	31.5	26.4	0.0%	76.1
OL5 10	7.1	5374.3	5735.5	3995.0	2.5	22.0	4.0	95.4	24.9	26.8	25.0	0.0%	79.1
OL5 11	7.0	6246.2	6643.1	4627.1	2.8	25.0	4.6	95.4	26.8	28.0	26.2	0.0%	76.4

OL5 12	6.9	5500.8	5867.5	4086.8	2.5	21.9	4.0	95.4	26.3	28.9	26.8	0.0%	75.2
OL5 13	7.0	187619.0	187619.0	130681.7	79.4	705.6	128.8	90.9	28.7	33.0	27.2	0.0%	74.5
OL5 14	7.0	2376.0	2583.0	1799.2	1.1	9.7	1.8	95.4	31.6	34.9	27.4	0.0%	74.0
OL5 15	7.0	24809.1	25550.9	17796.9	10.8	96.1	17.5	95.4	27.9	31.8	28.0	0.0%	71.2
OL5 16	7.0	976.4	1082.6	754.1	0.5	4.1	0.7	95.4	27.3	31.3	28.2	0.0%	70.0
OL5 17	7.0	4375.0	4691.1	3267.5	2.0	17.6	3.2	95.5	32.2	33.5	28.2	0.0%	69.8
OL5 18	7.0	7932.9	8390.8	5844.4	3.6	31.6	5.8	95.4	28.7	33.9	28.3	0.0%	69.3
OL5 19	6.7	17392.4	18063.1	12581.4	7.4	65.4	11.9	91.1	32.2	36.9	27.7	0.0%	64.2
OL5 20	7.0	1365.8	1503.3	1047.1	0.6	5.7	1.0	95.4			29.9	0.0%	64.2
OL5 21	7.0	15700.0	16344.7	11384.5	6.9	61.5	11.2	95.5	26.4	30.5	28.5	0.0%	68.7
OL5 22	7.0	6841.4	7261.0	5057.5	3.1	27.3	5.0	95.4	27.7	32.3	29.7	0.0%	64.6
OL5 23	7.0	17620.5	18294.4	12742.5	7.7	68.8	12.6	95.4	32.1	40.4	29.9	0.0%	63.2
OL5 24	7.0	5274.6	5631.5	3922.5	2.4	21.3	3.9	95.4	36.7	39.8	30.2	0.0%	61.8
OL5 25	7.0	11437.8	11995.8	8355.4	5.1	45.1	8.2	95.4	57.2	44.9	30.8	0.0%	59.6
OL5 26	7.0	18542.9	19229.0	13393.5	8.1	72.3	13.2	95.4	29.6	36.5	30.9	0.0%	59.8
OL5 27	7.1	1258.4	1387.6	966.5	0.6	5.3	1.0	95.4			31.1	0.0%	58.9
OL5 28	7.0	10031.4	10553.0	7350.4	4.5	39.7	7.2	95.3	36.4	47.3	31.4	0.0%	57.2
OL5 29	7.0	832.6	926.5	645.3	0.4	3.5	0.6	95.2	27.6	24.8	25.3	0.0%	74.4
OL5 30	7.0	8279.5	8748.8	6093.8	3.7	32.9	6.0	95.3	40.9	43.5	31.2	0.0%	57.7
OL5 31	7.0	8099.0	8562.4	5964.0	3.6	32.2	5.9	95.3	38.7	45.4	31.4	0.0%	56.9
OL5 32	7.0	3625.1	3903.6	2719.0	1.7	14.7	2.7	95.3			31.2	0.0%	57.1
OL5 33	7.0	11015.2	11562.8	8053.8	4.9	43.5	7.9	95.3	27.6	31.3	31.4	0.0%	56.0
OL5 34	7.0	107404.1	107404.1	74809.9	45.5	403.9	73.7	95.3	35.0	40.2	31.2	0.0%	57.5
OL5 35	7.1	5528.0	5895.8	4106.6	2.5	22.4	4.1	95.3	31.5	42.3	31.4	0.0%	55.6
OL5 36	7.0	4993.6	5338.3	3718.2	2.3	20.1	3.7	95.3	30.6	32.4	31.4	0.0%	55.3
OL5 38	7.0	3667.0	3947.7	2749.7	1.7	14.8	2.7	95.3	28.4	35.7	31.5	0.0%	54.8
OL5 39	7.1	1681.7	1842.5	1283.3	0.8	7.0	1.3	95.2			31.1	0.0%	56.4
OL5 40	7.0	549.4	616.9	429.7	0.3	2.3	0.4	95.3	30.1	26.4	26.1	0.0%	73.4
OL5 43	7.0	7618.1	8065.3	5617.7	3.4	30.4	5.5	95.2	31.7	28.6	28.5	0.0%	66.0
OL5 44	7.1	584.5	655.4	456.5	0.3	2.5	0.5	95.3	29.2	27.0	26.6	0.0%	72.1
OL5 46	7.0	2894.7	3133.0	2182.2	1.3	11.8	2.2	95.4	20.1	19.6	21.9	0.0%	87.9
OL5 47	7.0	51749.7	51749.7	36045.1	21.9	194.2	35.5	95.5	29.7	24.8	25.0	0.0%	82.2

OL5 48	7.1	427.7	482.9	336.3	0.2	1.8	0.3	95.4			25.9	0.0%	75.4
OL5 49	7.0	487.9	549.3	382.6	0.2	2.1	0.4	95.4	27.4	25.4	25.4	0.0%	79.2
OL5 50	7.0	1027.3	1137.9	792.6	0.5	4.3	0.8	95.2			27.5	0.0%	69.4
OL5 51	7.1	1019.9	1129.8	786.9	0.5	4.3	0.8	95.5	27.7	25.2	24.9	0.0%	82.7
OL5 52	7.0	2100.0	2289.3	1594.5	1.0	8.6	1.6	95.5			25.1	0.0%	82.1
OL5 53	7.0	1299.3	1431.6	997.2	0.6	5.4	1.0	95.7	21.0		19.0	0.0%	91.8
OL5 54	7.1	463.3	522.1	363.7	0.2	2.0	0.4	95.8	26.6	21.0	21.6	0.0%	72.0
OL5 55	7.0	1332.4	1467.3	1022.0	0.6	5.5	1.0	95.7		20.9	18.6	0.0%	89.2
OL5 56	7.0	866.1	962.9	670.7	0.4	3.6	0.7	95.6		24.6	18.5	0.0%	93.4
OL5 57	7.0	1877.3	2051.6	1429.0	0.9	7.8	1.4	95.7		25.6	19.3	0.0%	90.4
OL5 58	7.1	3109.2	3359.7	2340.1	1.4	12.7	2.3	95.6		23.4	24.4	0.0%	85.9
OL5 59	7.0	628.2	703.4	489.9	0.3	2.6	0.5	71.9	18.4	18.2	18.2	0.0%	56.3
OL5 60	7.0	5881.1	6263.5	4362.7	2.7	23.6	4.3	95.7	22.1	19.6	19.7	0.0%	89.2
OL5 61	7.0	4879.4	5218.9	3635.1	2.2	19.7	3.6	95.9	26.7	27.3	22.3	0.0%	84.1
OL5 62	7.0	1673.6	1833.8	1277.3	0.8	6.9	1.3	95.8	22.7		20.8	0.0%	87.3
OL5 63	7.0	2385.2	2592.8	1805.9	1.1	9.8	1.8	95.9		24.3	21.6	0.0%	85.3
OL5 64	7.0	3570.3	3845.9	2678.8	1.6	14.5	2.6	95.9	29.9	33.6	24.9	0.0%	75.8
OL5 65	7.0	1046.5	1158.6	807.0	0.5	4.4	0.8	95.9	26.4		23.1	0.0%	81.9
OL5 66	7.0	1923.5	2101.0	1463.4	0.9	7.9	1.4	95.9		28.6	24.1	0.0%	78.5
OL5 67	7.0	2652.5	2876.5	2003.6	1.2	10.8	2.0	96.0			26.7	0.0%	72.4
OL5 68	7.1	41971.0	41971.0	29234.0	17.9	159.2	29.1	96.0	29.4	29.7	26.8	0.0%	72.0
OL5 69	7.0	4885.3	5225.1	3639.4	2.2	19.6	3.6	96.0	29.2		26.0	0.0%	72.6
OL5 70	7.0	5508.2	5875.1	4092.2	2.5	22.1	4.0	96.0	29.8		27.3	0.0%	68.8
OL5 71	7.0	7964.2	8423.1	5866.9	3.6	31.7	5.8	96.0	27.8	31.7	29.0	0.0%	59.8
OL5 72	7.1	8392.7	8865.6	6175.1	3.8	33.6	6.1	96.0	34.3		29.9	0.0%	58.0
OL5 73	7.1	16399.0	17054.9	11879.2	7.3	64.7	11.8	95.9	29.5	34.2	31.2	0.0%	56.0
OL5 74	7.0	7450.2	7891.6	5496.7	3.3	29.7	5.4	95.9	34.8		31.5	0.0%	54.7
OL5 75	7.1	2683.3	2909.1	2026.3	1.2	11.0	2.0	95.9			32.3	0.0%	53.7
OL5 76	7.0	2241.8	2440.3	1699.7	1.0	9.2	1.7	95.7	45.7	35.9	32.7	0.0%	50.2
OL5 77	1.7	1306.2	1439.1	1002.4	0.2	1.3	0.2	91.4	32.9		30.9	0.0%	48.7
OL5 78	7.1	1407.5	1548.1	1078.3	0.7	5.9	1.1	95.8			31.8	0.0%	51.5
OL5 80	7.1	2030.7	2215.5	1543.1	0.9	8.4	1.5	95.9	30.4	29.8	29.0	0.0%	63.9

OL5 81	7.1	29686.8	30444.4	21205.3	13.0	115.4	21.1	95.8	30.2		30.5	0.0%	57.3
OL5 82	7.0	12215.7	12792.1	8910.1	5.4	48.3	8.8	95.9			27.7	0.0%	68.3
OL5 83	7.0	43856.6	43856.6	30547.3	18.6	164.9	30.1	95.9	30.3		28.3	0.0%	65.3
OL5 84	7.0	2523.8	2740.0	1908.5	1.2	10.3	1.9	95.8			30.0	0.0%	60.0
OL5 85	7.0	43102.1	43102.1	30021.8	18.2	162.1	29.6	96.0			26.1	0.0%	73.5
OL5 86	6.7	5300.0	5658.1	3941.0	2.3	20.4	3.7	96.0	27.1	25.8	26.8	0.0%	72.6
OL5 88	7.1	4180.7	4487.3	3125.5	1.9	17.0	3.1	96.0	27.4	25.9	26.2	0.0%	71.8
OL5 89	7.0	17070.8	17736.9	12354.2	7.5	66.7	12.2	96.0	27.2	24.5	25.2	0.0%	76.5
OL5 90	7.1	13181.7	13779.2	9597.6	5.9	52.2	9.5	96.0			24.8	0.0%	78.9
OL5 91	7.0	25387.9	26132.7	18202.1	11.1	98.3	17.9	95.9			24.0	0.0%	83.1
OL5 92	7.0	10007.5	10528.4	7333.3	4.5	39.6	7.2	96.0	25.6	24.4	25.3	0.0%	76.8
OL5 93	7.1	5983.5	6370.0	4436.9	2.7	24.2	4.4	95.9	22.8	23.0	24.0	0.0%	80.0
OL5 94	7.1	7700.2	8150.3	5676.9	3.5	30.9	5.6	96.0	25.8	24.6	24.7	0.0%	79.0
OL5 95	7.0	5514.4	5881.6	4096.7	2.5	22.1	4.0	95.9	24.1	23.9	24.4	0.0%	78.2
OL5 96	7.0	3281.5	3541.6	2466.8	1.5	13.3	2.4	95.9	26.0	22.1	22.9	0.0%	85.9
OL5 97	7.1	4626.8	4954.8	3451.1	2.1	18.8	3.4	95.9	26.7	21.9	23.1	0.0%	84.1
OL5 98	7.1	8049.1	8510.8	5928.0	3.6	32.2	5.9	95.9			23.5	0.0%	84.9
OL5 99	7.0	2525.1	2741.4	1909.5	1.2	10.3	1.9	95.9			22.9	0.0%	84.9
OL5 100	7.0	1207.9	1333.1	928.6	0.6	5.0	0.9	95.9	23.1	21.3	22.5	0.0%	86.5

Average	6.90	10399.18	10692.16	7447.38	4.50	40.00	7.30	95	29	29	27	0	72
Stdev	0.1	23368.24	23353.13	16266.09	9.89	87.91	16.04	3	6	7	4	0	11
n	94	94	94	94	94	94	94	94	71	67	94	94	94
t-stat	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
95% conf	0.016	4786.28	4783.18	3331.62	2.03	18.01	3.29	1	1	2	1	0	2
MIN	1	213	244	170	0	1	0	72	18	18	18	0	49
MAX	7	187619	187619	130682	79	706	129	96	57	47	33	0	93

Table 5.2 Summer NH_3 emissions from the primary lagoon at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M
University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date: 6/15/2005
Source: Lagoon-1
Area of Source: 6275 m^2
Number of Head: 2000 Dairy

Lagoon-1

	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	(°C)	(°C)	(°C)	(°C)	(%)	(%)
	6.5	18299.9	18982.9	13222.1	7.4	4.0	0.7	95.9		34.1	33.4	0.0	43.7
	7.0	28282.3	29037.4	20225.3	12.3	6.7	1.2	95.9	34.2	34.8	33.3	0.0	42.8
	7.0	38021.8	38762.5	26999.1	16.4	8.9	1.6	95.9			33.4	0.0	42.1
	7.0	26485.1	27234.7	18969.7	11.5	6.2	1.1	95.9		34.4	33.8	0.0	39.7
	6.8	15308.5	15946.5	11107.2	6.5	3.5	0.6	95.8	34.5	35.3	34.2	0.0	37.5
	7.0	7581.6	8027.6	5591.4	3.4	1.8	0.3	95.8			33.9	0.0	39.1
Average	6.9	22329.8	22998.6	16019.1	9.6	5.2	0.9	95.9	34.3	34.6	33.7	0.0	40.8
Stdev	0.2	10788.7	10889.4	7584.8	4.7	2.5	0.5	0.1	0.2	0.5	0.4	0.0	2.4
n	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
t-stat	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
95% conf	0.2	11322.1	11427.8	7959.7	4.9	2.7	0.5	0.1	0.2	0.5	0.4	0.0	2.5
MIN	6.5	7581.6	8027.6	5591.4	3.4	1.8	0.3	95.8	34.2	34.1	33.3	0.0	37.5
MAX	7.0	38021.8	38762.5	26999.1	16.4	8.9	1.6	95.9	34.5	35.3	34.2	0.0	43.7

Table 5.3 Summer NH_3 emissions from the secondary lagoon at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date: 6/15/2005
Source: Lagoon-2
Area of Source: 46094 m^2
Number of Head: 2000 Dairy

Lagoon-2

	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	(°C)	(°C)	(°C)	(°C)	(%)	[sL/min]
	6.6	13594.4	14200.3	9890.9	5.7	22.5	4.1	95.7		32	33.2	0	39.7
	7.0	10449.5	10982.4	7649.6	4.6	18.5	3.4	95.7	30	32.7	33.2	0	38.8
	7.0	11505.6	12065.3	8403.8	5.1	20.4	3.7	95.7			33.1	0	40.2
	7.0	13554.2	14159.4	9862.4	6.0	23.9	4.4	95.7		31	33.1	0	40.2
	7.0	11951.3	12521.6	8721.6	5.3	21.2	3.9	95.7	31.5	29.8	31.6	0	46.1
	7.0	11712.1	12276.7	8551.1	5.2	20.8	3.8	95.7			30.3	0	50.5
Average	6.9	12127.8	12700.9	8846.6	5.3	21.2	3.9	95.7	30.7	31.4	32.4	0.0	42.6
Stdev	0.2	1232.3	1260.5	878.0	0.5	1.8	0.3	0.0	1.1	1.3	1.2	0.0	4.7
n	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
t-stat	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
95% conf	0.2	1293.2	1322.9	921.4	0.5	1.9	0.4	0.0	1.1	1.3	1.3	0.0	4.9
MIN	6.6	10449.5	10982.4	7649.6	4.6	18.5	3.4	95.7	30.0	29.8	30.3	0.0	38.8
MAX	7.0	13594.4	14200.3	9890.9	6.0	23.9	4.4	95.7	31.5	32.8	33.3	0.0	50.5

Table 5.4 Summer NH_3 emissions from the solid separator at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date: 6/15/2005
Source: Solid Separator
Area of Source: 50 m^2
Number of Head: 2000 Dairy

	Solid Separator											
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	(°C)	(°C)	(°C)	(°C)	(%)	[sL/min]
	6.7	1.0	1.3	0.9	0.0	0.0	0.0	96.0	61.3	34.2	23.9	0.0	79.2
	7.0	1.0	1.3	0.9	0.0	0.0	0.0	96.1	56.2	38.8	25.1	0.0	76.0
	7.0	46.3	54.8	38.2	0.0	0.0	0.0	96.1	0.0	0.0	25.9	0.0	74.6
	7.0	1.0	1.3	0.9	0.0	0.0	0.0	96.1	54.1	37.6	26.4	0.0	71.3
Average	6.9	12.3	14.7	10.2	0.0	0.0	0.0	96.1	42.9	27.6	25.3	0.0	75.3
Stdev	0.2	22.7	26.8	18.6	0.0	0.0	0.0	0.0	28.8	18.5	1.1	0.0	3.3
n	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
t-stat	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
95% conf	0.3	36.1	42.6	29.7	0.0	0.0	0.0	0.1	45.7	29.5	1.7	0.0	5.2
MIN	6.7	1.0	1.3	0.9	0.0	0.0	0.0	96.0	0.0	0.0	23.9	0.0	71.3
MAX	7.0	46.3	54.8	38.2	0.0	0.0	0.0	96.1	61.3	38.8	26.4	0.0	79.2

Table 5.5 Winter NH_3 emissions from the open-lots at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date: 12/18/2005
Source: Open Lots
Area of Source: 8570 m^2 103000 Entire Area
Number of Head: 2000 Dairy

	Open Lots												
	Zero air Flowrate	NH3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year)	(°C)	(°C)	(°C)	(°C)	(%)	(%)
OL5 1	4.90	3250.17	3508.5	2443.8	1.0	9.3	1.7	97.5	7.8	7.2	7.8	0.0	70.9%
OL5 2	7.13	3764.08	4049.8	2820.8	1.7	15.5	2.8	97.5			7.4	0.0	71.8%
OL5 3	5.73	9921.93	10440.4	7272.0	3.6	32.2	5.9	95.4	7.6	7.8	7.1	0.0	73.3%
OL5 4	7.06	26873.19	27624.2	19241.0	11.8	105.0	19.2	97.5	7.3	7.0	7.8	0.0	73.5%
OL5 5	5.97	23518.12	24251.9	16892.1	8.8	77.9	14.2	97.5			7.8	0.0	74.4%
OL5 6	7.13	23619.83	24354.3	16963.4	10.5	93.4	17.0	97.4	6.8	6.8	7.3	0.0	75.8%
OL5 7	6.45	65558.27	65963.9	45945.6	25.7	228.9	41.8	97.4	6.1	6.6	6.8	0.0	76.0%
OL5 8	7.10	25624.26	26370.1	18367.5	11.3	100.7	18.4	97.4			6.7	0.0	76.5%
OL5 9	6.72	7133.15	7563.4	5268.1	3.1	27.3	5.0	97.4	6.2	6.3	6.7	0.0	75.3%
OL5 11	4.53	18545.86	19232.0	13395.6	5.3	46.9	8.6	97.4			6.6	0.0	78.5%
OL5 12	7.13	3772.33	4058.5	2826.8	1.7	15.6	2.8	97.4	6.2	6.2	6.4	0.0	77.3%
OL5 13	5.41	9869.70	10386.8	7234.7	3.4	30.2	5.5	97.4	5.8	5.8	6.6	0.0	73.0%
OL5 14	7.12	8262.45	8262.5	5755.0	3.6	31.7	5.8	97.4			6.6	0.0	72.0%
OL5 15	6.07	8421.43	8895.2	6195.8	3.3	29.0	5.3	97.4	5.8	6.6	6.6	0.0	70.2%

OL5 16	7.09	3955.71	4251.2	2961.1	1.8	16.2	3.0	97.5	6.3	5.9	6.5	0.0	70.0%
OL5 17	6.46	9392.13	9895.5	6892.5	3.9	34.4	6.3	97.5			6.4	0.0	71.7%
OL5 18	7.13	18079.04	18759.1	13066.3	8.1	71.9	13.1	97.5	5.8	7.4	6.6	0.0	71.4%
OL5 19	6.74	11821.61	12388.9	8629.2	5.1	45.0	8.2	97.5	6.5	5.8	6.6	0.0	70.2%
OL5 20	7.13	4310.95	4623.9	3220.7	2.0	17.7	3.2	97.5			6.3	0.0	65.6%
OL5 21	6.96	5563.58	5932.9	4132.4	2.5	22.2	4.1	97.6	6.2	7.0	6.1	0.0	62.8%
OL5 22	7.10	10232.32	10759.4	7494.2	4.6	41.1	7.5	97.6	7.0	6.3	6.2	0.0	60.1%
OL5 23	7.09	7297.83	7733.9	5386.9	3.3	29.5	5.4	97.6			6.6	0.0	58.1%
OL5 24	7.10	10415.82	10947.8	7625.4	4.7	41.8	7.6	97.6	7.8	10.2	6.7	0.0	54.7%
OL5 25	7.17	17131.73	17798.7	12397.3	7.7	68.7	12.5	97.6	8.1	7.7	6.9	0.0	52.0%
OL5 26	7.12	2755.15	2985.3	2079.3	1.3	11.4	2.1	97.6			6.9	0.0	52.3%
OL5 27	7.25	3188.43	3443.4	2398.4	1.5	13.4	2.5	97.5	7.7	8.2	7.0	0.0	52.4%
OL5 28	7.10	5291.68	5649.4	3934.9	2.4	21.6	3.9	97.4	8.2	9.0	7.2	0.0	50.4%
OL5 29	7.26	4060.16	4360.9	3037.5	1.9	17.0	3.1	97.3			7.7	0.0	48.0%
OL5 30	7.10	3537.11	3811.0	2654.4	1.6	14.6	2.7	97.3	11.3	8.1	8.2	0.0	46.9%
OL5 31	7.30	9594.43	10103.7	7037.5	4.5	39.7	7.2	97.2	9.2	11.8	8.4	0.0	47.0%
OL5 32	7.13	6279.59	6677.8	4651.3	2.9	25.6	4.7	97.2			8.6	0.0	48.5%
OL5 33	7.32	2234.51	2432.6	1694.3	1.1	9.6	1.7	97.2	11.5	9.6	9.0	0.0	48.5%
OL5 34	7.13	2154.92	2347.8	1635.3	1.0	9.0	1.6	97.1	9.8	10.6	9.0	0.0	47.8%
OL5 35	7.36	14512.61	14512.6	10108.4	6.5	57.5	10.5	97.1			9.1	0.0	50.1%
OL5 36	7.13	4669.92	4999.8	3482.5	2.2	19.2	3.5	97.1	9.6	9.9	8.7	0.0	51.7%
OL5 37	7.37	8885.03	9373.3	6528.7	4.2	37.2	6.8	97.1	8.7	8.6	8.2	0.0	52.1%
OL5 38	7.12	2731.92	2960.7	2062.2	1.3	11.3	2.1	97.1			7.8	0.0	53.0%
OL5 39	7.38	7555.78	8000.9	5572.8	3.6	31.8	5.8	97.1	6.9	8.5	7.4	0.0	53.8%
OL5 40	7.13	2507.38	2722.6	1896.3	1.2	10.4	1.9	97.1	7.0	7.4	7.4	0.0	55.3%
OL5 41	7.11	17801.12	18477.5	12870.1	7.9	70.7	12.9	97.1			7.3	0.0	56.6%
OL5 42	6.79	2838.37	3073.4	2140.7	1.3	11.2	2.0	97.1	6.6	9.5	7.0	0.0	56.8%
OL5 43	7.39	5322.15	5681.2	3957.1	2.5	22.6	4.1	97.1	7.8	6.6	6.8	0.0	59.1%
OL5 44	7.09	8427.54	8427.5	5870.0	3.6	32.2	5.9	97.2			6.6	0.0	59.9%
OL5 46	5.08	10143.31	10667.9	7430.5	3.3	29.2	5.3	97.1	5.9	5.6	6.4	0.0	60.9%
OL5 47	7.12	1273.65	1404.0	977.9	0.6	5.4	1.0	97.1			6.2	0.0	60.2%
OL5 48	5.82	36271.33	37019.6	25785.1	13.0	115.9	21.2	97.1	5.4	5.8	6.2	0.0	59.5%

OL5 49	7.02	2894.79	3133.1	2182.3	1.3	11.8	2.2	97.1	5.5	5.4	6.2	0.0	62.4%
OL5 50	6.46	6510.73	6917.9	4818.5	2.7	24.0	4.4	97.1			6.2	0.0	62.6%
OL5 52	4.47	48637.30	49292.5	34333.6	13.3	118.5	21.6	97.0	5.4	5.8	5.8	0.0	63.4%
OL5 53	7.13	4677.09	5007.3	3487.7	2.2	19.2	3.5	97.0			5.8	0.0	62.1%
OL5 54	5.41	3330.14	3592.9	2502.5	1.2	10.5	1.9	96.9	4.8	5.0	5.8	0.0	61.0%
OL5 55	7.13	4535.96	4859.6	3384.9	2.1	18.6	3.4	97.0	5.0	5.1	5.5	0.0	61.1%
OL5 56	6.04	3829.14	4118.2	2868.4	1.5	13.4	2.4	97.0			5.6	0.0	61.9%
OL5 57	7.12	3568.88	3844.4	2677.7	1.7	14.7	2.7	97.0	5.0	5.0	5.4	0.0	62.7%
OL5 58	6.41	16897.18	17560.7	12231.5	6.8	60.6	11.1	96.9	5.4	5.4	5.8	0.0	62.4%
OL5 60	5.07	18392.72	19076.9	13287.6	5.8	52.0	9.5	96.9	5.0	5.0	5.8	0.0	62.2%
OL5 61	7.12	18603.70	19290.6	13436.4	8.3	73.9	13.5	96.9	5.4	5.0	5.8	0.0	62.2%
OL5 62	5.84	5072.92	5421.1	3775.9	1.9	17.0	3.1	97.0			5.8	0.0	63.6%
OL5 63	7.07	4975.16	5318.9	3704.8	2.3	20.2	3.7	97.0	5.0	5.0	5.8	0.0	65.5%
OL5 64	6.33	2801.46	3034.3	2113.5	1.2	10.3	1.9	97.0	5.8	7.4	5.6	0.0	64.7%
OL5 65	7.10	3013.87	3259.0	2270.0	1.4	12.5	2.3	97.1			5.4	0.0	64.9%
OL5 66	4.98	59320.51	59832.2	41674.8	18.0	160.2	29.2	97.2	6.0	5.7	5.8	0.0	65.8%
OL5 67	7.12	4767.48	5101.9	3553.6	2.2	19.6	3.6	97.1	7.4	8.2	6.4	0.0	65.4%
OL5 68	5.70	17751.95	17751.9	12364.7	6.1	54.4	9.9	96.9			7.8	0.0	66.1%
OL5 69	6.62	10350.17	10880.4	7578.5	4.4	38.8	7.1	96.9	9.6	7.8	8.1	0.0	65.3%
OL5 70	7.12	62030.70	62498.2	43531.7	26.9	239.5	43.7	96.8	10.3	8.6	7.9	0.0	62.3%
OL5 71	6.86	8747.53	9231.6	6430.0	3.8	34.1	6.2	96.8			7.8	0.0	61.5%
OL5 72	7.13	9816.22	10331.8	7196.4	4.5	39.6	7.2	96.8	10.5	8.6	8.0	0.0	61.2%
OL5 73	7.03	2128.95	2320.2	1616.1	1.0	8.8	1.6	96.9	10.2	10.2	8.2	0.0	60.5%
OL5 74	7.10	3185.52	3440.3	2396.3	1.5	13.2	2.4	96.9			8.1	0.0	60.2%
OL5 75	7.14	2141.28	2333.3	1625.2	1.0	9.0	1.6	96.9	8.1	8.6	7.8	0.0	60.9%
OL5 76	6.65	1181.40	1304.5	908.6	0.5	4.7	0.9	97.0	7.8	9.2	7.5	0.0	60.8%
OL5 77	7.12	1002.10	1110.5	773.5	0.5	4.3	0.8	97.1			5.4	0.0	72.2%
OL5 78	5.20	1199.50	1324.0	922.2	0.4	3.7	0.7	97.1	5.4	5.2	5.4	0.0	75.4%
OL5 79	7.12	1302.87	1435.5	999.9	0.6	5.5	1.0	97.1	5.4	5.1	5.2	0.0	76.3%
OL5 80	5.89	989.86	1097.3	764.3	0.4	3.5	0.6	97.2			5.0	0.0	77.2%
OL5 81	7.12	1099.91	1216.4	847.3	0.5	4.7	0.9	97.2	4.6	4.6	4.6	0.0	77.9%
OL5 82	6.36	1072.60	1072.6	747.1	0.4	3.7	0.7	97.2	4.5	7.8	4.6	0.0	78.6%

OL5 83	7.13	984.84	1091.8	760.5	0.5	4.2	0.8	97.2			4.3	0.0	79.2%
OL5 84	6.69	1003.12	1003.1	698.7	0.4	3.6	0.7	97.2	3.7	4.3	3.9	0.0	79.3%
OL5 85	7.13	976.69	1083.0	754.3	0.5	4.2	0.8	97.1	3.3	4.1	3.4	0.0	81.1%
OL5 86	6.91	1283.24	1414.3	985.1	0.6	5.3	1.0	97.2			2.7	0.0	83.5%
OL5 87	7.12	970.54	1076.3	749.7	0.5	4.1	0.8	97.2	2.4	2.6	2.3	0.0	85.5%
OL5 88	7.03	1453.84	1597.9	1113.0	0.7	6.0	1.1	97.2	3.0	3.4	3.1	0.0	84.0%
OL5 89	7.13	1391.91	1531.4	1066.6	0.7	5.9	1.1	97.1			3.2	0.0	83.5%
OL5 90	7.16	1191.32	1315.2	916.1	0.6	5.1	0.9	97.1	1.1	1.8	2.2	0.0	86.7%
OL5 91	7.13	1758.01	1924.1	1340.2	0.8	7.4	1.3	97.1	0.8	0.7	1.7	0.0	88.9%
OL5 92	7.23	1183.07	1306.3	909.9	0.6	5.1	0.9	97.1			1.8	0.0	90.1%
OL5 93	7.05	1577.38	1730.6	1205.4	0.7	6.6	1.2	97.1	2.3	2.2	2.3	0.0	88.4%
OL5 94	7.28	1332.51	1467.4	1022.1	0.6	5.7	1.0	97.1	2.8	2.9	2.5	0.0	88.6%
OL5 95	7.12	1249.04	1377.5	959.4	0.6	5.3	1.0	97.1			2.5	0.0	88.4%
OL5 96	7.31	1130.09	1249.0	870.0	0.6	4.9	0.9	97.1	2.9	2.6	2.4	0.0	88.9%
OL5 97	7.08	1098.13	1214.5	845.9	0.5	4.6	0.8	97.0	2.0	2.5	2.0	0.0	90.5%
OL5 98	7.33	1048.70	1161.0	808.7	0.5	4.6	0.8	97.0			1.6	0.0	87.2%
OL5 99	7.10	872.93	970.3	675.9	0.4	3.7	0.7	97.1	0.3	-0.5	0.8	0.0	88.8%
OL5 100	7.35	921.58	1023.2	712.7	0.5	4.0	0.7	97.1	-0.6	-2.8	0.1	0.0	90.4%

Average	6.8	8912.8	9236.8	6433.7	3.6	31.9	5.8	97.2	6.1	6.2	6.0	0.0	67.6%
Stdev	0.7	12618.6	12740.7	8874.2	4.7	42.0	7.7	0.3	2.6	2.7	2.0	0.0	12.1%
n	96.0	96.0	96.0	96.0	96.0	96.0	96.0	96.0	64.0	64.0	96.0	96.0	96.0
t-stat	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
95% conf	0.1	2556.8	2581.5	1798.1	1.0	8.5	1.6	0.1	0.7	0.7	0.4	0.0	2.5%
MIN	4.5	872.9	970.3	675.9	0.4	3.5	0.6	95.4	-0.6	-2.8	0.1	0.0	46.9%
MAX	7.4	65558.3	65963.9	45945.6	26.9	239.5	43.7	97.6	11.5	11.8	9.1	0.0	90.5%

Table 5.6 Winter NH_3 emissions from the primary lagoon at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date:	12/21/2005	
Source:	Lagoon-1	
Area of Source:	46094	6275
Number of Head:	2000	2000

Lagoon-1

	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	(°C)	(°C)	(°C)	(°C)	(%)	[sL/min]
	7.04	486	547.0	381.0	0.2	0.1	0.0	96.8	12.7	15.7	15.0	0.0	26.5%
	4.52	560	628.3	437.6	0.2	0.1	0.0	96.8			13.8	0.0	30.3%
	7.13	1726	1889.8	1316.3	0.8	0.4	0.1	96.8	8.5	11.1	10.7	0.0	38.4%
	4.48	2544	2761.2	1923.2	0.7	0.4	0.1	96.9	10.3	8.0	9.6	0.0	40.7%
	7.12	1664	1823.5	1270.1	0.8	0.4	0.1	96.9	7.0	9.8	8.6	0.0	44.1%
								96.8	9.6	11.2	11.6	0.0	36.0%
Average	6.1	1395.9	1529.9	1065.7	0.6	0.3	0.1	0.1	2.4	3.3	2.8	0.0	7.3%
Stdev	1.4	869.7	936.9	652.6	0.3	0.2	0.0	5.0	4.0	4.0	5.0	5.0	5.0
n	5.0	5.0	5.0	5.0	5.0	5.0	5.0	2.8	3.2	3.2	2.8	2.8	2.8
t-stat	2.8	2.8	2.8	2.8	2.8	2.8	2.8	0.1	3.9	5.2	3.4	0.0	9.1%
95% conf	1.8	1079.9	1163.3	810.3	0.4	0.2	0.0	96.8	7.0	8.0	8.6	0.0	26.5%
MIN	4.5	485.8	547.0	381.0	0.2	0.1	0.0	96.9	12.7	15.7	15.0	0.0	44.1%
MAX	7.1	2543.8	2761.2	1923.2	0.8	0.4	0.1	96.8	12.7	15.7	15.0	0.0	26.5%

Table 5.7 Winter NH_3 emissions from the secondary lagoon at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date: 12/21/2005
Source: Lagoon-2
Area of Source: 46094
Number of Head: 2000

Lagoon-2

	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	(°C)	(°C)	(°C)	(°C)	(%)	[sL/min]
	6.78	1131	1249.5	870.3	0.5	1.0	0.2	96.7	N/A	N/A	4.99	N/A	61.3%
	7.13	990	1096.9	764.1	0.5	0.9	0.2	96.6			15.75633		39.3%
	7.13	779	868.1	604.7	0.4	0.7	0.1						
Average	7.0	966.4	1071.5	746.3	0.5	0.9	0.2	96.7			10.4		0.5
Stdev	0.2	176.9	192.0	133.7	0.1	0.1	0.0	0.1			7.6		0.2
n	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0			2.0		2.0
t-stat	4.3	4.3	4.3	4.3	4.3	4.3	4.3	12.7			12.7		12.7
95% conf	0.5	439.4	476.8	332.1	0.2	0.3	0.1	1.1			68.4		1.4
MIN	6.8	779.0	868.1	604.7	0.4	0.7	0.1	96.6			5.0		0.4
MAX	7.1	1130.5	1249.5	870.3	0.5	1.0	0.2	96.7			15.8		0.6

Table 5.8 Winter NH_3 emissions from the solid separator at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date: 12/21/2005
Source: Solid Separator
Area of Source: 500 m^2
Number of Head: 2000 Dairy

	Solid Separator											
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	(°C)	(°C)	(°C)	(°C)	(%)	[sL/min]
	7.13	684	763.9	532.1	0.3	0.014	0.0026	97.2	5.9	13	3.5	0	83.4%
	4.82	726	810.1	564.2	0.2	0.010	0.0019	97.2	0	0	4.8	0	76.8%
	7.12	798	889.1	619.3	0.4	0.017	0.0030	97.2	25.7	10.5	6.2	0	68.5%
Average	6.4	735.9	821.0	571.9	0.3	0.014	0.002	97.2	10.5	7.8	4.9	0.000	76.2%
Stdev	1.3	58.0	63.3	44.1	0.1	0.003	0.001	0.0	13.4	6.8	1.356	0.000	7.4%
n	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
t-stat	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
95% conf	3.3	144.1	157.2	109.5	0.2	0.008	0.001	0.0	33.4	17.1	3.369	0.000	18.5%
MIN	4.8	683.6	763.9	532.1	0.2	0.010	0.002	97.2	0.000	0.000	3.573	0.000	68.5%
MAX	7.1	798.3	889.1	619.3	0.4	0.017	0.003	97.2	25.730	13.000	6.285	0.000	83.4%

Table 5.9 Winter NH_3 emissions from the milking parlor at the open-lot dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy XXX
Comanche county, TX

Date: 12/21/2005
Source: Milking Parlor
Area of Source: 500 m^2
Number of Head: 2000 Dairy

	Milking Parlor											
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year	(°C)	(°C)	(°C)	(°C)	(%)	[sL/min]
	7.07	110	128.0	89.2	0.1	0.0024	0.0012	97.0	13.5	19.9	12.2	0.0	38.68%
	4.95	112	130.6	90.9	0.0	0.0017	0.0008	96.9			12.6	0.0	36.91%
	7.12	115	133.1	92.7	0.1	0.0025	0.0012	96.9	23.2	14.7	13.6	0.0	36.92%
Average	6.4	112.4	130.5	90.9	0.1	0.0022	0.0011	96.9	18.4	17.3	12.8	0.0	37.5%
Stdev	1.2	2.2	2.5	1.8	0.0	0.0004	0.0002	0.1	6.9	3.7	0.7	0.0	1.0%
n	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	3.0	3.0	3.0
t-stat	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	12.7	12.7	4.3	4.3	4.3
95% conf	3.1	5.6	6.3	4.4	0.0	0.0011	0.0005	0.1	61.6	32.9	1.9	0.0	2.5%
MIN	4.9	110.1	128.0	89.2	0.0	0.0017	0.0008	96.9	13.5	14.7	12.2	0.0	36.9%
MAX	7.1	114.6	133.1	92.7	0.1	0.0025	0.0012	97.0	23.2	19.9	13.6	0.0	38.7%

Table 5.10 Summer NH_3 emissions from the free-stalls at the free-stall dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy RJ
Comanche county, TX

Date: 7/14/2003
Source: Free-stall
Area of Source: 9790 m^2
Number of Head: 2100 Dairy

Area of the free-stall divisions (m^2)

Non-feed side	compost	feed side	water area
2700	3800	3090	200

	Free-stall barn/Non-feed side											
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.09	45453	46140.2	32137.9	19.8	4.6	0.8	97.3	30.1	31.3	33.1	NA	12.9
	7.09	33536	34292.2	23885.4	14.7	3.4	0.6	97.3	25.3		34.3	NA	11.8
	7.09	66000	66397.9	46247.9	28.5	6.6	1.2	97.2	24.0		34.6	NA	11.6
	7.09	15871	16518.2	11505.3	7.1	1.7	0.3	97.2	23.9		32.9	NA	10.6
	7.09	122959	121832.7	84859.8	52.2	12.2	2.1	97.2	25.6	29.0	31.9	NA	10.6
Average	7.1	56763.8	57036.2	39727.3	24.5	5.7	1.0	97.2	25.8	30.1	33.4	NA	11.5
Stdev	0.0	41251.7	40509.1	28215.7	17.4	4.1	0.7	0.1	2.5	1.7	1.1	NA	0.9
n	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	2.0	5.0	NA	5.0
t-stat	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	12.7	2.8	NA	2.8
95% conf	0.0	51220.7	50298.7	35034.4	21.6	5.0	0.9	0.1	3.2	14.8	1.3	NA	1.2
MIN	7.1	15870.7	16518.2	11505.3	7.1	1.7	0.3	97.2	23.9	29.0	31.9	NA	10.6
MAX	7.1	122958.8	121832.7	84859.8	52.2	12.2	2.1	97.3	30.1	31.3	34.6	NA	12.9

	Free-stall barn/compost side											
	Zero air Flowrate	NH3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	(µg/m^3)	(µg/m^2-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.09	3911	4204.4	2928.5	1.8	0.6	0.1	97.264	38.3	33.6	34.6	NA	11.6
	7.09	646	722.8	503.5	0.3	0.1	0.0	97.264	29.5	32.8	34.6	NA	11.1
Average	7.1	2278.6	2463.6	1716.0	1.1	0.3	0.1	97.3	33.9	33.2	34.6	NA	11.3
Stdev	0.0	2308.8	2461.8	1714.7	1.1	0.3	0.1	0.0	6.2	0.6	0.0	NA	0.3
n	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	NA	2.0
t-stat	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	NA	12.7
95% conf	0.0	20743.8	22118.7	15406.3	9.5	3.1	0.5	0.0	56.0	5.4	0.2	NA	3.1
MIN	7.1	646.0	722.8	503.5	0.3	0.1	0.0	97.3	29.5	32.8	34.6	NA	11.1
MAX	7.1	3911.1	4204.4	2928.5	1.8	0.6	0.1	97.3	38.3	33.6	34.6	NA	11.6
	Free-stall barn/ Feed side												
	Zero air Flowrate	NH3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	(µg/m^3)	(µg/m^2-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.09	23145	23875.7	16630.1	10.2	2.7	0.5	97	29.4		35.0	NA	11.32
	7.09	16717	17377.4	12103.8	7.5	2.0	0.3	97	29.4	32.3	35.3	NA	11.01
	7.09	133906	132400.6	92220.6	56.8	15.2	2.6	97	25.2	32.1	35.2	NA	11.2
	7.09	138068	136412.9	95015.3	58.5	15.6	2.7	97	26.1	28.8	30.9	NA	10.48
	7.09	55593	56160.6	39117.4	24.1	6.4	1.1	97	24.9		30.3	NA	11.42
Average	7.1	73485.5	73245.4	51017.4	31.4	8.4	1.5	97.2	27.0	31.1	33.3	NA	11.1
Stdev	0.0	58946.0	57749.4	40224.0	24.8	6.6	1.2	0.0	2.2	2.0	2.5	NA	0.4
n	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.0	5.0	NA	5.0
t-stat	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	4.3	2.8	NA	2.8
95% conf	0.0	73191.2	71705.3	49944.7	30.7	8.2	1.4	0.1	2.8	5.0	3.1	NA	0.5
MIN	7.1	16716.6	17377.4	12103.8	7.5	2.0	0.3	97.2	24.9	28.8	30.3	NA	10.5
MAX	7.1	138067.8	136412.9	95015.3	58.5	15.6	2.7	97.3	29.4	32.3	35.3	NA	11.4

Free-stall barn/Water Area												
Zero air Flowrate	NH3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity

	[sL/min]	Original	Corrected	(µg/m^3)	(µg/m^2-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.09	14069	14684.7	10228.3	6.3	0.1	0.0	97.3	30.1	31.3	33.1	NA	12.9
	7.09	26486	27236.0	18970.6	11.7	0.2	0.0	97.3	25.3		34.3	NA	11.8
Average	7.1	20277.9	20960.3	14599.4	9.0	0.2	0.0	97.3	27.7	31.3	33.7	NA	12.3
Stdev	0.0	8780.2	8875.1	6181.7	3.8	0.1	0.0	0.0	3.4		0.8	NA	0.8
n	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	NA	2.0
t-stat	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7		12.7	NA	12.7
95% conf	0.0	78886.7	79739.5	55540.7	34.2	0.6	0.1	0.0	30.8		7.6	NA	7.1
MIN	7.1	14069.4	14684.7	10228.3	6.3	0.1	0.0	97.3	25.3	31.3	33.1	NA	11.8
MAX	7.1	26486.4	27236.0	18970.6	11.7	0.2	0.0	97.3	30.1	31.3	34.3	NA	12.9

Table 5.11 Summer NH_3 emissions from the primary lagoon at the free-stall dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and
Science
Texas A&M
University
College Station, TX

Client: Dairy RJ
Comanche county, TX

Date: 7/15-16 2003
Source: Lagoon-1
Area of Source: 19200 m^2
Number of Head: 2100 Dairy

	Lagoon-1												
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.10	27393	**28145.5**	19604.1	12.1	20.0	3.5	96.7	31.0	30.3	31.2		10.6
	7.09	45666	**46351.2**	32284.9	19.9	33.0	5.8	96.7	30.3	31.1	30.6	0.883	9.9
	7.09	25691	**26437.1**	18414.2	11.3	18.8	3.3	97.2	27.5	26.6	25.9	0.969	17.3
	7.12	22727	**23455.3**	16337.2	10.1	16.7	2.9	97.3	27.9	27.1	26.5	0.823	16.3
	7.08	21312	**22028.5**	15343.4	9.4	15.7	2.7	97.3	27.9	27.9	26.8		17.6
	7.08	37201	**37945.3**	26429.9	16.3	27.0	4.7	97.1	30.0	31.2	31.4	0.896	16.0
	7.12	38659	**39396.0**	27440.4	17.0	28.1	4.9	97.1	30.8	31.4	32.2	0.786	16.2
	7.08	29917	**30674.5**	21365.6	13.1	21.8	3.8	97.1	30.3	31.8	32.4		15.2
Average	7.1	31070.6	31804.2	22152.5	13.6	22.6	4.0	97.0	29.5	29.7	29.6	0.9	14.9
Stdev	0.0	8592.4	8583.2	5978.4	3.7	6.1	1.1	0.2	1.4	2.1	2.7	0.1	3.0
n	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	5.0	8.0
t-stat	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.8	2.4
95% conf	0.0	7183.5	7175.7	4998.1	3.1	5.1	0.9	0.2	1.2	1.8	2.3	0.1	2.5
MIN	7.1	21312.3	22028.5	15343.4	9.4	15.7	2.7	96.7	27.5	26.6	25.9	0.8	9.9
MAX	7.1	45665.8	46351.2	32284.9	19.9	33.0	5.8	97.3	31.0	31.8	32.4	1.0	17.6

Table 5.12 Summer NH_3 emissions from the secondary lagoon at the free-stall dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy RJ Comanche county, TX

Date: 7/16/2003
Source: Lagoon-2
Area of Source: 17000 m^2
Number of Head: 2100 Dairy

	Lagoon-2												
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	($\mu g/m^3$)	($\mu g/m^2$-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.12	23760	**24495.4**	17061.7	10.5	15.5	2.7	97.14	28.02	30.83	28.91	0.78	10.72
	7.08	23108	**23838.7**	16604.3	10.2	15.0	2.6	97.17	27.45	27.98	28.10		9.95
	7.11	26132	**26880.6**	18723.1	11.6	17.0	3.0	97.20	28.12	28.21	27.56	0.91	9.66
	7.07	30503	**31261.2**	21774.3	13.4	19.6	3.4	97.28	29.10	27.19	25.87	0.93	
	7.13	27247	**27999.4**	19502.3	12.1	17.7	3.1	97.31	29.10	24.95	25.20	0.92	
	7.08	26944	**27695.3**	19290.5	11.9	17.4	3.0	97.33	28.70	27.12	24.41		
Average	7.1	26282.4	27028.4	18826.0	11.6	17.0	3.0	97.2	28.4	27.7	26.7	0.9	10.1
Stdev	0.0	2670.0	2680.1	1866.8	1.1	1.7	0.3	0.1	0.7	1.9	1.8	0.1	0.5
n	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	4.0	3.0
t-stat	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	3.2	4.3
95% conf	0.0	2802.0	2812.6	1959.1	1.2	1.8	0.3	0.1	0.7	2.0	1.9	0.1	1.4
MIN	7.1	23107.8	23838.7	16604.3	10.2	15.0	2.6	97.1	27.4	25.0	24.4	0.8	9.7
MAX	7.1	30503.0	31261.2	21774.3	13.4	19.6	3.4	97.3	29.1	30.8	28.9	0.9	10.7

Table 5.13 Summer NH_3 emissions from the composting area at the free-stall dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX
Client: Dairy RJ
Comanche county, TX
Date: 7/17/2003
Source: compost
Area of Source: 16600 m^2
Number of Head: 2100 Dairy

	compost												
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	(µg/m3)	(µg/m2-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.08	377	**427.3**	297.6	0.2	0.3	0.0	97.5	63.2	38.8	30.1		11.0
	7.12	626	**701.2**	488.4	0.3	0.4	0.1	97.5	39.4	38.8	30.2		11.3
	7.08	1151	**1271.6**	885.7	0.5	0.8	0.1	97.4	37.9	33.4	31.1	0.501	11.1
	7.12	473	**533.2**	371.4	0.2	0.3	0.1	97.4	64.6	43.5	31.9		11.1
	7.08	852	**947.8**	660.2	0.4	0.6	0.1	97.4	38.6	41.8	32.1		10.5
	7.08	1546	**1696.5**	1181.7	0.7	1.0	0.2	97.4	35.8	38.0	34.4	0.296	12.8
	7.11	815	**907.5**	632.1	0.4	0.6	0.1	97.3	39.7	38.2	34.2		12.4
	7.08	1872	**2046.1**	1425.2	0.9	1.3	0.2	97.3	39.2	37.1	35.8		11.6
	7.11	2296	**2497.6**	1739.7	1.1	1.5	0.3	97.3	34.1	38.8	35.1	0.295	13.7
	7.08	1352	**1488.0**	1036.4	0.6	0.9	0.2	97.3	37.4	40.5	34.6		11.4
	7.11	8136	**8601.0**	5990.8	3.7	5.3	0.9	97.2	44.9	41.4	37.2		11.5
Average	7.1	1772.4	1919.8	1337.2	0.8	1.2	0.2	97.4	43.2	39.1	33.3	0.4	11.7
Stdev	0.0	2193.4	2307.6	1607.3	1.0	1.4	0.2	0.1	10.6	2.7	2.4	0.1	0.9
n	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	3.0	11.0
t-stat	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	4.3	2.2
95% conf	0.0	1473.5	1550.3	1079.8	0.7	1.0	0.2	0.1	7.1	1.8	1.6	0.3	0.6
MIN	7.1	377.4	427.3	297.6	0.2	0.3	0.0	97.2	34.1	33.4	30.1	0.3	10.5
MAX	7.1	8136.4	8601.0	5990.8	3.7	5.3	0.9	97.5	64.6	43.5	37.2	0.5	13.7

Table 5.14 Summer NH_3 emissions from the crowding area at the free-stall dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station,
TX

Client: Dairy RJ
Comanche county, TX

Date: 7/17/2003
Source: crowding area
Area of Source: 925 m^2
Number of Head: 2100 Dairy

	crowding area												
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	(µg/m3)	(µg/m2-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	6.83	13145	13741.5	9571.4	5.7	0.5	0.1	97.5	63.2	38.8	30.1		11.0
	7.11	2406	2615.3	1821.6	1.1	0.1	0.0	97.5	39.4	38.8	30.2		11.3
	7.08	11862	12430.1	8657.9	5.3	0.4	0.1	97.4	37.9	33.4	31.1	0.501	11.1
	7.11	8493	8968.8	6247.0	3.9	0.3	0.1	97.4	64.6	43.5	31.9		11.1
Average	7.0	8976.5	9438.9	6574.5	4.0	0.3	0.1	97.5	51.3	38.6	30.8	0.5	11.1
Stdev	0.1	4799.4	4974.7	3465.0	2.1	0.2	0.0	0.0	14.6	4.1	0.9		0.1
n	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	1.0	4.0
t-stat	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2		3.2
95% conf	0.2	7636.9	7915.9	5513.6	3.3	0.3	0.0	0.0	23.2	6.6	1.4	0.0	0.2
MIN	6.8	2406.3	2615.3	1821.6	1.1	0.1	0.0	97.4	37.9	33.4	30.1	0.5	11.0
MAX	7.1	13144.8	13741.5	9571.4	5.7	0.5	0.1	97.5	64.6	43.5	31.9	0.5	11.3

Table 5.15 Summer NH_3 emissions from the open-lot at the free-stall dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy RJ
Comanche county, TX

Date: 7/18/2003
Source: open-lot
Area of Source: 38000 m^2
Number of Head: 2100 Dairy

	open-lot												
	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	(µg/m3)	(µg/m2-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.11	3758	**4042.9**	2816.0	1.7	5.7	1.0	97.18	25.56	31.21	30.79	0.51	15.21
	7.08	6761	**7178.0**	4999.7	3.1	10.1	1.8	97.21	30.13	33.04	31.44		13.99
	7.11	5790	**6168.7**	4296.6	2.7	8.7	1.5	97.20	25.80	30.81	31.90	0.70	12.66
	7.07	1661	**1820.5**	1268.0	0.8	2.6	0.4	97.17		32.73	33.13		12.31
	7.11	13815	**14425.4**	10047.7	6.2	20.4	3.6	97.14	33.59	37.86	34.72		11.45
	7.12	1615	**1770.7**	1233.3	0.8	2.5	0.4	97.11	34.70	38.77	35.18	0.70	11.36
	7.07	921	**1022.4**	712.1	0.4	1.4	0.3	97.08		38.32	34.22		11.56
	7.11	1290	**1421.2**	989.9	0.6	2.0	0.4	97.07	34.01	39.67	34.82		12.29
Average	7.1	4451.3	4731.2	3295.4	2.0	6.7	1.2	97.1	30.6	35.3	33.3	0.6	12.6
Stdev	0.0	4368.4	4542.7	3164.1	2.0	6.4	1.1	0.1	4.1	3.7	1.7	0.1	1.4
n	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	6.0	8.0	8.0	3.0	8.0
t-stat	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.6	2.4	2.4	4.3	2.4
95% conf	0.0	3652.1	3797.8	2645.3	1.6	5.4	0.9	0.0	4.4	3.1	1.4	0.3	1.1
MIN	7.1	920.8	1022.4	712.1	0.4	1.4	0.3	97.1	25.6	30.8	30.8	0.5	11.4
MAX	7.1	13815.0	14425.4	10047.7	6.2	20.4	3.6	97.2	34.7	39.7	35.2	0.7	15.2

Table 5.16 Summer NH_3 emissions from the separated solid at the free-stall dairy.

CAAQES-The Center of Agricultural Air Quality Engineering and Science
Texas A&M University
College Station, TX

Client: Dairy RJ
Comanche county, TX

Date: 7/15/2003
Source: Separated solid
Area of Source: 109 m^2
Number of Head: 2100 Dairy

Separated solid

	Zero air Flowrate	NH_3 Concentration (ppb)		Mass Concentration	E. Flux	ERs	EFs	Barometric Pressure	Surface temp	Chamber temp	Amb. temp	Chamber RH	Amb. humidity
	[sL/min]	Original	Corrected	(µg/m3)	(µg/m2-s)	(kg/day)	(kg/cow-year)	(kPa)	(°C)	(°C)	(°C)	(%)	g/m3
	7.09	673	**752.7**	524.3	0.3	0.0	0.0	97.6	38.9	29.5	NA	NA	9.6
	7.09	9649	**10160.0**	7076.7	4.4	0.0	0.0	97.6	32.6	30.9	NA	NA	10.2
	7.09	2611	**2832.5**	1972.9	1.2	0.0	0.0	97.6	32.4	34.3	NA	NA	11.2
	7.10	966	**1071.3**	746.2	0.5	0.0	0.0	97.4	32.2	35.9	NA	NA	9.8
Average	7.1	3474.8	3704.1	2580.0	1.6	0.0	0.0	97.6	34.0	32.7	NA	NA	10.2
Stdev	0.0	4203.6	4400.0	3064.7	1.9	0.0	0.0	0.1	3.3	3.0	NA	NA	0.7
n	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	NA	NA	4.0
t-stat	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	NA	NA	3.2
95% conf	0.0	6688.9	7001.4	4876.7	3.0	0.0	0.0	0.2	5.2	4.7	NA	NA	1.1
MIN	7.1	673.3	752.7	524.3	0.3	0.0	0.0	97.4	32.2	29.5	NA	NA	9.6
MAX	7.1	9649.1	10160.0	7076.7	4.4	0.0	0.0	97.6	38.9	35.9	NA	NA	11.2

Table 5.17 Winter NH_3 emissions from the different GLAS of the free-stall dairy.

Ammonia	Number of Samples	Concentration (PPM)	Stdev (among samples)	cv	Concentration ($\mu g/m^{3)}$	Flow (L/min)	E Flux ($\mu g/m^2/s$)	Area (m^2)	ER ($\mu g/s$)	ER (kg/day)	EF (kg/yr/head)
Compost	3	17.4	9.5	54%	12110.3	5	5.3	16600	88171.4	7.6	
Freestall	5	36.4	18.7	51%	25349.4	5	11.1	6500	72268.0	6.2	
Dry Open Lot	3	6.5	3.5	55%	4494.9	5	2.0	36100	71169.6	6.1	
Wet OpenLot	4	14.1	3.4	24%	9817.5	5	4.3	1900	8181.3	0.7	
Separated Solids	2	9.3	0.9	9%	6505.6	5	2.9	109	311.0	0.0	
Lagoon 1	6	2.0	0.5	23%	1362.9	5	0.6	19200	11476.8	1.0	
Lagoon2	6	0.4	0.3	61%	298.3	5	0.1	17000	2224.5	0.2	
Sum	**29**	-	-	-	-	-	-	**97409**	**253802.6**	**21.9**	**2.52**

VITA

Name: Atilla Mutlu

Address: Biological and Agricultural Engineering
147-A Scoates Hall
Texas A&M University
College Station, TX 77843

Email Address: atilla@tamu.edu

Education: Ph.D., Biological and Agricultural Engineering, Texas A&M University at College Station, TX. 2007

M.S., Agricultral Engineering, The Cukurova University, Adana, Turkey. 1999.

B.S., Agricultral Engineering, The Cukurova University, Adana, Turkey. 1996.