Animal Operations and Air Quality

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Outline

I. Introduction

II. Efforts for estimating emissions and impacts

III. Control strategies

IV. Researches in MSU AAQRF

V. Problem solving
I. Introduction
Agriculture:
Satisfying the demand for food

(Anders, 2010)
Agriculture:
Satisfying the demand for food

- Increased human population
- Increased consumption of animal protein
- Concentrated animal feeding operations (CAFO)
## Changes in Agricultural Production

### History:
- Family farm system
- Small operations
- Resources were cycled: a closed loop for most nutrients
- Low productivity

### Now:
- Farms grew larger
- Became specialized
- Productivity increased
- Nutrients concentrated in certain regions
- Disconnected nutrient cycle
Environmental issues

Water quality

Air quality
(Mitloehner, 2009)
Atmospheric emissions, transport, transformation, and deposition of trace gases

(Aneja, et al., 2006)
Air emissions from animal production

- PM
- Odor
- GHG
- VOC
- NH₃
- H₂S
Odor

- Often show at the top of air pollution complaints on animal operations
- Hundreds of compounds
- Interactive effects
- Subjective

Microbial decomposition of animal waste

NH₃, H₂S, VOCs...
• By-product due to the relatively inefficient conversion of feed N into animal product.
Environment impacts of NH$_3$

- Eutrophication (Excess N deposition)
- Aerosol formation (Fine particle precursor)
- Soil acidification (Nitrification processes)
- Health effect
• Aerodynamic equivalent diameter (AED)
• PM10 and PM2.5

Coarse particles tend to be deposited in the upper airways of the respiratory tract.

Fine particles can reach and be deposited in the smallest airways (alveoli) in the lungs.
• Primary particles
  • Feed handling, animal activity, waste, road dust (fugitive)

• Secondary particles

\[ \text{SO}_2, \text{NO}_x \] + \[ \text{NH}_3 \] → Sulfate, nitrate, and ammonium salts

• Carrier of odors and airborne microorganisms
Coarse, fine, and ultrafine PM have different compositions

(From EPA PM Supersites project)
• GWP of major GHGs
  – CH4 : 21
  – N2O : 310
  – CO2 : 1

• CO2 generated by animal
  – biogenic in nature or “carbon neutral”

• Carbon Footprint: The net sum of all GHG emissions in CO2e per unit of production
US GHG emissions (CO2e) by sector

- Residential: 5%
- Commercial: 6%
- Agriculture: 8%
- Industry: 20%
- Transportation: 28%
- Electricity Generation: 33%

(EPA, 2006)
Animal operations:
A major source of CH4 & N2O

(EPA, 2005)
• Produced as manure decomposes anaerobically

• Toxic at high levels (workplace limits set at 10 ppm)

• Possible chronic health impact from low, long-term exposure (some states limit property line levels to 0.05-0.1 ppm)
VOCs are formed as intermediate metabolites in the degradation of organic matter in manure.
- Under aerobic conditions, oxidized to CO2 and water
- Under anaerobic conditions, converted to CH4 and CO2

- Odorous
- Health effect
- Participate in atmospheric photochemical reactions
- Precursors to O3 and PM2.5
### Importance of AFO Emissions at Different Spatial Scales

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Global, Regional</th>
<th>Local, Property Line</th>
<th>Primary Effects of Concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odor</td>
<td>*</td>
<td>****</td>
<td>Nuisance, quality of life</td>
</tr>
<tr>
<td>VOC</td>
<td>***</td>
<td>**</td>
<td>Odorous, ozone formation</td>
</tr>
<tr>
<td>H$_2$S</td>
<td>*</td>
<td>***</td>
<td>Odorous, health</td>
</tr>
<tr>
<td>NH$_3$</td>
<td>****</td>
<td>**</td>
<td>Atmospheric deposition</td>
</tr>
<tr>
<td>PM</td>
<td>*</td>
<td>***</td>
<td>Health, haze</td>
</tr>
<tr>
<td>GHG</td>
<td>***</td>
<td>*</td>
<td>Global climate change</td>
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</table>

(NRC, 2003)
Air Quality Regulations

• 1997 Clean Air Act Amendments

  – National Ambient Air Quality Standards (NAAQS)
    Standards set by the federal EPA for the maximum levels of air pollutants that can exist outdoors without negative affects on human health and welfare.

  – Six criteria pollutants
    O₃, CO, SO₂, NO₂, Lead (Pb), PM (PM₁₀, PM₂.₅)
Regulate air emissions from AFO

- Permitting requirements
  - Clean Air Act (CAA)

- Reporting requirements if their emissions reach specified thresholds
  - Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
  - Emergency Planning and Community Right-to-Know Act (EPCRA).
EPA’s GHG proposal


• EPA estimates that 40 to 50 of the largest operations must begin reporting by March 31, 2011 (for calendar year 2010)

• Only emissions from manure management systems are to be considered
  – Enteric fermentation emissions exempt
II. Efforts for estimating emissions and impacts
Aerosol measurement

Flow Measurement and Control

Sample inlet

Filter (FRM)

TEOM

Beta gauge
Filter sampling System

- Size-Selective Inlet
- Denuders
- Filter
- Flow controller
- Pump
TEOM
(Tapered-Element Oscillating Microbalance)

- Uses a vibrating collection substrate to collect the particles.
- The change in “load” will change the frequency of oscillation and that is used to calculate the mass concentration.
Beta Gauge

- Uses the carbon-14 radioactive source and measures the attenuation of radiation through the filter containing the sample.

(Hinds. Aerosol Technology.1999)
PM2.5 Chemical Speciation Sampler

- PTFE filter: PM$_{2.5}$ mass and elements – EDXRF
- Nylon filter: ion species – IC
- Quartz filter: OC & EC – NIOSH 5040 thermo-optical method
Cascade Impactors
A chamber method used for lagoon NH₃ sampling

(Aneja et al., 2000)
Open-path sampling: optical detection device

(Amon et al., 1997)
Odor sampling and measurement

Sampling bag

or

Sampling canister

Olfactometry

or

GC - MS
The challenges

Air emissions from individual farm can vary depending on many factors.

Scientific understanding of AFO air emissions and their effects requires the expertise of many disciplines.

Direct measurements of AFO emissions are expensive and difficult.
Emission factors
The mass of the pollutants emitted per AU per year

- Most local, state, and federal agencies rely on emission factors to develop emission inventories

- Represents the sum of the annual mean emission rates from housing, manure storage/treatment and land application; based on average annual conditions and typically a composite of various animal sizes and types.
GHG emission inventories

- Official GHG inventories are reported annually by each country to the United Nation Framework Convention on Climate Change (UNFCCC).

- The Kyoto protocol restricts the total GHG emissions of each signature country and the protocol provides an opportunity for emission trading within signature countries. Within the U.S. there is also the potential for emissions trading.

- The Intergovernmental Panel on Climate Change (IPCC) has developed guidelines for estimating and reporting emissions of GHG from AFOs (IPCC, 2006)
Estimating CH$_4$ emission using the IPCC approaches

Manure CH$_4$ emission

Enteric fermentation CH$_4$ emission

Total CH$_4$ emission

= VS$ \cdot B_0 \cdot 0.67 \cdot MCF$

Excreted volatile solid

CH$_4$ conversion factor

maximum CH$_4$ producing capacity

Swine: 4.2 g head$^{-1}$ day$^{-1}$
Steers: 145 g head$^{-1}$ day$^{-1}$
Dairy cows: 351 g head$^{-1}$ day$^{-1}$
Estimating N₂O emission using the IPCC approaches

\[ N \text{ excretion rate} \times N₂O \text{ emission factor} = \text{Direct N₂O emission} \]

- \(0.31-1.10\) kg N (1000kg BW)\(^{-1}\)day\(^{-1}\)
- \(0.001-0.02\) kg N₂O-N/kg N
The NAEMS project

In order to ensure compliance with regulation requirements and create a national methodology for estimating AFO air emissions

- The National Air Emissions Monitoring Study (NAEMS) under the Air Compliance Agreement with 2,600 participating AFOs.

- Measure air emissions at 24 sites (Covers all major types of swine, dairy and laying hen facilities) in nine states over a two-year period (2007 to 2009)

- Measurements include: PM, NH$_3$, H$_2$S and VOC
NAEMS Monitoring Plan – Layer houses (NC2B site)

- Barn 3
- Stage 1 Fans
- Barn 4

- Instrument shelter
- Anemometer
- Activity sensor
- Current switch
- Static pressure port
- RH/Temp probe
- PM monitor
- Thermocouple
- Air sampling
- Air inlet
- Wind sensor
- RPM sensor
- Solar sensor
- Exhaust fan
- Heated raceway
Tunnel ventilated barns with 17-48” fans on both ends of each barn
On-Farm Instrument Shelter (OFIS)
TEOM/PM sampler control units

Envirionics 4040 gas mixing system

TE450C H₂S analyzer

INNOVA 1412 multi-gas analyzer

NH₃, CO₂, SO₂, H₂S, and Zero gas tanks

Environics®
GAS DILUTION SYSTEM
Factors affecting AFO emission

Air emissions from AFOs depend on manure characteristics and how the manure is managed.

- pH/temperature of manure
- Aerobic or anaerobic microbial environment
- Precursors present in the manure (N, S)
- Wet/dry manure management systems
- Manure storage time
Emission models

- To calculate site-specific emissions, using the local design and operating parameters.
- To quantify and evaluate the effectiveness of the various control strategies
- To simulate seasonal and geographic variations in emission factors
# Emission models

<table>
<thead>
<tr>
<th>Statistical models</th>
<th>N-mass flow models</th>
<th>Process based models</th>
</tr>
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</table>
| • Can be useful in assessing the accuracy of mechanistic approaches. | • Mass balance approach  
• Simulate the N flow over the different stages of emissions | • Mechanistic  
• Consider each of the processes occurring on a typical farm |
Emission models

- Emission models increase the simplicity of emission estimation. Various emission models have been developed to fit different objectives for the estimation.

- It would be important to improve temporal resolution as well as geographical resolution of emission models to meet the requirement of recent chemical transport modeling.

- Much work remains to be done because of the number of variables in practice.
Air quality models

- Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere.

- Based on inputs of meteorological data and source information like emission rates, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and, in some cases, secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere.
Why do we need air quality models?

- Quantitative estimates of impacts over a wide area geographical area (limited measurements)
- Conduct detailed source contribution analyses
- Source mitigation and control scenario evaluation
- Evaluate impacts of future/proposed sources
- Air quality tracking tool
- Substantial cost and schedule advantages over monitoring
Air quality modeling system

- Meteorological model
  - Meteorological & geophysical data preprocessors
  - Emission data

- Post processing & graphical display programs

- Particle model
- Dispersion model
- Photochemical model
Regulatory air quality models

AERMOD

- Steady –state plume model
- Near-field impact
- Non-reactive pollutants
- Permitting and area-wide planning

CALPUFF

- Non-steady-state puff model
- Long range transport
- Complex wind
- Dry-wet deposition
- S&N chemistry
More information

- Both models are available on EPA’s Technology Transfer Network - SCRAM site
  http://www.epa.gov/ttn/scram/

- CALPUFF web site: http://src.com
Current status of air quality modeling

• Good performance for O₃ and PM₂.₅ concentrations. Relatively poor performance for nitrate and organic aerosols.

• Relatively good understanding of oxidant chemistry, but limited understanding of organic PM.

• Uncertainties in model inputs (emissions, meteorology, boundary conditions) limit model accuracy.

(Zhang, 2007)
III. Control strategies
Environmental Stewardship

• Environmental stewardship is a set of principles to help producers and advisors make decisions that will maximize the benefits of manure and minimize problems for the environment.
Environmental Stewardship

1. Awareness of Environmental Risks
2. No Point Source Discharges
3. Balance in the Use of Nutrients
4. Nutrient Plan for Land Application
5. Be a Good Neighbor
6. Know the Rules
7. Considers Environment before Expansion
Whole farm nutrient balance

**Inputs**
- Feed
- Animals
- Fertilizer
- Irrigation
- Legume N

**Managed Outputs**
- Animals
- Crops
- Manure

**Losses or Soil Storage**

**Feed**

**Manure**

Farm boundary
Strategies to improve nutrient balances

1. Efficient use of manure nutrients in crop production
2. Alternative livestock feeding programs
3. Marketing of manure nutrients
4. Manure treatment
Manure utilization plan
Addresses manure production on a farm and how the manure nutrients are utilized

1. Manure generation and other sources of nutrients
2. Manure nutrient availability
3. Crop selection and crop nutrient requirements
4. Best management practices (BMPs)
5. Summary of laws, rules, and regulations
Manure management systems

- Manures are almost exclusively used as soil amendments for agricultural crop production.
- Solid manure, liquid manure, litters, composts, and lagoon effluents represent the most common types of manure that are now applied to soils through a variety of spreading, tillage, and irrigation practices.
Proper management practices

- Adherence to proper nutrient management plans
- Maintenance/improvement of nutrient uptake efficiency and prevention of feed spoilage
- Maintenance of proper ventilation
- Maintenance of drainage and manure removal systems
- Maintenance of loading rates and pH for anaerobic lagoons
- Regular cleaning of buildings and quick disposal of mortalities
Proper management practices

• If possible, long-term stockpiling of manure should be avoided, and stockpile size should be minimized.
• Many odorous compounds are carried on dust particles and therefore, strategies to reduce odors are often related to strategies that reduce dust emissions.
• Odor decreases exponentially with distance. Establishing a sufficient distance between AFO facilities and neighbors with consideration of prevailing winds can be an effective way to minimize odor nuisance.
A whole farm systems approach is often required

- Air emission
  - Housing facilities
  - Manure storage systems
  - Land application sites
Housing facilities
Potential emission control practices

- Frequent manure removal (belt transport, scrape or flush)
- Using bedding/dry manure systems instead of liquid manure systems
- Chemical additives on animal litter
- Ration/diet manipulation
- Oil sprinkling
- Exhaust air treatment (biofilters, wet scrubbing, etc.)
Manure storage facilities
Potential emission control practices

- Using various types of covers (straw, cornstalks, or synthetic) to reduce emissions
- Urine/feces segregation
- Proper aeration
- Biological treatment
- Acidification
Land application
Potential emission control practices

- Direct injection (liquid manure)
- Rapid incorporation (by plowing or similar techniques) into soil
IV. Researches in MSU AAQRF
Animals and Housing

- AAQRF at Michigan State University
- 12 environmental rooms
- Each room: H 2.14 m × W 3.97 m × L 2.59 m
Animals and Housing

- Cow, heifer or Steer (1)
- Finishing pigs (6)
- Turkeys (20)
- Broiler chickens (50)
- Laying hens (56-80)
Air sampling and measurement system

Gas samples were sequentially monitored from each room and incoming air.

**Incoming air**
- Room 1
- Room 2
- Room 3
- Room 4
- Room 5
- Room 6
- Room 7
- Room 8
- Room 9
- Room 10
- Room 11
- Room 12

**Sampling manifold**

**Model 17C**
- NH₃, NO, NO₂

**Model 55C**
- CH₄

**BINOS**
- CO₂ / O₂

**INNOVA**
- CO₂, CH₄, N₂O, NMTHC, NH₃
Data collection and analysis

• Software control (LabVIEW v. 8.2)
  – Purge for 9.5 min, data collection for 5.5 min
  – One measurement cycle is 195 min.
  – 7 to 8 daily observations per room

• Data analyzed using mixed model (SAS v. 9.1)
  – Date was a random variable and room was treated as nested term within diet
Species and diets of the studies

**Broilers**
- Reduced N vs. control
- 0 and 15% DDGS
- 0, 10%, 20% DDGS
- 3*2 Reduced N and litter amendment PLT
- With or without supplemental methionine

**Laying hens**
- 0 and 15% DDGS
- 0, 10%, 20% DDGS
- 2*2 100%, 110% NRC 2, 3AA
- With or without supplemental methionine

**Turkeys**
- 0 and 20% DDGS
- 2*2 100%, 110% NRC 2, 3AA

**Finishing pigs**
- 0 and 20% DDGS

**Steers**
- 0, 40%, 60% DDGS
- 0, 60% or 60% DDGs plus added copper and molybdenum
- Quillaja, yucca, or no extract

**Heifers**
- High and low rumen degraded protein
- Quillaja, yucca, or no extract

**Dairy cows**
- Typical Western Midwestern or Southeastern U.S. diets

**Finishing pigs**
- 0 and 20% DDGS

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- Typical Western Midwestern or Southeastern U.S. diets
Effects of dietary strategies on CH4 emissions

Broilers
- Reduced N vs. control
  - 3*2 Reduced N and litter amendment PLT
- 0 and 15% DDGS
- 0, 10%, 20% DDGS
- 2*2 0, 20% DDGS with or without organic or inorganic trace minerals
- With or without supplemental methionine

Laying hens
- 0 and 15% DDGS
- 0, 10%, 20% DDGS
- 2*2 100%, 110% NRC 2, 3AA

Turkeys
- 2*2 0 and 20% DDGS
- 15% DDGS with or without microbial or chemical additive

Finishing pigs
- 0 and 20% DDGS

Steers
- 0, 40%, 60% DDGS
- 0, 60% or 60% DDGs plus added copper and molybdenum

Heifers
- High and low rumen degraded protein
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Dairy cows
- Typical Western Midwestern or Southeastern U.S. diets
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P<0.10
GHG emissions in CO$_2$e

GHG emission (g kg BW$^{-1}$ day$^{-1}$ in CO$_2$e)

- Broiler
- Laying hen
- Turkey
- Finishing pig
- Steer
- Heifer
- Dairy cow

- N2O
- CH4
- CO2
N balance in a turkey tom study

Input 100%
- Feed, 1826 g/bird
- Hatch toms, 1.4 g/bird

Output 102.3%
- Air emissions, 217 g/bird
- Excretion, 1066 g/bird
- Ending toms, 588 g/bird

100% NRC vs. 110% NRC
- Higher N retention (33.8% vs. 30.9%)

+3AA vs. +2AA
- Higher N retention (33.2% vs. 31.5%)
- Less NH₃-N emission (9.9% vs. 12.4%)

Diagram showing:
- N in ending toms: 32%
- N in excretion: 58%
- NH₃-N emission: 11%
- N₂O-N emission: 1%
V. Problem solving
Units for atmospheric Species

- **Concentration:**
  - The amount (or mass) of a substance in a given volume divided by that volume.
  - Expressed as mole/m$^3$, µg/m$^3$, ...

- **Mixing ratio:**
  - The ratio of the amount (or mass) of the substance in a given volume to the total amount (or mass) of all constitutes in that volume.
  - Expressed as ppm, ppb, ...
Conversion between units

At T(K), P(Pa)

- \( C(\text{mole/m}^3, \text{P,T}) = \frac{P}{(8.314 \times T)} \)
- \( C(\text{ppm}) = \frac{C(q, \text{mole/m}^3)}{C(\text{mole/m}^3) \times 10^6} \)
- \( C(\mu g/m^3) = \frac{C(\text{ppm}) \times P \times M_q}{(8.314 \times T)} \)

At \( T_0 = 298K, P_0 = 1.013 \times 10^5 \text{Pa} \)

- \( C(\text{mole/m}^3) = 40.89 \)
- \( C(\text{ppm}) = \frac{C(q, \text{mole/m}^3)}{40.89 \times 10^6} \)
- \( C(\mu g/m^3) = \frac{C(\text{ppb}) \times M_q}{24.45} \)

At \( T_0 = 298K, P_0 = 1.013 \times 10^5 \text{Pa} \)
1 ppb SO2 = 2.61µg/m³,
1 ppb H2SO4 = 4.01µg/m³,
Influence of pH on NH₃ and H₂S

- \( \text{H}_2\text{S} \leftrightarrow \text{H}^+ + \text{HS}^- \)
- \( K_{a1} = [\text{H}^+][\text{HS}^-]/[\text{H}_2\text{S}] \)
- \( [\text{H}_2\text{S}]/[\text{HS}^-] = [\text{H}^+]/K_{a1} \)

- \( \text{NH}_4^+ \leftrightarrow \text{NH}_3 + \text{H}^+ \)
- \( K_a = [\text{NH}_3][\text{H}^+]/[\text{NH}_4^+] \)
- \( [\text{NH}_3]/[\text{NH}_4^+] = K_a/[\text{H}^+] \)
Problem 1

- NH₃ concentration is 10 mg/m³ at T=273K, P=1.013*10⁵Pa. What is the mixing ratio in ppm?
Problem 2

- A company wants you to evaluate an experimental compound to use to reduce NH$_3$ emissions from the deep pit in a swine house.
- In a preliminary study, you added 10 mL of the compound to 1 L of waste which resulted in the pH of the waste being reduced from 8.5 to 5.5. The untreated waste has total ammoniacal-N [NH$_3$+NH$_4^+$] concentration of 250 mgN/L and [H$_2$S+HS$^-$] of 5 mg/L.
- What are the changes in NH$_3$ and H$_2$S concentrations (based on theory) in the waste before and after application of the amendment?
- (Given pK$_{a1}$=7.1 for H$_2$S, pK$_a$=9.3 for NH$_3$ )