Air Emissions from Layer Facilities

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Building Environment
Research & Education

Agricultural and
Biological Engineering

Purdue University
Presentation Topics

- Building Emission Research History
- Measurement Projects and Methods
  - Airflow
  - Gases
  - Odor
  - Dust
- Baseline Air Emissions
- Air Emission Controls
- Consent Agreement
Building Air Emissions Research

1992
- N. European survey
- Purdue
  - NH₃, H₂S
  - New mobile lab, IPPA

1997
- Gas, odor
- Monsanto, 8 finishers
- NPB, 2 rooms
- EPA Methods
  - Gas, PM, odor
  - EPA/PSF C.D.

2002
- Gas, odor
- Purdue and UMC
  - Gas, PM, odor
  - USDA APECAB

2003
- Purdue, UM, TAMU, ISU, UIUC, NCSU
- sweeten, Heber, Jacobson

2004
- Ohio C.D.
  - NH₃, PM
  - Purdue and OSU

2007
- NH₃, PM, H₂S, VOC
  - Purdue and ???
  - AFOCAFO

2007
- Gas, PM
  - Univ. of MN
  - Odor surveys, tests

- Sweeten, Heber, Jacobson
  - 2003
Single-Speed Fan Airflow

- Fan operation
- Fan static pressure
- Fan performance curve, degradation
- Fan removal and test at BESS lab
- FANS tests (AMCA transfer standard)
- Small vane anemometers
Fan with Plastic Shutter

Dirty was 8-13% < cleaned
Dirty was 14-24% < published

Static Pressure, Pa

Airflow, m³/s
Sampling probes, 10-115 m long

Bypass pumping circuit

9.5 mm OD, 6.4 mm ID Teflon

Barn 7 calibration

Barn 8 calibration

Leak test circuit

Pressure gage

Air valve

Rotameter (5 L/min)

6-port diluter

6-solenoid manifold

Bag fill port

Mass flow meter

Flow restrictors

Exhaust

P: pump
S: solenoid
M: manifold
F: filter

Analyzer

NH₃

H₂S

CO₂

CH₄/VOC

Cal gas circuit

Cal gases

C₆H₁₄/CH₄

SO₂

H₂S

NH₃

NO

CO₂

Zero air

J8

J6

Bag fill port

Pressure gage

Rotameter (5 L/min)

6-port diluter

6-solenoid manifold

Exhaust

1

1

F

P

S

P1

P2

M1

M2

M3

M4

S1

S2

S3

S4

S12

S14

F

C

1

1

Bypass pumping circuit

9.5 mm OD, 6.4 mm ID Teflon

Sampling probes, 10-115 m long

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Bypass pumping circuit

9.5 mm OD, 6.4 mm ID Teflon

Sampling probes, 10-115 m long
- Multiple locations (24)
- Prevent condensation
- Monitor pressure (0-1 psi)
- Monitor flow (0-10 L/min)
- Bypass pumping
- Proper surfaces (Teflon)
- Low residence time (<60 s)
- Regular leak tests
- Grab sampling provision
- Calibration gas provision
- Can add analyzers
Gas Sampling at Exhaust Locations

- Extractive sampling
- Filtered air
- All Teflon
- Random sampling
- Select primary representative exhaust fan (PREF)
On-Farm Instrument Shelter

- Space for instruments usually unavailable
- Instrument protection and security
- Key to quality assurance
- Analyst comfort
- Mobile

Top Quality DAQ Systems with Remote Access
Odor Sampling

- Use gas sampling system
- Freeze fans during sampling
- 2-3 replications
- Flush and precondition bags
- Include background
Physical Factors of Odor

Odor: Property or quality of a thing that affects, stimulates, or is perceived by the sense of smell.

- Odor concentration (OC), OU/m³
- Odor intensity, I
- Persistence, I vs. OC
- Hedonic tone, HT
- Hedonic tone behavior, HT vs. OC
- Character descriptions
- Frequency of occurrence
- Duration of occurrence
Odor and Gas Dispersion
Odor Concentration, OU/m³
14 Dilution Levels
- Dilution Ratios: 8-66,000
- Triangular Forced-Choice
- Yes/No Mode
- Single Sniffing Port
- 10 L Sample Size
- 8 panelists
- Standard D/T Dial: 2, 4, 7, 15, 30, 60
- Dial contains 12 positions, alternating between "blanks", 100% carbon filtered air, and the D/T values.
- The Teflon coated sniffing mask is ergonomically designed to fit your nose comfortably.
- Check valves allow for comfortable breathing with your nose in the mask.
Odor Intensity

- Relative perceived psychological strength of odor
- Suprathreshold levels only (>ODT)
- Static Odor Intensity Referencing Scale (n-b in water)
  - Five concentrations of n-butanol with 3X progression
  - Often used by field odor inspectors
  - Objectively match intensities

<table>
<thead>
<tr>
<th>Scale #</th>
<th>N-butanol in water, ppm</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>No odor</td>
</tr>
<tr>
<td>1</td>
<td>250</td>
<td>Very faint</td>
</tr>
<tr>
<td>2</td>
<td>750</td>
<td>Faint</td>
</tr>
<tr>
<td>3</td>
<td>2,250</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>6,750</td>
<td>Strong</td>
</tr>
<tr>
<td>5</td>
<td>20,250</td>
<td>Very strong</td>
</tr>
</tbody>
</table>
**Hedonic Tone**

- *Degree to which an odor is subjectively perceived as pleasant or unpleasant*
  - Perceptions vary widely among people
    - An emotional reaction
    - Personal odor preference and experience
  - -10 (extremely unpleasant) to +10 (extremely pleasant)

*DT and intensity are not sufficient to evaluate odor nuisance, e.g. biofilters reduce the odor offensiveness.*
Real-Time Dust Measurements
Monitoring Plan at Laying House

Wind Direction: West
Wind V. (m/s): 14.0

04/28/02 08:17:20

04/28/02 08:17:20

Lab wall T 11.4
dP5 (Pa) 24.8

Lab T 29.1
Bar. P (kPa) 97.5

Smpl time (m:s)
9:27

ppm NH₃
25.3

ppm H₂S
17

ppm CO₂
1359

ppm NH₃
1.6

ppm H₂S
452

ppm CO₂
2

ppm NH₃ (IR)
2

Building airflow (m³/s): 186

PM10 (µg/m³)
294
397

Filter (%)
48
58

T1-4

Manure pit

11.8

Air

RH (%)
77

T1-4

21.6

Cages

19.2

dP1 (Pa)
-13.2

dP2 (Pa)
-11.8

T11

48

1

2

T5-9

20.0

Fans operating:

Current methods tests: 1. TEOM wind break wall, 2. Infrared NH₃ monitor.

186 m³/s × 414*(17 – 2)/(273+20) = 340 g/d
Collocated TEOM PM10 in layer barn (baseline test)

TEOM TSP data in Missouri swine barns (abatement test)
Collocated PM10, PM2.5, TSP
Process Monitoring

- Animal activity
- Heaters
- Evaporative cooling
- Curtains
- Feeders
- Flushing
- Oil sprinkling
- Traffic
- Weather
Two emission projects ‘01-’04

- Mechanically ventilated livestock buildings
- Continuous emission monitoring (source)
  - Multiple gas sampling points
  - Gases (NMHC, CH₄, NH₃, H₂S, traces)
  - PM₁₀, TSP, PM₂.₅
- Grab samples (bags, traps, canisters)
- Reliable emission measurements

Control of Air Pollutant Emissions from Swine Housing
CAPESH (funded by EPA and Premium Standard Farms)

APECAB Project (USDA-IFAFS)
CAPESH Project (EPA and PSF)
Air Emissions from a Laying Barn

- 73, 122-cm fans
- 37 m x 183 m house
- Ceiling inlets
- 10 rows of hens
- Under cage slot

246,000 hens

Stage 1: 4 fans
Stage 2: 5 fans
Stages 3-6: 9 fans
Stage 7: 15 fans
Stage 8: 13 fans

Fan inlets
Stored litter
2001/02 Laying House Study

- 29 complete days of analysis over 6 months.
- Two sets of gas analyzers
  - Set 1: used at one fan except for one (1) month
  - Set 2: used at eight (8) exhaust locations
- Daily means are based on averages of both sets of analyzers and 12, 2-h means.
Hourly Mean Ventilation and MWPS Design Values

Compared to 4.0 and 0.5 ft³/min-bird for summer and winter, converted to m³/s-building for 246,336 hens
Overall Mean = 703 m$^3$/h-AU, compared to 451 and 965 m$^3$/h-AU for winter & summer in Europe (Seedorf et al., 1998)
Carbon Dioxide Concentrations

The graph shows the concentration of carbon dioxide (CO2) over time. The concentration values are plotted against the date, with the x-axis representing specific dates from December 1 to June 15. The y-axis represents the concentration in parts per million (ppm). The graph includes two datasets labeled 'CO2-1st' and 'CO2-2nd', indicated by blue diamonds and red squares, respectively.
Carbon Dioxide Emissions

Emission, kg/day

Date

CO2-1st
CO2-2nd
Hydrogen Sulfide Concentrations

Date

Concentration, ppb

H2S-1st

H2S-2nd
Hydrogen Sulfide Emissions

![Graph showing emissions of H2S-1st and H2S-2nd over time.](image)
Odor Concentrations ($\text{OU}_E/\text{m}^3$)

- **Exhaust**
  - Mean: 316 $\text{OU}_E/\text{m}^3$, $n=13$

- **Inlet**
  - Mean: 51 $\text{OU}_E/\text{m}^3$, $n=13$

Day of test, mm/dd
- 2/27
- 3/13
- 3/27
- 4/10
- 4/24
- 5/8
- 5/22
- 6/5
Odor Emission

- Mean = 50,400 OUE/s
- = 65.6 OUE/s-AU
- = 7.53 OUE/s-m²

Ventilation Rate, m³ s⁻¹

- Exhaust T
- Inlet T

Emission Rate

Temperature, °C

Mean = 50,400 OUE/s
mc=36.4%
pH=8.4
mc=26.0%
pH=8.3
mc=25.0%
pH=8.3

Emission, OUE/s-1 AU⁻¹

Day of Test

Summary of Odor Emissions

- Mean exhaust air $H_2S$ concentration was 20 ppb.
- Mean $H_2S$ emission rate was 5.6 $\mu g/s$-AU.
- Mean hedonic tone of exhaust air was -5.
- Mean exhaust odor intensity was 3200 ppm BIW.
- Mean exhaust odor concentration was 316 $OU_E/m^3$.
- Mean odor emission was 66 $OU_E/s$-AU.
Laying House
Ammonia Concentrations

![Graph showing ammonia concentrations over time with dates from 12/1 to 6/5. The graph compares concentrations in exhaust, cage, and inlet areas.]
# Mean NH$_3$ Emissions (29 days)

<table>
<thead>
<tr>
<th></th>
<th># hens</th>
<th>lb/d</th>
<th>tons/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Actual</strong></td>
<td>246.4K</td>
<td>852</td>
<td>155</td>
</tr>
<tr>
<td><strong>Projected</strong></td>
<td>4M</td>
<td>13,069</td>
<td>2385</td>
</tr>
<tr>
<td><strong>Projected</strong></td>
<td>28.9K</td>
<td>100</td>
<td>16.6</td>
</tr>
</tbody>
</table>
Mean $\text{PM}_{2.5} = 1.1 \pm 0.3$, $\text{PM}_{10} = 16 \pm 3.4$, $\text{TSP} = 63 \pm 15$ g/d-AU
PM$_{10}$ Concentrations, Emission Rates

The graph shows the concentration of PM$_{10}$ and emission rates over time. The concentration is measured in $\mu g/m^3$ and the emission rate in kg/d.

- **PM concentration**: Represented by blue diamonds. The concentration values range from approximately 100 to 1000 $\mu g/m^3$.
- **PM emission**: Represented by red squares. The emission rate values range from approximately 0 to 20 kg/d.

The dates on the x-axis include 12/1, 12/29, 1/26, 2/23, 3/23, 4/20, and 5/18.
## Overall Means (6 days)

<table>
<thead>
<tr>
<th>Variable</th>
<th>24-h</th>
<th>Day</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ventilation, m³/s</strong></td>
<td>288±37</td>
<td>326±38</td>
<td>196±22</td>
</tr>
<tr>
<td><strong>PM$_{2.5}$, µg/m³</strong></td>
<td>39±8.0</td>
<td>47±7.7</td>
<td>19±8.7</td>
</tr>
<tr>
<td><strong>PM$_{10}$, µg/m³</strong></td>
<td>518±74</td>
<td>611±44</td>
<td>293±103</td>
</tr>
<tr>
<td><strong>TSP, µg/m³</strong></td>
<td>1887±563</td>
<td>2268±718</td>
<td>961±22</td>
</tr>
<tr>
<td><strong>PM$_{2.5}$, g/d-AU</strong></td>
<td>1.1±0.3</td>
<td>1.4±0.3</td>
<td>0.4±0.3</td>
</tr>
<tr>
<td><strong>PM$_{10}$, g/d-AU</strong></td>
<td>16±3.4</td>
<td>20±2.9</td>
<td>6.3±3.4</td>
</tr>
<tr>
<td><strong>TSP, g/d-AU</strong></td>
<td>63±15</td>
<td>80±15</td>
<td>21±7.9</td>
</tr>
</tbody>
</table>
## Mean PM$_{10}$ Emissions (29 days)

<table>
<thead>
<tr>
<th></th>
<th># hens</th>
<th>lb/d</th>
<th>tons/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>250K</td>
<td>16</td>
<td>2.6</td>
</tr>
<tr>
<td>Projected</td>
<td>4M</td>
<td>249</td>
<td>41</td>
</tr>
<tr>
<td>Projected</td>
<td>9.7M</td>
<td>604</td>
<td>100</td>
</tr>
<tr>
<td>Projected</td>
<td>24.2M</td>
<td>1510</td>
<td>250</td>
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TSP x 3 = 123
Aerial Pollutant Emissions from Confined Animals Buildings
## Summary: Average Two HR Barns

### Emission rates

<table>
<thead>
<tr>
<th>Birds</th>
<th>NH3 (Lb/d)</th>
<th>H2S</th>
<th>PM10 (ton/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250,000 birds</td>
<td>722</td>
<td>0.7</td>
<td>26.9</td>
</tr>
<tr>
<td>4 million birds</td>
<td>11,544</td>
<td>11.6</td>
<td>430.4</td>
</tr>
</tbody>
</table>

Based on preliminary data processing with continuous measurement data, one day a month from Dec. 2002 to Jan. 2004, except for July 2003.

### Bird numbers

<table>
<thead>
<tr>
<th>Bird number</th>
<th>NH3 (100 lb/d)</th>
<th>PM10 (100 ton/yr)</th>
<th>PM10 (250 ton/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird number</td>
<td>34,600</td>
<td>5,090,000</td>
<td>12,700,000</td>
</tr>
</tbody>
</table>

TSP \( \times 3 = 236 \)
Monitoring Plan for Ohio Site A

- Thermocouple
- Air sampling (1-13)
- Anemometer (SVA)
- RH/Temp probe
- Static pressure port
- TEOM PM monitor
- Activity sensor
- Wind sensor
- Solar sensor

**Floor plan (201 m x 21 m)**

**Barn 1**
- F25
- F22
- F38
- F13
- Instrument shelter
- F1
- OFIS
- Pit
- Cages

**Barn 2**
- F26
- F29
- F1
- Pit
- Cages

**Vibration sensor on each fan**
Monitoring Plan for Site B in Ohio

- Thermocouple
- Air sampling (1-13)
- Anemometer (SVA)
- RH/Temp probe
- Static pressure port
- TEOM microbalance
- Vibration sensor on each fan
- Activity sensor
- Wind sensor
- Solar sensor

Barn 2 (161.6 m x 15.85 m)

Instrument shelter

Barn 2 (belt batteries)

Lab

Vibration sensor on each fan
Manure Additive Study, 1999

- First QAQC-based contract
- Web-based Labview data monitoring
- Biweekly calibrations
- 39 reactors

Hood failure

PC DAQ
Gas sampling system (GSS)
Backup Analyzers

Calibration notebooks

Reactor room
50% manure dilution emitted more odor after 2-3 weeks.

7 of 35 products reduced NH$_3$ by 3-15% (P<0.05).

7 of 35 products reduced H$_2$S by 23-47% (P<0.05).

No products reduced odor emissions (P<0.05).
Biocurtain ~$3.5/pp

Gas probe

PM10 inlet

Baffle
Particulate Impaction System
Misting Ammonia Absorbers
Pit Ventilation Fans
Belt Battery Houses
Other Abatement Methods

- Feed modification (testing now)
- Calmer chickens (will test)
Nuisance Suits

- Neighbors seek for:
  - Actual damages
  - Punitive damages
  - Injunction to close the operation
  - Court order for abatement of odour

- Iowa
  - Supreme Court ruling in 1998
  - 14 lawsuits on the books

- Missouri
  - 52 neighbors v. Continental Grain: $5.2M award
  - 60 nuisance suits against PSF since August, 2002

Sources: Miner, 1997; van Sickle, 2003; Lee, 2004
State Lawsuits

- Ohio v. Buckeye Egg Farms
  - Must convert deep pit barns to belt-batteries
  - Revoked operating permits, July, 2003
  - Closed down one facility, November, 2003
- California legislation SB-700
Federal Lawsuits

- Authority: U.S. Clean Air Act of 1990
  - Air and water issues
  - $350,000 penalty
  - Effluent pond emission monitoring
  - Barn emissions monitoring
  - Test soybean oil sprinkling
  - Air issues
  - $880,000 penalty
  - Barn emissions monitoring
  - Test dust and ammonia abatement
  - Short term tests indicated 700 tons PM/yr > 250 limit!
## USDA National Research Initiative in Air Quality
**March 11, 2004**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornell University, Ithaca, N.Y.</td>
<td>$400,365</td>
</tr>
<tr>
<td>Florida A&amp;M University, Tallahassee, Fla.</td>
<td>$100,000</td>
</tr>
<tr>
<td>Iowa State University, Ames, Iowa</td>
<td>$1,399,971 (3 awards)</td>
</tr>
<tr>
<td>Kansas State University, Manhattan, Kan.</td>
<td>$477,775</td>
</tr>
<tr>
<td>Montana State University, Bozeman, Mont.</td>
<td>$421,184</td>
</tr>
<tr>
<td>NASA Langley Research Center, Hampton, Va.</td>
<td>$223,052</td>
</tr>
<tr>
<td>North Carolina State University, Raleigh, N.C.</td>
<td>$479,818</td>
</tr>
<tr>
<td>Purdue University, West Lafayette, Ind.</td>
<td>$460,000</td>
</tr>
<tr>
<td>University of Connecticut, Storrs, Conn.</td>
<td>$466,130</td>
</tr>
<tr>
<td>USDA’s ARS, Lubbock, Texas</td>
<td>$196,646</td>
</tr>
<tr>
<td>USDA’s FS, Seattle, Wash.</td>
<td>$475,059</td>
</tr>
</tbody>
</table>

**Total: $5,100,000**
National Livestock Compliance Agreement

- What will livestock industry do?
  - Pay for nationwide monitoring project
  - Comply with laws based on results

- What will U.S. EPA do?
  - Grant temporary safe harbor
  - Forgive all past violations
  - Convert data into policy
  - Enforce rules following project

Source: John Thorne: C&M Capitolink
Description of Emissions Study

- Selected farms will represent pork, egg, broiler, turkey and dairy production
- Two years of continuous barn emission data
  - Extractive sampling of gases
  - Real-time dust measurements
- Effluent ponds monitored every season
  - Open path FTIR and UV sensors
  - Tomography
  - Backward Lagrangian stochastic modeling
- Standardized design and operating procedures

Source: John Thorne: C&M Capitolink
Real-Time Emission Data to be Collected by Study

- Ammonia – chemiluminescence
- NOx - chemiluminescence
- Hydrogen sulfide – Pulsed-Fluorescence
- Carbon dioxide – Photoacoustic Infrared
- FTIR for ambient gas measurements
- PM (PM$_{2.5}$, PM$_{10}$) – (TEOM)
- VOC: GC-MS (32 samples per site)
- TSP: integrated samples with Illinois method.
- Building airflow (fan status, pressure, vane anemometer, FANS)
- Include ambient measurements of PM, gases
Operational Data to be Collected by Study

- Heating, flushing, feeder, and fan operation
- Temperature and humidity
- Building static pressure
- Animal activity
- Lighting
- Wind speed and direction
- Solar radiation
- Animal inventory and mass
- Manure production
- Manure removals
- Manure, feed and water analysis
- Milk production
- Egg production
Questions?

T.T. Lim
Indiana

Larry Jacobson,
Minnesota

Amy Schmidt,
Missouri

B.H. Baek,
Texas

Ji-Qin Ni
Indiana

A.J. Heber
Indiana