Wet Scrubbers for Recovering Ammonia Emissions from Poultry Facilities for Nitrogen Fertilizer

Lingying Zhao, Associate Professor
Lara Jane Hadlocon, Graduate Research Associate
Roderick Manuzon, Research Associate

Department of Food, Agricultural and Biological Engineering
The Ohio State University

Acid Spray Scrubber

Spray acid wet scrubbers -- effective in NH_3 recovery, low pressure drop, and feasible for poultry operations.

- Average NH_3 scrubbing efficiency 70% in field and 81% in lab.
- Scrubbing effluent liquid is produced as fertilizer.
- It is feasible to run the wet scrubber at poultry farms
- Dust issue needs to be resolved for smooth scrubber operation

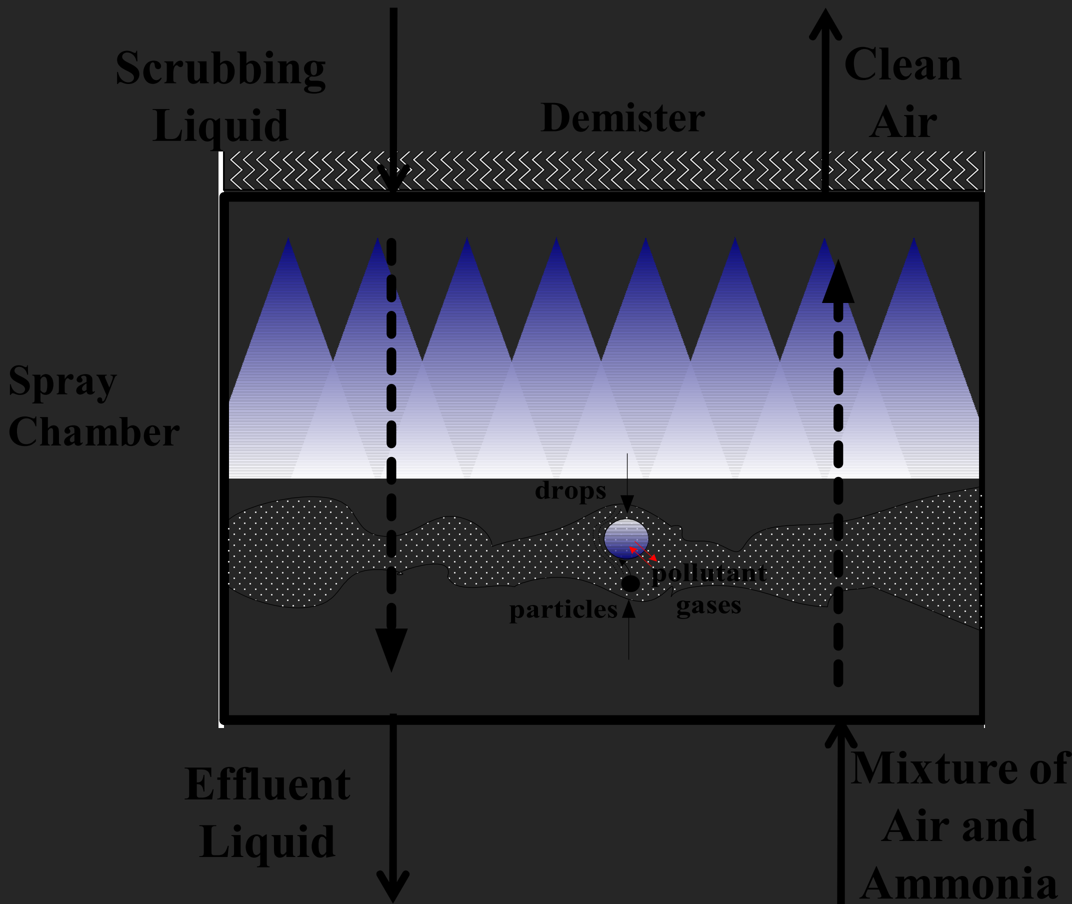
Outline

- Introduction, need analysis, and the project objectives
- Step1--Laboratory simulation of ammonia absorption in a spray scrubber
  - Optimization of wet scrubber design and operating parameters
  - Development of a prototype acid spray wet scrubber
  - A modeling tool for design acid spray wet scrubbers
- Step II -- A full-scale scrubber for a poultry composting facility
- Step III--Field evaluation of operation and maintenance of the full-scale wet scrubber
- Wet scrubber effluent as nitrogen fertilizer
- Economical analysis of the wet scrubber operation
- Conclusions

Introduction & Need Analysis

- Ammonia (NH_3) emission impacts health and ecosystems
- Animal production contributes about 80% of anthropogenic NH_3 emissions to the atmosphere, a very significant nitrogen nutrient loss.
- High cost of natural gas resulted high cost of nitrogen fertilizer for farming
- Wet scrubbing technology is effective in recover NH_3 emision and packed-bed wet scrubbers have been used at European animal farms.
- Packed-bed wet scrubbers cause high back pressure on fans and are not feasible to run with fans at the U.S. poultry farms, which are axial fans that can drive large airflow with small pressure drop.
- There is a need to develop wet scrubbers that can work with fans used at poultry farms in the U.S.

NH_3 Absorption in Acid Spray Scrubber



NH_3 acid spray scrubber:

- uses spray nozzles to generate liquid droplets for absorbing NH_3
- H_2SO_4 is used as scrubbing liquid:

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO$$

Objectives

- Develop wet scrubbers for NH_3 recovery from exhausts of poultry buildings and poultry manure composting facilities.
- Evaluate the performance, maintenance, and cost of the wet scrubbers at a commercial poultry farm to assess the technical practicality and economic feasibility.
- Explore the processes to convert the scrubber effluent into nitrogen fertilizer
- Disseminate and demonstrate the wet scrubber technology and its applications through various existing extension programs, workshops, and scientific and extension publications.

Factors Affecting NH_3 Spray Absorption

Wet Scrubber Efficiency

Design Variables

- nozzle type & size
- nozzle spacing
- scrubber dimensions
- number of stages
- flow configuration

Environment Variables

- NH_3 concentration
- air temperature
- relative humidity

Operation Variables

- nozzle operating pressure
- scrubbing liquid flow rate
- droplet velocity
- droplet distribution
- liquid pH
- airflow rate
- air velocity

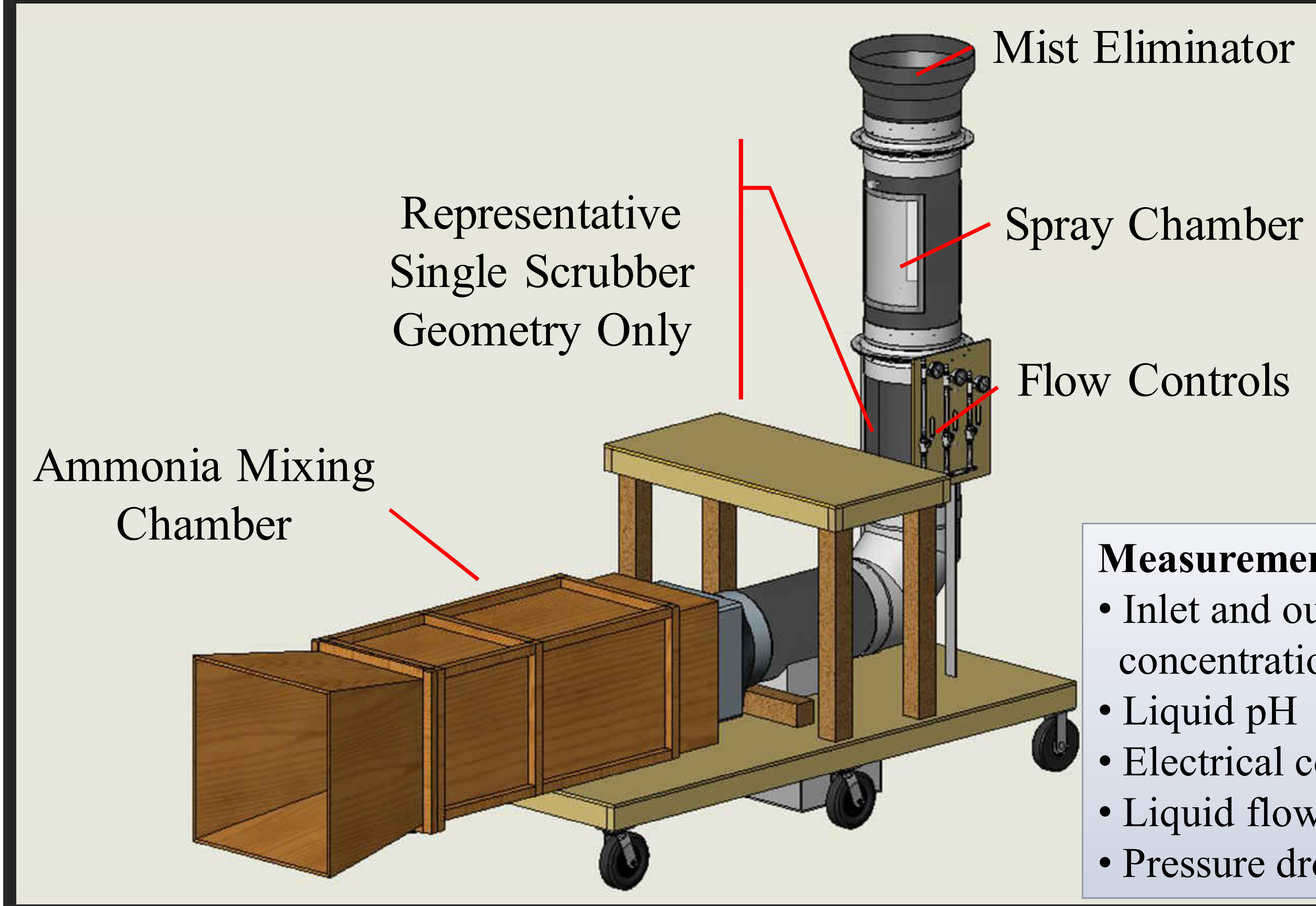
Step I:
Laboratory Simulation

OBJECTIVES:

Laboratory simulation of ammonia absorption in a spray scrubber for

- Optimization of wet scrubber design and operating parameters,
- Development of a prototype acid spray wet scrubber, and
- A modeling tool for design acid spray wet scrubbers.

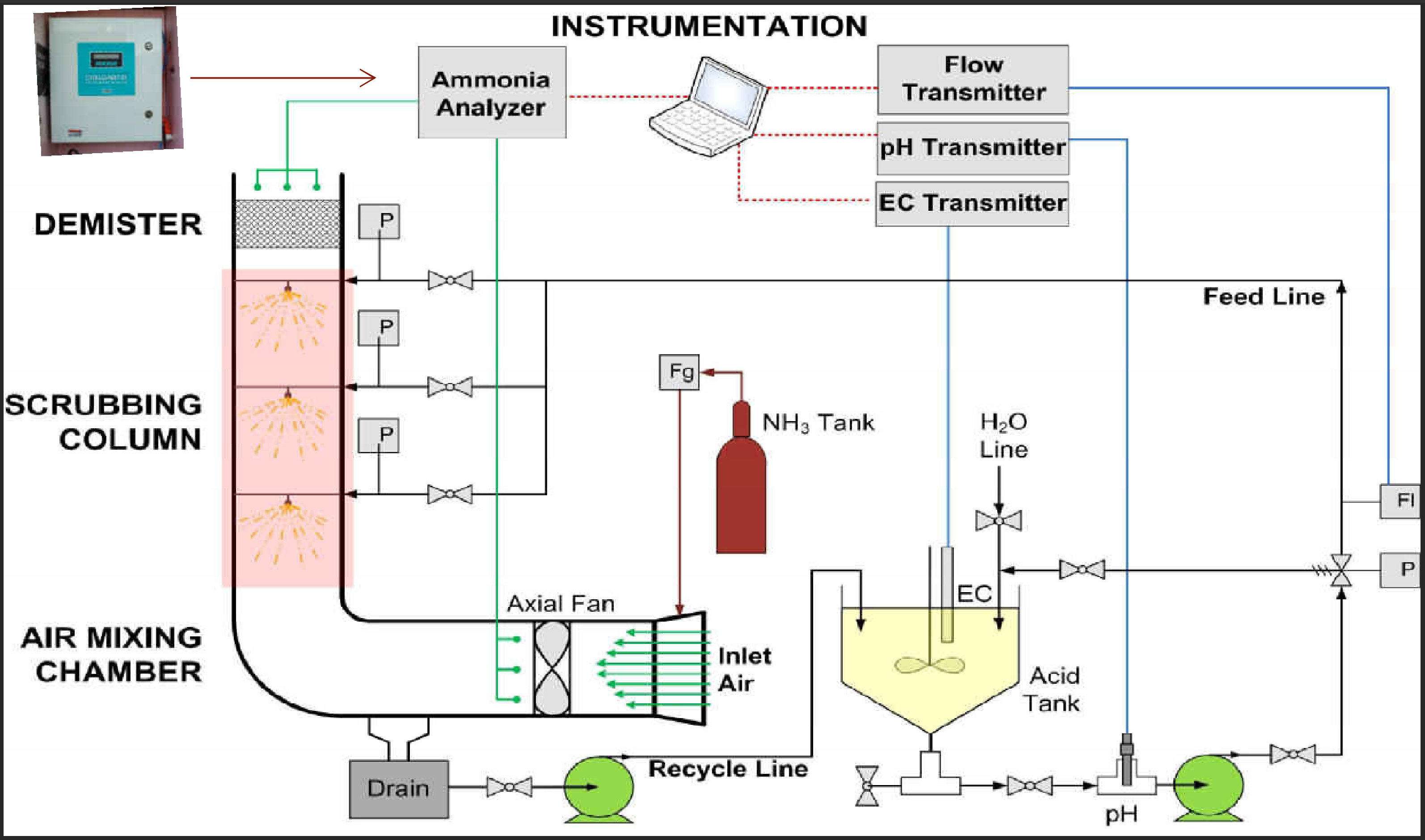
Laboratory Simulation of NH_3 Scrubber

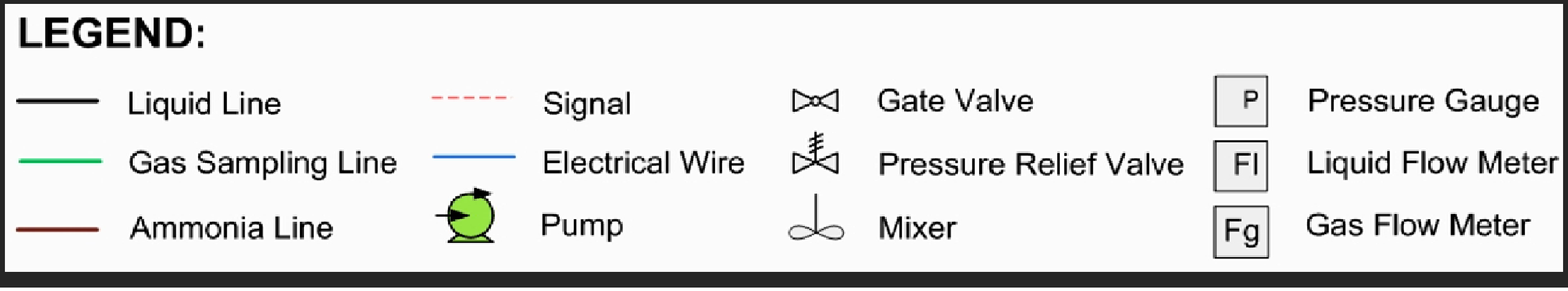


Measurements:

- Inlet and outlet NH_3 concentrations
- Liquid pH
- Electrical conductivity
- Liquid flow rate
- Pressure drop

Schematic of the wet scrubber simulator

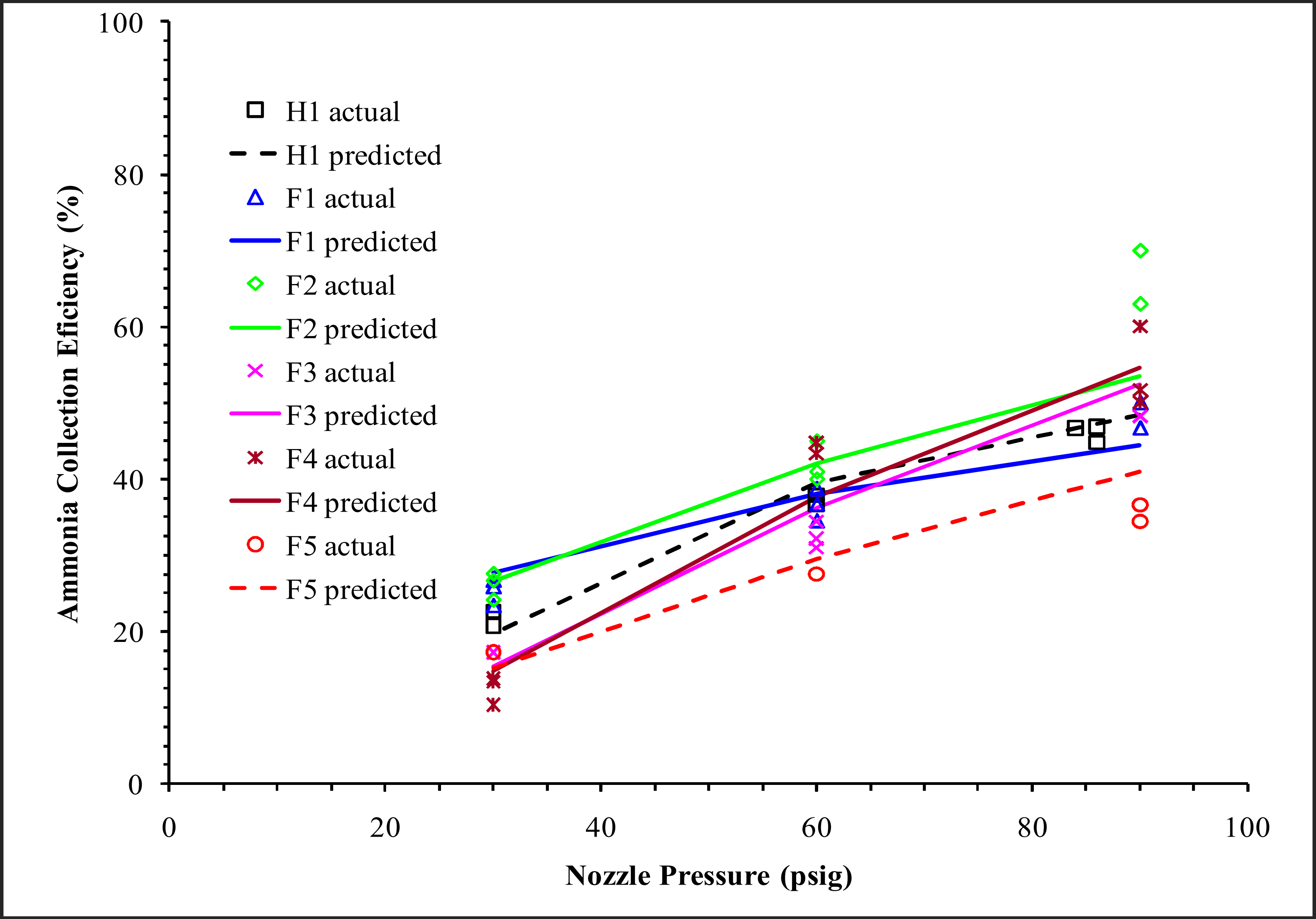




Optimization Experimental Design

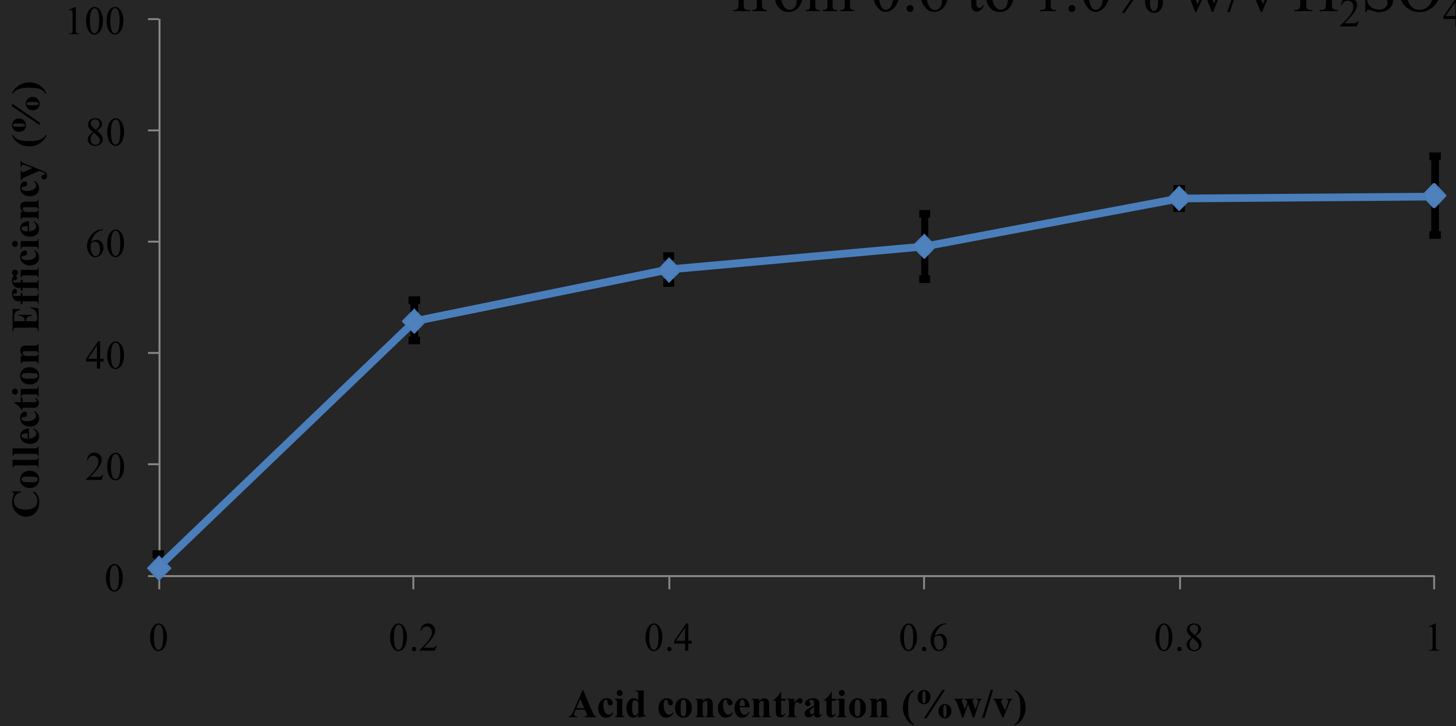
Tests	Factors	Levels	Measurements
1	nozzle type and characteristics	6 nozzles (F1,F2,F3,F3,F4, H1, H2) 3 Pressures (30, 60, 90 psig)	• NH_3 collection efficiency • flow rate • spray Angle • spray Height • droplet size and distribution
2	sulfuric acid concentration	6 concentrations (0.0, 0.2, 0.4, 0.6, 0.8, and 1.0% w/v)	• NH_3 collection efficiency • pH/amount of acid
3	nozzle position	3 distances (61, 97, and 132 cm)	• NH_3 collection efficiency • position
4	average air velocity	5 speeds (2, 3, 4, 5 and 5.3 m/s)	• NH_3 collection efficiency • air velocity
5	inlet NH_3 concentration	9 concentrations (10, 20, 30, 50, 80, 100,200, 300, 400 ppm)	• NH_3 collection efficiency • inlet NH_3 concentrations
6	air temperature	3 temperatures (12, 22, and 30^0C)	• NH_3 collection efficiency • inlet NH_3 concentrations • air temperature

Single Nozzle Efficiency Plots



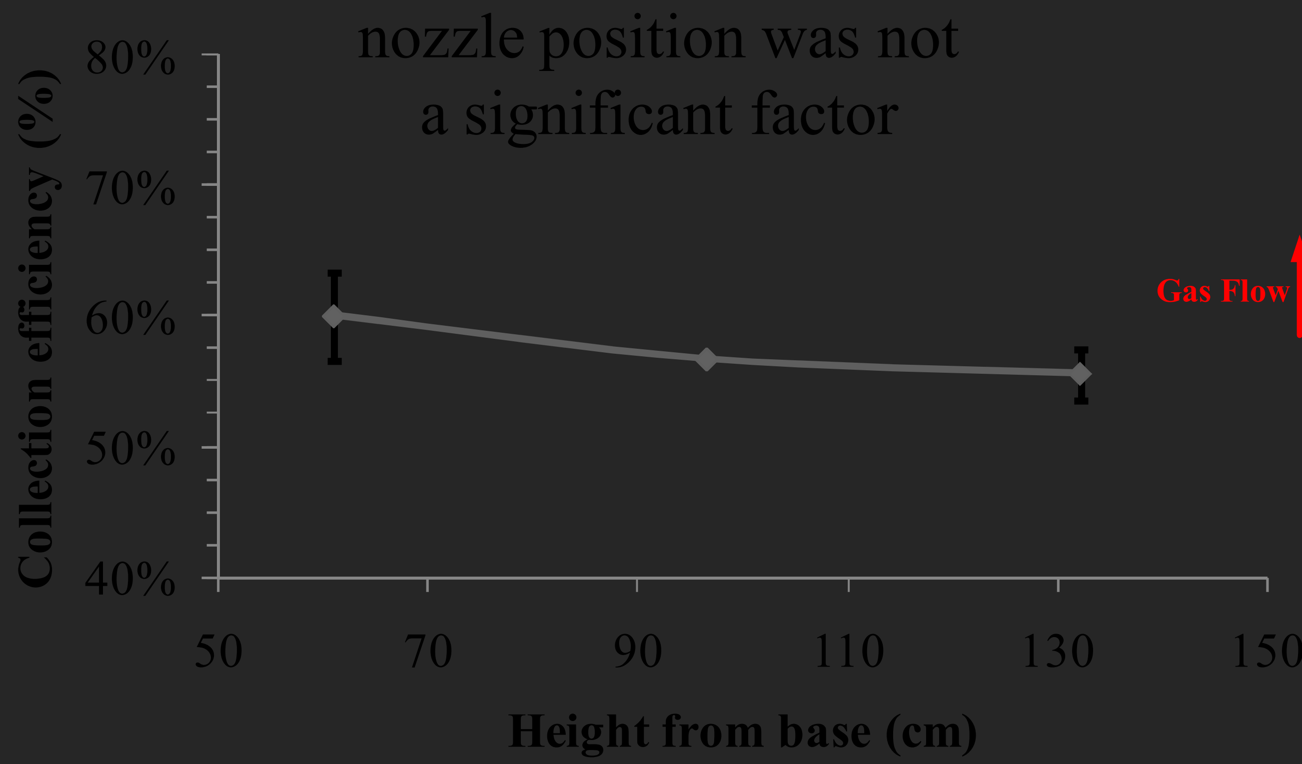
Effect of Acid Concentration

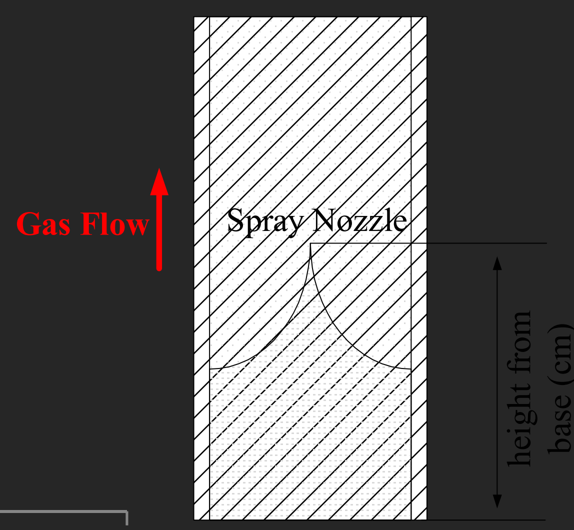
maximum absorption was obtained from 0.6 to 1.0% w/v H_2SO_4



No significant difference (alpha=0.05) between 0.6 to 1% w/v H_2SO_4 and beyond (Manuzon et al. 2007)

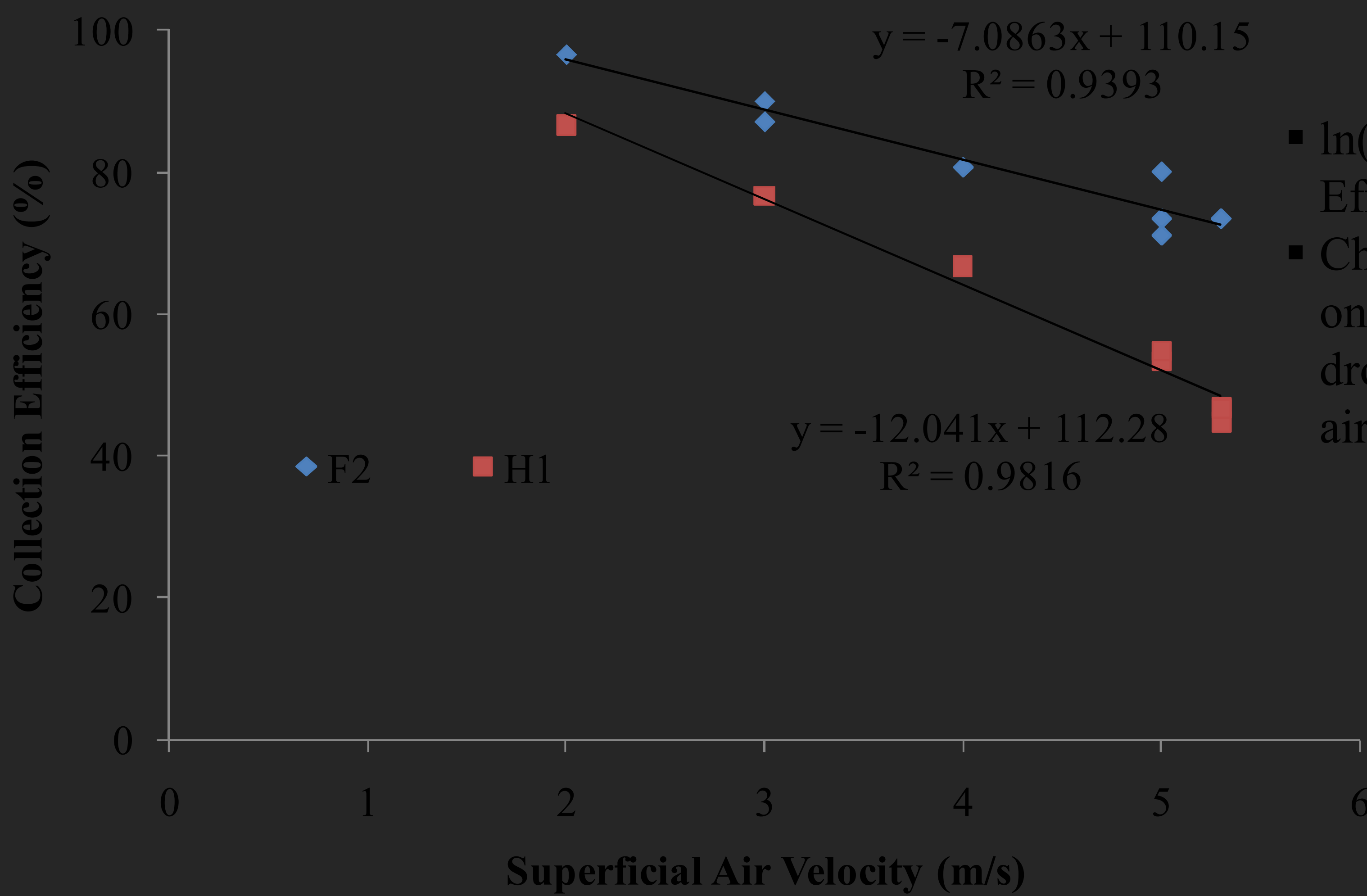
Effect of Nozzle Position





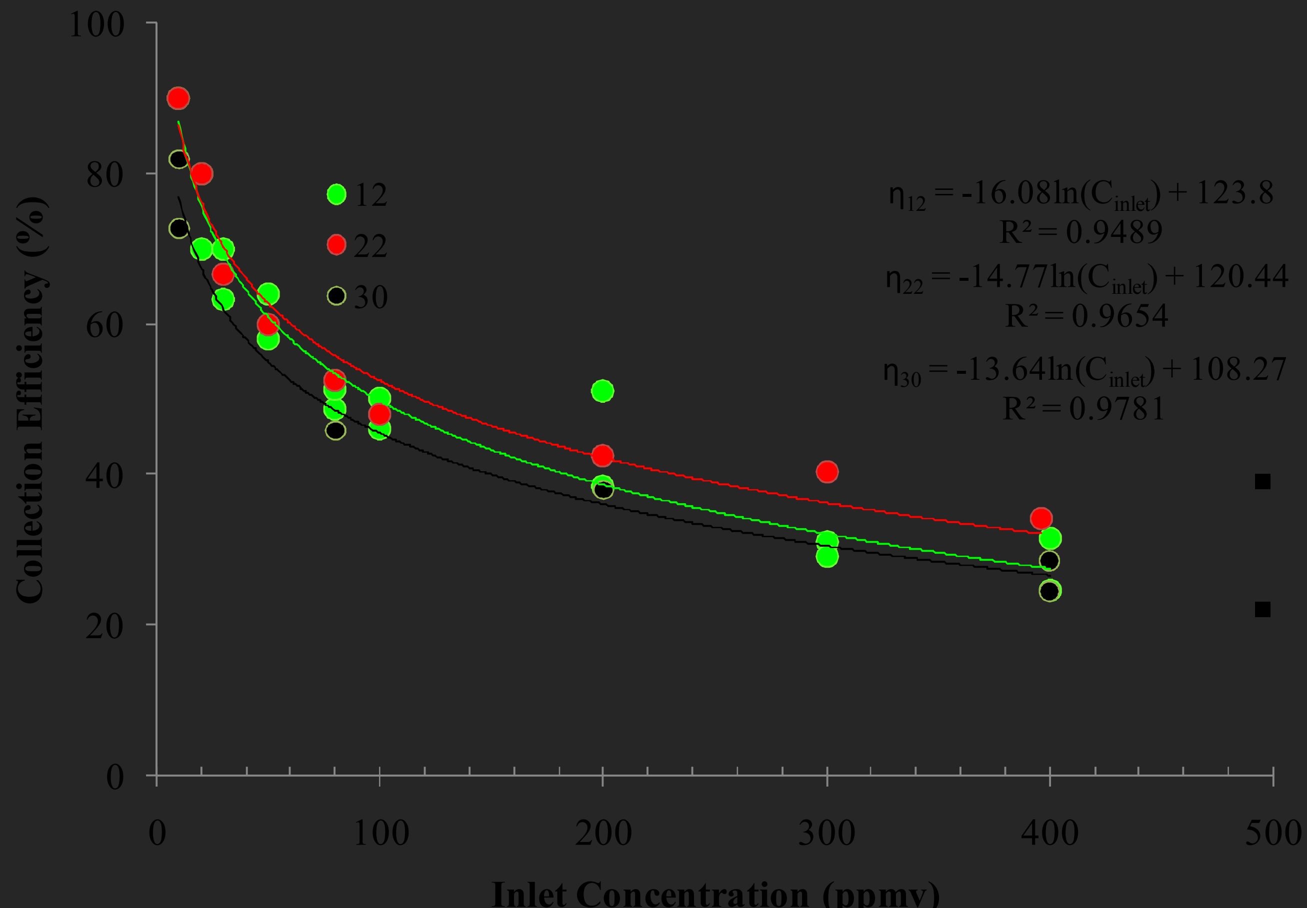
No significant difference (alpha=0.05) between any position

Effect of Superficial Velocity



- ln(Velocity) ↑- Efficiency ↓
- Change depends on nozzles (i.e. droplet size and air drag)

Effect of Inlet NH_3 Concentration & Temperature



- ln(Concentration) ↑- Efficiency ↓
- Significant difference (alpha=0.05) between performance at 22^{0}C and 30^{0}C

NH_3 Absorption Model

$$\eta = 100 - [C_0 + C_1\,\theta + C_2 d_o^{\,2} + C_3 H^2 + C_4 \Delta P^{0.5} + C_5 Q_L]^{0.5}$$

where:

η = ammonia collection efficiency (%)
θ = spray angle in degrees
d_o = orifice diameter in mm
H = spray height in cm
ΔP = nozzle pressure in KPa
Q_L = liquid flowrate in liter/min
C_0 =+5.731E+3
C_1=+4.197E+1
C_2=+3.267E+4
C_3=-2.394E+0
C4=+3.995E+2
C5=+7.337E+2

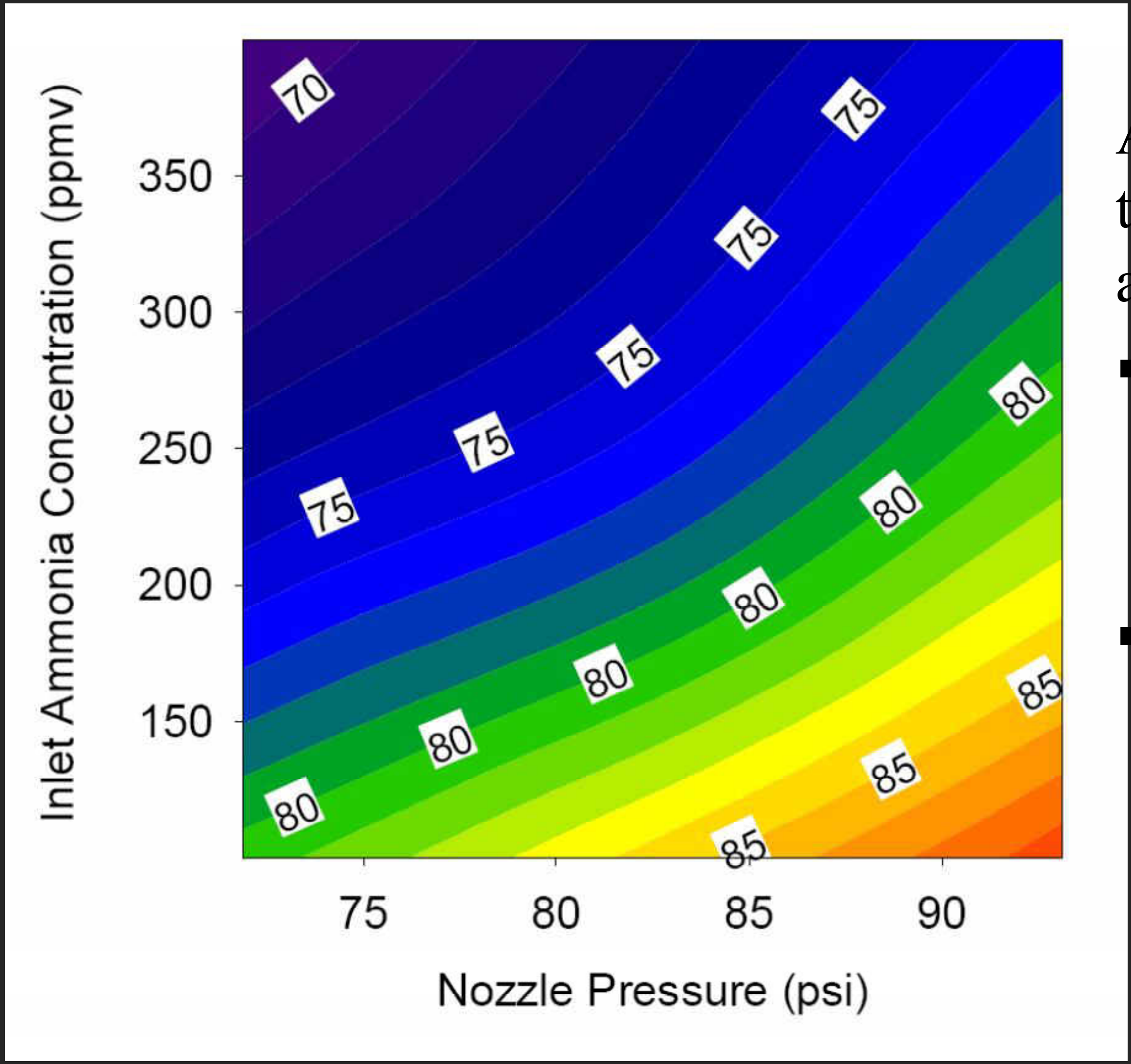
Important Variables:

- Pressure
- Orifice diameter

Variables not included due to poor fit:

- PIV measured Sauter-Mean droplet size
- PIV measured air velocities
- Cone Volume
- Droplet Concentration

Lab-Simulated Scrubber Performance



Air Velocity = 4 m/s, N=20, R^2=0.98

At a pressure of 90 psi, the scrubber efficiencies are:

- 75% - at inlet NH_3 concentration of 400 ppm_v
- 87% - at inlet NH_3 concentration of 100 ppm_v

Summary and Conclusions

- Optimum design, operation conditions for acid spray wet scrubber have been identified:
  - operating pressure (↑), efficiency (↑)
    there is a need to balance efficiency, liquid flow, and power consumption
  - nozzle position- no significant effect
  - sulfuric acid concentration ≥ 1%w/v H_2SO_4
  - increasing log(inlet temperature and concentration) decreases efficiency
- A prototype acid spray wet scrubber module has been developed
- A model have been developed to describe NH_3 spray absorption for designing optimized wet scrubbing process
- Need to further evaluate and improve the model to improve accuracy and applicability.

Step II:
Scale-up Design of Optimized Wet Scrubber

OBJECTIVES:

1. Develop a full-scale wet scrubber for poultry buildings and manure composting facilities
2. Maintain high efficiency and optimized conditions of the large-scale wet scrubber

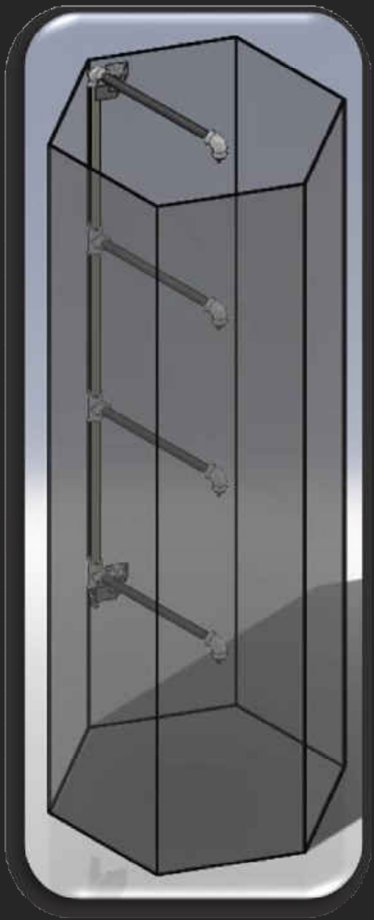
Scale-Up Method & Criteria

1. Module development
   Single Column Module[2] (SCM)- a single vertical column of scrubber section of the big scrubber
    - eliminates spray coagulation effects due to side-by-side sprays
    - optimization of
      - Span
      - Shape
      - Staging
2. Geometry Optimization
    - Large scale field conditions may lead to uneven flow distribution in the wet scrubber
    - CFD modeling with actual velocity verification

3. Liquid Recycling- determines effluent liquid saturation rate and fertilizer quality of the scrubber effluent

[2] patent pending

SCM Optimization Results



Final SCM Design

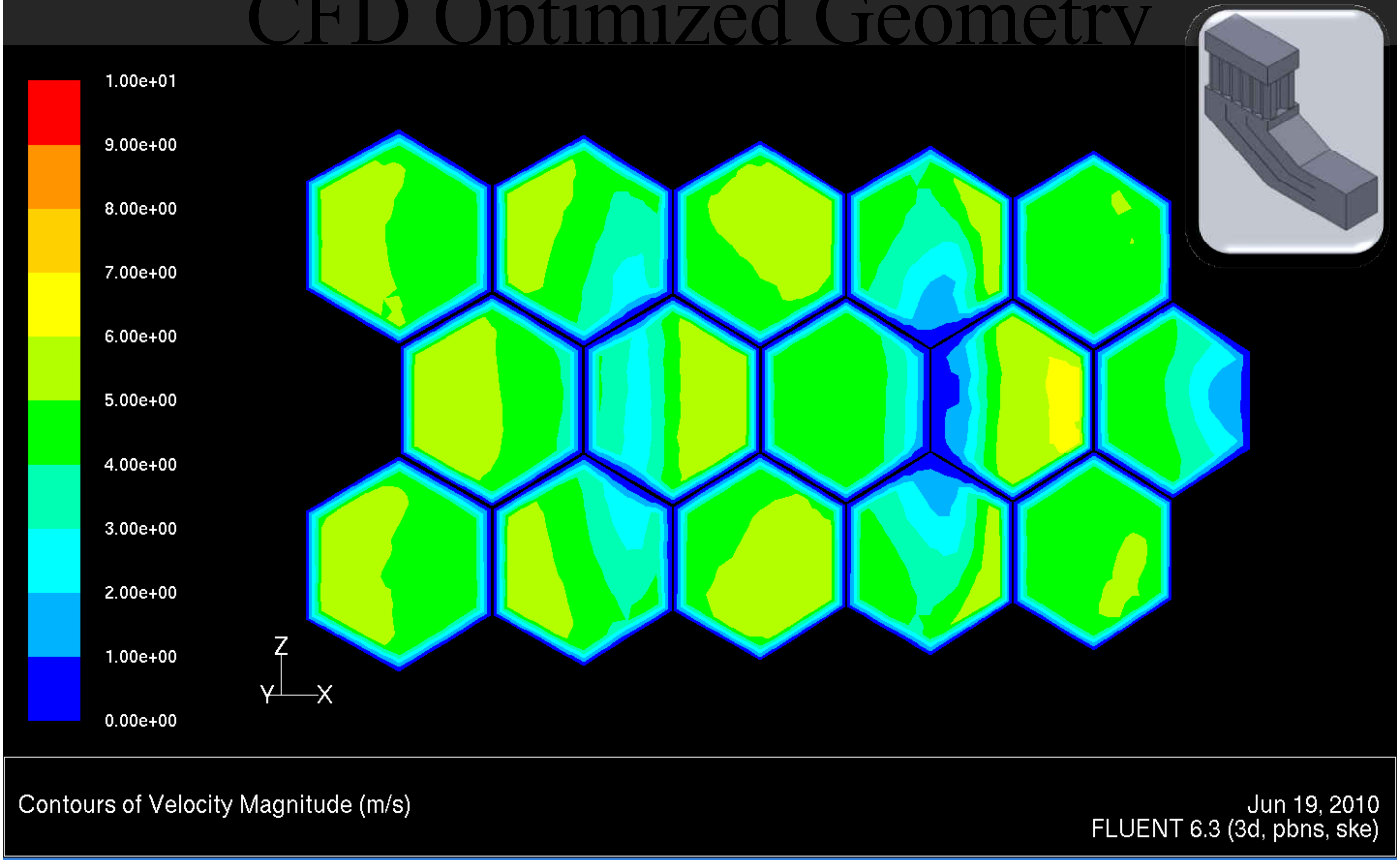
(patent pending)

Test	Levels Examined[3]	Design Setting
span	14, **18**,24 in	18 in
shape	round, square, **hexagon**	hexagon
stage	1, 2, **3**	4

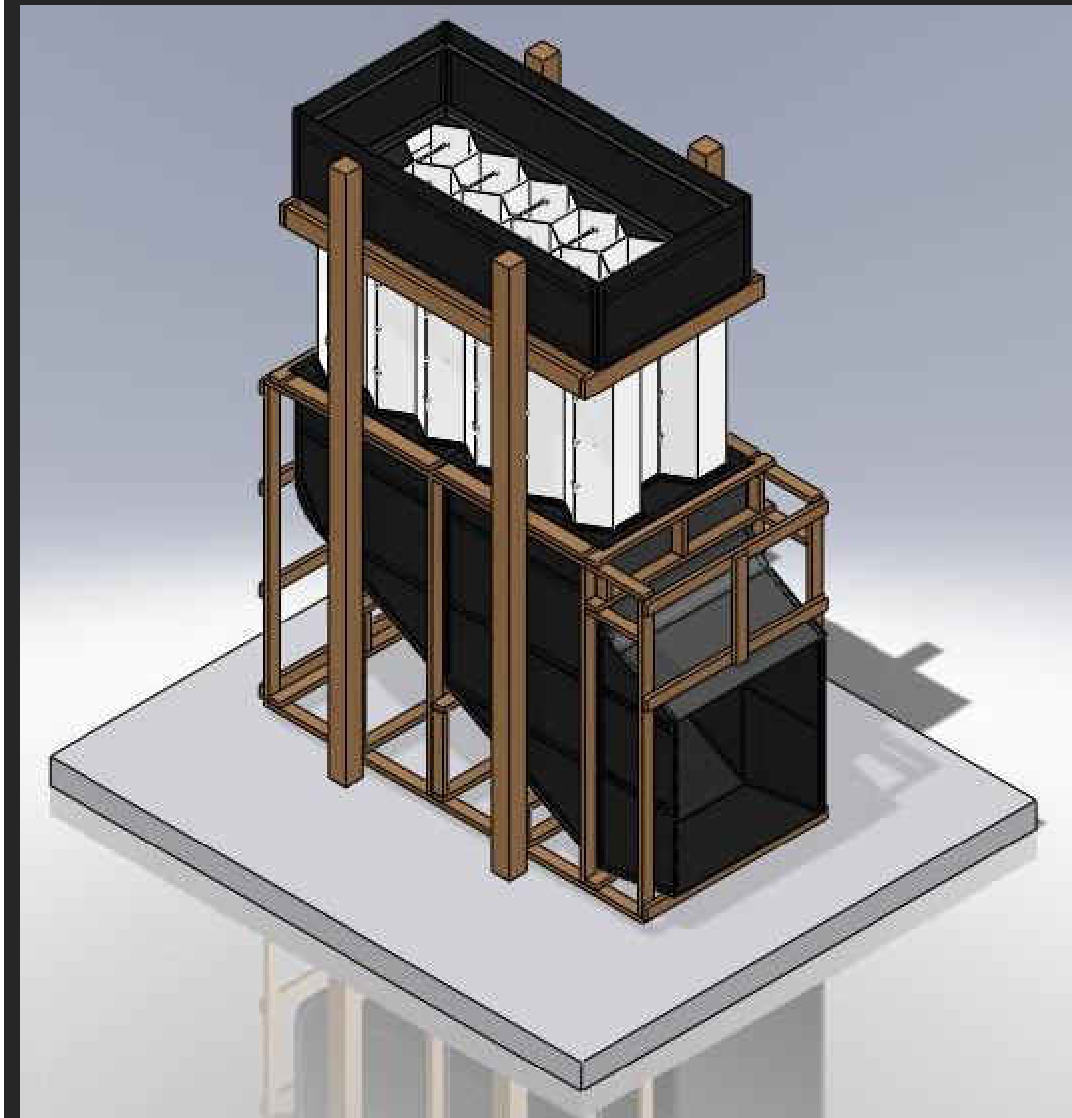
[3]optimum point in bold red

- 4th stage was added as a safety factor
- 3 stages were used in actual operation

CFD Optimized Geometry



Full-Scale Scrubber Design



Basic Features:

- Design consist of 15 modules
- Material of Construction is PVC and ABS
- Total Height=4.2 m (14 ft)
- Number of Nozzles=15
- Base Area=3.7 m^2 (40 ft^2)
- Total Weight=1 ton
- Nozzles are self cleaning
- Mode of operation is semi batch, cycle = 1 week
- Instrumentation:
  - pH control
  - PLC controls for pumps and motors

Step III:
Field Evaluation

OBJECTIVES:

1. Evaluate the scrubber performance at a poultry composting facility in Ohio
2. Assess quality of liquid effluent of the scrubber
3. Assess economic feasibility of NH_3 wet scrubber operation

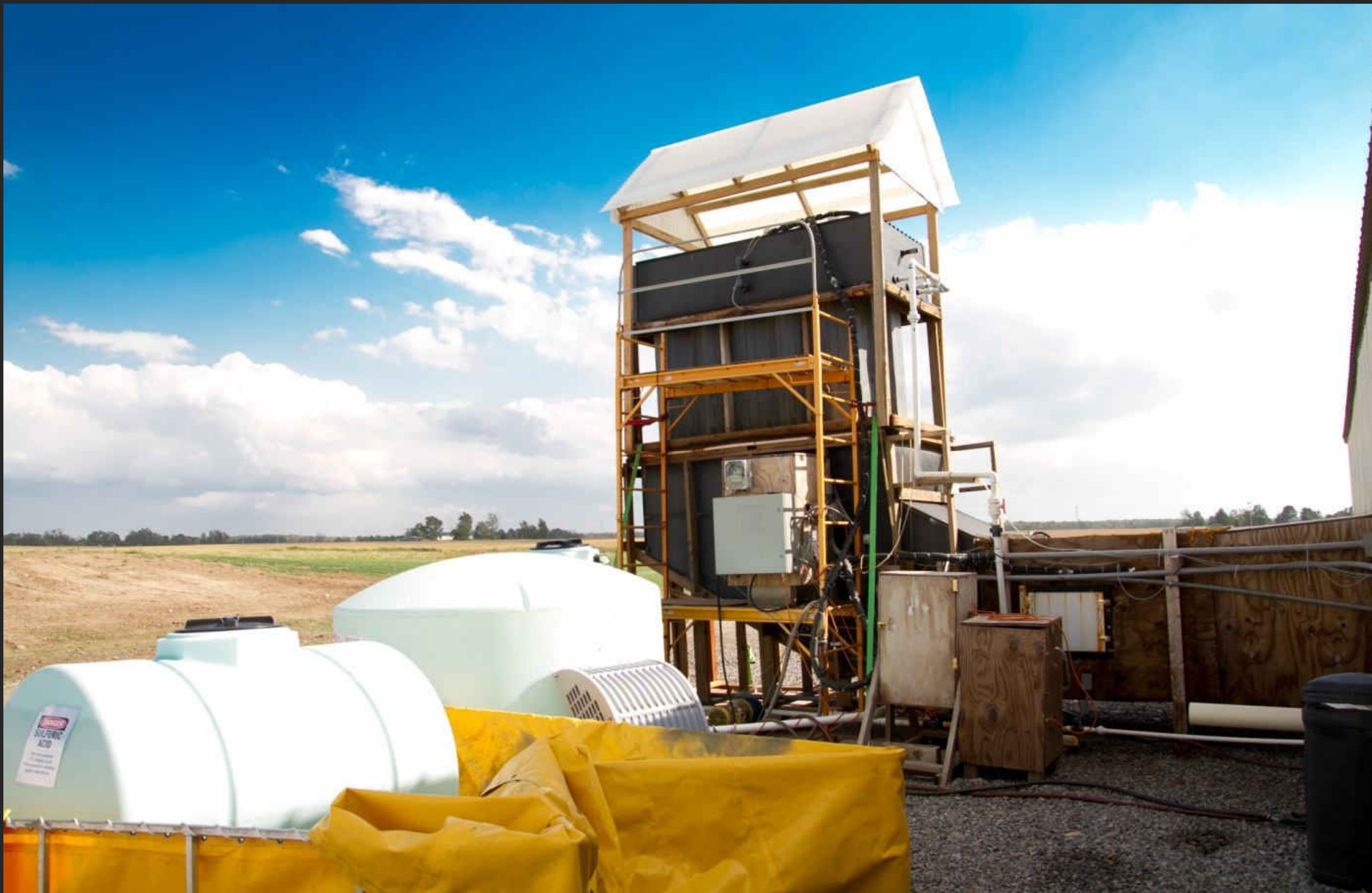
Site Description

Compost house exhaust streams:

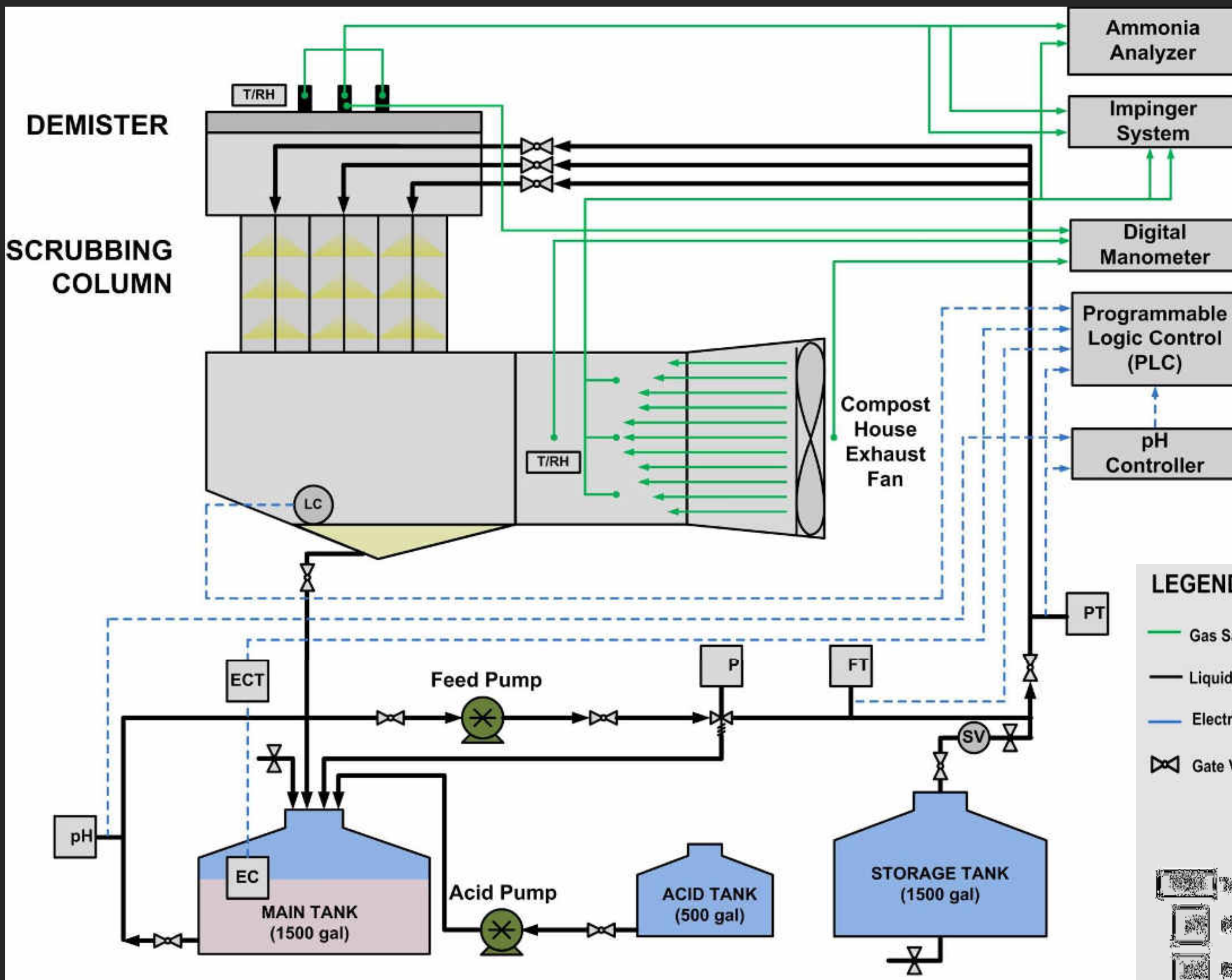
- NH_3 Concentration:100-400 ppm_v
- Air flow Rate: 18,000 m^3/h per fan
- Estimated NH_3 Emission: 100 tons/yr

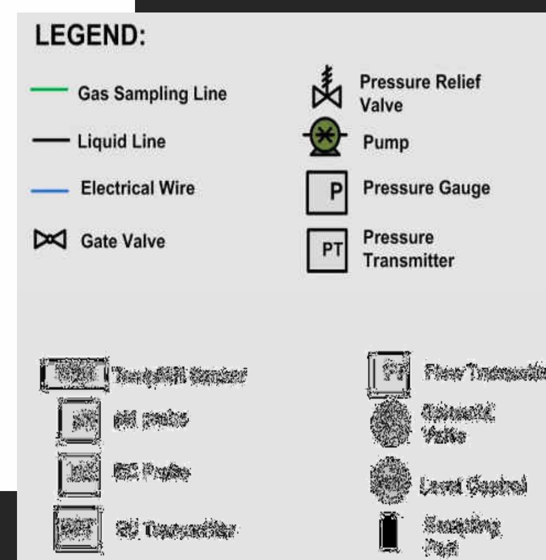
A composting house in Ohio processing manure from 4 adjacent manure-belt layer barns housing 828,000 laying hens.

A Full-Scale Acid Spray Wet Scrubber



Schematic of the Scrubber & Instrumentation





Field Measurement Plan

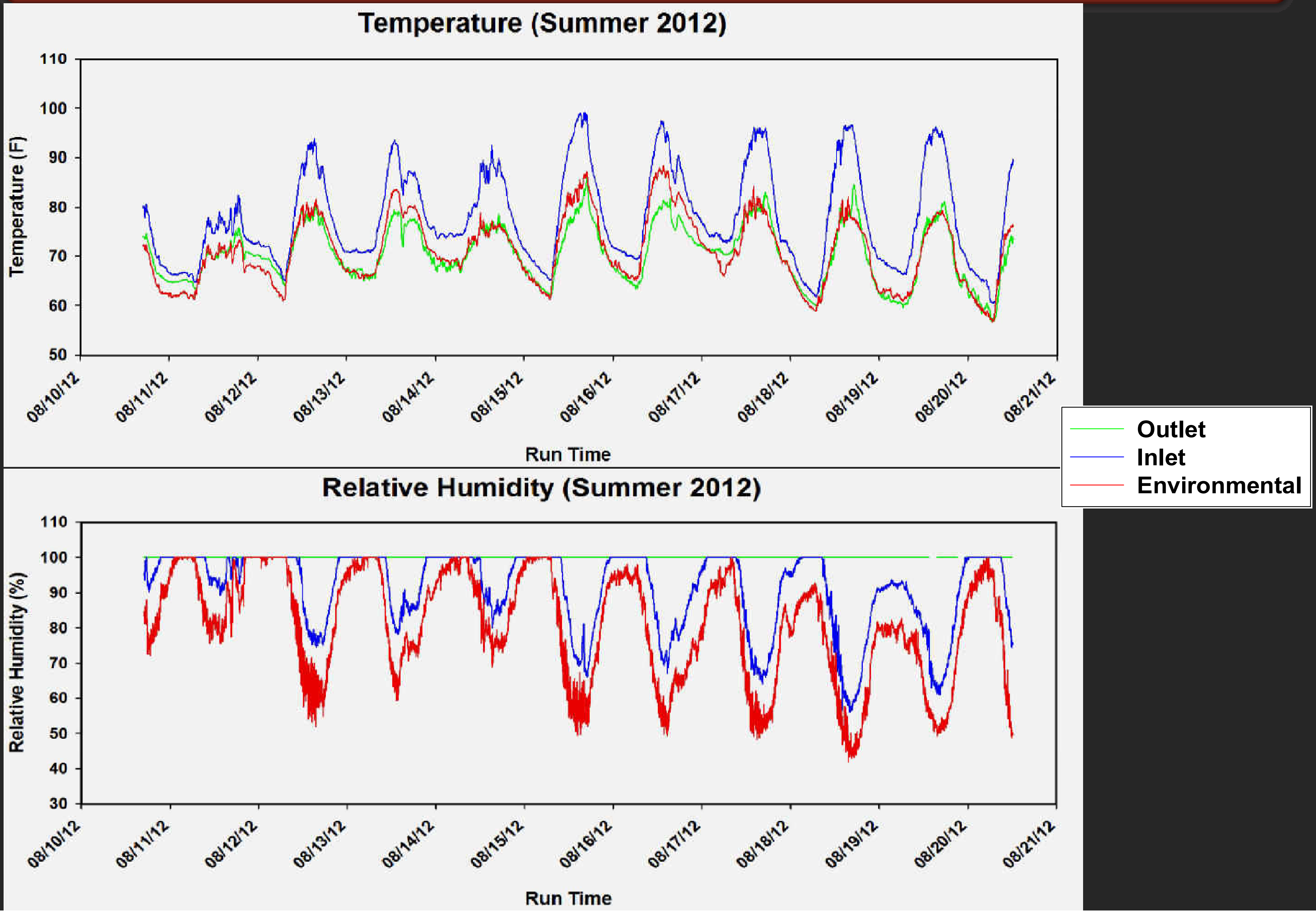
The scrubber is batch tested three times for each season of the year. Each batch test runs continuously for 10 days until saturation of ammonium sulfate in the tank. Measurement parameters are as follows:

Categories	Parameters
Scrubber performance parameter	Ammonia concentrations at inlet and outlet of the wet scrubber, air temperature & relative humidity
	Effluent liquid: Ammonium content, nutrient content
Material & energy consumption	Electricity, water, acid, air filter, ammonium sulfate production
Operating and control parameters	pH, flow, pressure, liquid conductivity, scrubber pressure drop

Field Environmental Conditions

	Environmental Air		Inlet Air		Outlet Air	
Season 2012	Temperature (ºF)	RH (%)	Temperature (ºF)	RH (%)	Temperature (ºF)	RH (%)
Winter (12/23-1/1) (1/6-1/13)	38.92 (±6.73)	90.10 (±7.15)	44.75 (±6.04)	99.40 (±2.73)	44.01 (±6.27)	99.99 (±0.14)
Spring (6/8-6/15)	69.63 (±3.46)	51.75 (±10.92)	81.69 (±12.28)	72.27 (±19.54)	74.85 (±11.39)	90.25 (±15.80)
Summer (7/13-7/27) (8/10-8/20)	75.31 (±9.25)	76.10 (±16.20)	82.44 (±10.12)	89.34 (±12.93)	74.96 (±7.29)	98.31 (±10.03)
Fall (9/6-9/16)	67.42 (±9.18)	83.45 (±17.46)	73.51 (±10.97)	87.01 (±13.60)	68.22 (±8.82)	100 (±0.00)

Scrubber Air Conditions

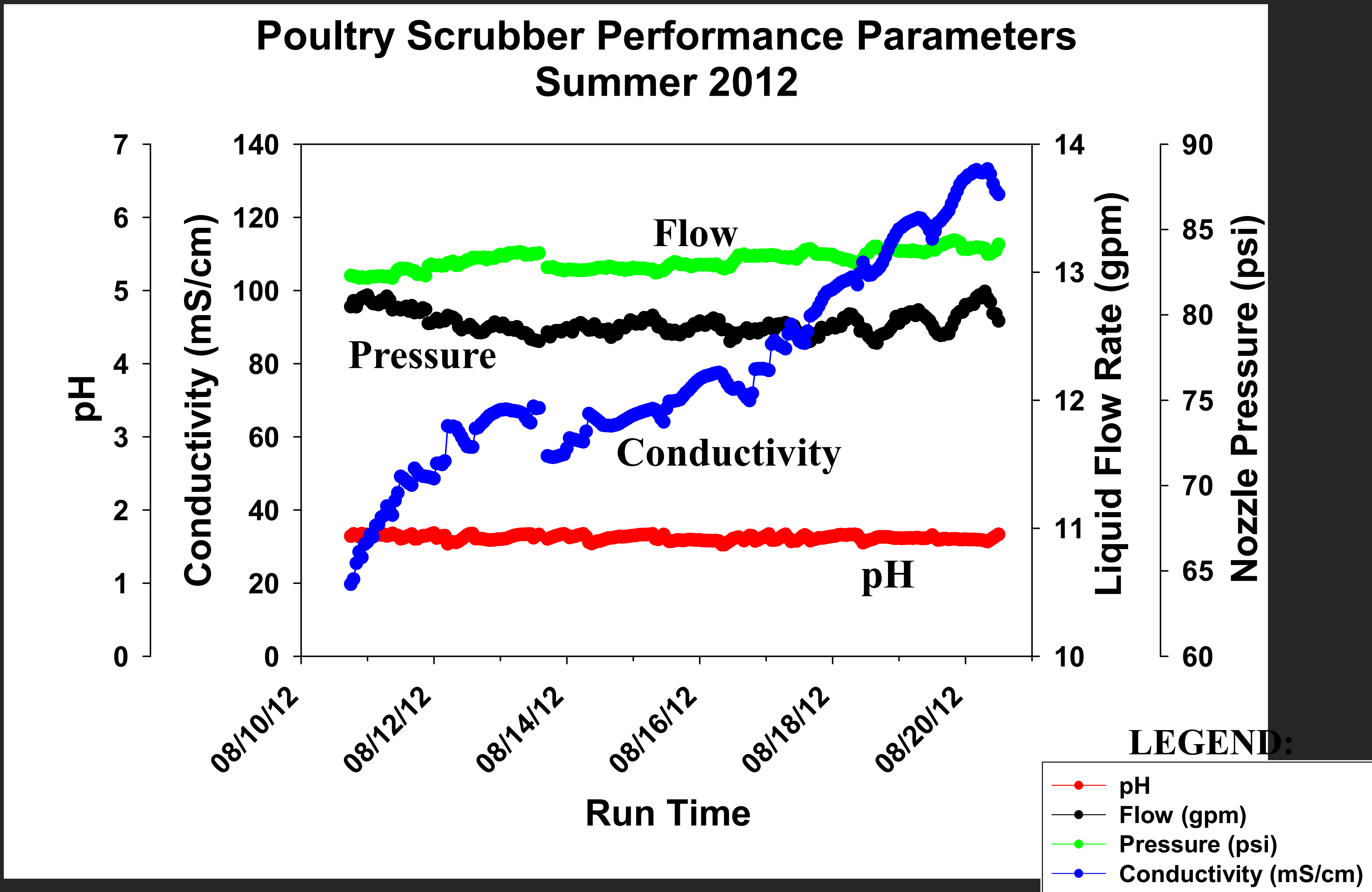


Operating Parameters

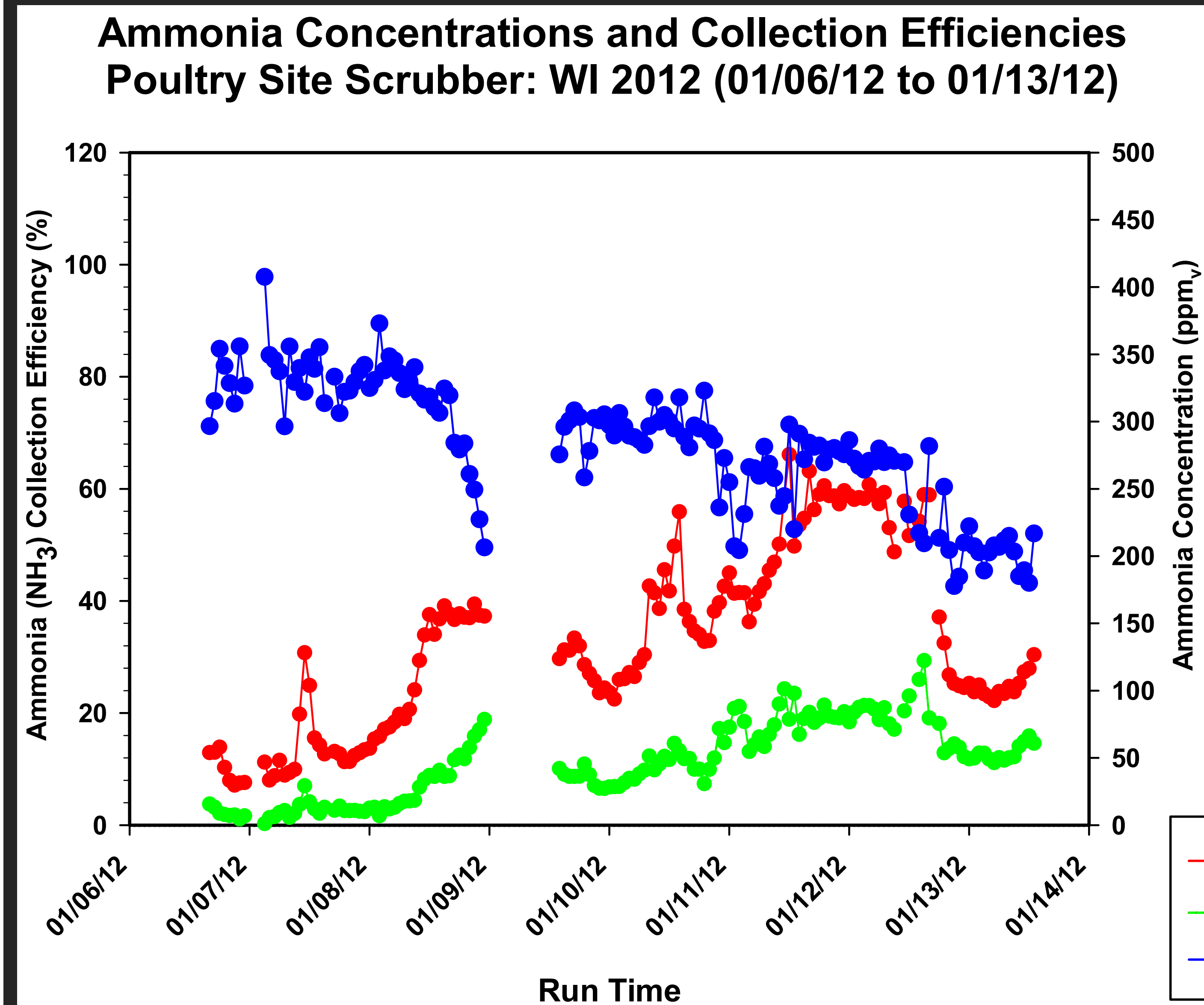
Parameter	Winter	Spring	Summer	Fall
pH	1.99 (±0.13)	1.59 (±0.07)	1.62 (±0.05)	1.58 (±0.09)
Nozzle pressure (psi)	90.34 (±1.77)	83.07 (±5.82)	82.35 (±7.25)	86.77 (±3.68)
Liquid flow rate (gpm)	11.60 (±0.19)	13.48 (±0.66)	12.47 (±1.10)	11.28 (±0.50)
Airflow rate without air filter (cfm)	12107.28 (±127.08)			
Airflow rate with air filter (cfm)	3789.325 (±217.92)			
Pressure drop (Pa)	9.5 (±1.13)			

The scrubber reduces fan flow by 11.71%. Due to dust problems, the use of an air filter is needed, which further reduces fan flow by 72.37%.

Indication of Stable Operation



Scrubber Performance (Winter 2012)



Inlet NH_3 (ppm$_v$)

Min: 29.60

Max: 275.29

Ave: 137.61 (66.45)

Outlet NH_3 (ppm$_v$)

Min: 1.03

Max: 122.19

Ave: 46.89 (27.99)

Efficiency (%)

Min: 42.64

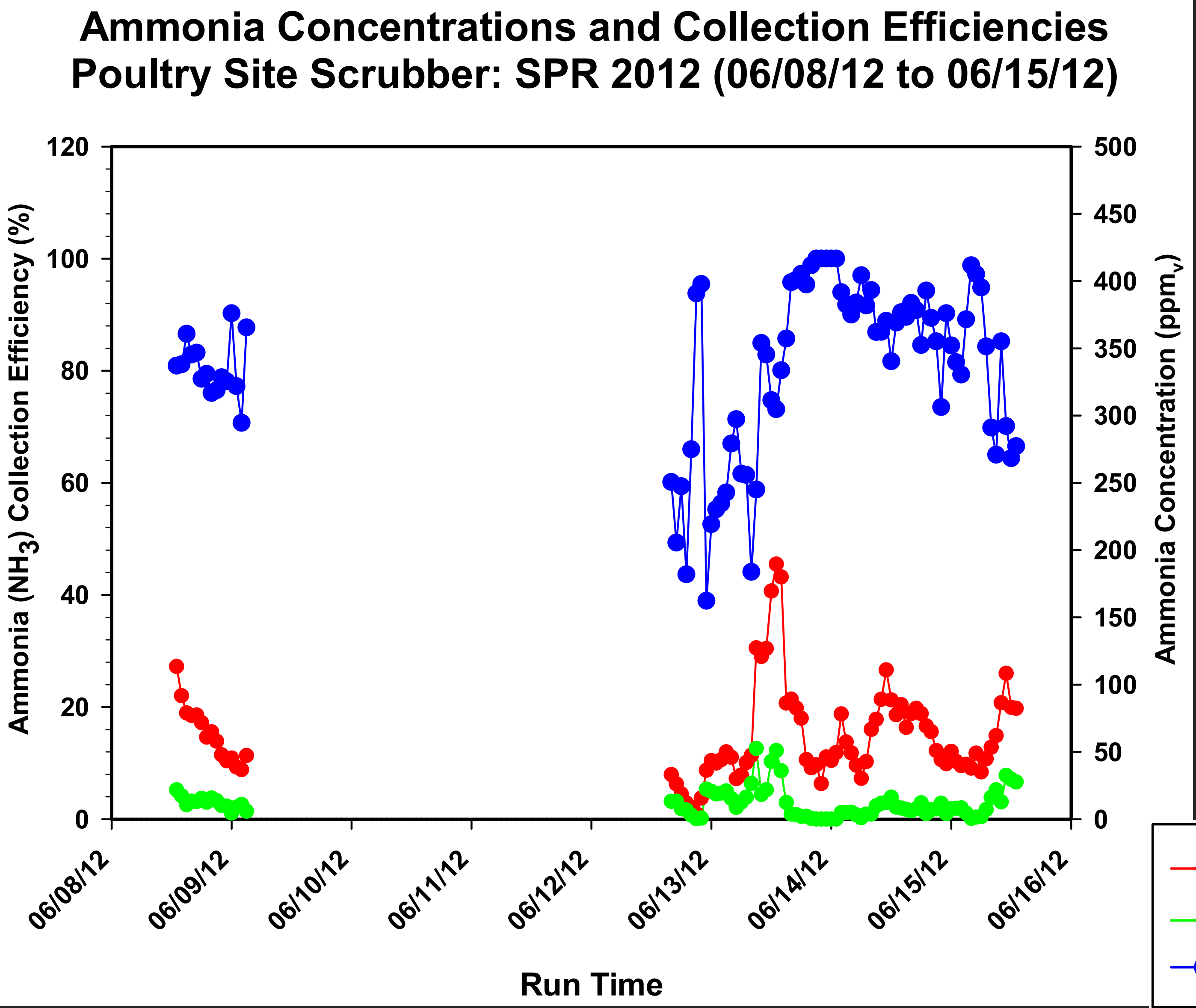
Max: 97.79

Ave: 67.90 (11.35)

LEGEND:

- Inlet NH_3 Concentration
- Outlet NH_3 Concentration
- Efficiency

Scrubber Performance (Spring 2012)



Inlet NH_3 (ppm_v)
Min: 3.81
Max: 189.52
Ave: 62.33 (34.68)

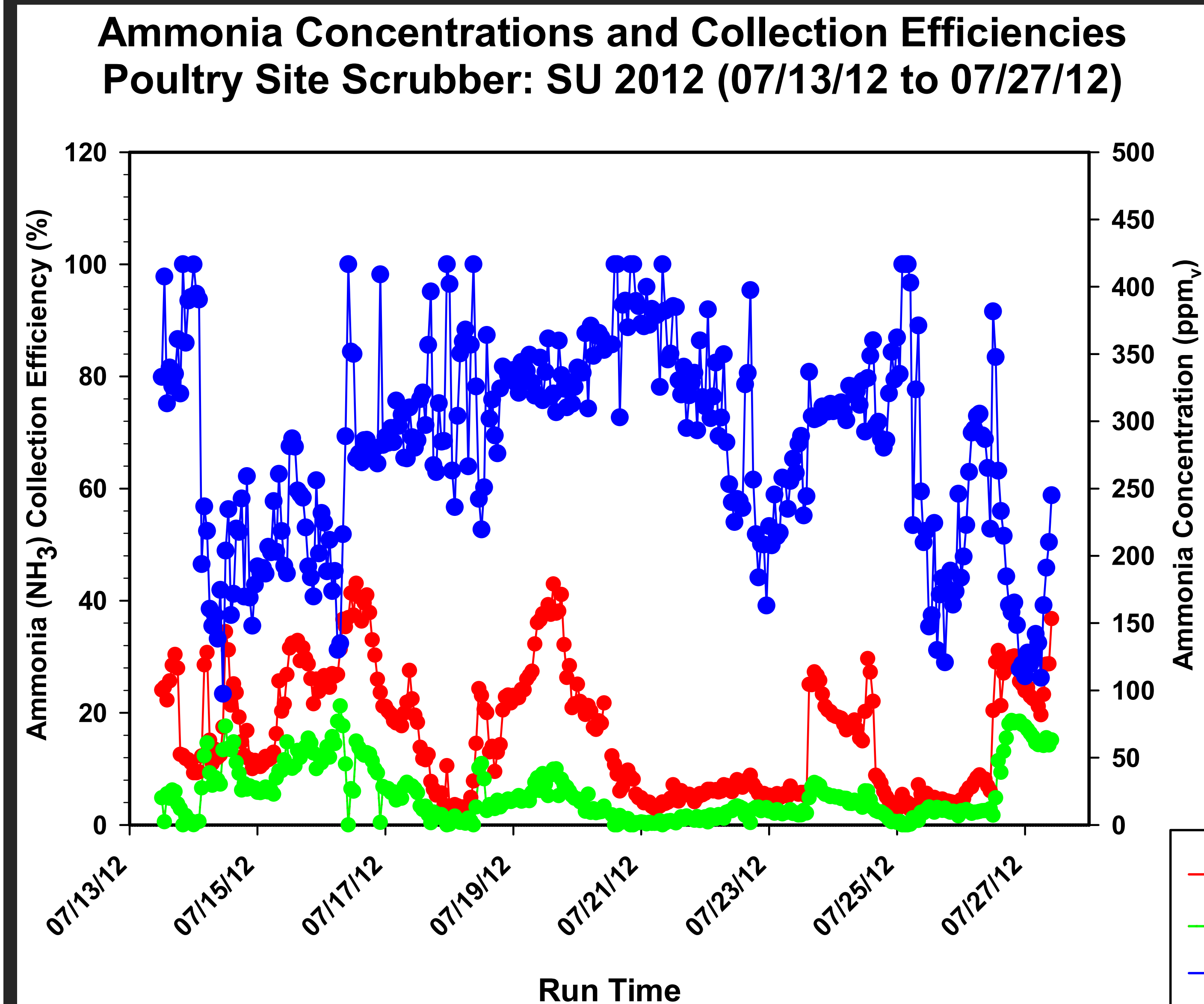
Outlet NH_3 (ppm_v)
Min: 0.00
Max: 52.43
Ave: 11.66 (10.70)

Efficiency (%)
Min: 38.95
Max: 100
Ave: 80.71 (14.88)

LEGEND:

- Inlet NH_3 Concentration
- Outlet NH_3 Concentration
- Efficiency

Scrubber Performance (Summer 2012)



Inlet NH_3 (ppm_v)

Min: 9.88

Max: 179.51

Ave: 67.32 (44.93)

Outlet NH_3 (ppm_v)

Min: 0.00

Max: 88.38

Ave: 22.33 (20.40)

Efficiency (%)

Min: 23.39

Max: 100

Ave: 67.99 (18.33)

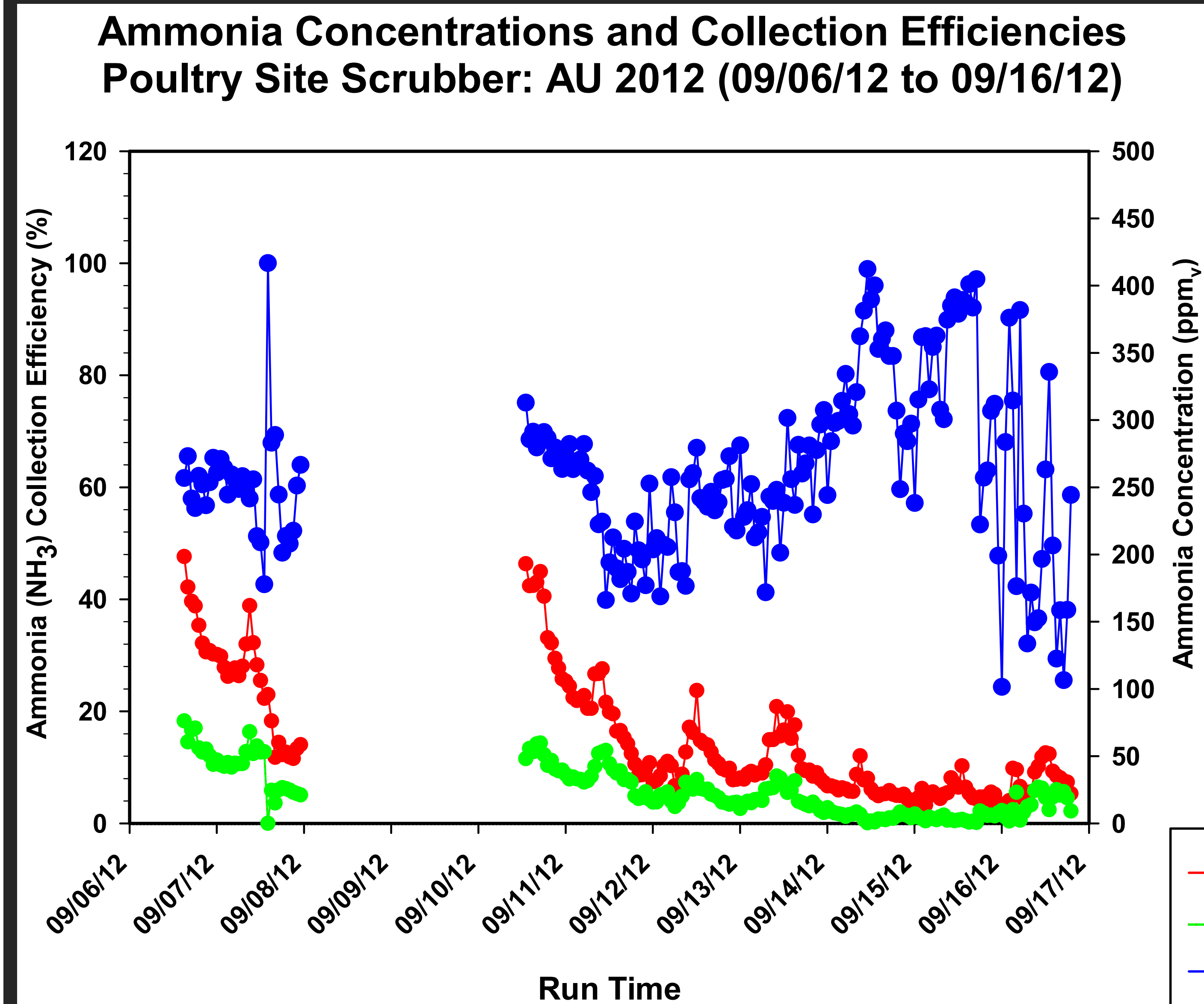
LEGEND:

Inlet NH_3 Concentration

Outlet NH_3 Concentration

Efficiency

Scrubber Performance (Autumn 2012)



Inlet NH_3 (ppm_v)
Min: 12.55
Max: 198.44
Ave: 61.19 (44.94)

Outlet NH_3 (ppm_v)
Min: 0.00
Max: 76.13
Ave: 23.27 (17.89)

Efficiency (%)
Min: 24.35
Max: 100
Ave: 63.09 (15.32)

LEGEND:

Summary of the Scrubber Efficiencies

	Winter	Spring	Summer	Fall
Inlet NH_3 Concentration (ppm_v)				
Min	29.6	3.81	9.88	12.55
Max	275.29	189.52	179.51	198.44
Average	137.61 (±66.45)	62.33 (±34.68)	67.32 (±44.93)	61.19 (±44.94)
Outlet NH_3 Concentration (ppm_v)				
Min	1.03	0	0	0
Max	122.19	52.43	88.38	76.13
Average	46.89 (±27.99)	11.66 (±10.70)	22.33 (±20.40)	23.27 (±17.89)
Efficiency (%)				
Min	42.64	38.95	23.39	24.35
Max	97.79	100	100	100
Average	67.90 (±11.35)	80.71 (±14.88)	67.99 (±18.33)	63.09 (±15.32)

Challenges

- Significant Challenges Encountered:
  - Freezing during winter operation
  - Pump failure due to acid solution and high pressure liquid flow
  - Nozzle clogging due to dust
- Solutions developed:
  - Installation of heating tapes prevented line freezing during winter
  - Use of a magnetic drive chemical pump provided reliable and smooth operation.
  - Installation of air filters and appropriately sized water filters
  - Solutions developed:
- Unresolved issue:
  - Air filter resulted in increased pressure drop and reduced airflow of 50-70%
  - An electrostatic precipitator (ESP) dust abatement device is under development at OSU

A Preliminary Economic Analysis of the Wet Scrubber Operation

OBJECTIVES:

1. Examine if it is economically feasible to run the wet scrubbers on poultry farms

Effluent Characterization

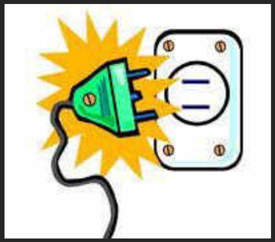
Parameters	Winter	Spring	Summer
pH	1.96	1.46	1.56
Conductivity (mS/cm)	117.8	24.86	51.7
NH_3-N (mg/L)	34416.67 (±2611.07)	23350 (±383.41)	38525 (±1341.92)
Phosphorus, P (mg/L)	1.45 (±0.17)	2.29 (±0.06)	3.51 (±0.01)
Potassium, K (mg/L)	9.93 (±0.10)	6.93 (±0.02)	14.21 (±0.50)
Ammonium-Sulfate (g/L)	324.61 (±24.63)	220.23 (±3.62)	363.36 (±12.66)
Ammonium-Sulfate (%)	32.46 (±2.46)	22.02 (±0.36)	36.35 (±1.27)

Commercial Fertilizer

Fertilizer	% N (w/w)	% $(NH_4)_2SO_4$ (w/v)	pH
Scrubber Effluent	2.83-4.63	22-36%	1.46-1.96
Wynyard Technologies, Inc.[1]	4.12-4.89	32-38%	5
Plantfood Co, Inc.[2]	7	54%	6.5-7

Sources:
[1]http://www.bayercropscience.ca/English/LabelMSDS/386/File.ashx
[2]http://www.plantfoodco.com/lib/pdfs/PFC-Liquid-Fertilizer/PFC-Liquid-Fertilizer-7-0-0.pdf

Material & Energy Consumption



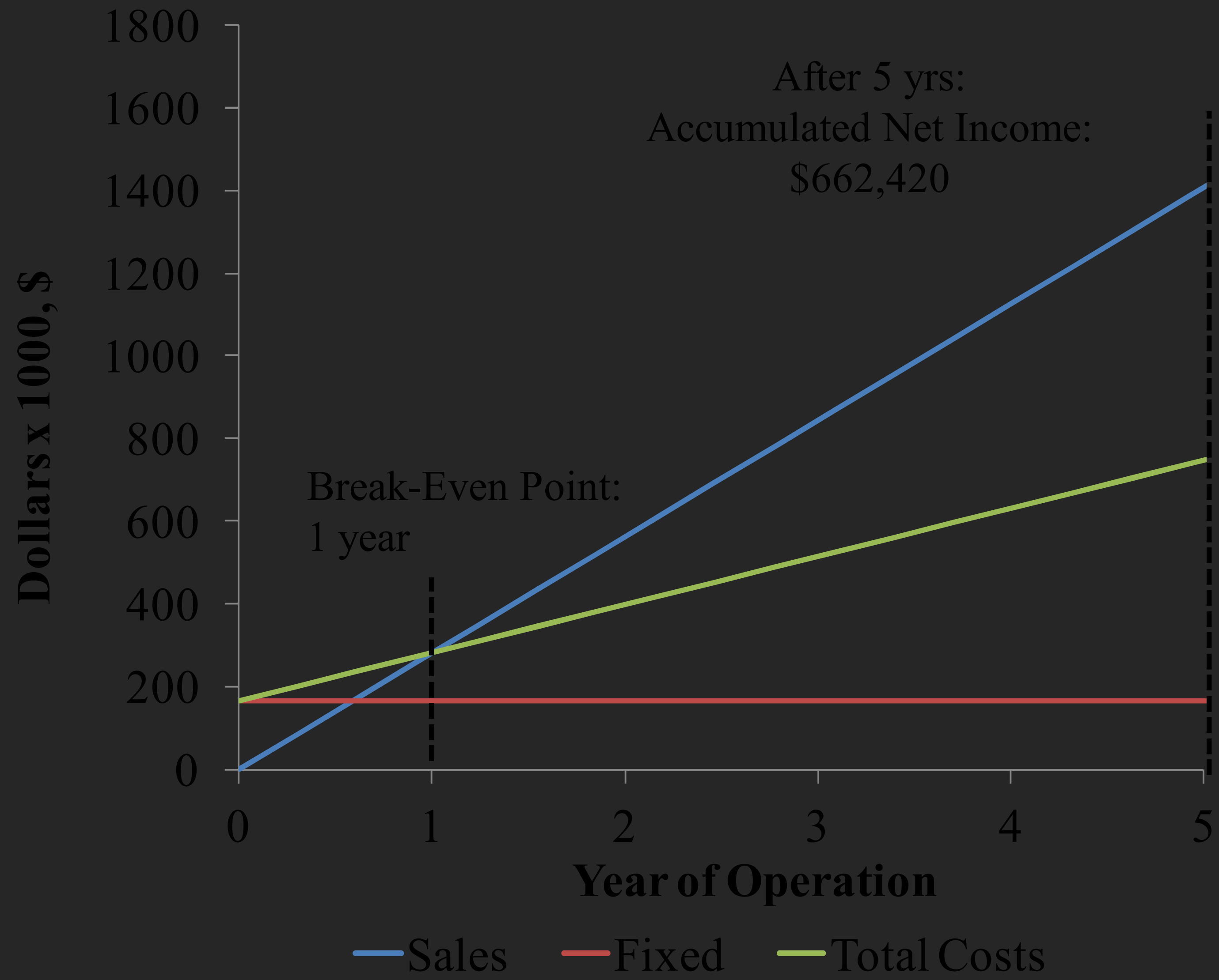
Consumption	Winter	Spring	Summer	Fall	Average
Water Loss Rate (gal/d)	23.58 (±13.62)	49.23 (±11.87)	37.74 (±21.97)	43.69 (±8.81)	37.50 (±18.27)
Acid Consumption Rate (gal/d)	1.55 (±0.70)	1.50 (±1.18)	1.97 (±1.53)	1.75 (±1.95)	1.77 (±1.38)
Energy Consumption (KWh)	754.75	636.58	1063.21	1021.67	882.36

Cost Analysis of Scrubber Operation

Item	Cost per Fan, $	Total Cost per Facility, $
Scrubber Structure	5000.00	60000.00
Instrumentation & Controls		
Programmable Logic Control	345.00	4140.00
pH controller & sensor, pressure sensor	953.00	11436.00
Conductivity probe & transmitter	400.00	4800.00
Flow Meter	498.00	5976.00
Level Sensor	80.00	960.00
Tanks and Pipings	2000.00	24000.00
Pumps	4000.00	48000.00
Installation Cost	500.00	6000.00
Capital Cost	**13776.00**	**165312.00**
Annual Acid Cost	5814.45	69773.40
Annual Water Cost	712.51	8550.12
Annual Electricity Cost	2583.54	31002.45
Operating Cost	**9110.50**	**109325.97**
Maintenance Cost	**584.00**	**7008.00**
TOTAL	**23470.50**	**281645.97**
Ammonium Sulfate Fertilizer (an estimation of 54 tons/yr/scrubber)	**(23626.96)**	**(283523.52)**

There is a net profit in producing ammonium sulfate fertilizer after one year of continuous and stable wet scrubber operation.

Break Even Economic Analysis



Conclusions

- A full-scale acid spray scrubber prototype has been developed in lab, scaled-up to a full wet scrubber for poultry operation, and evaluated in a commercial poultry farm for its ammonia absorption performance, operation and maintenance cost.
- NH_3 scrubbing efficiency varied from 75% to 87% in lab as ammonia concentrations varied from 100 to 400 ppm_v. However, in field operation, the efficiency varied from 63% to 80% seasonally.
- The average scrubber operating conditions were: 12.21 gal/min liquid flow, 85.63 psi liquid pressure, and 9.5 Pa pressure drop.

Conclusions (cont.)

- Water consumption rate was observed to be 37.50 gal/day; sulfuric consumption rate was 1.8 gal/day; electricity use was 882 KWh, and ammonia sulfate fertilizer production rate was 54 tons/year.
- A preliminary breakeven economic analysis was conducted. The breakeven point was about 1 year operation (648 tons). A stable wet scrubber operation would result in a net income from production of ammonium fertilizer.
- Large reduction on airflow (50-70%) was observed due to installation of air filter for dust control. Only 11% of flow reduction accounted to the spray scrubber. Further development is needed to resolve the dust issue for the wet scrubber operation.

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Thank You!

Lingying Zhao

Associate Professor and Extension Specialist
Dept. of Food, Agri. and
Biological Engineering
The Ohio State University
Phone: (614) 292-2366
Fax: (614) 292-9448
Email: zhao.119@osu.edu

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