Acid Spray Scrubbers for Recovering Ammonia Emissions from Animal Facilities

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Acid Spray Scrubbers for Recovering NH₃ Emissions from Animal Facilities

1. Introduction
   - What are Spray Scrubbers?
   - Spray versus Packed Scrubbers
   - Why Spray Scrubbers are Best for AFOs?

2. Development of a NH₃ Spray Scrubber
   - Lab Simulation Apparatus
   - Factors Affecting Spray Scrubber Performance
   - Optimization of Scrubbing performance
   - Lab Spray Scrubber Performance

3. Full-Scale Scrubbers
   - Actual Full-Scale Scrubbers
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4. Conclusions
NH₃ acid spray scrubber

- gas scrubbing device to absorb ammonia (NH₃) from the air,
- use small droplets to enhance air and liquid mass transfer contact,
- use dilute sulfuric acid (H₂SO₄) as scrubbing liquid:
  \[ 2\text{NH}_3 + \text{H}_2\text{SO}_4 = (\text{NH}_4)_2\text{SO}_4. \]
Spray scrubbers have:

- lower back pressure,
- lesser airflow restriction,
- needs bigger volume compared to packed scrubbers.

Why use Spray Scrubbers for AFOs?

Spray vs. Packed

http://www.triplemfiberglass.com
http://www.sugarudyog.com
Why Use Spray Scrubber for AFOs?

- Spray scrubbers - very promising for AFOs:
  - Lower Air Flow Reduction
  - Easy to Retrofit in existing Animal Facilities
- Proper design is needed for optimum NH$_3$ absorption in AFOs:
  - Increase efficiency
  - Lower footprint
  - Minimize pumping cost
  - Reduce/eliminate clogging
Optimization of NH₃ Spray Scrubbing
Factors Affecting Spray Absorption of NH$_3$

- **Design Variables**
  - nozzles type & characteristics
  - nozzle spacing
  - scrubber dimensions (length, diameter)
  - number of stages
  - flow configuration

- **Operation Variables**
  - nozzle operating pressure
  - scrubbing liquid flow rate
  - scrubbing liquid pH
  - scrubbing liquid saturation rate
  - droplet size distribution
  - gas loading rate (liquid to gas ratio)

- **Environment Variables**
  - inlet NH$_3$ concentration
  - inlet air temperature
  - PM presence (varies with location and time both diurnal and seasonal)
**Scrubbing Chamber and Air-Mixer Simulator Apparatus**

**Measurements:**
- Inlet and outlet ammonia concentration
- Liquid pH & Electrical Conductivity
- Liquid Flow Rate
- Fan Back Pressure

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**Diagram:**
- Mist Eliminator
- Spray Chamber
- Flow Controls
- Representative Single Scrubber Geometry Only
- Ammonia Mixing Chamber
- Scrubbing Chamber and Air-Mixer Simulator Apparatus

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**Ohio State University**
95% of predictions deviated by not more than 5% of the actual

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

where:
- \( \eta \) = ammonia collection efficiency (%)
- \( \theta \) = spray angle in degrees
- \( d_o \) = orifice diameter in mm
- \( H \) = spray height in cm
- \( \Delta P \) = nozzle pressure in KPa
- \( Q_L \) = liquid flowrate in liter/min

- \( C_0 = +5.731E+3 \)
- \( C_1 = +4.197E+1 \)
- \( C_2 = +3.267E+4 \)
- \( C_3 = -2.394E+0 \)
- \( C_4 = +3.995E+2 \)
- \( C_5 = +7.337E+2 \)
How to choose the right nozzle for NH₃ spray absorption?

- Nozzle pressure - highly affects absorption performance
- As nozzle pressure ↑
  - NH₃ collection efficiency, spray angle ↑
  - droplet size ↓

(positive effect on scrubber performance)

- Nozzle orifice diameter - independent of pressure
- As orifice diameter ↓
  - flow rate, droplet diameter ↑
  - surface area increases ↑

(positive effect on scrubbing performance and operation)

- **Balance** between orifice size and nozzle pressure is needed to get the right flow and surface area that yields the maximum NH₃ collection efficiency.
- Nozzle size must account for clogging during field actual operation.
Effect of Superficial Air Velocity

- $y = -7.0863x + 110.15$
  - $R^2 = 0.9393$

- $y = -12.041x + 112.28$
  - $R^2 = 0.9816$

- Collection Efficiency (%)
  - Superficial Air Velocity (m/s)

- Velocity ↑ Efficiency ↓
- Change depends on nozzle (i.e. droplet size and air drag)
Effect of Inlet NH$_3$ Concentration and Temperature

\[ \eta_{12} = -16.08 \ln(C_{\text{inlet}}) + 123.8 \]
\[ R^2 = 0.9489 \]
\[ \eta_{22} = -14.77 \ln(C_{\text{inlet}}) + 120.44 \]
\[ R^2 = 0.9654 \]
\[ \eta_{30} = -13.64 \ln(C_{\text{inlet}}) + 108.27 \]
\[ R^2 = 0.9781 \]

- \( \ln(\text{Concentration}) \) \( \uparrow \)
- Efficiency \( \downarrow \)

- Significant difference (alpha=0.05) between performance at 22$^\circ$C and 30$^\circ$C
Performance of a Optimized Single Stage Spray Scrubber

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>nozzle type</td>
<td>pin jet with plain orifice</td>
</tr>
<tr>
<td>shape</td>
<td>full cone</td>
</tr>
<tr>
<td>spray angle</td>
<td>90°</td>
</tr>
<tr>
<td>orifice size</td>
<td>0.06096 mm</td>
</tr>
<tr>
<td>span</td>
<td>61 cm (24 in)</td>
</tr>
<tr>
<td>flow rate</td>
<td>1.82 l/min</td>
</tr>
<tr>
<td>duct size</td>
<td>36 cm (14 in)</td>
</tr>
<tr>
<td>air velocity</td>
<td>4 m/s (800 ft/min)</td>
</tr>
<tr>
<td>L/G</td>
<td>7E-5</td>
</tr>
<tr>
<td>efficiency</td>
<td>90% at 30 ppm</td>
</tr>
</tbody>
</table>
Spray Scrubber Performance Curve

Setting a pressure of 90 psi:
- 75% - min collection efficiency at 400 ppm
- 87% - max collection efficiency at 100 ppm

Air Velocity = 4 m/s,
N=20, R^2=0.98
Features of OSU Lab-Scale Spray Scrubber

- High Ammonia Removal Efficiency (70%-90%) at inlet NH$_3$ levels of 100-400 ppm
- Low Fan Back Pressure/Air Flow Reduction
- End product is Ammonium Sulfate (N+S), a fertilizer,
- Can Work with High Air Velocity AFO Exhaust Fans
- Low Footprint
Full-Scale NH₃ Acid Spray Scrubbers
## Wet Scrubber Field Testing Sites

<table>
<thead>
<tr>
<th>Field Testing Site</th>
<th>NH₃ Concentration (ppmv)</th>
<th>Airflow (ft³/min)</th>
<th>Other Gases of interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry Manure Composting House</td>
<td>100-400</td>
<td>16,000</td>
<td>CO₂, N₂O</td>
</tr>
<tr>
<td>Deep-pit Swine Facility</td>
<td>4-25</td>
<td>450</td>
<td>CO₂, H₂S, CH₄</td>
</tr>
<tr>
<td>Covered Swine Manure Storage</td>
<td>30-50</td>
<td>1</td>
<td>CO₂, H₂S, CH₄</td>
</tr>
</tbody>
</table>
A Scrubber
for a Poultry Manure Compost Facility
Scrubbers for Swine Facilities

Pit Fan Scrubber

Manure Storage Scrubber
## Research Challenges Encountered

<table>
<thead>
<tr>
<th>Problems</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High dust loading clogs line filters and nozzles</td>
<td>Proper sizing of line filters and installation of air filters</td>
</tr>
<tr>
<td>Corrosive liquid and high pressure makes pumping difficult</td>
<td>Replaced pump</td>
</tr>
<tr>
<td>Liquid line freezing during winter</td>
<td>Installed heat tapes and insulation on lines</td>
</tr>
</tbody>
</table>

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Conclusions

- NH₃ Spray Scrubbing - optimized through Lab Simulations
  - Nozzles selection - balance between orifice size and operating pressure to optimize scrubbing efficiency, scrubber size, pumping cost, and clogging
  - Air velocity - lowered to obtain high collection efficiency and prevent droplet drift
  - Scrubber design - based on the expected variation in inlet NH₃ concentrations

- An optimized lab-scale scrubber was developed with 70% to 90% collection efficiency (inlet NH₃ levels ranging from 100 to 400 ppm), low footprint, low pressure drop (0.05 to 0.1 in w.c.) and can work at high air speeds (less than 4 m/s).

- Full-Scale scrubbers have been set up but still have challenges to overcome, such as nozzle clogging.
Acknowledgements

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