Evaluation of Gases in Oxygen-Limited Silos & the Role of Ventilation

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Ensiling Process

- Cut forage (e.g. alfalfa) is blown into silo, an “air exclusion” environment
- Aerobic respiration uses oxygen and plant sugars to produce CO$_2$, H$_2$O and heat
- Shift to anaerobic respiration occurs after ~ 48 hours
  - pH decreases as plant sugars are fermented to ethanol, acetic and lactic acids
  - Process continues for ~ 2 weeks
  - Release of nitrous oxides (NO) occurs early in anaerobic respiration process
- Allows storage of high-nutrient food and conveyor removal for feeding

Photo: www.apec.umn.edu/faculty/kolson/apec3811.html
Forced Air Ventilation

Power transfer unit
Occupational Hazards Associated With Tower Silos

- Falls
- Machinery accidents
- Asphyxiation
- Organic dust inhalation
- Toxic Gas inhalation
  - Silo Filler’s Disease
    - Associated with NO$_2$ inhalation
    - Symptoms include dyspnea, cough, weakness and headache
    - Can have delayed onset (2-3 week)
    - Incidence of 5 per 100,000 Ag workers, 20% mortality (Zwemer et al., 1992)
WA Fatality Assessment & Control Evaluation (FACE) Program Investigation

- Tragic accident occurred at this farm two years earlier
- Two teenage workers were apparently overcome by gases or asphyxiated; both were found deceased within the silo headspace
  - The exact circumstances are unknown as no one witnessed the accident
- Conditions during this investigation were similar to those occurring on the day of this accident
  - When accident occurred, silo had been filled to approximately the same level 3-4 days earlier
Study Goals

- Determine whether a person could be overcome at or near the hatch face
- Evaluate NO$_x$ exposure working around and in silos
- Assess efficacy of ventilation as used in practice
- Evaluate gases present in this type of silo
Study Location:
A Dairy Farm in Eastern WA
2 Hay Silos Evaluated

- Common characteristics:
- Oxygen-limiting design
- Harvestore® Brand
- Approximately 25 years old
- Approximately 90 feet tall
- Filled with recently cut alfalfa hay
Sampling Protocol

- Measurements recorded:
  - Oxygen ($O_2$)
  - Nitrogen Dioxide ($NO_2$)
  - Carbon Dioxide ($CO_2$)
  - Ventilation wind speed (to estimate ventilation rate)
  - Ambient weather (temperature, relative humidity, wind speed)
Methods: Instrumentation

Gastech GT 208: CO$_2$ and O$_2$

QRAE Plus Multi-gas Monitor: NO$_2$, O$_2$, CO, LEL

Key Features of Gas Monitors:
- Direct Read Instrumentation
- Data Logging (Up to 10 hrs)
- Relatively Compact

TSI VelociCheck Anemometer
Sampling Protocol

• Personal monitor and headspace readings collected simultaneously

• Pre-ventilation readings recorded:
  • At hatch,
  • 1 foot below hatch,
  • 4-5 foot increments below hatch,
  • low point of silage (data logging set to 10 seconds)

• Ventilation readings
  • Low point of silage measured for 20-25 minutes

• Post-ventilation readings
  • 5-10 minutes
Sampling Challenges

- **Sampling at height (~90 ft)**
  - Fall Protection: full body harness with double lanyards secured to anch. points
  - Raising and lowering equipment
  - Securing instrumentation

- **Sampling within a confined space**
  - Lowered tubing into silo headspace by securing it to an aluminum pole
  - Never broke plane of silo hatch with hands

- **Sampling within a high humidity environment**

- **Possible effects of interfering gases**
Results: Pre-ventilation Oxygen (Silo 1)
Results: Pre-ventilation CO₂ (Silo 1)

WISHA STEL = 3% (30,000 ppm)  
TWA = 0.5% (5,000 ppm)
Results: Pre-ventilation NO$_2$ (Silo 2)

WISHA STEL = 1 ppm
NIOSH IDLH = 20 ppm
Results: Effects of Ventilation $O_2$ (Silo 1)
Results: Effects of Ventilation $O_2$ (Silo 2)

![Graph showing the effects of ventilation on oxygen levels over time. The graph indicates an increase in oxygen levels from 0 to 25% over the course of 35 minutes. The graph also notes that ventilation stopped at 25 minutes.](image-url)
Results: Effects of Ventilation NO$_2$ (Silo 2)

WISHA STEL = 1 ppm
Results: A Closer Look at NO$_2$ (Silo 2)

WISHA STEL = 1 ppm
Summary of Findings: Pre-Ventilation

• Gas concentrations on the silo roofing were not found to be hazardous

• Hazardous conditions found within 1 ft of the hatch face and in all areas sampled in head space
  – Oxygen <10%
  – Nitrogen dioxide >50ppm

• High humidity evident in condensation observed in tubing

• Unexpected readings from CO and LEL sensors
Summary: Effects of Ventilation

- Oxygen concentration increased to ambient levels in ~ 8-15 minutes
  - Required less time in Silo 2
- Nitrogen dioxide levels (Silo 2) required ~15 minutes to reach <1 ppm
- Nitrogen dioxide levels rose above 1 ppm within 3 minutes after ventilation was stopped
- Marked decrease in air flow from duct opening to hatch face (50 - 60%)
Conclusions

• A person could be overcome by gases if they break the plane of the hatch face
• Gas exposure outside the hatch face did not exceed recommended levels
• Continuous ventilation is recommended if entering a silo
• No one should go in a silo unless they must and they follow proper confined space procedures