Monitoring of the Atmosphere on the International Space Station with the Air Quality Monitor

William T. Wallace and Thomas F. Limero
KBRwyle

Leslie J. Loh
JES Tech

Paul D. Mudgett and Daniel B. Gazda
NASA Johnson Space Center
Background

• **Need:** Assessment of the trace VOCs in spacecraft atmosphere to protect crew and system health
  • Archival samples used exclusively until ISS (1-2 week missions)
  • Longer duration missions require more real-time information
  • Volatile Organic Analyzer (VOA) delivered to ISS in Sept. 2001.
    • GC/IMS
    • Operated for 8 years
    • Mass/volume not acceptable for future missions
    • Reduce crew time and reliance on spacecraft resources
Air Quality Monitor (AQM)

- AQM combines gas chromatography with differential mobility spectrometry
- GC carrier gas and detector make-up gases are recirculated air
- 3 kg, 25.4 cm x 15.2 cm x 13.2 cm
- 2 units used simultaneously on ISS; different GC columns (DB5 / VF624)
- First 2 units delivered March 2013; one operational through 1/15 and one through 1/16
- Second 2 units delivered 12/15; one began operation in 2/16 and one in 3/16
Background

• The AQM monitors trace concentrations of 23 targeted volatile organic compounds in the ISS atmosphere (Non-target detection capability)
  • Years of archival data from spacecraft was used to select the target compounds
  • Compounds on the target list had one or more of the following characteristics
    • Compounds frequently detected in spacecraft atmosphere (ethanol, acetone, xylenes, and 2-butanolone)
    • Compounds with significant toxicity at low concentrations, even though they are detected infrequently on spacecraft (benzene)
    • Compounds that can affect an ECLS system (siloxanes and 2-propanol)
    • The target list is fluid, dictated by experience and changes in materials of construction or ECLS systems
# Required Target List

<table>
<thead>
<tr>
<th>Compound</th>
<th>Concentration Range (mg/m³)</th>
<th>Potential Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>Ethanol</td>
<td>0.5</td>
<td>7</td>
</tr>
<tr>
<td>Acetone</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>2-Propanol</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>1-Butanol</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>Ethyl Acetate</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Xylenes (m,p)</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>Xylene (o)</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>2-Butanone</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Hexane</td>
<td>0.5</td>
<td>8</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Hexamethylcyclotrisiloxane</td>
<td>0.2</td>
<td>6</td>
</tr>
<tr>
<td>Octamethylcyclotetrasiloxane</td>
<td>0.2</td>
<td>6</td>
</tr>
<tr>
<td>Decamethylcyclopentasiloxane</td>
<td>0.2</td>
<td>6</td>
</tr>
<tr>
<td>Trimethylsilanol</td>
<td>0.2</td>
<td>6</td>
</tr>
<tr>
<td>Hexanal</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>Propenal</td>
<td>0.03</td>
<td>1</td>
</tr>
<tr>
<td>1,2- Dichloroethane</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Trending Only</td>
<td>Trending Only</td>
</tr>
</tbody>
</table>
Background

• The data from the AQM is used by the NASA Toxicologist to assess the air quality aboard the ISS
• Some archival sampling continues
• The AQM can also provide data for ECLS troubleshooting
• In case of contingency, the AQM can help to monitor clean up efforts
What is Differential Mobility Spectrometry?

Draper Labs, microAnalyzer V2.0 Series Product Family Manual
Technical Overview

Positive Mode

- Reactant Ion Peak (RIP) \( \text{H}_3\text{O}(\text{H}_2\text{O})_N^+ \)
- Analytes

Negative Mode

- Reactant Ion Peak (RIP) \( \text{O}_2(\text{H}_2\text{O})_N^- \)
- Analytes
• Use scan runs to determine detection parameters (GC retention time, RF voltage, polarity, and compensation voltage) for each compound
• Parameters are used to establish GC and $V_c$ windows at specific RF and polarity
• GC method table developed, which directs the software where to find the peaks
AQM Details

Improvements in current AQM over previous on-board air analyzers

- Replaceable sieve cartridges for scrubbing carrier gas
  - Extends life of instrument
- Preconcentrator purge
  - Removes excess water from preconcentrator; simplifies spectra
- Wireless communication
  - Reduces need for crew time; MCC can interface remotely
- Battery operation
ISS Data and Module Survey

- AQMs generally located in U.S. Lab
- After validation, survey begun to assess potential differences in contaminants for LAB, Columbus, and JEM
- One unit stayed in LAB while other moved to other modules
- AQM 1 (unit 1003) survey began on 4/10/14 in Columbus
- AQM 1 moved from Columbus to JPM on 6/6/14
- Survey completed on 7/23/14 when unit returned to LAB
- AQM 2 (unit 1004) survey began on 9/19/14 in Columbus
- AQM 2 moved from Columbus to JPM on 11/20/14
- Survey completed on 1/19/15
ISS Data - Isopropanol

- Isopropanol concentrations often spike with USOS vehicle dockings
  - AQMs started ≤ 1 hour prior to scheduled hatch opening
  - Open squares – AQM 1 located in Columbus module
  - Open triangles – AQM 1 located in Japanese Pressurized Module

National Aeronautics and Space Administration
ISS Data - Acetone

Acetone Concentration (mg/m$^3$)

AQM 1003

AQM 1005
ISS Data - Ethanol

- Science requirements for ethanol: 0.5 mg/m$^3$ – 7 mg/m$^3$ (SMAC – 2000 mg/m$^3$)
- Calibration range sufficient based on historical concentrations
- Ethanol increases in 2014 and 2015; above calibration range; required manual analysis for estimated concentrations
- For second delivery, secondary ethanol calibration prepared (~ 6 mg/m$^3$ – 13.5 mg/m$^3$); smaller sample size used to prevent saturation
ISS Data – Ethyl Acetate

- Ethyl acetate concentrations often spike with Russian vehicle dockings
  - AQMs started ≤ 1 hour prior to scheduled hatch opening
  - Open squares – AQM 1 located in Columbus module
  - Open triangles – AQM 1 located in Japanese Pressurized Module
ISS Data – Trimethylsilanol

Trimethylsilanol (mg/m$^3$)

AQM 1004

HTV-4

HTV-5

AQM 1018

Trimethylsilanol (mg/m$^3$)
Troubleshooting, Contingencies, and Continuing Issues
ECLSS Effects

- mid-May 2015: activated carbon filters placed in Node 1 to reduce atmospheric siloxanes leading to DMSD in U.S. condensate
ECLSS Effects

- AQM not calibrated for DMSD
  - Low vapor pressure makes preparation of air standards difficult/impossible
- Peak position discovered during testing of water inlet
- Intensity of DMSD peak in ISS air does not correspond with decreased siloxane intensity

AQM 1004

AQM 1018
Use of AQM for Troubleshooting

• Installation of Node 1 charcoal filters - decrease in LAB siloxanes but no decrease in condensate DMSD
• Suspicion that transient higher siloxane levels present in Node 3 near CHX
• AQM 1005 moved to Node 3 to monitor siloxane levels during condensate collection following routine 30-day dry-out of CHX
Use of AQM for Contingencies

- January 14, 2015 AM: Ammonia release alarm on ISS
- Crew donned masks, evacuated to RS, and closed hatches
- Operated remotely, AQM one of several real-time instruments used to confirm no ammonia present (official confirmation via Dräger tubes)
• When fresh sieve packs present, negative mode RIP is hydrated superoxide, $O_2(H_2O)_N^-$
• As CO$_2$ enters the system, RIP becomes $O_2\cdot CO_2(H_2O)_N^-$
• Change in composition affects ionization chemistry and sensitivity towards compounds detected in negative mode; requires manual analysis of negative mode analytes
• Use of alternative sorbent materials in sieve packs could help to reduce CO$_2$ effects
- Change in negative mode RIP is reproducible after sieve pack change out
- Decrease in positive mode intensity shows that system is becoming dirtier
  - Increase in DMS temperature could potentially improve cleanliness
Summary

• AQMs have been successfully operating on ISS for 4.5 years
• Usage has been shown in nominal, contingency, and investigative situations
• Some lessons learned during initial deployment (expanded ethanol calibration, sieve cartridge changes, etc.)
• Introduction of CO$_2$ into system continues to be problematic
Acknowledgements

• Funding: Human Health and Performance Contract # NNJ15HK11B
• JSC Toxicology and Environmental Chemistry Labs
  • Steve Beck
  • Vanessa de Vera
  • Patti Cheng
  • Samantha Garza
• KBRwyle Engineering
  • Thad Outhier
  • Jared Jones