Measuring Oxygen Concentration in a Fuel Tank Ullage

William Cavage
AJP-6320 Fire Safety Team
Wm. J. Hughes Technical Center
Federal Aviation Administration
Outline

• Background

• Technologies/Methods Examined

• Test Equipment and Procedures

• Results
  − Previous Results
  − Calibration Gas Exposure
  − Flight Simulation

• Summary
Background

- FAA has been seeking to improve fuel tank safety in the wake of TWA Flight 800 in July of 1996
  - Rule published requiring extensive flammability reduction on both future built and existing aircraft on present types
- The measurement of ullage oxygen concentration is important to the fuel tank inerting community when researching methods, validating models, and certifying systems
  - FAA method for measuring ullage oxygen concentration at reduced ullage pressures has been successful but can be cumbersome
  - Emerging products have the potential to simplify and improve upon R&D / Certification work for fuel tank inerting
Technologies/Methods Examined

• Improved FAA gas sampling method
  – Made design changes to OBOAS regulated sample train and packaging based on lessons learned during FAA flight testing
  – New system is lighter, smaller, quieter, but not proven to have equivalent level of safety

• Light Absorption with unregulated gas sample train (Oxigraf)
  – Unregulated sample train uses a sensor that measures infrared light absorption using a tunable laser diode (TLD technology)
  – Proprietary software used to interpret spectral data

• Optical fluorescence using in situ probe (ASF)
  – Small fiber optic probe uses spectrometer to interpret coherent light signal which is highly dependent on temperature/pressure
  – Used in situ (in place) which has many advantages (low power, small size/weight, rapid response) but also has limitations
Light Absorption Method using TLD

Oxigraf O2N2 Flight Test Oxygen Analyzer
Optical Fluorescence (ASF) Used In Situ
Testing Performed

• First – had all methods used in a PVC tube which was flooded with various calibration gases at various temperatures and altitudes
  – Also examined response time of method by seeing how long it took for instrument to go from 5% to 15% (within 0.1% of stability)

• Second - installed the available methods in test tank and exposed them to simulated CWT ullage environment and flight cycle
  – Used existing 17 cubic foot aluminum fuel tank in altitude chamber
  – Put fuel in tank as well as inerted the ullage with nitrogen
  – Performed simulated mission with ground heat up, ascent, cruise, and descent with simulated inerting system performance
  – Temperature between 110 & -10 ºF, altitudes 0-36K feet
Block Diagram of Fuel Tank Ullage Simulation

Environmental Chamber

Fuel Tank Test Article

- Temperature (T)
- Vent
- Drain

Fuel

- Radiant Heater

Sample Return Gas Sample

Key
- Gas Sample Tubing
- Instrumentation Wire
- Fiber Optic Cable

Compressed Air

- Spectrometer Computer
- Secondary Computer

DAS

- Optical Fluorescence O₂ Analyzer
- Light Absorption O₂ Analyzer
- FAA Method O₂ Analyzer
- Pressure Transducer

Computer

- Fiber Optic Sensor
- Fiber Optic Sensor

Light Absorption O₂ Analyzer

Optical Fluorescence O₂ Analyzer

FAA Method O₂ Analyzer

Pressure Transducer

Sample Return Gas Sample

Compressed Air

Environmental Chamber
Results – Previously Acquired Data

- Previously performed tests illustrated how the optical fluorescence method in situ could follow trends of FAA method with large magnitude errors
  - Had trouble giving valid numbers at low partial pressures
  - Also the temperature cycling of the mission seemed to effect the data adversely
Results – Calibration Gas Exposure

• Exposed all methods to the stated calibration gases at several altitudes and temperatures typical of a commercial transport airplane fuel tank ullage
  – Preliminary data with optical fluorescence system did not do well so manufacturer went off to work out the problems
  – the FAA method and light absorption method duplicated calibration gases well (+/- 0.2% O₂ from 5-15% O₂)

• The light absorption method was the fastest responding method with the FAA method and the optical fluorescence method in a distant second (more than twice as slow)
  – The optical fluorescence has the potential to be the fastest when developmental software is made more streamlined
  – FAA method will never be significantly faster
Results – Airplane Fuel Tank Simulation

- Measured fuel tank test article ullage \([O_2]\) with both the FAA method and the light absorption method
- Results of Oxigraf and FAA method very close
- The inerting of test tank erratic due to problems, but this illustrates the small advantage of rapid response
Summary

• Both the FAA method and the light absorption method duplicate calibration gases well at a variety of conditions and both agree on oxygen concentration measurements made during a simulation of an inert commercial transport airplane fuel tank flight cycle
  – Light absorption system has faster response time but appears to be of little advantage
  – Light absorption system already performed some flight testing and is slated for more with several OEMs / Operators

• Optical fluorescence method still working out problems but slated for more chamber examinations in May