Space Experiment Concepts: Cup-Burner Flame Extinguishment

Fumiaki Takahashi
National Center for Microgravity Research
Cleveland, Ohio
Fumiaki.Takahashi@grc.nasa.gov

Supported by NASA OBPR
Acknowledgment

In-House

GBEX-Gaseous Burner Extinguishment Experiment

GRC
Roger Forsgren (PM)
Scott Numbers
Dennis Stocker

NCMR
Peter Sunderland

ZIN
Gregory Funk
Dale Robinson
David Althausen
Mike Jamison
Rita Cognition

Akima
David Bennett

NRA-99

Physical and Chemical Aspects of Fire Suppression in Extraterrestrial Environments

NIST
Gregory Linteris (co-I)

ISSI
Viswanath Katta (co-I)
Background

- **NASA’s Fire Safety Approach**
  - *Fire prevention plays a key role*
    - fire safety program for manned space flight has been based on controlling the materials flammability and eliminating ignition sources
  - *Space exploration expands platform*
    - longer duration missions to the moon, Mars, or aboard the International Space Station (ISS) increase the likelihood of fire events
    - various gravity levels affect fire behavior
      - ISS: $\mu g$, lunar: $1/6g$, Martian: $1/3g$
Objectives

◆ Space Fire Suppression Processes & Technology
  ● Be prepared for space fire suppression!
    ⇒ need better understanding of physical and chemical suppression processes in reduced gravity environments simulating various missions
  ● Develop space fire suppression technology
    ⇒ the results must provide useful data leading to technology development of fire suppression systems in various platforms
Organizing Questions  

**Fire Suppression**

- **Fire-Extinguishing Agent Effectiveness in Space Environments**
  1. What is the relative effectiveness of candidate suppressants to extinguish a representative fire in reduced gravity, including high-O$_2$ mole fraction, low-pressure environments?
  2. What are the relative advantages and disadvantages of physically acting and chemically acting agents in space fire suppression?
  3. What are the O$_2$ mole fraction and absolute pressure below which a fire cannot exist?
  4. What effect does gas-phase radiation play in the overall fire and post-fire environments?
  5. Are the candidate suppressants effective to extinguish fires on practical solid fuels?

- **Space Fire Suppression Technology Development**
  7. How can idealized space experiment results be applied to a practical fire scenario?
  8. What is the optimal agent deployment strategy for space fire suppression?
Agent Effectiveness

◆ Cup-Burner Method:  
  - dynamic co-flow diffusion flame
  - **Standard Test**

  ⇒ the most widely used test specified in national and international standards (NFPA 2001, AS 4214, ISO 14502)

  ⇒ measure the minimum extinguishing concentration (MEC) which renders the “inhibited” air incapable of supporting diffusion flame combustion

  ⇒ the minimum design concentration of a gaseous **agent** for a fire protection system is determined by adding at least 30% to the cup-burner MEC value by manufacturer

  ⇒ the third party approval (e.g., UL, Factory Mutual) of a fire extinguishing **system** requires large-scale pan fire tests in relation to the cup-burner MEC values
**MEC** Minimum Extinguishing Concentration

![Graph showing MEC values for different hydrocarbon types and fire suppression agents.]

- **Gaseous hydrocarbon**
  - Propane
  - Heptane
  - JP-5
  - JP-8
  - 5606
  - 83282

- **Liquid hydrocarbons**
- **Jet fuels**
- **Lubricants**

**Sources:**
- Hamins et al. (1994)

**Figure Legend:**
- Halon 1301
- FC-31-10
- FC-218
- FC-318
- FM-200
- HFC-227
- HFC-236
- HFC-124
- HFC-125
- HFC-134a
- FC-116
- HFC-22
- HFC-32/125
- N2
Laboratory Flame vs. Real Fire

◆ Cup- Burner Flame Behavior:

- Relatively system independent:
  ⇒ the MEC is nearly independent of the fuel cup size, chimney size, fuel velocity, and oxidizer velocity
  ⇒ the cup-burner MEC values are nearly equal to those for low strain rate counterflow diffusion flames

- Scale model of a real fire:
  ⇒ flame segments subjected to various strain rates, including stabilized/spreading edge diffusion flames
  ⇒ flame flickering and separation in 1g, affecting the air and agent entrainment into fire zone
  ⇒ extinguishment occurs via dynamic blow-off process rather than global extinction typical of counterflow diffusion flames

http://www.me.uwaterloo.ca/~ew eckman/fire/firehome.htm
GBEX  Gaseous Burner Extinguishment EXperiment
GBEX in CIR

- OXIDIZER + AGENT INLET
- ULTRASONIC ATOMIZER
- COMBUSTION INTEGRATED RACK
- CUP BURNER
- CHIMNEY
- FUEL INLET
- IGNITER
GBEX  Gaseous Burner Extinguishment EXperiment

Dimensions: 5/8 Scale

Burner: 17 mm ID
Chimney: 51 mm ID × 350 mm length

Test Matrix:

Fuel: CH₄
Oxidizer: O₂-N₂ mixture
  Oxygen mole fraction: 0.21, 0.3
  Velocity: 1 – 12 cm/s
Agent: CO₂, N₂, He, Water Mist, Inert Gas/Water Mist
Gravity: µg
Pressure: 1 atm, 0.7 atm
Microgravity Science Glovebox
MSG Microgravity Science Glovebox

- **Dimensions:**
  - *Burner:* 12 mm ID
  - *Chimney:* 79 mm square × 187 mm length

- **Test Matrix:**
  - *Fuel:* CH$_4$
  - *Oxidizer:* Air
  - *Velocity:* 1 – 50 cm/s
  - *Agent:* N$_2$
  - *Gravity:* µg
  - *Pressure:* 1 atm
FSEE Fire Suppression in Extraterrestrial Environments

Drop/KC-135 Rig

- Computer & I/O Box
- Chimney
- Cup Burner
- Chamber
- Batteries
- PIV-MZI Optics
- Flow Modules
Dimensions: Full Scale

Burner: 28 mm ID
Chimney: 85 mm ID × 533 mm length

Test Matrix:

Fuel:
Gas: CH₄, C₂H₆, C₃H₈
Liquid: n-C₇H₁₆, CH₃OH
Solid: trioxane (3[CH₂O]), PMMA

Oxidizer: O₂-N₂ mixture
Oxygen mole fraction: 0.21 – 0.3
Velocity: 3 – 20 cm/s

Agent: CO₂, N₂, He, Ar
CF₃H(HFC-23), C₃F₇H (HFC-227ea), CF₃Br (Halon 1301)
Water Mist, Inert/Water Mist, Microencapsulated Water

Gravity: μg, lunar (1/6 g), Martian (1/3 g), 1g
Pressure: 0.7 – 1 atm
Dynamic Flame Extinguishment

**Experiment (1g)**

Methane Air + 15.9% CO₂

\[ U_{CH₄} = 0.92 \text{ cm/s} \]
\[ U_{ox} = 6.7 \text{ cm/s} \]

**Direct Numerical Simulation (0g)**

Methane Air + 30.7% He

\[ U_{CH₄} = 0.92 \text{ cm/s} \]
\[ U_{ox} = 10.7 \text{ cm/s} \]

- Full chemistry (GRI Mech 1.2)
- Radiative loss
- Mixture rules

Extinguishment Limits

Answering to Organizing Questions

- *Cup-burner flame extinguishment experiment can:*
  1. measure the relative effectiveness (MEC) of candidate suppressants in low-g, including high-O₂, low-P environments
  2. determine the $X_{O2}$ (LOI) below which a fire cannot exist
  3. examine the effect of radiation in fire and post-fire environments
  4. reveal advantages/disadvantages of physical/chemical agents
  5. measure the agent effectiveness for practical solid fuels
  7. provide an idealized space experiment applicable to a practical fire scenario
  8. produce useful data in relation to agent deployment strategy
Conclusions

- **Space Fire Suppression Processes & Technology**

  ⇒ Space experiment concepts of cup-burner flame extinguishment have been conceived to address to the key issues (i.e., organizing questions) in space fire suppression

  ⇒ Cup-burner flame extinguishment experiment can reveal physical and chemical suppression processes and provide agent effectiveness data useful for technology development of space fire suppression systems in various reduced-gravity platforms