FIRE SUPPRESSION IN LOW GRAVITY USING A CUP BURNER

Fumiaki Takahashi
National Center for Microgravity Research on Fluids and Combustion
NASA Glenn Research Center
Cleveland, OH 44135
E-mail: Fumiaki.Takahashi@grc.nasa.gov, Fax: (216) 977-7065, Phone: (216) 433-3778

Gregory T. Linteris
Fire Research Division
National Institute of Standards and Technology
Gaithersburg, MD 20899

Viswanath R. Katta
Innovative Scientific Solutions Inc.
Dayton, OH 45440

Longer duration missions to the moon, to Mars, and on the International Space Station increase the likelihood of accidental fires. The goal of the present investigation is to: (1) understand the physical and chemical processes of fire suppression in various gravity and O_2 levels simulating spacecraft, Mars, and moon missions; (2) provide rigorous testing of numerical models, which include detailed combustion-suppression chemistry and radiation sub-models; and (3) provide basic research results useful for advances in space fire safety technology, including new fire-extinguishing agents and approaches.

The structure and extinguishment of enclosed, laminar, methane-air co-flow diffusion flames formed on a cup burner have been studied experimentally and numerically using various fire-extinguishing agents (CO_2, N_2, He, Ar, CF_3H, and $Fe(CO)_5$). The experiments involve both 1*g* laboratory testing and low-*g* testing (in drop towers and the KC-135 aircraft). The computation uses a direct numerical simulation with detailed chemistry and radiative heat-loss models. An agent was introduced into a low-speed coflowing oxidizing stream until extinguishment occurred under a fixed minimal fuel velocity, and thus, the extinguishing agent concentrations were determined. The extinguishment of cup-burner flames, which resemble real fires, occurred via a blowoff process (in which the flame base drifted downstream) rather than the global extinction phenomenon typical of counterflow diffusion flames. The computation revealed that the peak reactivity spot (the reaction kernel) formed in the flame base was responsible for attachment and blowoff of the trailing diffusion flame. Furthermore, the buoyancy-induced flame flickering in 1g and thermal and transport properties of the agents affected the flame extinguishment limits.

This research was supported by NASA's Office of Biological and Physical Research, Washington, D.C.

Conference-Workshop on Strategic Research to Enable NASA's Exploration Missions Cleveland, Ohio, June 22, 2004

Fire Suppression in Low Gravity Using a Cup Burner

Fumiaki Takahashi
National Center for Microgravity Research, Cleveland, Ohio

Gregory T. Linteris
National Institute of Standards and Technology, Washington, D.C.

Viswanath R. Katta
Innovative Scientific Solutions, Inc., Dayton, Ohio

Background

- Longer duration missions to Mars, the moon, or aboard the International Space Station increases the likelihood of fire events
- NASA's fire safety program of manned space flights is based largely upon controlling the materials flammability and eliminating ignition sources
- This project investigates fire suppression in the reduced-gravity environment

Objectives

- Understand physical/chemical processes of fire suppression in various gravity and O_2 levels simulating spacecraft, Mars, and moon missions
- Provide rigorous testing of analytical models, which include comprehensive combustion and suppression chemistry
- Provide basic research results useful for advances in space fire safety technology, including new fire-extinguishing agents and approaches

Approach

Experiment:

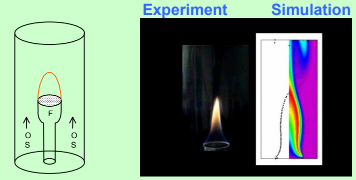
- Using a cup burner, which resembles real fires, measure the critical extinction mole fraction of fire suppression agents for selected fuels
- Determine physical/chemical effects of agents on flame structure/suppression processes

Computation:

- Simulate unsteady fire suppression phenomena in various flames using a 2D code with detailed chemical reaction and radiation models

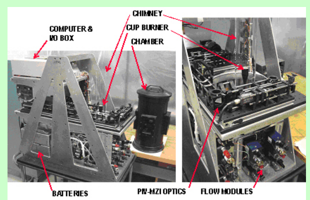
Cup Burner Flames (1g)

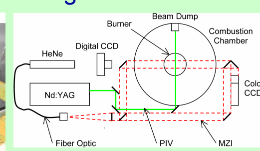
- Simulations with full chemistry predict the experiment in Minimum Extinguishing Concentration, flame shape, flickering frequency (~11 Hz)



d =2.8 cm, U_{CH4}= 0.92 cm/s, U_{air}= 10.7 cm/s

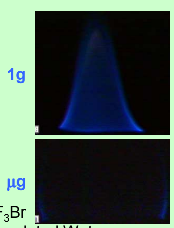
Drop/KC-135 Rig





Diagnostics:

Particle image velocimeter (PIV)
Mach-Zehnder interferometer (MZI)

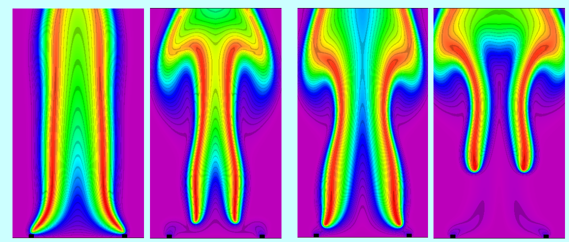


Parameters:

Fuel: Gas: CH_4, C_2H_6, C_3H_8
Liquid: n-C_7H_{16}, CH_3OH
Solid: trioxane (3[CH_2O]), PMMA
Oxidizer: O_2-N_2 mixture
Oxygen mole fraction: 0.21 – 0.3
Velocity: 3 – 20 cm/s
Agent: CO_2, N_2, He, Ar
CF_3H(HFC-23), C_3F_7H (HFC-227ea), CF_3Br
Water Mist, Inert/Water Mist, Microencapsulated Water
Gravity: μ*g*, lunar (1/6 *g*), Martian (1/3 *g*), 1g
Pressure: 0.7 – 1 atm

Numerical Simulations (1*g*)

- Suppression of cup-burner flames occurs via blowoff rather than global extinction typical of counterflow diffusion flames

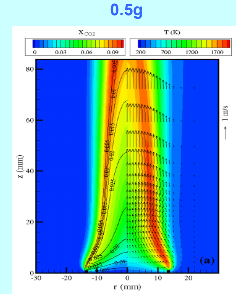


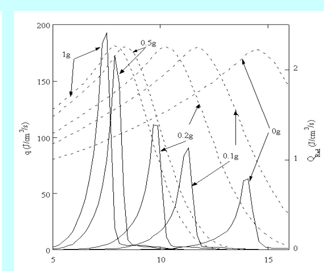
5.0% CO_2 in Air | 14.5% CO_2 in Air | 10.05% CF_3H in Air | 10.1% CF_3H in Air

Numerical Simulations (low-*g*)

- Flame flicker (~11 Hz) ceases at < 0.5 *g*
- Heat-release rate decreases with reducing *g*, while radiative heat loss remained const

0.5g





Agent Effectiveness

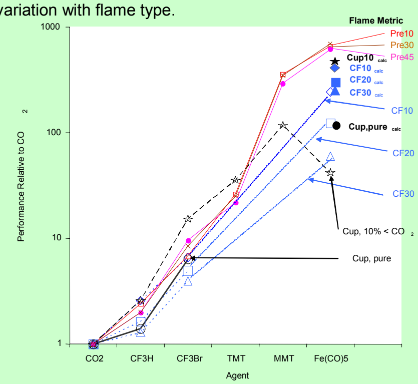
- The effectiveness of a fire-extinguishing agent depends upon the flame characteristics.

Phosphorus is:

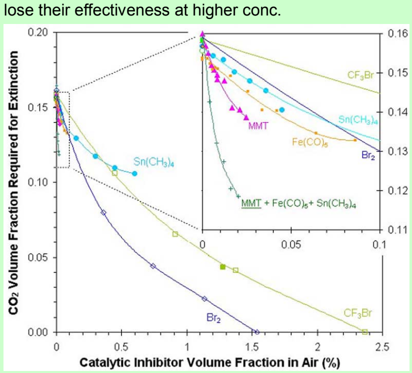
3 x <u>better</u> than CF_3Br in counterflow* flames
17 x " " " " premixed** "
<u>but</u> ½ as good as " " cup burner "

* Macdonald et al. Combust Flame 116:166 (1999) ** Korobeinichev et al. HOTWC 2000 p. 164.

- Performance advantage of chemically active agents over CO_2: variation with flame type.



- Catalytic inhibitors are better than CF3Br at low concentrations, but lose their effectiveness at higher conc.



Flame Flicker in 1*g*

- Flame flicker affects suppression processes and the flickering frequency varies with CO2 content and co-flow velocity

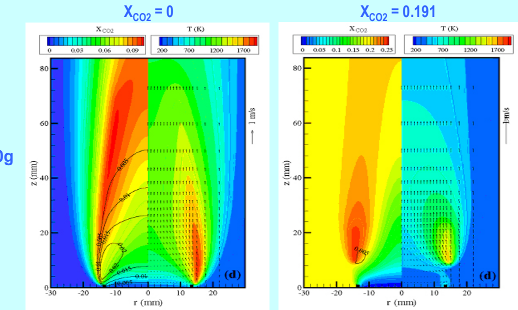
Conclusions

- Suppression of cup-burner flames occurs via blowoff rather than global extinction typical of counterflow diffusion flames.
- Performance of agents is highly dependent upon the flame characteristics.
- Chemical agents reduce concentration (and amount) of inert agent required for suppression.
- Flame flicker (~11 Hz) affects suppression processes and ceases at < 0.5 *g*.
- Flame tip opens in low *g* due to radiative heat loss.
- Critical CO_2 concentration in 0*g* is ~32% higher than in 1*g*.

Numerical Simulations (low-*g*)

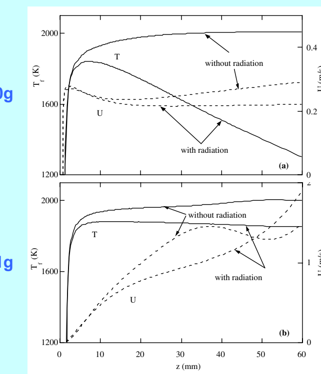
- Flame tip opens at low *g* due to radiative heat loss
- Critical CO2 concentration at 0*g* is ~32% higher than in 1*g*

0g



0g

1g



Key findings from numerical work

- Form vorticies in 1g
- Extinguish due to flame base de-stabilization
- Have tips that open in 0-g (due to radiation losses)
- Flicker at ~11 Hz. in 1-g, but as g decreased, flicker decreased (below 0.5 g, don't flicker).
- Require 32% more CO2 to extinguish in 0g than in 1g.