Fighting Fires in Space with Water Mist

September 21, 2016
Vienna, Austria

Angel Abbud-Madrid

Thierry Carriere
Apollo 1

January 27, 1967

Lessons learned:

* Switch from 100% O₂ to air

* Materials flammability
Oxygen candle

KClO₄ → KCl + 2O₂ → Air

OXYGEN GENERATOR

OXYGEN OUTLET
FILTER
FIRING PIN
KClO₄
KCl + 2O₂
Air

RELIEF VALVE
INSULATION
Fire suppression in spacecraft

Halon
(CF₃ Br)

Chemical

Carbon Dioxide
(CO₂)

Physical
Objectives for Alternative System

- Per unit mass effectiveness
- Non-toxic and non-corrosive
- No need for masks and oxygen tank
- Cooling of flame and surroundings
- Ease of clean-up
- No need for de-orbiting
- Refilling of extinguisher
Motivation (1997)

Montreal Protocol (1994)

Water mist

$\text{CF}_3\text{Br}$ (Halon)

$\text{H}_2\text{O}$
Determine effect of:

- Water amount
- Droplet size
Numerical Model Results (CH$_4$-air, $\phi=1$, 1 atm)
GROUND TESTING
Determine effect of:

- Water amount
- Droplet Size

Gravity
Free fall (Weightlessness)

Fall height = 3000 m

Time ≈ 25 sec
Free fall tests (no gravity effects)
Free fall around Earth (Space Shuttle)
Flight Experiment
MIST apparatus
Hardware Integration

Mist apparatus

Mist inside combustion vessel

Rack inside SPACEHAB module

SPACEHAB inside Shuttle

Combustion vessel inside rack
Crew Training
STS-107 Shuttle Mission (January 16, 2003)
Mist in Orbit
Results: $\text{C}_3\text{H}_8$-air flame (Droplet CMD = 30 $\mu$m)

- $\phi = 0.7$
- CMD = 30 $\mu$m
- $\omega_w = 0.2\%$
- $\omega_w = 2.5\%$
- $\omega_w = 3.3\%$
- Extinction at $\omega_w = 4.8\%$

Burning velocity vs. leading edge position graph:

- DRY FLAME
- MOIST MIXTURE

LEADING EDGE POSITION (cm) vs. BURNING VELOCITY (cm/s) graph with experimental data points.
Portable Fire Extinguisher

- Piston valve
- Bladder
- Pressure cylinder
- Water
- Perforated stand pipe
- Propellant gas - N₂
Microgravity tests
ISS life extension: 2020 → 2028
Replacement of CO₂ extinguishers
ISS Water Mist Portable Fire Extinguisher project

WATER
MIST
PFE
Water Mist Portable Fire Extinguisher (WM PFE)

Titanium bellows tank

![Diagram of Titanium Bellows Tank with Water and Nitrogen compartments]
FIRE SCENARIOS ONBOARD THE ISS

- Oxygen candle
- Open Cabin
- Elevated \( \text{O}_2 \) module
- Li-ion batteries
- Racks
ISS Fire Scenarios tests

1) Open Cabin Fire (PMMA sheets, 55 kW)
ISS Fire Scenarios tests

2) Elevated Oxygen Fire
   (PMMA crib, 30% O₂, 85 kPa)
ISS Fire Scenarios tests

3) Li-ion Battery Fire (2 units, PMMA crib)
ISS Fire Scenarios tests

4) Oxygen Candle Fire
ISS Fire Scenarios tests

5) Rack Fire
Final test with prototype PFE
Flight PFE units (Total: 9)
First 2 PFEs delivery (Cygnus OA-4 mission)
First PFEs delivery (Atlas V launch, 12/06/15)
Cygnus arrival to ISS (12/08/15)
Coming up ... October, 2016 (Last unit)
Future destinations ...
The Mist crew .... In memoriam
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