Solid combustion research in microgravity as fundamentals for fire safety in space

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Fire in Spacecraft

Apollo 1 (1967)

Astronauts from the left: V. Grissom, E. White, R. Chaffee

Fire safety: a most important issue for manned mission
Two issues on fire safety in space (1)

Concept to design spacecraft atmosphere

Two issues on fire safety in space (2)

Test is in 1G.

Can we guarantee fire safety?

NASA flammability test for electric cable
(NASA NHB8060.1C, (1991))
Cause of fire in spacecraft

- No other possible causes (on the ground: smoking, criminal fire, cooking)
- Enormous amount of electric cable

Question

Which is more flammable, in 1G or μG?
《Sample》

Sample : Nichrome wire (coated with polyethylene)
Current value : 0~20A, 5.5ohm/m
Current supply time: 0.2-1.2s, continuous
O2 % : 21%, 40%
Pressure : 100kPa

《Experimental condition》

<table>
<thead>
<tr>
<th>Sample outer diameter r: Do [mm]</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core wire diameter: Di [mm]</td>
<td>0.5</td>
</tr>
<tr>
<td>PE Insulation thickness: δ [mm]</td>
<td>0.15</td>
</tr>
</tbody>
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Ignition by continuous current
Experimental setup

He-Ne Laser
Sample
Special filter
Collimate lens
Condenser lens
Half mirror
Chamber
Mirror
Mirror
High-speed camera
Sample Holder
DV Camera
Current Source

Experimental setup with MZ & HSV

Ignition by continuous current
Experimental fact(1) – Ignition limit -

1G, PE, 12.5A

μG, PE, 12.5A

Extension of ignition limit in μG

Sample wire:
Polyethylene insulation (φ0.8mm)
Nichrome core (φ0.5mm)
In longer microgravity time

![Graph showing ignition delay time vs applied power]

- Ignition (20s μG, DAS)
- Ignition (4.5s μG, MGLAB)
- Ignition (2.5s μG, COSMOTORRE)
- Ignition (1G, Ground)

Ignition limit in 20s μG
Ignition limit in 4.5s μG
Ignition limit in 2.5s μG
Ignition limit in 1G

DAS: O₂ 19-21%, Others O₂ 21%, Continuous current supply

Applied power (P) = I²R, [R: Ω/cm]

Minimum current decreases with increase in available microgravity time
Spreading flame over wire insulation in Micro G PE#2 (id.0.5mm, od.0.8mm), O2=35%
Experimental results – effects of gravity and core wire -

- Significant decrease in LOC in μg than 1g for both samples.
- Cu gives higher LOC than NiCr. Cu shows minimum LOC in 1g.
Experimental system under preparation
International Space Station (ISS)
図 4.1-1 多目的実験ラック外観（イメージ図）
Conceptual description of test system

ISS experiments

**Diagnostics**

**Color cameras**
(0.05mm/pixel, 0.2mm/pixel)

**High speed camera**
(Max. 2000fps)

**Back light image**

**IR image**

**Michelson imaging**

O$_2$, CO$_2$, H$_2$O concentrations are controlled.

Courtesy by H. Torikai (Hirsaki U.)
Sample feeder

ISS experiments
Pictures of combustion duct

External View

Sample holder to be set in the duct
Flammability map on wire ignition
The conditions where flame arises at the place without any pilot source.

Electric Current (A)

O₂

Upper oxygen limit in space craft

Flame along wire ignited in μ G

Current limit by power source

1G Region

μ G Region

Region 1

Region 2

Region 3

Region 4

(30%)
Flammability map on spreading flame

The extinction limit of the existing flame.

- Extinction region in μ G
- Upper oxygen limit line in space craft
- Limit given by reaction rate
- Extinction limit in 1G
- Extinction limit in μ G

Air flow speed (cm/s)

O₂

LOI (1G)

LOI (μ G)

Extinction limit in μ G

μ G Flame

ISS experiments
Fire safety is one of the most essential issues for future long term manned space mission.

Significant extension of flammable limit in μG. Two important data on wire flammability in μG will be taken, ie. (1) ignition map, (2) Extinction map

Experimental setup for ISS experiments are on going.

International collaboration would be effective way to give more advancement in the research.
ACKNOWLEDGMENTS

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