

Fire Suppression Tests Using a Handheld Water Mist Extinguisher Designed for Spacecraft Application

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The National Aeronautics and Space Administration (NASA) is funding development work on next-generation astronaut-occupied spacecraft to replace the Space Shuttle and to transport crews to the International Space Station (ISS), the moon, asteroids, and Mars. As part of the overall effort to provide all new subsystems to the crew capsule, the agency is reevaluating all elements of its current onboard fire-protection methodology and technologies. NASA uses carbon dioxide (CO₂) for fire suppression on the ISS. Although it is effective, CO₂ presents a serious health concern inside sealed enclosures such as spacecraft. ADA Technologies, Inc. is part of the team designing and testing a fine water mist (FWM) portable fire extinguisher (PFE) prototype suitable for use in the ISS and future occupied spacecraft and planetary habitats. There are multiple reasons for selecting water over other suppressant agents. Among them are its excellent suppression effectiveness on a unit-mass basis, its lack of toxicity, ease of clean-up, its compatibility with spacecraft operations, and the ability to recycle the agent and refill the extinguisher on long-duration missions. The prototype microgravity FWM portable fire extinguisher (Figure 1) developed by ADA Technologies has several key features:

- 1) Physical separation of the gas and water in a single storage tank to allow operation under any gravity condition, or in the absence of gravity;
- 2) Use of water and nitrogen as the fire suppression fluids; they are non-toxic to the crew and compatible with spacecraft environmental systems, and make the unit refillable during an extended mission;
- 3) Straightforward hand-held operation with a manual valve for rapid discharge;
- 4) A design adaptable for use in the confined and cluttered space of experiment / instrument racks of the ISS and future spacecraft.



Figure 1. ADA Technologies prototype FWM extinguisher.

The first stage of the flight hardware qualification process now underway is the definition of system requirements. Performance requirements constitute a key element of system requirements, yet NASA does not currently have any standard fire test that can be conducted to qualify handheld extinguishers for space operation. The project team set out to define several fire scenarios representative of the existing fire hazards aboard the ISS. In this paper, we summarize the development of two standard fire tests: (1) a lithium-ion battery fire and (2) a heavily obstructed ISS rack fire, similar in some respects to the FAA handheld hidden fire test. The lithium-ion bat-

tery fires were conducted at the NASA White Sands Test Facilities (WSTF) in New Mexico, and the obstructed rack tests were conducted at ADA Technologies in Colorado. The FWM PFE prototype was also used to develop and evaluate additional scenarios, not included in this paper: an open cabin fire (using class A combustibles) and an oxygen generator runaway event.

Lithium Ion Fire Test. One of the most common flammable materials aboard the ISS is the electrolyte found in the lithium-ion batteries that power a variety of electronic items, from laptops to cameras. A battery fire is probably the most likely fire scenario that may one day develop in a spacecraft, because of the increasing presence of high-power density batteries in many applications. For this test, two camcorder battery packs (4 cells each) were stacked on top of a heat source and overheated to trigger a thermal runaway event inside the bottom pack, directly in contact with the heat source. A fire then developed and the cells in the bottom pack started to vent violently. The fire propagated to acrylic (PMMA) sheets positioned above the packs and to the housing of the upper pack. Fifteen seconds after all bottom cells vented, a professional NASA firefighter located 5.5 ft away from the batteries discharged the FWM extinguisher on the fire. The firefighter operated the extinguisher until the flames were suppressed, typically less than 3 seconds. He was also instructed to recommence discharging if flames reappeared. Five suppression tests were performed with the FWM extinguisher. Three tests were also performed with a commercial extinguisher containing 14 lb of CO₂.

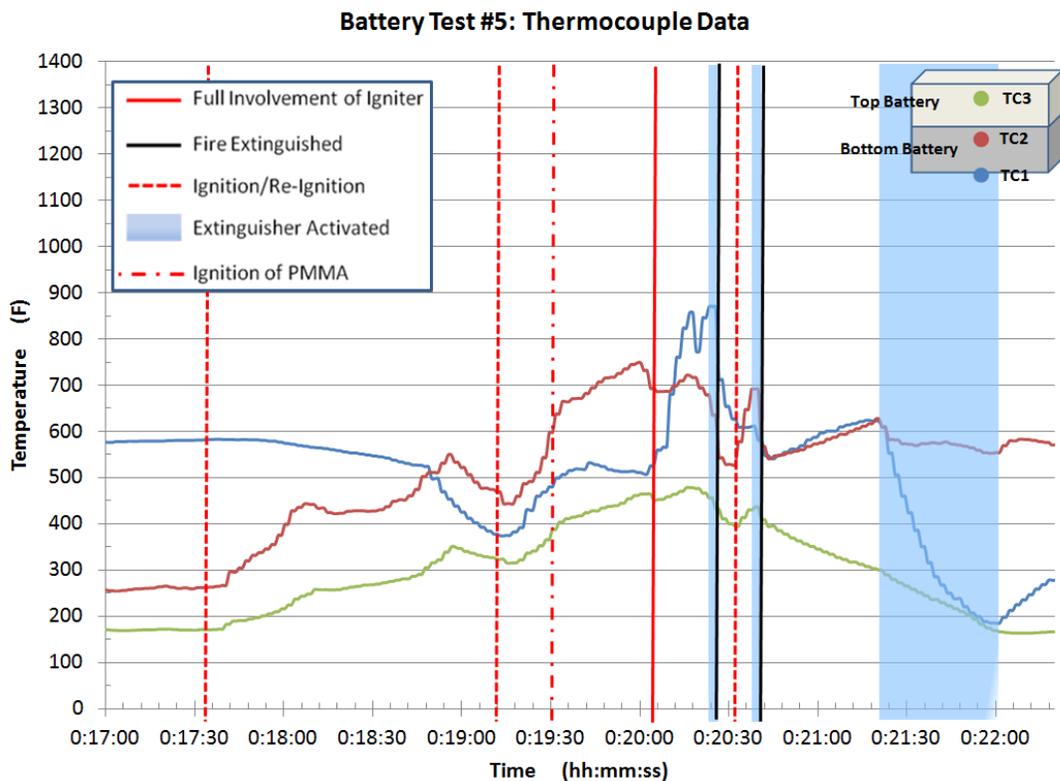


Figure 2 shows data from three thermocouples affixed to the battery packs during a suppression test using FWM. The FWM discharge began at time 20:20 (min:sec) and lasted only a few seconds as flames were immediately suppressed. A second FWM pulse was applied shortly after as flames reappeared (at time 20:40). The batteries did not seem to re-ignite after this point and the firefighter was instructed to completely discharge the extinguisher at time 21:20 to cool the test articles. Monitoring the test for another 15 minutes showed no re-ignition. This pattern was observed in all 5 FWM suppression tests (5/5 extinguished in two short pulses). The amount of wa-

ter in the two pulses needed to extinguish these fires was less than 1.5 lb (the extinguisher initially contained 6 lb of water). In comparison, suppression with CO₂ was much more difficult. One of the 3 fires was not extinguished despite using the whole 14-lb charge of the extinguisher. In the other 2 fires, 5.9 and 9.1 lb of agent, respectively, had to be used to prevent the packs from re-igniting. This fire scenario clearly demonstrated the high cooling capability of FWM, compared to a gaseous agent, and its ability to stop rapidly a realistic lithium-ion battery thermal runaway in a spacecraft.

Obstructed ISS Rack Fire Test. ISS racks are closed volumes of standard size installed along walls of the ISS and containing a variety of vehicle systems and scientific modules. They are normally closed and equipped with smoke detectors. Should a fire be detected inside a module, a crew member might have to discharge blindly a handheld extinguisher inside a heavily packed rack through a fire port located on the front panel of the rack. A rack replica was assembled (Figure 3) to test the effectiveness of the FWM extinguisher in a highly obstructed rack and compare its performance against that of gaseous extinguishers (CO₂ and N₂). Packing factors of 50% and 75% were used and the extinguishers were discharged from two locations, inside a volume far removed from the location of the flames. Carbon dioxide and high-pressure N₂ were quickest to extinguish all obstructed flames, likely because of their high flow rate and the turbulence they generated inside the various cavities of the rack. However, the overall success rate was also near 100% with low-pressure N₂ and FWM, despite a much lower initial plume momentum. This low momentum affected only the extinguishment time. Transport of water droplets was also observed. Most droplets did not reach the flames, as the path from extinguisher to flames was extremely tortuous. However, droplets with diameter less than 15 μm were clearly observed near the flames, showing that they were small and light enough to be entrained by the flow of propellant nitrogen diffusing throughout all the cavities of the rack. In all cases, the flames were extinguished by local displacement of oxygen resulting in an unsustainable combustion environment.

Conclusions. Two standard fire tests representative of fire hazards that might be found onboard the ISS are presented: a lithium-ion battery fire and an obstructed rack fire. The standard fire tests will be conducted to qualify handheld extinguishers for space operation. Fine Water Mist, CO₂ and N₂ PFEs were used to develop and refine the scenarios and challenge the fires. The results showed that FWM was a very effective medium to extinguish the selected battery fire and was an adequate medium to extinguish obstructed rack fires. Carbon dioxide was effective in the rack scenario but had limited effectiveness on the battery fire. Further testing is being planned to assist in finalizing test standard details. These test standards will also be of use as the FWM PFE design is optimized for use on Space Station.



Figure 2. ISS obstructed rack replica (shown here without front panel).