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Microgravity flammability limits of ETFE insulated wires exposed to external radiation

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Abstract

The present work studied the normal gravity (1 g) and microgravity (μg) flame spread limits (LOC) of ETFE insulated copper wires exposed to an external radiant flux. Experiments with sample wires of a 0.50 mm copper core and 0.30 mm ETFE insulation thickness were conducted in oxygen concentrations ranging from 20% to 32% and external radiant fluxes from 0 to 25 kW/m^2. Microgravity experiments conducted in parabolic flights showed that μg reduced the Limiting Oxygen Index of the material. The addition of an external radiant flux further extends the Limiting Oxygen Concentration (LOC) for flame spread over ETFE insulated wires. Microgravity reduced heat losses and allowed the flame to propagate in lower oxygen concentrations. The addition of an external radiant flux further compensates for lower flame temperatures in reduced oxygen concentrations and further extends the LOC of the material. Limiting Oxygen Index (LOI) results obtained with ETFE were also compared to available results with PE and show that μg conditions have a larger impact in ETFE than PE. The results of this work are relevant given that the flammability of materials is routinely tested without considering the effects of environmental variables and according to the results presented in here may not be indicative of the absolute flammability limits.

Keywords: Microgravity; Ethylene-tetrafluoro-ethylene (ETFE); Limiting Oxygen Concentration (LOC); External radiation

1. Introduction

The risk of a fire during a space mission has motivated ample research in spacecraft fire safety. Over the years researchers have studied the differences between flame spread in normal (1 g) and microgravity (μg) conditions using different fuels such as plastics, paper sheets and electrical cables. Findings from these studies have shown that in low flow velocities typical of spacecraft ventilation

Abbreviations: FR, fire resistant; PE, polyethylene; HRP, heat release parameter; HRR, heat release rate; LOC, Limiting Oxygen Concentration; LOI, Limiting Oxygen Index; MOC, Maximum Oxygen Concentration; ETFE, ethylene-tetrafluoro-ethylene; PMMA, poly methylmethacrylate.

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systems, μg results in higher flame spread rates, lower flammability limits, and different flame extinction mechanisms when compared to 1 g [1–10].

Electrical cables and harnesses have been identified as a possible source of fires in a spacecraft and their combustion in microgravity has received significant attention. Kikuchi et al.[6] studied the effects of wire temperature and size, oxygen concentration, ambient pressure, and carrier gas on the flame spread over ETFE insulated wires. In these experiments the authors found that the combination of μg and preheating of the wire core resulted in an increase in the flame spread rate in comparison to 1 g. The same authors also found that smaller wire sizes resulted in higher spread rates, and that as wire size increased the difference between microgravity and normal gravity flame spread rates decreased. Fujita et al. [11] studied the effect of oxidizer flow speed in flame spread over PE insulated wires. One key finding was that in μg, flame spread rate had a maximum at flow velocities around 0.10 m/s, which are similar to those induced by air ventilation systems inside a spacecraft. This agreed with observations by Olson and collaborators [1,2], who also found that flow velocities ranging from 0.06 to 0.10 m/s resulted in the highest flame spread rate over thin cellulosic fuels.

Fujita et al. [8] studied the ignition delay and ignition limits of PE insulated nichrome wires subject to short-term excess current. The results showed that the minimum current required for ignition and ignition delay times decreased in microgravity. Expanding on the ignition of short-term overloaded wires, Takano et al. [9] investigated the LOC for the ignition of PE insulated nichrome wires. In this study, the LOC was defined as the oxygen concentration below which ignition does not occur given a certain current supply. The results showed a reduction in the LOC in μg. Takahashi et al. [10] also observed that microgravity results in lower LOC for flame spread over PE insulated copper and nichrome wires, which was related to the elimination of natural convection and the resulting increased heating of the unburned insulation.

As microgravity fire safety research has shifted to the study of ignition and extinction limits, the types of fuels have also changed. Except a few studies, the majority of microgravity flame spread research has been conducted using materials that help the basic understanding of the problem, like for example thin cellulosic paper, PMMA sheets or PE insulated wires. Still, microgravity flame spread experiments with more practical materials used in space applications are less common. Development of a next generation of space exploration vehicles with elevated oxygen concentrations and reduced ambient pressure cabins [12] has brought attention to the flammability behavior of FR materials under these cabin atmospheres [13–17]. Fire resistant materials have a LOI greater than 21%. The LOI is defined as the minimum oxygen concentration that supports a candle like flame [18]. Some of these studies have shown that although FR materials are not flammable in normal atmospheric conditions, they can become flammable in elevated oxygen concentrations, reduced ambient pressure, or microgravity. Also, studies on the effect of an external radiant flux on the flammability of materials have shown that an external radiant flux extends the flammability limits of materials below the LOI [19–21].

Fire resistant wire insulation materials are extensively used in spacecraft. One material that has been used in insulation and wire harnesses is ETFE. In standard atmospheric conditions ETFE has a LOI of 30% [22]. Based on the work described above it is possible that the flammability of ETFE may be extended in microgravity and under external heating, and constitutes the objective of the present work. This objective is accomplished by studying the LOI and LOC of ETFE insulated wires subject to an external radiant flux in both 1 g and μg. In addition, the ETFE insulated wire LOI results are also compared to results with PE insulated wires obtained by Takahashi et al. [10]. The comparison helps understanding whether the effect of μg in the LOC can be predicted using non fire-resistant materials such as PMMA, PE, etc.

2. Experiment configuration

A schematic of the experimental apparatus is shown in Fig. 1. The apparatus and supporting equipment is designed to fit in an experimental flight rack for microgravity experiments. The main component of the apparatus is a 60 mm in diameter and 250 mm long flow duct made of Pyrex. The ETFE insulated wire is placed at the centerline of the duct and it is fed via a spool system located at both ends of the tube. The combustion products are filtered with an air filter located downstream of the duct. A suction fan (Sanyo Denki 9GV0612P1H031) attached to the air filter is used to induce a recirculating airflow throughout flow duct. Honeycomb flow straighteners placed at both ends of the tube are used to ensure flow uniformity. A constant airflow speed of 0.12 m/s through the flow duct was used for all experiments. This flow velocity simulates typical airflow speeds found in spacecraft ventilation systems. Also, it has been found that opposed flame spread rates have maximum values around these flow rates [1,2,8,10,11].

Two 300 mm long halogen heaters (Ushio UH-USC-CL300) with a peak wavelength emission of 1.2 microns are mounted directly on top and