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Pressure Effects on Oxygen Concentration Flammability Thresholds of Materials for Aerospace Applications

ABSTRACT: Spacecraft materials selection is based on an upward flammability test conducted in a quiescent environment in the highest-expected oxygen-concentration environment. However, NASA's advanced space exploration program is anticipating using various habitable environments. Because limited data is available to support current program requirements, a different test logic is suggested to address these expanded atmospheric environments through the determination of materials self-extinguishment limits. This paper provides additional pressure effects data on oxygen concentration and partial pressure self-extinguishment limits under quiescent conditions. For the range of total pressures tested**,** the oxygen concentration and oxygen partial pressure flammability thresholds show a near linear function of total pressure. The oxygen concentration/oxygen partial pressure flammability thresholds depend on the total pressure and appear to increase with increasing oxygen concentration (and oxygen partial pressure). For the Constellation Program, the flammability threshold information will allow NASA to identify materials with increased flammability risk because of oxygen concentration and total pressure changes, minimize potential impacts, and allow for development of sound requirements for new spacecraft and extraterrestrial landers and habitats.

KEYWORDS: test methods, flammability, aerospace materials, combustion, microgravity

Introduction

NASA's goal of traveling to the moon, Mars, and beyond through the development of an advanced human space exploration program requires advanced technology and spacecraft hardware design. Environment selection should be flexible to optimize complex mission operations. The ambitious objectives of the Constellation Program limit the ability to select a firmly defined atmosphere. Hypoxia, decompression sickness, and materials flammability are important factors that must be controlled when selecting spacecraft atmospheres [*1*]. Applicability of flammability test data needs to be broad to allow optimal design of multiple spacecraft, extraterrestrial landers and habitats, and surface vehicles. Current test data on spacecraft materials flammability is limited to previously anticipated atmospheric environments. Possible atmospheric conditions have expanded considerably. A test logic is needed to obtain comprehensive materials flammability information to provide flexibility for spacecraft environment selection.

Background

Spacecraft fire safety emphasizes fire prevention, which is achieved primarily through the use of fire-resistant materials. Materials selection for spacecraft is based on conventional flammability acceptance tests along with prescribed quantity limitations and configuration control for items

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that are non-pass or questionable [*2*, *3*]. The test required is NASA-STD-6001, *Upward Flame Propagation (Test 1)* [*4*].

Test 1 is the primary method used to evaluate flammability of materials intended for use in habitable spacecraft environments. This test exposes materials to a standard ignition source in a quiescent environment at the highest-expected spacecraft oxygen-concentration to identify materials that will self-extinguish and not transfer burning debris [*4*]. The method consists of an upward flammability test conducted with a well-defined igniter flame at the bottom of a vertically mounted sample. If a material burns for less than 15.2-cm (6-in.), the material passes. Because of the current test logic, the existing materials flammability database contains mostly data in maximum oxygen concentrations of 30 percent by volume and 71.1 kPA (10.2 psia) total pressure. Spacecraft environments with higher oxygen content at lower total pressures [*5*] would be more advantageous for important mission operations, such as extravehicular activities.

NASA Johnson Space Center (JSC) White Sands Test Facility (WSTF) developed a method that will provide flammability threshold information [*6*]. The flammability threshold information will be valuable for new spacecraft and extraterrestrial habitation module designs. For the Constellation Program, the flammability threshold information will allow NASA to identify materials with increased flammability risks from oxygen concentration and total pressure changes, minimize potential impacts, and allow for development of sound requirements for extraterrestrial landers and habitats [*1*, *7*]. The following section provides additional experimental information related to pressure effects on the oxygen concentration flammability thresholds for common aerospace materials

Experimental

The test materials that were evaluated included plastics [Delrin®[1], polyethylene (PE), Teflon®[2] TFE, Zytel® 42, and Kel-F] and elastomers [Silicone Rubber, Viton®[3] A, Buna S, Buna N, Neoprene, and polyethylene/propylene diene (EPDM)]. Table 1 provides the tradename and chemical composition of the materials. The samples were 6.4-cm (2.5-in.) wide and at least 15.2-cm (6-in.) long; the sample lengths were selected to provide a burn length of at least 15.2 cm, which is consistent with the failure criteria established in Test 1 [*4*]. All samples had a thickness of approximately 1.5 mm (0.06 in.).

[1] Delrin® is a registered trademark of E. I. DuPont de Nemours & Co., Wilmington, Delaware.
[2] Teflon® is a registered trademark of E. I. DuPont de Nemours & Co., Wilmington, Delaware.
[3] Viton® is a registered trademark of DuPont Dow Elastomers, Wilmington, Delaware.

TABLE 1 – *Materials Tested*

Generic or Trade Name	Chemical Name or Composition
	Plastics
Delrin®[a]	polyoxymethylene (acetyl stabilized polyacetal)
PE	polyethylene
Teflon®[a] TFE	polytetrafluoroethylene (PTFE)
Zytel®[a] 42	polyamide 6,6 (Nylon 6,6)
Kel-F® 81	polychlorotrifluoroethylene (PCTFE)
	Elastomers
Silicone Rubber	polysiloxane
Viton ®[b] A	copolymer of vinylidene fluoride and hexafluoropropylene
Buna S	polystyrene/butadiene
Buna N	polyacrylonitrile/butadiene
Neoprene	polychloroprene
EPDM	polyethylene/propylene diene

[a] Delrin®, Teflon®, and Zytel® are registered trademarks of E. I. DuPont de Nemours & Co., Wilmington, Delaware.
[b] Viton® is a registered trademark of DuPont Dow Elastomers, Wilmington, Delaware.

Tests in quiescent environments were conducted in a 1400-L flammability chamber connected to a vacuum pump with air, oxygen, and nitrogen supplies, which met the Test 1 requirements [*4*]. Flammability burn/no-burn transition testing in quiescent environments was also conducted following Test 1 procedures. The testing was conducted sequentially as recommended by ASTM D 2863 and used a step size of 1 percent oxygen by volume [*8*]. The upward flammability limiting oxygen indices (ULOIs) were calculated with the "up-and-down method for small samples" [*9*]. This method has been adopted by both ISO 4589 [*10*] and ASTM D 2863 for determining the "minimum oxygen concentration required to support combustion of plastics" [8]. In this study, the maximum oxygen concentrations (MOCs), which consistently result in self-extinguishment, were determined.

The MOC was the level of oxygen concentration where at least five samples passed the burning criteria [4] in the ULOI vicinity and where at least one sample failed in the environment that contained 1 percent more oxygen by volume. To evaluate pressure effects, the oxygen concentration flammability thresholds were determined at 48.2 kPa (7 psia), 85.3 kPa (12.4 psia) and 101.3 kPa (14.7 psia). The lowest total test pressures were limited to 48.2 kPa (7 psia) based on a previous study. This study indicated that the power penalty to the spacecraft air cooling subsystem due to reduced pressure puts a practical minimum cabin design pressure of around 50.5 kPa (7.35 psia) [5]. Data obtained in 85.3 kPa (12.4 psia) and 101.3 kPa (14.7 psia) were initially reported in 2002 [6]. The maximum oxygen partial pressures that resulted in self-extinguishment were calculated at various total pressures based on the MOC.

Results and Discussion

For the 48.2 to 101.3 kPa (7 to 14.7 psia) total pressure range, the oxygen concentration and partial pressure flammability thresholds show a near linear function of total pressure. The dependency of oxygen concentration/oxygen partial pressure flammability thresholds on total pressure appears to increase with increasing oxygen concentration (and oxygen partial pressure) thresholds. The experimental test results are summarized in Table 2 and Figures 1 and 2.

Kel F-81, PTFE, Zytel,®[1] Silicone, and Viton have higher oxygen concentration and oxygen partial pressure flammability thresholds than the rest of the polymers tested. Interestingly, these materials are also considered more resistant to ignition in many of the various ignition susceptibility tests in 100 percent oxygen.

Oxygen concentration or oxygen partial pressure flammability threshold dependency on total pressures needs to be evaluated using additional materials to establish general correlations for flammability parameters. The availability of data on dependency of oxygen concentration or partial pressure self-extinguishment limits on total pressure will allow identification of flammability risks associated with oxygen concentration or total pressure changes and minimize their potential impacts on spacecraft safety. Furthermore, these data will allow closer evaluation of fire risks and increased flexibility in choosing spacecraft internal atmospheres, which could lead to increased efficiency of mission operations. Current technological advances and emergency operations that may involve spacecraft depressurization would benefit from flammability threshold studies at total pressures outside the 48.2 to 101.3 kPa (7 to 14.7 psia) range.

TABLE 2 — *Oxygen concentration, oxygen partial pressure and total pressure flammability limits for selected materials at ambient initial temperatures*

	48.2 kPa (7 psia) total pressure		85.3 kPa (12.4 psia) total pressure		101.3 kPa (14.7 psia) total pressure	
Material	MOC (vol %)	MOP (psia)	MOC (vol %)	MOP (psia)	MOC (vol %)	MOP (psia)
PTFE	53	3.7	46	5.7	42	6.2
Kel-F 81	76	5.3	56	6.9	53	7.8
Silicone	28	2.0	23	2.8	21	3.1
Zytel 42	25	1.8	23	2.8	23	3.4
Viton A	29	2.0	21	2.6	21	3.1
Buna S	18	1.3	17	2.1	16	2.4
Neoprene	18	1.3	17	2.1	16	2.4
Buna N	18	1.3	16	2.0	15	2.2
EPDM Rubber	18	1.3	16	2.0	16	2.4
Polyethylene	18	1.3	18	2.2	17	2.5
Delrin	13	0.9	12	1.5	11	1.6

MOC = Maximum oxygen concentration which consistently results in material self-extinguishment.
MOP = Maximum oxygen partial pressure when extinguishment occurs (based on MOC).

[1] Zytel® is a registered trademark of E. I. DuPont de Nemours & Co., Wilmington, Delaware.

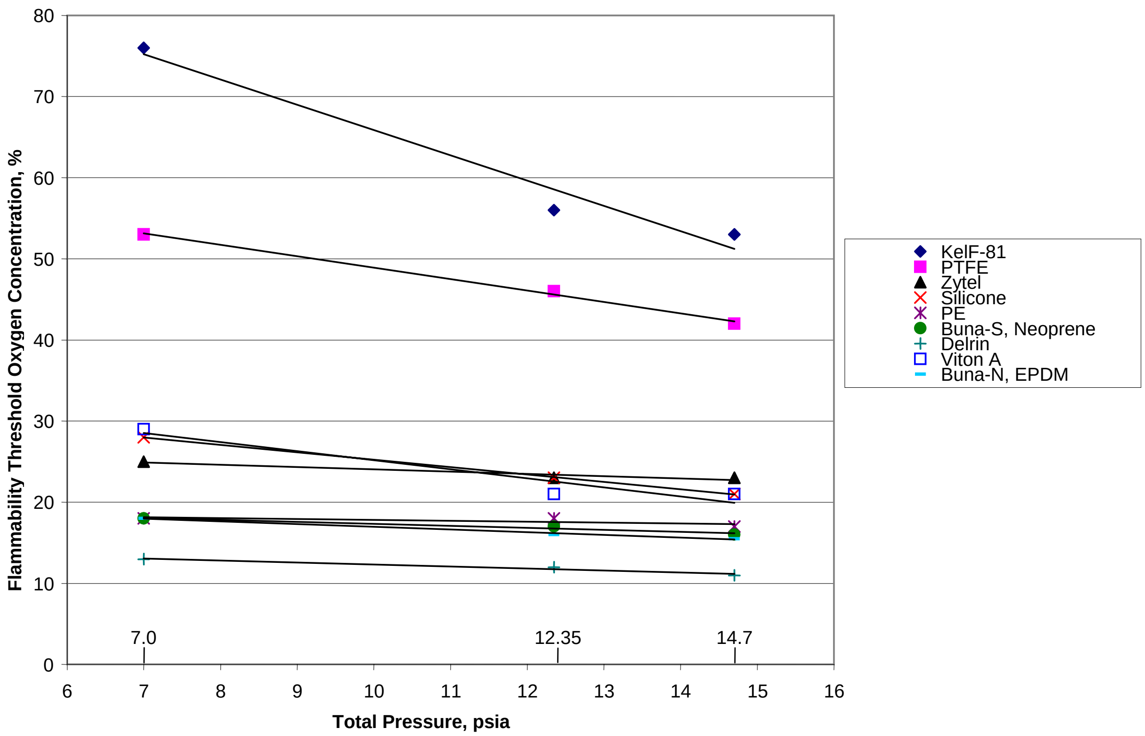

Figure 1 — *Oxygen concentration and total pressure flammability limits at ambient initial temperatures*

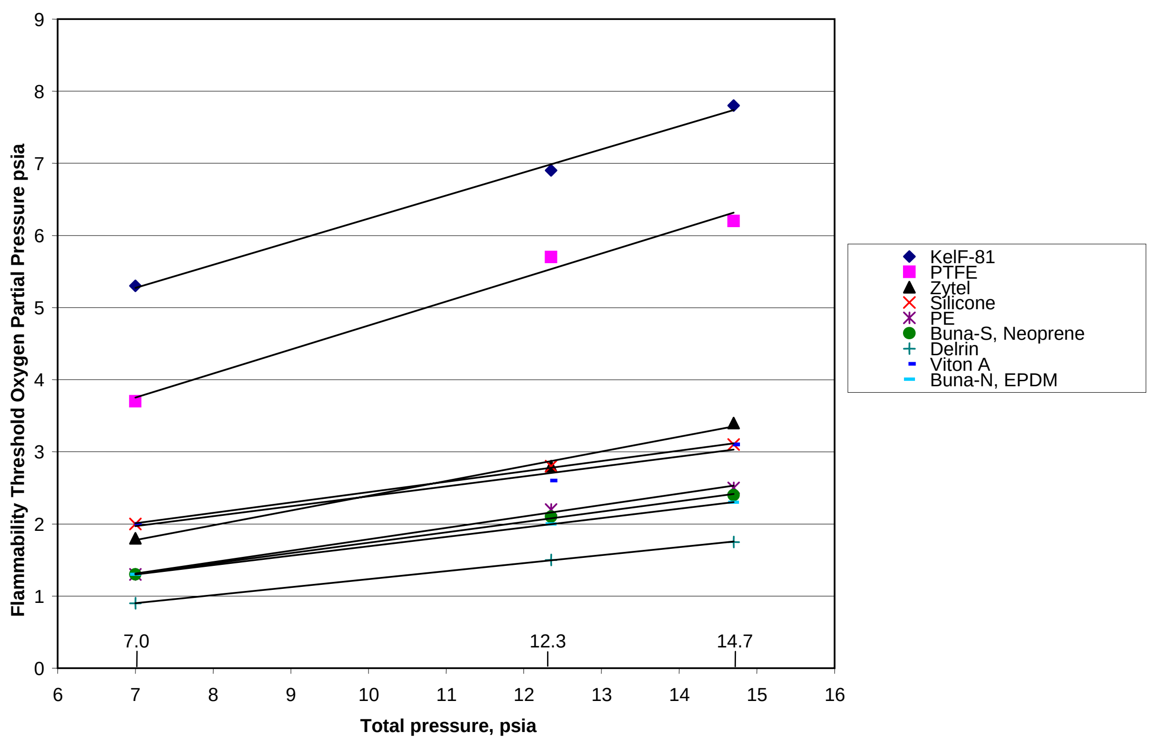

Figure 2 — *Oxygen partial pressure and total pressure flammability limits at ambient initial temperatures*

Conclusions and Recommendations

The effect of total pressure on oxygen concentration flammability thresholds is greater for materials with higher thresholds. To determine if this relationship holds outside the 48.2 to 101.3 kPa (7 to 14.7 psia) range further testing is recommended. Testing additional materials will provide general flammability parameter correlations and predict flammability behavior for other materials. The flammability threshold information will be valuable to the development of new spacecraft and extraterrestrial habitation module designs. The data will provide a knowledge base for material selection to support the needs of advanced aerospace programs and mitigate spacecraft fire risks.

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