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Technical Note: Some Issues Related to the Selection of Polymers for Aerospace Oxygen Systems

Abstract:

Materials intended for use in aerospace oxygen systems are commonly screened for oxygen compatibility following NASA STD 6001. This standard allows qualification of materials based on results provided by only one test method. Potential issues related to this practice are reviewed and recommendations are proposed that would lead to improved aerospace oxygen systems safety.

Keywords: oxygen systems, polymers, safety, ignition, flammability, aerospace materials

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Introduction

Aerospace materials intended for oxygen service are commonly screened for oxygen compatibility [1 - 5]. NASA STD 6001 establishes NASA program requirements for evaluation, testing, and selection of materials to preclude unsafe conditions related to oxygen compatibility [6]. Materials intended for use in liquid and gaseous oxygen systems of space vehicles and ground support equipment must meet the criteria of Test 1 (upward flame propagation) in NASA STD 6001 for nonmetallic materials in environments less than or equal to 375 kPa (50 psia), or Test 17 (upward flammability in GOX). At pressures higher than 375 kPa, materials must meet the criteria of Test 13A or Test 13B (mechanical impact), as applicable.

Materials that do not meet the criteria of the required tests but remain candidates for use must be verified acceptable in the use configuration by analysis or testing and specifically approved by the responsible NASA Center materials organization. System evaluations are conducted only to demonstrate the acceptability of configurations that result from using flammable or otherwise incompatible materials. Polymeric materials that have passed Test 13 criteria are considered fully oxygen-compatible. The practice of selecting materials based only on Test 13 criteria requirements could subject aerospace oxygen systems to unnecessary risks.

Discussion

Tests 13A and 13B basically follow the ASTM G86 procedures [7]. For a material to be acceptable, 20 samples must not react when impacted at 98 J (72 ft-lb_f). If one sample out of 20 reacts, 40 additional samples must be tested without any reactions.

The Test 13 method allows testing samples with different surface areas; as a consequence, the energy density input into the sample (impact energy/surface area) is variable. The energy density could be larger, even considerably larger for samples with a lower surface area than the impact area of the striker pin, which could conversely affect materials reactivity. A higher impact energy density can lead to increased reactivity; on the other hand, a decreased impact area can reduce the

probability of impacting a “hot spot,” where ignition could be initiated. Consequently, specifying only the total impact energy of 98 J provides an incomplete picture that may be insufficient to draw definite conclusions about material reactivity.

Qualifying materials based only on results from a single method that simulates only one ignition source could be risky. There may be other ignition sources in oxygen systems that could ignite materials with a different mechanism than that simulated by mechanical impact. These mechanisms could lead to ignitions even if the materials pass this particular test; consequently, not all materials passing Test 13 may be adequate. It has been indicated [8] that, under conditions of higher mechanical impact energies, nitrile rubber was less reactive than Viton^{®1} and silicone; yet most oxygen system designers know that nitrile rubber is not the best choice when oxygen compatibility is concerned. Furthermore, the mechanical impact test logic has been shown to be deficient [9], which increases the risk of relying solely on its results. Additionally, mechanical impact test methodology drawbacks were reported [10, 11].

For the period 1993 to 2003, the NASA Lessons Learned database lists nine events involving oxygen systems, of which five resulted in fires and in four cases the potential system fires were prevented. All events occurred either on space systems, aerospace ground support facilities, or NASA test facilities. Of the five cases which resulted in oxygen fires, one resulted in major facility destruction; three were related to the materials used; one to an improperly mounted component; and one to the existence of particles. During 1993 to 2003, there was at least one additional oxygen-system fire that resulted in major damage to an aerospace test facility; one contributor to this event was related to improper material usage.

For oxygen system fires to occur, the right combination of factors has to exist. There are known instances of oxygen systems used safely for years; then, when a fire occurred, an investigation revealed design or material applications that made the forensic experts wonder how

¹ Viton[®] is a registered trademark of E. I. Du Pont de Nemours & Co., Wilmington, Delaware.

the system had operated safely for so long. The obvious conclusion is that a past history of safe use should not preclude adapting better practices.

Recommendations

For *existing systems*, discontinue the practice of qualifying materials for oxygen service based on results from only one test method. More importantly, discontinue the practice of qualifying materials at energy levels lower than 98 J based on a summary systems analysis accounting only for mechanical impact events. Perform a systems hazards analysis according to NASA TM 104823 [12] or an industry standard method, such as ASTM G63 [13] or ASTM G94 [14]. Evaluate potential ignition sources, their likeliness of occurrence, and their severity. If appropriate, the hazards analysis will identify the suitable tests to be performed and test conditions, while providing recommendations for a suitable safety factor. The safety factor is necessary to take into account configurational dependency of test results and test data uncertainty. Based on analysis and test results, mitigating actions can be considered. Recommendations for both material and component testing might be suitable.

For *new oxygen systems*, a systems evaluation should be part of the design process, and it should be performed prior to systems buildup. A materials preselection during the initial phase of design should be followed by a final selection performed upon completion of a hazards analysis and the analysis of results obtained from the recommended testing.

The mechanical impact test reports and databases should also provide reactivity information based on energy density.

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