ARTICLE IN PRESS

Fire Safety Journal xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Flame spread limits (LOC) of fire resistant fabrics

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ARTICLE INFO

Keywords:
Environmental conditions
Flame resistant
Flame spread
LOC

ABSTRACT

Selecting fabrics based on their fire resistance is important for professions with substantial fire risk such as firefighters, race car drivers, and astronauts suits. Generally, fire resistant materials are tested under standard atmospheric conditions. However, their flammability properties can change when the ambient conditions deviate from standard atmospheric conditions. Particularly in high altitude locations, aircraft, and spacecraft, the pressure and oxygen concentrations are different than in a standard atmosphere. Also, the presence of external radiation (i.e. overheating component or nearby fire) can reduced the fire resistance of a material. In this work, an experimental study was conducted to analyze the influence of environmental variables such as oxygen concentration, ambient pressure, and external radiant heat flux on the flame spread limits of two different fire resistant fabrics: Nomex HT90-40 and a blend made of Cotton/Nylon/Nomex. Ambient pressure was varied between 40 and 100 kPa and ambient oxygen concentrations were decreased until the Limiting Oxygen Concentration (LOC), limiting conditions which would permit flame propagation, were found. Experiments were conducted using no external radiant flux or a radiant flux of 5 kW/m^2 to examine the influence of the presence of a nearby heat source. Among the results, it was found that as ambient pressure is reduced the oxygen concentration required for the flame to propagate must be increased. The external radiant heat flux acts as an additional source of heat and allows propagation of the flame at lower oxygen concentrations. An analysis of the propagation limits in terms of the partial pressure of oxygen suggest that the LOC of a material is not only determined by heat transfer mechanisms but also by chemical kinetic mechanisms. The information provided in this work helps characterize increased flammability risk of materials when in environments different from the standard atmospheric conditions at which they are typically tested.

1. Introduction

It is well known that the flammability of a material does not only depend of its chemical and physical properties, but also of the surrounding conditions at which it is exposed. When a material is exposed to a fire in different environmental conditions its behavior can change dramatically. Therefore, from a fire safety point of view, it is vital to understand how these environmental conditions can affect the burning characteristics of a material. Changes in ambient pressure, oxygen concentration, forced flow, an external heat flux or gravity are some of the most relevant environmental variables studied in this context.

Pressures lower than atmospheric are particularly important in high altitude locations or pressurized vehicles such as aircrafts or spacecrafts. Typically, inside of an aircraft, cabin pressure can range depending on the altitude between 84 and 75 kPa according to the Federal Aviation Administration (FAA) regulations [1], in order to maintain passenger comfort and minimize structural damage. In high altitude cities, ambient pressure can reach even lower values; for example, El Alto in Bolivia at about 4050 m above sea level or Lhasa on the Tibetan Plateau at 3650 m above sea level where atmospheric pressures are near 61 and 67 kPa, respectively. There are some other examples, like spacecraft applications, where the entire environment needs to be carefully controlled in order to optimize the atmospheric conditions required to support human habitation while minimizing launch weight and all risks involved [2]. Moreover, NASA is being considering the use of reduced pressure environments with elevated oxygen concentrations (55–70 kPa and 27–32 vol% of O_2) to reduce the preparation time needed to prevent decompression sickness in ExtraVehicular Activity (EVA), among other reasons. However, these conditions are substantially different from the standard conditions (100 kPa, 21 vol% of O_2) used to test the materials and might not account for an external radiation source such as an adjacent fire or an overheated element. This work addresses the effect of some of these variables, specifically reduced pressure, elevated oxygen concentration and an external radiant heat flux on the flammability characteristics of

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http://dx.doi.org/10.1016/j.firesaf.2017.03.072
Received 16 February 2017; Accepted 15 March 2017

Please cite this article as: Thomsen, M., Fire Safety Journal (2017), http://dx.doi.org/10.1016/j.firesaf.2017.03.072

fire resistance fabrics.

Several researchers have shown interest in the study of the flammability properties of materials and their flame spread behavior under different environmental conditions. Fereres et al. [3] studied the effect of pressure on ignition delay time and critical mass flux for ignition of thick PMMA samples finding that both parameters decrease as ambient pressure is reduced, suggesting an increase in the flammability risk at low pressures. Kleinhenz [4] studied Nomex III burning in an downward configuration under different environmental conditions and found that the flame spread rate decreased as ambient pressure was reduced. Olson et al. [5] conducted experiments using Nomex HT90-40 and found that the limiting oxygen concentration (LOC) required for flame spread in microgravity is about 4 vol% of O_2 lower than the one in normal gravity. Hirsch et al. [6,7] tested different materials to identify their flammability risk under different oxygen concentrations and ambient pressure. Their results showed that the LOC depended inversely on the total pressure; however, they also noticed an opposite linear trend when considering the partial pressure of oxygen. Nakamura and Aoki [8] studied the flammability of thin samples of cellulosic paper under the effects of sub-atmospheric ambient pressure and different oxygen concentrations. Their results showed a wider flammable range at lower pressures, presenting the same linear trend found in [6].

Of particular interest, it has also been the presence of an external heat radiant source in flammability related studies, since it can represent a common setting when a fire is exposed to an adjacent fire or an overheating element. Quintiere et al. [9] measured ignition and lateral flame spread of different materials using a decaying heat flux, from the study a testing method from the American Society for Testing Materials (ASTM) was established to measure specific parameters useful in the prediction of ignition and fire behavior in combustible materials. Osorio et al. [10] studied the limiting conditions for flame spread of fire resistant fabrics focusing in the effects an external heat flux and oxygen concentration using a forced flow velocity for a fabric sample burning on one side. Their results showed that for a given oxygen concentration there is a minimum external heat flux that allows flame spread to occur.

In the present work experiments were developed to study the effect of reduced ambient pressure, an external heat flux and oxygen concentration on the limiting conditions for flame spread over thin fire resistant fabric samples burning on a downward configuration under the influence of a forced/mixed flow. The results from this work could provide a better understanding of flammability characteristics of flame resistant materials and their suitability for use in different environments.

2. Experimental apparatus

The experiments were conducted in an upgraded version of an existing experimental apparatus to study the flammability of solid combustible materials under varied ambient conditions [11]. The apparatus basically consists of a laboratory scale combustion tunnel that is incorporated in a pressure vessel permitting the simultaneous control of: oxygen concentration, ambient pressure, flow velocity and external radiant heat flux. A photograph of the pressure chamber and a schematic of the apparatus are shown in Figs. 1 and 2, respectively. The tunnel has a 125 mm x 125 mm cross section and 600 mm total length. The first 350 mm of the duct serves as a flow conditioner, where inlet gases pass sequentially through perforated stainless steel plates, a 30 mm layer of 3–5 mm borosilicate beads and 40 mm thick, aluminum honeycomb with 6 mm cells before entering the test section. This configuration was tested with hot-wire anemometry, at atmospheric pressure and found to provide steady flow that was uniform to within ± 3.5% at the duct outlet.

The last 250 mm segment of the duct is used as the test section. Flat samples are located vertically at the midplane of the duct with both

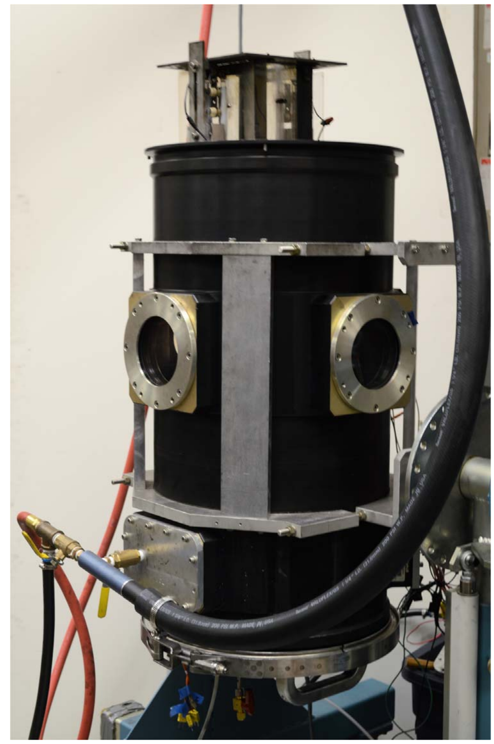

Fig. 1. Pressure chamber.

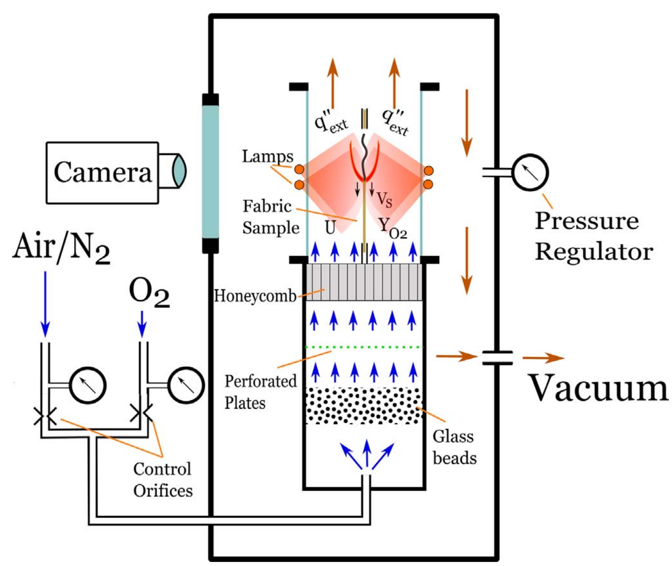

Fig. 2. Schematic of experimental apparatus.

sides exposed to the flow. During the present experiments two materials were tested: a single layer of Nomex HT90-40 (Stern and Stern Industries Inc., Hornell, NY, USA) and a single layer of a fabric blend made of 29% Cotton, 31% Nylon and 40% Nomex (Magnafabrics, Denton, NC, USA). Nomex is the registered name for a flame resistant and high temperature resistant fabric made by DuPont [12]. It is made from a synthetic aromatic polyamide polymer and its structure is composed by long strong flexible chains that compose the fibers. Given its structural characteristics, Nomex does no melt, drip or sustain combustion in normal air conditions however when exposed to high temperatures pyrolyzes and leaves a char residue. The area density for the Nomex HT90-40 and the blend fabric are 24.41 and 20.72 mg/cm^2, respectively. Both of these materials, pure Nomex and the fabric blend, are characterized as fire resistant and have been studied previously by the senior author laboratory [10] in the context of understanding the