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Contemporary technologies of early detection of fire in space vehicles

A.A. Vasiliev[a,*], G.Yu. Grigoriev[a], A.S. Lagutin[a], S.S. Nabiev[a,*], A.V. Pisliakov[a], N.N. Samotaev[b], A.V. Sokolov[c]

[a] National Research Centre "Kurchatov Institute", Russia
[b] National Research Nuclear University MEPhI, Moscow, Russia
[c] LLC Delta-S, Moscow, Russia

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ABSTRACT

A fairly reliable method of fire detection at an early stage is suggested and proved. The method is based on the monitoring of the air chemical composition, which changes strongly due to thermal decomposition (pyrolysis) of overheated combustible materials that are starting to smolder. It is at this stage of incipient fire that adequate measures can be taken for fire extinction with simple tools or, in the case of overheating of electrical equipment, for switching off this equipment automatically using a signal from the fire protection system thereby eliminating the fire hazardous situation. Fire detectors and microcontrollers are designed. These gas fire detectors are particularly suitable at the objects with active ventilation, for example, at space vehicles.

1. Introduction

The problems of fire safety in Space vehicles are under intense discussions now, a number of international research programs are ongoing [1–3]. Fire detectors of different types, which are currently in wide use in industrial safety systems and on maintenance of domestic and nondomestic premises, provide reliable fire detection only at the intense burning stage of fire, i.e. on intensive smoldering of combustible materials and on open flame stages. The operation principle of these fire detectors is based on different physical effects, such as: light scattering on fume particles or on air density fluctuation, ion capture by fume particles, change of resistance of temperature sensor, etc.

A fairly reliable method of early stage fire detection is the monitoring of the air chemical composition, which changes strongly due to thermal decomposition (pyrolysis) of overheated combustible materials that are starting to smolder. These methods of the detection of pyrolysis products were suggested in [4–13]. It is at this stage of incipient fire that adequate measures can be taken for fire extinction with simple tools [14,15] or, in the case of overheating of electrical equipment, for switching off this equipment automatically using a signal from the fire protection system thereby eliminating the fire hazardous situation. The presence of gases released at this initial stage of burning (smoldering) is determined by the composition of combustible materials, though in most cases it is possible to distinguish the main gas components typical for early stage of fire [16–18].

The most commonly used devices that currently used as a tool for early detection of fire are gas fire detectors (GFD) equipped with sensing elements capable of detecting gases released on smoldering or burning of different materials. It is important to stress that GFDs can detect the initial process of burning using the results of analysis of the ambient air composition and changes in the concentrations of gases that exceed the preset threshold; this threshold for most of taggant gases (CO, hydrogen, hydrocarbons, etc.) is by two to four orders lower than at the open flame stage and is equal to several tens of ppm.

2. Part 1. Preferable detectors for early stages of fire

Comparative tests of fire detectors of different types carried out in standard fire chambers of the All-Russian Institute of Fire Protection in 2012–2014 (in chambers sized (10 ± 1) m (length); (7 ± 1) m (width); (4.0 ± 0.2) m (height), see Fig. 1) confirmed explicitly the advantage of gas fire detectors in comparison with smoke fire detectors of different types and designs.

It was found that GFDs react much faster to the factors of fire at the initial stage (smoldering fire source). In this connection, it was suggested to extend appreciably the area of their application (Russian standard SP 5.13130.2009), taking into account the detection capability of these instruments.

Comparative fire-response tests of gas fire detectors (GFDs) and smoke fire detectors (SFDs) for standard test fires of the TF-2 (pyrolysis smoldering of wood), TF-3 (smoldering with cotton incandescence), and TF-9 (smoldering without cotton incandescence) types

* Correspondence to: Kurchatov complex of chemical and physical technology, Russia.
E-mail addresses: A-A-Vasiliev@yandex.ru (A.A. Vasiliev), nss2k7@yandex.ru (S.S. Nabiev).

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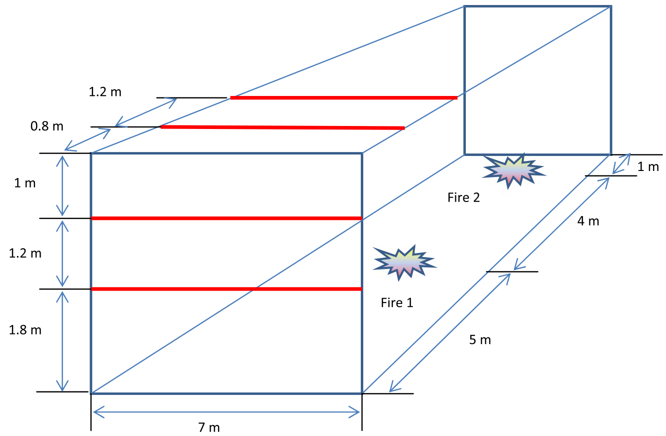

Fig. 1. Layout of measuring bars (indicated in bold) in a fire chamber. Spots "Fire 1"and "Fire 2"show the location of test fire points.

were made with the following equipment:

- Combined fire alarm devices (gas, heat) IP101/435-1-A1/2 "Expert" (Certificate of Conformity No. ROSS RU.BB05.N00865, Certificate of fire safety No. SSPB.RU.OP002.V01840) of modifications ("P") and ("N") produced by LLC "ETRA- spetsavtomatika" (Novosibirsk, Russia), http://www.etra.ru/, further in text: Ep - with a semiconductor sensor or Eh with an electrochemical sensor;
- Gas fire detectors IP 435-3A "SENSIS" with an electrochemical sensor (Certificate of fire safety No. SSPB. RU.OP073.V00272) produced by LLC "Delta-S" (Zelenograd, Russia), www.deltagaz.ru, further in text: Dl
- smoke fire detectors IP212-27SI TU7113-007-76000014-2007 produced by "System Engineering" (Russia), http://www.si2005.ru, further in text: Si.
- Smoke fire detectors Apollo 50007, further in text: Ap.

A multichannel recorder of the "Cassandra" model produced by LLC "Delta-S" (Zelenograd, Russia), www.deltagaz.ru, was used as a gas analyzer.

When carrying out fire tests of fire alarm devices according to GOST 53525, measurements of the optical smoke density were taken with 4 smoke optical densimetersIOPD-5 (hereinafter IOPD) produced by LLC SPEK, (S.Petersburg, Russia) http://spec.ru/main/.

Each of the4 measuring bars (indicated in red in Fig. 1) incorporated devices of one type from those listedabove.

More detailed information on the test program and results is given in reports by the All-Russian Institute of Fire Protectionof the RF Ministry for Emergency Situations, while in this paper, following [34], we will cite the results only of the key experiments.

2.1. Smoldering of cotton fabricTF-9

Cotton fabric being heated on an electric stove at the temperature of about 250 °C was used as a fire source situated in the center of the fire chamber ("Fire 1" in Fig. 1). It was detected that the carbon monoxide concentration begins to rise earlier than the smoke density, is sustained for a longer time and takes more to decline (see Fig. 2a and b).

An actuation sequence of fire alarm devices and actuation time are summarized in Table 1 (see the symbolic notation above).

As can be seen, the first to come into action were fire alarm devices with electrochemical sensors located on the ceiling. Only two out of eight smoke detectors were activated. Types of activated alarm devices: SFDs –21%, GFDs –79%.

2.2. Smoldering of cotton fabricTF-3

In this experiment, a cotton wick complying with section A.1. of GOST R 53325 was taken as a fire source. However, in order to complicate the task, only 9 yarns were taken out of the wick, the fire source was brought to the far-off wall from the fire alarms ("Fire 2" in Fig. 1). The complete duration of the experiment was of 2468 s. Variations of the carbon monoxide concentration and the smoke density for two measuring bars are plotted in Fig. 3a and b.

It is significant that in the course of the experiment no SFDs came into action, while the amount of activated GFDs was of 68%!.

2.3. Pyrolytic smoldering of wood material (TF-2)

Fire source: wooden bars being heated on an electric stove at the temperature of about 350 °C brought to the far-off wall from the fire alarms ("Fire 2" in Fig. 1). The complete duration of the experiment was 2532 s. An actuation sequence of fire alarm devices and actuation time are summarized in Table 2 (see the symbolic notation above).

As can be seen, the first to come into action were fire alarm devices with electrochemical sensors located on the ceiling. The greatest number of activated SFDs was those located on the wall. Types of activated alarm devices: SFDs–31%, GFDs–69%.

2.4. Smoldering of cotton fabric with a deterrent as a ceiling beam TF-3

For this experiment, a beam was adjusted on the fire chamber ceiling 1.5 m away from the far-off wall according to Fig. 1. The fire source was placed within 8 m from the far-off wall. The fire source was made of a smoldering 30-yarn wick. The complete duration of the experiment was 2131 s

Variations of the carbon monoxide concentration and the smoke density for two measuring bars are plotted in Fig. 4a and b.

An actuation sequence of fire alarm devices and actuation time are summarized in Table 3 (see the symbolic notation above).

Gas fire detectors have been found to give a faster response to fire factors at the initial stage (glowing spot); in this connection, it was suggested in SP 5.13130.2009 to increase appreciably their application range, taking into account their detectability.

In all the experiments, all of the gas fire detectors (GFDs) came into action regardless of their location (a ceiling, a wall). At the same time, not all of the smoke fire detectors (SFDs) were actuated. It should be noted that SFDs located on the ceiling failed to come into action at a low capacity of the fire spot (pyrolysis), possibly due to the smoke cooling down and reduced speed of its movement which impaired the conditions of its entering into the smoke box.

In the course of the test spot capacity decrease, the time of a FD response increased due to a decrease of the general energy performance of the process. In the test spots with the minimum capacity (experiment No. 9: smoldering of cotton wicks) 4 GFDs came into action on the wall and on the ceiling, and no SFDs were actuated.

The character of the smoke distribution is related to the thermal convective column power: as the capacity the fire spot declines, the thermal column power becomes insufficient for transportation of smoke particles to all of the SFDs which results in a smaller number of actuated SFDs and increased response time.

The character of filling the room with carbon monoxide gas (CO) is nearly uniform, with a certain priority towards a ceiling on the fire spot capacity increase, that is, we may speak about a convective-and-diffusion scenario of the room spatial filling with carbon monoxide, which means a possibility of placing GFDs not only on a ceiling, but also on a wall.

At its initial stage, fire usually takes four main steps: thermal destruction (smoldering) of solid combustible material, smoke release, flame with smoke, and open flame. Detecting the fire at the first step