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FIRE SAFETY EXPERIMENTS ON "MIR" ORBITAL STATION

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Introduction

The actuality of investigating combustion of various substances under microgravity is related to increasing fire hazard probability on spacecrafts. Higher power levels of onboard power systems of long-life space station under development, first of all of the International Space Station (ISS) "Alpha", and fulfillment of scientific experiments and technological operations employing high temperatures, require additional measures on preventing fires. The main trends of investigations, required for solution of this problem, were discussed at IAF-94 in Moscow [1].

The process of heterogeneous combustion of most materials under zero-g without forced motion of air is practically impossible. However, ventilation is required to support astronauts' life and cool equipment. The presence of ventilation flows in station compartments at accidental ignition can cause a fire. An additional, but exceedingly important parameter of the fire risk of solid materials under zero-g is the minimum air gas velocity at which the extinction of materials occurs. Therefore, the conception of fire-safety can be based on temporary lowering the intensity of ventilation and even turning it off.

To substantiate the conception suggested, quantitative data are required. Short-time realization of microgravity on drop towers and flying laboratories not always enables obtaining of reliable results. It is expedient to study the limiting conditions of combustion by this way only in the case of gas-phase burning of solid materials. If combustion occurs on the surface of materials, then laboratory simulation of microgravity not limited by time seems to be a more effective approach.

The essence of the approach consists in suppression of free convection that is practically absent in the case of microgravity. The intensity of free convection in combustion of a sample with the characteristic dimension d is characterized by the Grashof number:

$$Gr = g\beta\rho^2 d^3 \Delta T/\mu^2 = g\rho^2 d^3 \Delta T/\mu^2 T.$$

It follows from the Grashof number expression that convection can be suppressed on the ground by reducing the air density ρ, i.e. the pressure value. Besides, the influence of free convection can be decreased additionally by placing a burning sample between two horizontal plates. To simulate the process of combustion in forced motion of gas, the experiment should be performed at the same Reynolds number and oxygen concentration as on the orbital station. To realize the approach described, a laboratory experimental device was developed on which experiments are being currently performed. As an example, Fig. 1 shows results obtained from investigation of gas-phase combustion of acrylic plastic (PMMA) on a drop tower and simulation of diminished gravitation on the laboratory device. The range of the applicability of these approaches can be determined only through space experiments.

Therefore, the information on the limiting conditions of combustion under natural conditions is needed from both scientific and practical points of view. It will enable to judge about the reliability of results of ground-based investigations and develop a conception of fire safety of inhabited sealed compartments of space stations to by provided be means of nontraditional and highly-effective methods without both employing large quantities of fire-extinguishing compounds and hard restrictions on use of polymers.

In this connection, an experimental installation was created to study the process of heterogeneous combustion of solid non-metals and to determine the conditions of its extinction under microgravity [2]. This installation was delivered to the orbital station "Mir" and the cosmonauts Viktorenko and Kondakova performed initial experiments on it in late 1994.

Experimental Installation and Procedure of Experiments

The experimental installation is shown in Fig. 2. The installation consists of a combustion chamber with an electrical systems for ignition of samples, a device for cleaning air from combustion products, an air-suction unit, air pipes and a control panel.

The combustion chamber is the basic component of the installation, it is a channel of rectangular section (150 by 80 mm) which is 320 mm in length. The chamber has two rotatable devices in the form of drums on which experimental samples are attached, six samples on each drum. The chamber has two rectangular windows to visualize the process and record it on a video tape. They are arranged on its lateral surfaces, perpendicular to each other. At the inlet of the combustion chamber, a safety mesh and removable metallic shutter are installed. The igniter is a spiral electric heater. There are two igniters in the combustion chamber, one of which is reserval.

The air-suction unit is a suction fan with a flow regulator; it provides preset velocities of the incoming flow. The installation employs a so-called open scheme, i.e. the gas mixture leaving the chamber is filtered and enters the habited compartment of the space station. The installation is controlled from the control panel.

The whole experiment is controlled by telemetry and recorded with two video cameras located at two different places. Besides the picture, parameters are recorded to determine the velocity of the air flow incoming to the samples, the time points of switching on/off the devices, etc. The combustion chamber temperature is also controlled.

An experiment is conducted as follows. The shutter is removed from the combustion chamber. The sample to be tested is installed along the centerline of the chamber with the rotatable devices. Power is supplied to the control panel. The suction-fun is turned on and air motion in the chamber required for ignition is established. Then, the ignition system is turned on and the hot spiral is brought to the sample. When flame appears, it is removed and a required flow regime is established by means of the air-suction unit. The velocity of the incoming flow can be changed in experiment from its maximum value of 20 cm/s down to zero. When the combustion of sample is over, the combustion chamber is ventilated with the maximum air flow rate. After that, a similar procedure is performed with the next sample, etc.

The experimental procedure described was developed on the ground with an analogue of the space installation.

Objectives of Investigation

In the initial series of experiments, 12 samples were burnt. On one of the drums, 6 samples of cotton (which is a representative of smouldering materials) were fixed, and on the other, 6 samples of PMMA (burning in a gas-phase regime) were fixed. The PMMA samples were plates of 1 by 8 by 60, 2 by 8 by 60 and 3 by 8 by 60 mm dimensions. The cotton samples were cords with metallic bases inside.

The main objectives of experiments of this series were as follows:

a) verification of the reliability of the installation in orbital flight;

b) verification of the experimental procedure;

c) investigation of combustion of two types of materials under microgravity at various velocities of the incoming air flow.

Tentative experimental results

Experiments with each smouldering material sample were conducted at fixed velocities of the incoming flow. Results were obtained for the velocities of 20, 12, 5, 3 and 2 cm/s.

In the experiment with the last (sixth) sample, it had been planned to turn the suction-fan off after its ignition, i.e. to reduce the velocity of the incoming flow down to zero; however, this plan failed for some technical reasons. Tentative results of the tests are given in Table 1.

Table 1

Smouldering material test results

Sample number	1	2	3	4	5	6
Air flow velocity, cm/s	20	12	5	3	2	?
Ignition time, s	3	2	4	3	3	2
Combustion time, s	14	18	20	21	21	22
Burning rate, mm/s	4.3	3.3	3.0	2.9	2.9	2.7

Experiments with the first two PMMA samples of 1 mm thickness were performed with constant velocities of the incoming air flow of 3 and 2 cm/s. In experiments with the remaining four samples of 2 and 3 mm thickness, the velocity was reduced from 2 cm/s down to zero. After the samples became charred half of their lengths at the constant velocity of the incoming air flow of 2 cm/s, the suction-fan was turned off. In doing so, the flame changed for about 10 to 15 s. It became spherical and changed its color from yellow-orange to light-blue. Before the flame extinction, flashes on a background of fading light-blue fluorescence were observed. Tentative results of the tests are given in Table 2.

Table 2

PMMA test results

Sample number	1	2	3	4	5	6
Air flow velocity, cm/s	3	2	2→0	2→0	2→0	2→0
Ignition time, s	8	4	8	4	2	5
Total combustion time	82	146	89	101	153	49
Combustion time at preset flow velocity, s		131	39	70	122	-
Extinction-out time, s	-	-	15	10	7	49
Burning rate, mm/s					0.03	
Sample thickness, mm	1	1	2	2	3	3

The tests were performed at the air pressure in the compartment of about 660 mm mercury. The oxygen partial pressure of 152 mm mercury corresponded to its 23 % concentration.

The results presented in this work will be refined and analyzed after the video tapes are returned to earth and the video recording of the experiments is treated by computer.

Conclusion

The aims of the pilot experiments on combustion of materials aboard the "Mir" space station has been mainly achieved. The installation has demonstrated its suitability for conducting investigations of combustions of non-metal structural materials under microgravity. The results obtained show that combustion of materials ceases when the velocity of forced flow diminishes, i.e. there is a limiting admissible velocity of ventilation flows at which arising combustion zone extinguishes. The work accomplished is a substantiation to proceed experiments on investigation of parameters of combustion of non-metal structural materials on both the existing "Mir" space station and the ISS "Alpha" under development.

References

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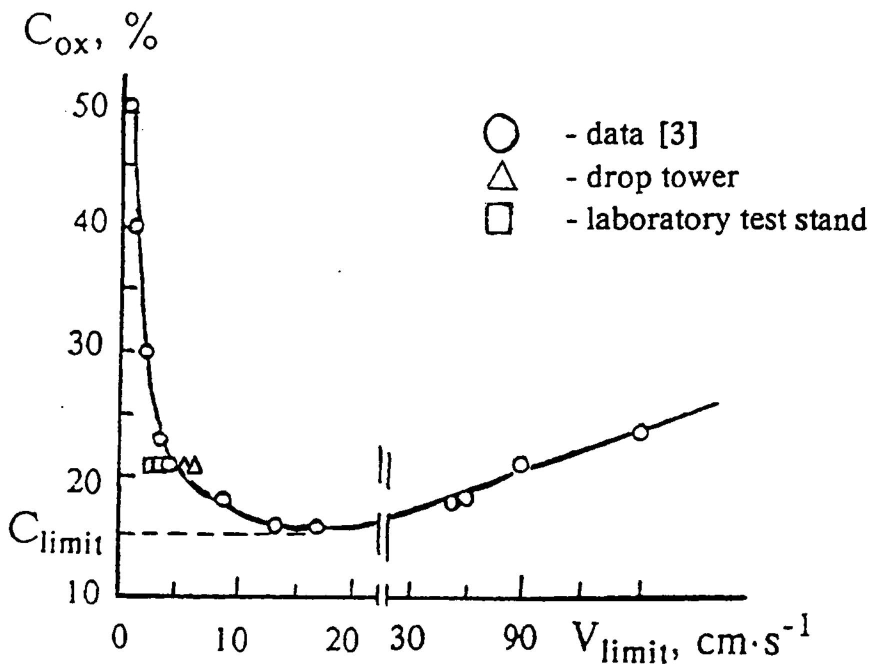

Fig.1. Limiting flow velocity for PMMA combustion versus oxygen concentration

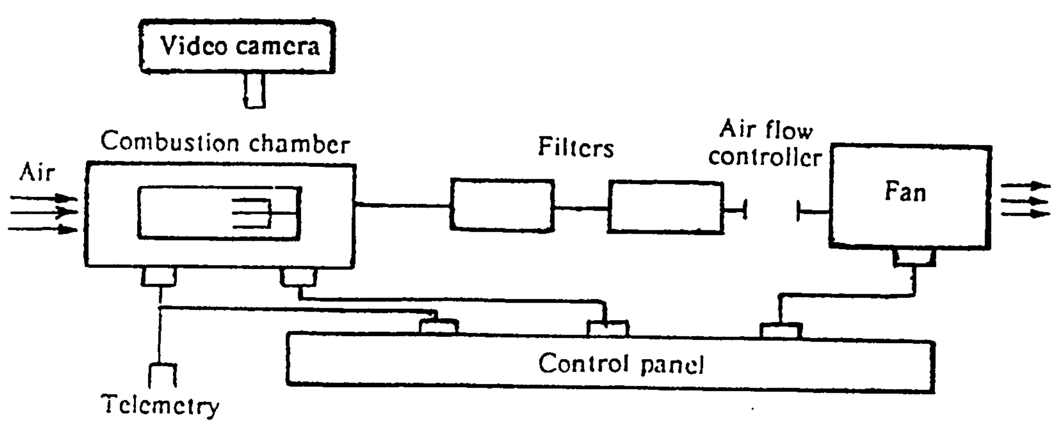

Fig.2. Space experimental installation