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Combustion

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20.1 Introduction

Combustion is a rapid, self-sustaining chemical reaction that releases a significant amount of heat and as such involves elements of chemical kinetics, transport processes, thermodynamics and fluid mechanics.

Combustion is a key element in many technological applications in modern society. In itself, combustion is one of the most important processes in the world economy. Combustion underlies almost all systems of energy generation, domestic heating and transportation propulsion. It also plays a major role at all stages in the industrial transformation of matter, ranging from the production of raw materials to the complex assembly of industrial products. Although combustion is essential to our current way of life, it poses great challenges to society's ability to maintain a healthy environment and to preserve vital resources for future generations. Improved understanding of combustion will help us to deal more effectively with the problems of pollution, global warming, fires, accidental explosions and the incineration of dangerous waste. In spite of extensive scientific research since more than a century, many fundamental aspects of combustion are still poorly understood.

The objectives of scientific research on microgravity combustion are initially to increase our knowledge of the fundamental combustion phenomena that are affected by gravity, then to use the research results to advance science and technology related to combustion in terrestrial applications and finally to tackle questions of security related to fires on board spacecraft. The following review articles [1–5] are to be consulted, for those who would be interested to look further into the role of microgravity in combustion research.

20.2 Why Combustion Is Affected by Gravity?

Microgravity combustion scientists undertake experiments both in ground-based microgravity facilities and in orbiting laboratories and study how flames behave under microgravity conditions.

Microgravity research allows the conduct of new experiments in which buoyancy-induced flows and sedimentation are virtually eliminated. Combustion usually involves large temperature increases resulting in a consequent reduction in density, ranging from a factor of two to ten depending on the situation. As a result of this density change, the combustion processes in normal gravity are usually strongly influenced by natural convection. The rise of hot gas creates a buoyancy-induced flow favoring gas mixing from the fuel, oxidizer and combustion products. Under conditions of reduced gravity, natural convection is cancelled (or greatly reduced), and therefore the characteristics of combustion processes can be profoundly altered.

The reduction of buoyancy-induced flows has several features that are particularly useful for fundamental and applied scientific research on combustion. By eliminating the effects of natural convection, a quiescent environment is created, conducive to more symmetrical results. This facilitates comparisons with numerical modeling results and with theories. Furthermore, the elimination or drastic reduction of buoyancy-induced flows can reveal and highlight weaker forces and flows that are normally masked, such as electrostatics, thermocapillarity and diffusion. Lastly, the elimination of disturbances caused by buoyancy forces can increase the duration of experiments, thus allowing the examination of the phenomena over larger time scales.

For purposes of simplification, the numerical models developed in combustion research often assumed that the mixture of the initial components is homogeneous. Sedimentation affects combustion experiments involving drops or particles, since the components with the highest density will be driven down into the gas or liquid, and hence their movement relative to other particles creates an asymmetric flow around the falling particle. The presence of these concentration gradients in the mixture before combustion complicates the interpretation of experimental results. In normal gravity conditions, experimenters must implement devices to stabilize and homogenize dispersed media, for example, supports, levitators or stirring devices. In microgravity, gravitational settling is nearly eliminated, allowing the stabilization of free droplets, particles, bubbles, fog and droplet networks for fundamental studies on ignition and combustion in heterogeneous media.

To date, scientific research in combustion has shown major differences in the structure of different flames burning either in microgravity or under normal gravity. Besides the practical implications of these results in terms of combustion efficiency, pollutant control and flammability, these studies have established that a better understanding of the sub-mechanisms involved in the overall combustion process is possible by comparing the results obtained in microgravity with those obtained in normal gravity.

20.3 Reduced Gravity Environment for Combustion Studies

While microgravity is the operational environment related to Earth-orbiting space laboratories, it is important to note that "ground-based facilities" allowing gravity reduction also serve the scientific community and enable relevant combustion studies to be carried out. Experiments conducted in suborbital sounding rockets, during the parabolic trajectory of an aircraft laboratory, and free-fall drop towers, significantly complement the limited testing opportunities available aboard the International Space Station. In fact, the contributions of research conducted in these so-called ground-based microgravity facilities have been essential to the acknowledged success of microgravity combustion research. These helpful facilities allow us to consider microgravity as a tool for combustion research, in the same way as an experimenter can vary pressure or temperature; microgravity can also act on the gravitational acceleration parameter. Additional contributions of high value to microgravity combustion research come from "normal-gravity" reference ground tests and from analytical modeling.

Some results can be cited here to illustrate how so many combustion processes are affected by gravity. As an example of spectacular results, stationary premixed spherical flames (i.e., flame balls), whose existence was predicted by theory but had never been confirmed by any experiments in normal gravity, were observed uniquely in microgravity [6]. Recently, flame extinguishment experiment conducted on droplet combustion has demonstrated radiative and diffusive extinction, combustion instabilities, lower flammability limits and unexplained vaporization after visible flame extinction. This behavior ever brought back before leads to the possible existence of cool-flame chemistry [7]. The inhibition of flame spreading along both solid and liquid surfaces is of primary importance in fire safety. Experimental studies have revealed major differences between normal and reduced gravity conditions, concerning the ignition and flame spreading characteristics of solid and liquid fuels.

While most microgravity combustion experiments have been conducted in dedicated and unique experimental apparatus, the recent commissioning of the Combustion Integrated Rack (CIR) in the FCF experimental rack (Fluid Combustion Facility) aboard the ISS should enable more investigators to have access to this microgravity environment [8].

20.4 Conclusions

Compared to experimental combustion studies in laboratories, the number of microgravity experiments is small. Nevertheless, important discoveries have already emerged from microgravity combustion investigations. The numerous facilities existing now, both "ground-based" microgravity facilities and on board the ISS, made available to the scientific community by space agencies, suggest that new microgravity combustion experiments will significantly advance fundamental understanding in combustion science. It is hoped that this will help to maintain a healthy environment and preserve vital resources for future generations.

References

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