

EVALUATION OF THE WATER SPRAY IMPACT ON PREMIXED HYDROGEN-AIR-STEAM FLAMES PROPAGATION

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INTRODUCTION

In the hypothetical case of a severe accident in a nuclear reactor with core meltdown, the interaction of the hot core with the cooling water can generate large amounts of hydrogen. It can also result due to oxidation of metals present in the corium pool or in the basemat during the molten corium-concrete interaction phase. This hydrogen is transferred into the containment (and transported therein) by convection loops arising essentially from condensation of steam released via the RCS break or during corium-concrete interaction. Depending on mixing in the containment atmosphere, the distribution of hydrogen is more or less homogeneous. If considerable hydrogen stratification exists, then local concentration of hydrogen may become substantial, and may exceed the lower flammability limit. In case of ignition, the subsequent pressure loads may adversely affect the containment.

To preserve the containment integrity, several safety systems could be used. Among them, spray systems and hydrogen Passive Autocatalytic Recombiners (PARs) have been extensively studied at Institut de Radioprotection et de Sûreté Nucléaire (IRSN) in France.

The spray primary function is to remove heat and condense steam in order to reduce pressure and temperature in the containment building. In case of hydrogen release inside the containment, sprays homogenize the hydrogen distribution and may lead to “de-inertization” of the mixture through the condensation of steam on water droplets.

To keep the containment atmosphere inert during the in-vessel hydrogen production phase, Severe Accident Management Guidelines (SAMG) recommend postponing the spray system activation at least 6 hours after the beginning of core degradation. During this time, hydrogen concentration would be reduced by recombination. In case of ignition, the water sprays can affect the flame propagation. Indeed, the role of water sprays on premixed flame propagation is complex and depends strongly on several parameters such as the liquid water fraction, droplets distribution, droplets size.

The aim of the present work is to bring preliminary results on the effect that the water spray could have on premixed hydrogen-air-steam flame behavior in case of combustion.

EXPERIMENTAL SET UP

Laminar and turbulent flame propagation regimes are considered and two highly instrumented facilities are used.

The behavior of laminar premixed hydrogen-air-steam in presence of water spray has been investigated experimentally in a 60-L (i.d. 48-cm) spherical chamber. It consists of a spherical stainless steel vessel equipped with 4 quartz windows (100 mm diameter, 50 mm thickness). The maximum operating pressure and temperature are respectively 50 bars and 250°C. Two tungsten electrodes were located along a diameter of the sphere. Instrumentation includes pressure transducers (Kistler), pressure gauges (MKS) and gas sample lines to analyze the mixtures by GC/MS. The visualization of the flame was obtained via a Schlieren diagnostic previously described [1]. It is coupled with a numerical high speed camera (Photron APX). Before each test, the chamber was vacuumed and the residual pressure was lower than 3 Pa. The gases were introduced using the partial pressure method. The synthetic air consisted of 21 vol. % O₂ + 79 vol. % N₂.

For turbulent flames, experiments are carried out in the vertical facility ENACCEF. This facility consists of a 3.3 m-long stainless steel acceleration tube and a larger cylindrical dome volume whose top is at the height of 5.0 m. The inner diameter of the acceleration tube is 0.154 m and for the dome 0.738 m. The acceleration tube is equipped with two tungsten electrodes at 0.138 m from the bottom of the facility as a low-energy ignition device.

The instrumentation of the facility consists of 16 UV-sensitive photomultipliers mounted across silica windows located along the acceleration tube and the dome wall and nine pressure transducers (7 PZT and 2 PCB transducers). Gas sampling is performed at six different locations in the acceleration tube and one in the dome.

RESULTS

The experimental results show that ignition of initial inert gas mixture is possible when water spray is activated.

Moreover and according to the hydrogen concentration and to the water droplet size, different behaviors have been identified:

- √ For large droplets ($d > 250 \mu\text{m}$) and regarding to the ratio s between flame and droplet velocities, two situations have been distinguished: i) for high values of s ($s \gg 1$) no significant effects have been observed. ii) for small values of s ($s \sim 1$), water droplets evaporation occurs and flame wrinkling is observed.
- √ For small droplets, flame front is wrinkled due to the turbulence induced by water droplet especially for low H_2 concentration.

Even if the use of spray enhances the turbulence, sprays-premixed flame interaction leads to low pressure values. On the other hand and due to the induced turbulence, it has been observed that sprays increase the pressure slope for lean hydrogen-air mixtures.

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