CFD Simulations of Hydrogen Deflagration in Slow and Fast Combustion Regime

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Highlights

- A new CFD model of hydrogen deflagration in the ENACCEF facility is proposed.
- Turbulence modelling using the Transition SST model gives satisfactory results.
- The heat loss in the ENACCEF facility should include radiation and convection.

1. Introduction

The severe accidents at Three Mile Island (USA) in 1979 and more recently at Fukushima (Japan) in 2011 showed the importance of chemical hydrogen hazard in nuclear reactors. The risk of hydrogen release into the reactor's containment is related directly to the Light Water Reactors (LWRs) in which normal water is used as the coolant and neutron moderator. In the case of nuclear core overheating hydrogen can be produced as a result of cooling water break down in the high temperature of 2200 ^{o}C. Finally, a flammable mixture of hydrogen and air present in the containment can be formed. The flammability range of hydrogen and air at the atmospheric pressure and ambient temperature are between 4 and 75 vol.%. An ignition of such a flammable mixture pose a deflagration with the characteristic subsonic speed of the reaction front.

This work presents CFD results for hydrogen deflagrations in the ENACCEF facility (Orlean, France). The ENACCEF facility is a vertical apparatus composed of two parts: an acceleration tube and a dome. The corresponding heights of these two elements are 3.2 m and 1.7 m, and their internal diameters are 0.154 m and 0.738 m, respectively. The experiments were performed in the frame of the SARNET2 EU project by *Centre National de la Recherche Scientifique (CNRS)* in collaboration with *Institut de Radioprotection et de Sûreté (IRSN)* [1-2]. The effect of the following blockage ratios: BR = 0, 0.33 and 0.63 on flame propagation and pressure dynamics in uniform mixture of hydrogen (13 vol.%) and air (87 vol.%) were examined in that project.

A CFD model of hydrogen deflagration in the ENACCEF facility has been developed to better understand the phenomenon and to validate the obtained solution by a comparison with the experiments. Our previous work presented CFD results for the blockage ratio BR = 0 (without obstacles). These prior results were obtained for the standard k-ε turbulence model and adiabatic conditions [3]. The present CFD model has been developed applying 4-equation turbulence model and taking into account heat loss to the environment by radiation. The computations have been performed for the blockage ratios BR = 0 and 0.63. The time profiles of the axial flame front position and the absolute pressure in the ENACCEF facility have been obtained. These new results have been compared to the experimental results provided by IRSN.

2. Methods

The CFD model was defined in ANSYS Fluent 18.2. The equations for continuity, momentum, energy and the progress variable were solved in a 2D axisymmetric geometry. The *Transition SST* turbulence model and the discrete ordinates (DO) radiation model were used for modelling turbulence and radiative heat transfer, respectively. The Zimont turbulent flame speed closure models were employed in the computations. The laminar flame speed was calculated from Liu and MacFarlane correlation which was implemented into ANSYS Fluent by a User-Defined Function [4]. Ignition of the mixture was initiated by patching the progress variable equal to 1 into a circular region of 0.003 m radius around the ignition point (axial position 0.138 m).

3. Results and discussion

Figure 1 compares the experimental axial flame front position (AFFP) profiles obtained for BR = 0 (RUN 160) and 0.63 (RUN 153) to the profiles predicted with our previous and present CFD models. The comparison shows that the current CFD model captures the AFFP profiles very well.

Figure 2 compares the experimental absolute pressure profiles obtained for BR = 0 and 0.63 to the profiles predicted with our previous and present CFD models. The comparison demonstrates that the onset of pressure rise is predicted too early for the experiment with BR = 0.63 (RUN 153). Moreover, it is clear that the two CFD models overestimate the maximum absolute pressure in the ENACCEF facility. Since the calculations for BR = 0.63 are still in progress, the results are presented for adiabatic conditions. This is why the plateau is observed at the end of the calculated pressure profiles (RUN 153).

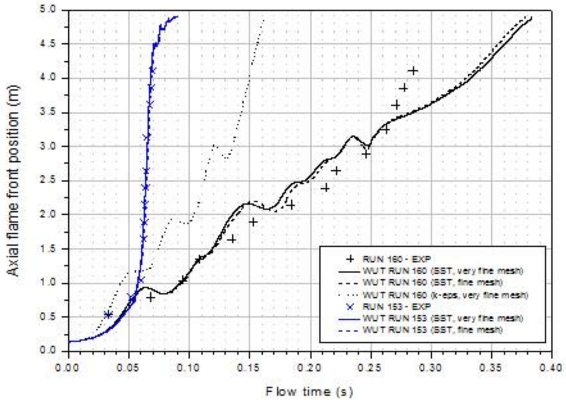

Figure 1. Comparison of the axial flame front position profiles for the hydrogen-air deflagration in the ENACCEF facility. WUT – our CFD results, EXP – experimental results.

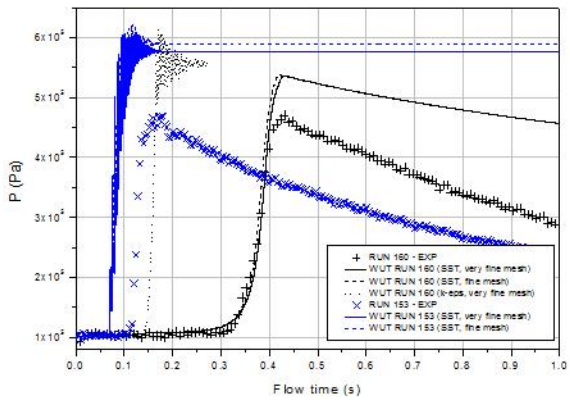

Figure 2. Comparison of the absolute pressure profiles for the hydrogen-air deflagration in the ENACCEF facility. WUT – our CFD results, EXP – experimental results.

4. Conclusions

The results of this work show that the proposed CFD model gives satisfactory results for modelling deflagration in the ENACCEF facility. The accuracy of our present CFD model using the Transition SST turbulence model is better than our previous CFD model using the standard k-ε turbulence model. It is believed that the observed overestimation of the maximum pressure in the ENACCEF facility can be decreased if the convective heat loss is considered.

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Keywords
CFD; hydrogen hazard; deflagration; ENACCEF