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# CFD Simulation for Diluents Effect on the $H_2$ Flame Propagation in the ENACCEF Facility

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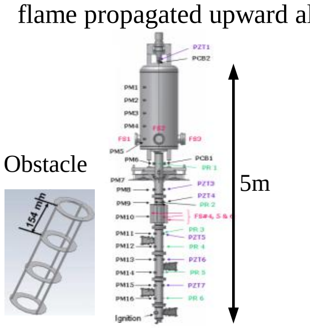
## 1. Introduction

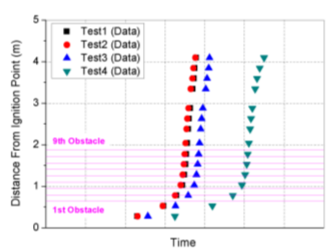
A numerical analysis result of severe accidents in APR1400 containment showed that steam was discharged into the containment before a hydrogen release from the reactor core [1]. It is necessary to know how the steam affects on the hydrogen flame propagation. Thus, a hydrogen flame propagation test in the ENACCEF facility with a blockage ratio of 0.63 was performed by adding 10%, 20%, and 30% diluents to the hydrogen-air mixture with a hydrogen concentration of 13% to investigate the steam effect on the hydrogen flame propagation [2]. The proposed CFD analysis methodology [3] based on a test data of a hydrogen flame propagation without diluents should be validated for the test data with diluents to enhance its applicability to a real plant.

## 2. Hydrogen Flame Propagation Test with Diluents

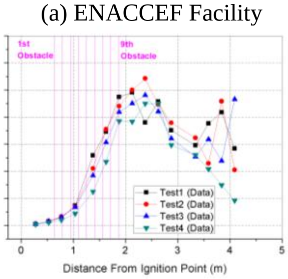
A $H_2$ flame propagation test (Fig. 1(a)) by varying an initial diluents concentration from 10 % to 30% (Table 1) was performed by IRSN [2]. Carbon dioxide and helium gases were used as diluents to a hydrogen-air mixture. The hydrogen was ignited at the bottom region and then its flame propagated upward along the test facility.



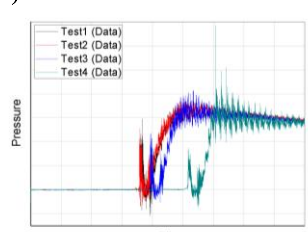

(a) ENACCEF Facility




(b) Flame Front Time of Arrivals




(c) Flame Speed




(d) Pressure Behavior (PCB2)

**Figure 1. ENACCEF Facility and Test Results**

Table 1. Initial Test Conditions with Diluents

| | $H_2$ Molar Fraction (%) | Air Molar Fraction (%) | Diluents Molar Fraction (%) |
|---|---|---|---|
| Test-1 | 13 | 87 | 0 |
| Test-2 | 13 | 77 | 10 |
| Test-3 | 13 | 67 | 20 |
| Test-4 | 13 | 57 | 30 |

Diluents : $CO_2$ and He

The test results show that the flame propagation slows down as the diluent concentration increases from 0% to 30% (Fig. 1(b)). In particular, the measured flame front time of arrival (TOA) after passing the first obstacle in Test-4 is about 45% later when compared to that of Test-1. This may be explained by the fact that a disturbance of the hydrogen-air chemical reaction rate is proportional to the amount of the diluent concentration. However, all flames in Test-1 to Test-4 are accelerated when the flames pass the nine obstacles, and produce a pressure build up (Fig. 1(c) and (d)). Thus, about a 34% difference of the flame speed between Test-1 and Test-4 around the first obstacle is decreased to about 18% difference when the flame arrives at the ninth obstacle. This means that the turbulence generation around the obstacles may decrease the diluent effect on the hydrogen flame propagation.

## 3. CFD Analysis

### *3.1 Grid Model and Flow Field Models*

A 3-dimensional grid model with a half symmetric condition representing the ENACCEF facility was generated by the hexahedral cells with a cell length of 2 - 10 mm. The generated cell number in the grid model was about 3,100,000. The wall condition with a constant temperature of 298 K was applied on the outer surface of the grid models. The spark ignition model was introduced to simulate a spark operation by the electric device in the test facility. The governing equations used in this study were the Navier-Stokes, the energy and the species transport equations with a coupled solver algorithm implemented in the CFX-13 [4]. A turbulent flow was modeled by the DES-SST turbulent model [4]. The turbulent flame closure (TFC) model with a model constant of A = 2.0 [4] was used to simulate the hydrogen flame propagation. The time step size for these CFD calculations was 0.005 - 0.1 ms to assure a CFL number below 1.0. The laminar flame speeds according to the hydrogen and diluent concentrations [2,3] were given as the input data of the TFC model in the CFD calculations.

### *3.2 Discussion on the CFD Simulation Results*

A comparison of the flame positions for Test-2 to Test-4 between the test and CFD results (Fig. 2) showed that the CFD results accurately predicted the test data with an error range of about 10% except the flame position at PM16 in Test-2. The flame position in the CFD result was defined as the instant when the gas temperature increased to about 850 K at the locations of PM1 to PM16. The CFD results for the flame positions at PM8 to PM14 in Test-4 (region A in Fig. 2) showed a different behavior when compared to the test results. This may mean that a flame acceleration in the CFD results started earlier than that of the test data.

The flame's fast passing through the obstacles gave rise to a compression effect, which increased the pressure up to about 1.5 - 2.0 bar in the CFD results. These calculated values accurately predicted the test results with an error range of about 40%. In addition, the predicted maximum pressures for Test-2 and Test-3 (Fig. 3) by the CFD calculations showed a good agreement within an error range of 10% when compared to the test results. However, the predicted maximum pressure for Test-4 showed about a 100% difference, and a different pressure behavior when compared to the test result. To find a reason for these differences, a detailed analysis on the CFD and test results including an uncertainty analysis of a pressure sensor should be performed.

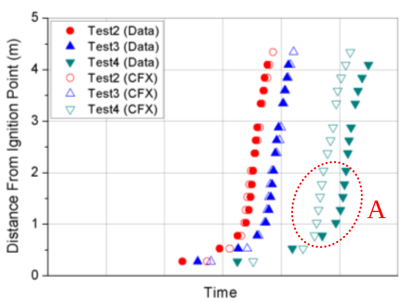
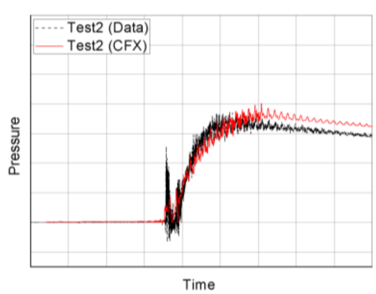
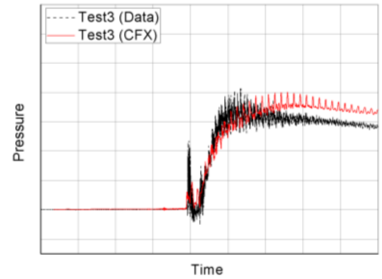


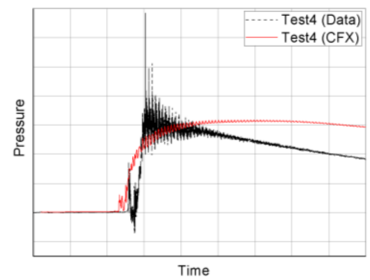

**Figure 2. Comparison of Flame Position between the CFD and Test Results (Test-2, Test-3, and Test-4)**




(a) Pressure Behavior at PCB2 (Test-2)




(b) Pressure Behavior at PCB2 (Test-3)




(c) Pressure Behavior at PCB2 (Test-4)

**Figure 3. Comparison of Pressure between the CFD and Test Results (Test-2, Test-3, and Test-4)**

## 4. Conclusion and Further Research

From the CFD simulation results for the diluents effect on the hydrogen flame propagation in the ENACCEF facility, we found that the CFX-13 with the TFC combustion model can accurately predict a hydrogen flame propagation if a laminar flame speed is chosen according to the hydrogen and diluent concentrations. However, to accurately predict the pressure behavior of the test result with 30% diluents, a detailed analysis on the CFD and test results will be performed.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. J. T. Kim, et al., "Numerical Analysis of the Hydrogen-Steam Behavior in the APR1400 Containment during a Hypothetical Total Loss of Feed Water Accident", *J. of Comput. Fluids Eng.*, Vol. 10, No. 3, 2005.
2. A. Bentaib and N. Chaumeix, "SARNET $H_2$ Combustion Benchmark; Specification of ENACCEF Tests", Technical Report, IRSN, 2011.
3. A. Bentaib, et al., "Final Results of the SARNET $H_2$ Deflagration Benchmark Effect of Turbulence of Flame Acceleration", *Proc. of 5$^{th}$ ERMSAR-2012*, Cologne, Germany, March 21-23, 2012.
4. Ansys, Inc., "CFX-13.0 Manual", 2011.