# CFD Analysis for a Hydrogen Flame Acceleration in the IRWST Facility

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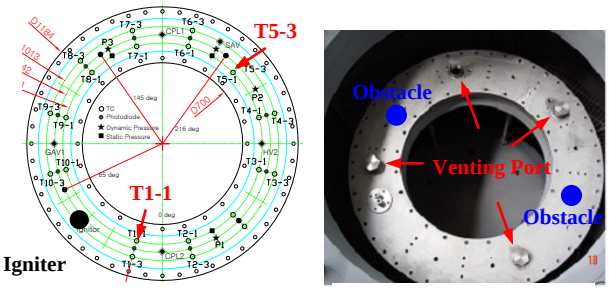
## 1. Introduction

A scaled-down experiment was performed to investigate the physical mechanism of the hydrogen flame acceleration and overpressure buildup in the IRWST annulus geometry by KAERI [1]. However, to evaluate the possibility of a hydrogen flame acceleration and transition from deflagration to detonation (DDT) in the APR1400 IRWST, a computational fluid dynamic (CFD) analysis with a validated combustion model on the basis of the scaled-down test results is needed. To develop the validated CFD analysis methodology, the CFD analysis should be performed against the experimental results with various conditions of hydrogen concentrations and geometry configurations.

## 2. $H_2$ Flame Acceleration Test in the IRWST Facility

The hydrogen flame acceleration test was performed using the scaled-down IRWST facility (Fig. 1) by varying the hydrogen concentrations of 11.8% to 18.6%, the presence of an obstacle, and the existence of a venting port [1]. Four venting ports with the diameter of 50 mm were initially covered by a plastic film. This film was ruptured when the pressure of the IRWST test facility was increased to about 0.8 bar from the initial value. Two obstacles with the width of 40 mm were installed, and its blockage ratio (Eq. (1)) is 0.92. In Eq. (1), D and d represent the width of the IRWST annulus and the obstacle, respectively. The inner and outer diameters of the IRWST facility with a height of 120 mm are 800 mm and 1080 mm, respectively.

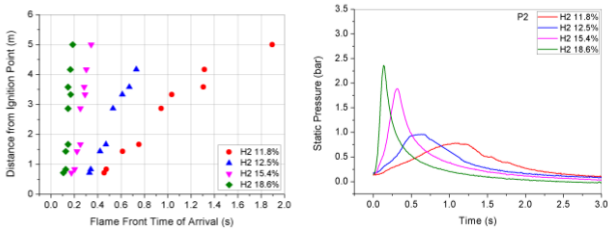
$$BR = 1 - (d/D)^2 \qquad (1)$$



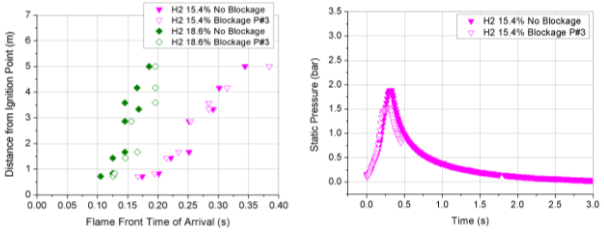

(a) Measurement and Igniter Locations

(b) Venting Port and Obstacle Locations

**Figure 1. Scaled-down IRWST Test Facility**




(a) Flame front TOAs and pressure variations according to $H_2$ 11.8% to $H_2$ 18.6% without venting ports and obstacles




(b) Flame front TOAs and pressure variations at $H_2$ 15.4% and $H_2$ 18.6% with venting ports and obstacles

**Figure 2. Experimental Results**

The IRWST test results (Fig. 2(a)) show that the measured flame front time of arrivals (TOA) difference between T1-1 and T5-3 is decreased from about 1.89 s to about 0.185 s and the measured overpressure at P2 is increased from about 0.78 bar to 2.36 bar as the hydrogen concentration increases from 11.8% to 18.6%. This may be explained by the fact that the higher combustion energy of the hydrogen-air chemical reaction induces the faster flame propagation, and results in the higher overpressure buildup. The presence of the venting port and obstacle does not give much effect on the measured flame front TOAs and overpressure buildup (Fig. 2(b)) because the venting port's diameter and the obstacle width are not large when considering of the geometry of the IRWST facility. In addition, the number of the venting port and obstacle are small.

## 3. CFD Analysis

The test results obtained with the hydrogen concentration of 11.8%, 15.4%, and 18.6% were chosen to compare with the CFD analysis results.

### *3.1 Grid Model, Initial and Boundary Conditions*

A 3-dimensional grid model simulating the IRWST facility was developed. A wall condition with a constant temperature of 293 K was applied on the outer surfaces of the grid model. In order to evaluate the effect of the cell length on the hydrogen flame propagation, three sensitivity calculations were performed by changing the cell length as 2.5 mm, 5 mm, and 10 mm (Table 1). The ignition model [2] was introduced to simulate the spark operation by the electric device in the test facility. The hydrogen concentrations of 11.8%, 15.4%, and 18.6% were given in the whole grid model as the initial condition.

**Table 1. CFD Sensitivity Calculation Conditions**

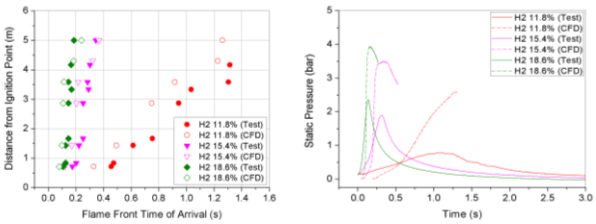
| $H_2$ | Cell Length [mm] | Time Step Size [ms] | Laminar Flame Speed [m/s] |
|---|---|---|---|
| 11.8% | 5 | 0.1 | 0.18 |
| 15.4% | 2.5, 5, 10 | 0.05, 0.1, 0.2 | 0.50 |
| 18.6% | 5 | 0.1 | 0.71 |

*3.2 Flow Field Models for Hydrogen Combustion*

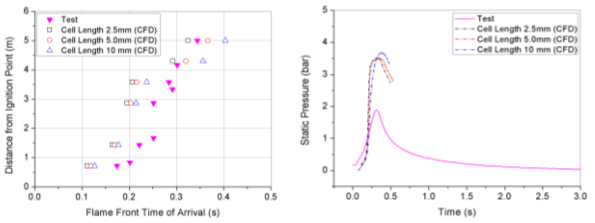
The governing equations used in this study were the Navier-Stokes, the energy and the species transport equations with a coupled solver algorithm implemented in the CFX-11 [3]. Turbulent flow was modeled by the DES-SST turbulent model [3]. The turbulent flame closure (TFC) model [3] with the model constant of 5.0 was used to simulate the hydrogen flame propagation. To find out a proper time step size in the transient calculation for the hydrogen flame acceleration, a sensitivity calculation with the time step size of 0.05 ms, 0.1 ms, and 0.2 ms (Table 1) was conducted.

*3.3 Discussion on the CFD Results*

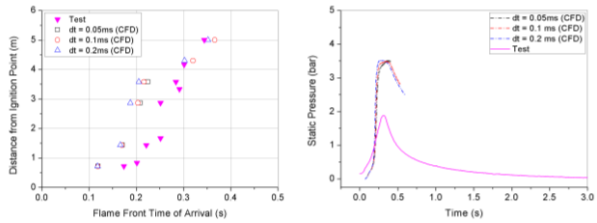
In regards to the CFD results for the hydrogen concentration of 11.8% to 18.6% (Fig. 3(a)), the calculated flame front TOAs by using the cell length of 5 mm and the time step size of 0.1 ms predict the test data with an error range of about ±30%. However, the calculated peak pressures at P2 overestimate the test data as much as about 0.7 to 2.0 times. The reason of these pressure differences between the CFD results and the test results may be explained by the fact that the time span of 0.01 s used in the test was a large value to capture the pressure behavior. Thus, the measured peak overpressure at P2 in the test results may be lower than the actual value occurred in the hydrogen flame acceleration. The mesh sensitivity calculation results for the hydrogen concentration of 15.4% (Fig. 3(b)) show that the predicted flame front TOAs and peak pressures at P2 are consistent with an error range of about ±30%. In addition, the sensitivity calculation results by changing the time step size (Fig. 3(c)) for the hydrogen concentration of 15.4% show the consistent flame front TOAs and peak pressures at P2 with an error range of about ±30%.




(a) Predicted Flame Front TOAs and Overpressure at P2 for $H_2$ 11.8%, 15.4%, and 18.6% (Cell Length: 5 mm, Δ t = 0.1 ms)




(b) Predicted Flame Front TOAs and Overpressure at P2 for $H_2$ 15.4% varying the Cell length as 2.5 mm, 5 mm, and 10 mm




(c) Predicted Flame Front TOAs and Overpressure at P2 for $H_2$ 15.4% varying the time step size as 0.05 ms, 0.1 ms, and 0.2 ms

**Figure 3. CFD Results**

## 4. Conclusion and Further Research

From the CFD analysis results for the IRWST test results, we know that the CFD analysis with the TFC combustion model and DES-SST turbulent model can reasonably simulate the hydrogen flame acceleration phenomena in the annulus geometry for various hydrogen concentrations of 11.8% to 18.6%. However, a detailed analysis to investigate the pressure differences between the CFD results and the test data should be performed.

## ACKNOWLEDGEMENTS

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