Flame Acceleration Tests with Hydrogen Combustions

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1. Introduction

According to the domestic and foreign regulations, a detonation or DDT (deflagration to detonation transition) by a hydrogen combustion should be prohibited to occur in a containment of a nuclear power plant[1,2]. A hydrogen control in the IRWST(In-containment Refueling Water Storage Tank) under a severe accident still remains a debatable issue to be solved in APR1400[3,4]. The characteristics of the hydrogen flame in the IRWST expected during the station black-out (SBO) and total loss of feed water (LOFW) accidents have been evaluated based on a sigma-lambda criteria from the simulation results by the numerical codes such as GASFLOW. And it was found that hydrogen mixture was non-flammable most of the accident time when the non-condensed steam was released into the free volume of the IRWST, but there existed a small period of time with a high possibility of a flame acceleration during the SBO accident because most of the steam discharged from sparger was well condensed[5]. Therefore, detail analysis and experiment of the hydrogen flame should be required to fix a DDT possibility by the hydrogen combustion in the IRWST of the APR1400.

Most experiments on the hydrogen combustion have been limited only to straight pipes or channels. However, the hydrogen flame acceleration phenomena in the IRWST with a closed annular path may be different from those in the straight path in respect to a centrifugal force and degree of freedom in flame propagation etc. So, an experiment of hydrogen combustion in a closed annular chamber is needed to find out the geometrical effect on the flame propagation and to validate the numerical results. KAERI has been performing the experiments of the hydrogen combustion in the IRWST. As the fist stage, flame acceleration tests with the hydrogen combustions are studied preliminarily for a circular straight pipe to confirm the characteristics hydrogen flame propagation, and to evaluate flame detection systems.

2. Experimental Setup

The test facility consists of a visualization system, a combustion chamber, a data acquisition system, and an electric spark igniter system as shown in Figure 1. A shadow system and high speed camera are used to visualize the flame propagation. The flame acceleration is achieved by providing an expansion vessel attached to combustion chambers as shown in Figure 2. The 7 combustion chambers are connected to offer flame acceleration path. Each combustion chamber is a circular pipe which has 215mm of inner diameter and 300mm of length. The ignition node is installed at the end-center of the combustion chamber 1. The combustion chamber 7 includes two optical windows for visualization. A rupture disk is installed between the combustion chamber 7 and the expansion chamber. The rupture disk, which is used to accelerate the flame, is made of a plastic vinyl with 0.08mm thickness, and ruptures at about 0.1bar pressure difference between the combustion chamber and the expansion chamber which remains an atmospheric pressure.

The flame velocity is estimated by analyzing some flame images obtained by the shadow and high speed camera system with a temporal resolution of 1,000 frames per second.

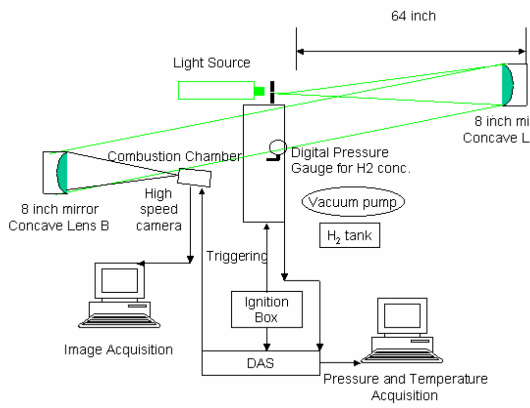


Figure 1. Test facility

The experimental parameters are an initial gas

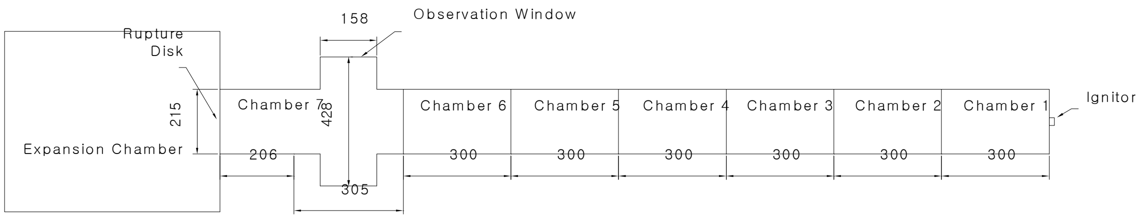


Figure 2. Combustion chamber

temperature and obstacles. To investigate the effect of the initial gas temperature, electric heaters are installed on the outer surface of the combustion chamber. One or two crosswise obstacles, as shown in Figure 3, partially block the flame path, and the blockage ratio is 27.6%. One is installed between the chamber 2 and 3, and the other is between the chamber 4 and 5. All the tests were carried out at a 9% hydrogen concentration at an atmospheric pressure.

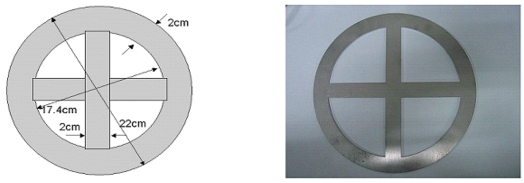


Figure 3. Schematic and photograph of obstacle

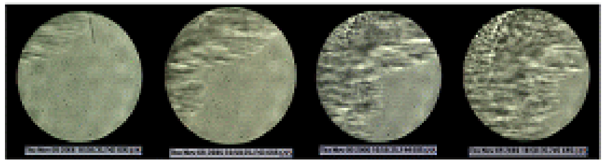
3. Results and Discussions

The preliminary test results are summarized in Table 1. C-Test1 and C-Test2 in Table 1 have the same conditions, that is, the initial gas temperature is a normal room temperature, and no obstacles are used. The repeatability of the flame velocity is estimated at about ±16%. According to the C-Test3, an increase of the initial gas temperature up to 50 ^{o}C has only a little effect on the flame velocity. C-Test4 and C-Test11 are to observe the effect on the flame acceleration according to the obstacles. When two obstacles are installed across the flame path, the flame velocity increases up to 75m/s. A flame acceleration is achieved by the generation of an additional turbulence in a expansion flow ahead of the flame, e.g. by the interaction of the flow with obstacles. It is necessary to study the acceleration mechanisms and to classify obstacles bound to repeatedly occur in reactor containments according to their influences.

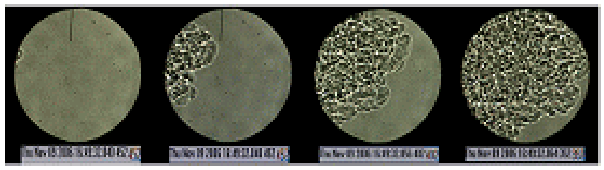
Figure 4 shows the flame images obtained by the shadow and high speed camera system. As shown in Figure 4, the flame front is not perpendicular to the flame propagation direction. This is why the hydrogen concentration is not uniform but stratified due to a density difference even though two diaphragm pumps are used to mix the hydrogen gas before an ignition.

Table 1. Test conditions and results

Test series	Initial gas temperature(^{o}C)	Obstacles	Flame velocity(m/s)
C-Test1	Room temp.	Non	2.38
C-Test2	Room temp.	Non	1.73
C-Test3	50	Non	1.92
C-Test4	Room temp.	Two (2,3) (4,5)	75
C-Test11	Room temp.	One (2,3)	6.25



(a) C-test4



(b) C-test11
Figure 4. Visualization results

4. Conclusion

To investigate the DDT possibility by a hydrogen combustion in the IRWST of the APR1400, flame acceleration tests with hydrogen combustions were studied for a circular straight pipe.

An increase of the initial gas temperature up to 50 ^{o}C had only a little effect on the flame velocity. When two obstacles were installed across the flame path, the flame velocity increases up to 75m/s.

More detail flame acceleration experiments in the straight pipe will be performed to develop and evaluate the flame detection and flame speed measurement technique by using fine thermocouples, pressure sensors, and photo sensors. Finally, the flame sensing techniques will be applied to find out the geometrical effect on the flame propagation in the IRSWT.

Acknowledgments

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