

# **Quenching Distance Measurement for the Control of Hydrogen Explosion**

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## **Introduction**

Hydrogen combustion is one of the major factors that influence the safety of nuclear power plant reactor under severe accident scenario. Installation of quenching meshes in a compartment has been suggested to prevent flame propagation among compartments and to maintain equipment survivability [1, 2]. It has been found that quenching meshes could effectively confine hydrogen combustion. In this regard, the characteristics of flame quenching for the control of hydrogen combustion are experimentally investigated with the focus on the effects of steam addition and initial pressure on quenching distances.

## **Experimental Setup**

Experimental apparatus, as schematically shown in Fig.1, consists of a mixing chamber, a combustion chamber, and an electric spark circuit for ignition. The fuel used was C.P. grade (>99%) hydrogen and was premixed with air in a mixing chamber where the equivalence ratio of mixture is determined based on partial pressure. Steam was added to the mixture where the mixture fraction was determined based on saturated vapor pressure at the temperature of mixture. The combustion chamber was a cylindrical closed vessel with an inside diameter of 50mm. It had two ports for filling and purging and had a pressure regulator to adjust the initial pressure of mixture (Fig. 2). The spark electrodes mounted at the center of the chamber were flanged with glass plates. The glass plates have the effect of suppressing ignition altogether when the electrodes are approached to within a critical distance [3]. This critical distance was defined as quenching distance in the present study. The gap length was adjusted by a built-in micrometer.

## Results and Discussions

### Effect of the Initial Pressure

Quenching distances at various hydrogen/air mixtures measured over a range of initial pressures are shown in Fig. 3. Previous study [4] showed that quenching distance is proportional to the flame thickness,  $\delta$ , which is expressed as,

$$\delta \sim \frac{\lambda}{C_p \rho_u S_L} \sim \frac{\lambda T_u}{C_p M} \frac{1}{p} \frac{1}{S_L} \quad (1)$$

which resulted from the phenomenological analysis of deflagration wave. Properties of  $C_p$  and  $\lambda$  are less sensitive to temperature and pressure, while the laminar burning velocity,  $S_L$ , is highly sensitive to those parameters. The burning velocity [5] normalized by that for atmospheric pressure  $S_L(p=1)$  can be fitted as,

$$\frac{S_L}{S_L(p=1)} = 1 + 0.0069(\log_{10} p) - 0.30586(\log_{10} p)^2 - 0.0661(\log_{10} p)^3 + 0.04736(\log_{10} p)^4 \quad (2)$$

Consequently, quenching distances near atmospheric pressure can be approximated to be inversely proportional to initial pressure for all hydrogen mixture ratios from Eq. (1) and the results shown in Fig. 4 substantiate it.

### Effect of the Steam Addition

The effect of steam addition on quenching distances is shown in Fig. 4 for stoichiometric hydrogen/air mixture. For the mixture without adding steam, the result clearly demonstrates the inverse proportionality of quenching distance to pressure. Steam is added under saturated condition such that the initial temperature increases with steam addition. The effect of temperature increase is known to decrease the quenching distance. Considering this effect, the result shows that the addition of steam increases the quenching distance. The steam added in hydrogen/air mixture plays a role of the sink as inert gas because of its large heat capacity. So, the quenching distance is more or less increased through the addition of steam to hydrogen/air mixture as shown in Fig. 4.

We have checked the possibility of estimation of quenching distance based on the relation of burning velocity and flame thickness as previously explained. Most previous experiments demonstrated that quenching distance has its minimum value near stoichiometry, which has also been confirmed in the present experiment as shown in Fig. 3. However, burning velocity of hydrogen/air mixture has its maximum at the rich condition of hydrogen mixture ratio of 0.42 due to dissociation of hydrogen [6]. This discrepancy can lead to the limitation of the above-mentioned 1-D phenomenological model.

Effect of steam addition on quenching distances may also be considered by accounting the effect of steam on burning velocity. Heat loss to wall and wall termination (radical termination) are dominant chemical processes in wall-induced quenching, while chain-branching reactions and dissociations of reactants plays a significant role in flame

propagation. Eq. (1), resulting from the phenomenological model, could not describe properly the hydrogen oxidation kinetics between these two different phenomena. Consequently, the quenching distance estimated based on the phenomenological model showed a much larger quenching distance compared to the experiment when steam is added. One possibility of this discrepancy is that steam is one of the most effective third body influencing three-body recombination reaction, which is often exothermic. This has decreasing effect on quenching distance.

## **Acknowledgment**

This work has been carried out under the Nuclear R&D Program by MOST.

## **References**

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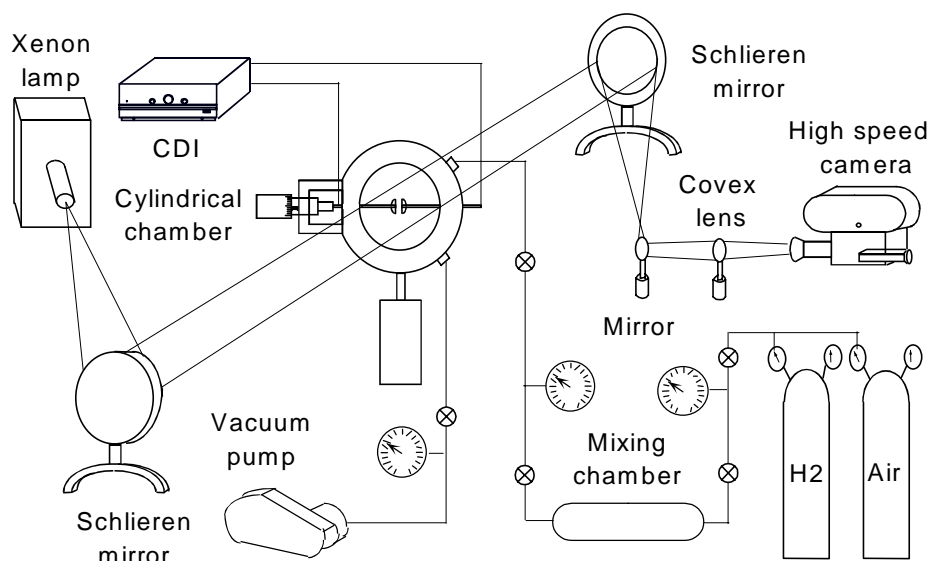


Figure 1 Schematic of Experimental Setup.

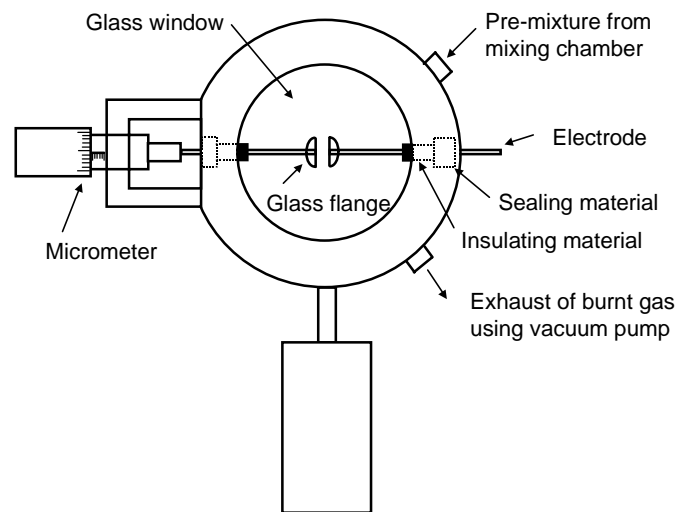


Figure 2 Schematic of Combustion chamber.

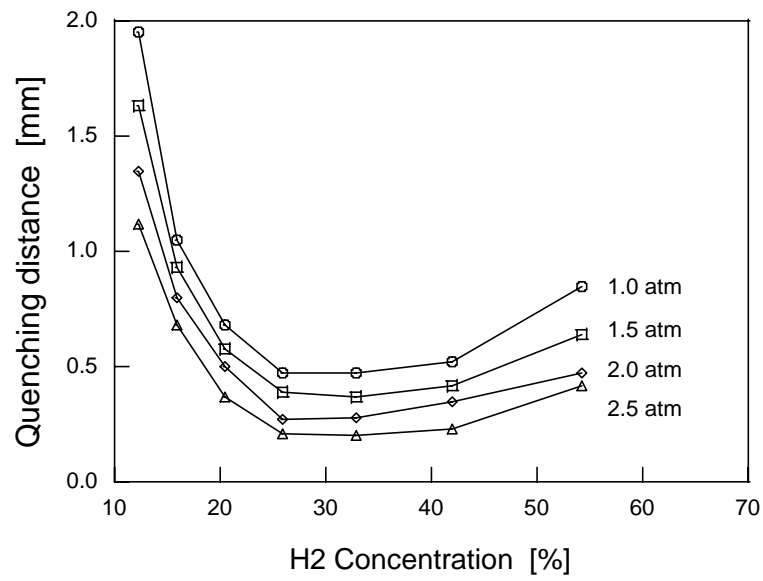


Figure 3. Quenching distance of Hydrogen/Air mixture with H<sub>2</sub> concentration.

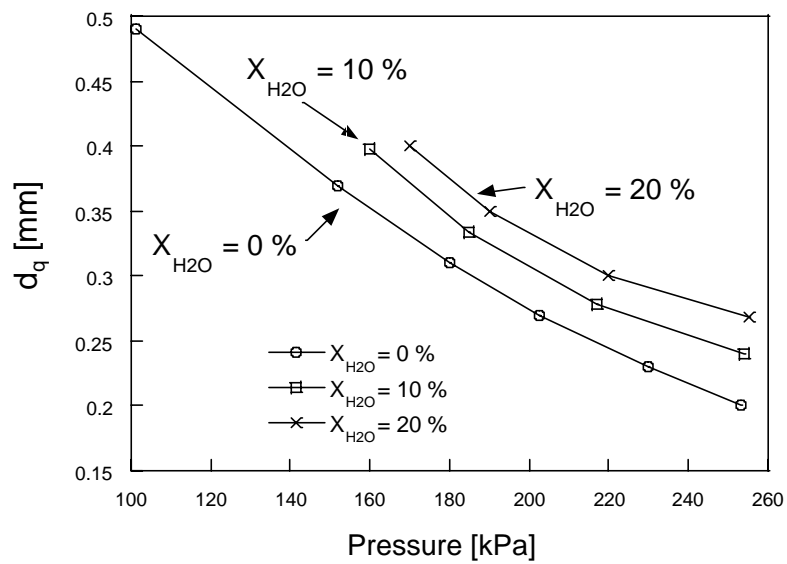


Figure 4. Quenching distance of H<sub>2</sub>/Air/Steam mixture with H<sub>2</sub>O concentration.