# 3 Dimensional monitoring of $H_2$ clouds as a model of FCV exhaust gas

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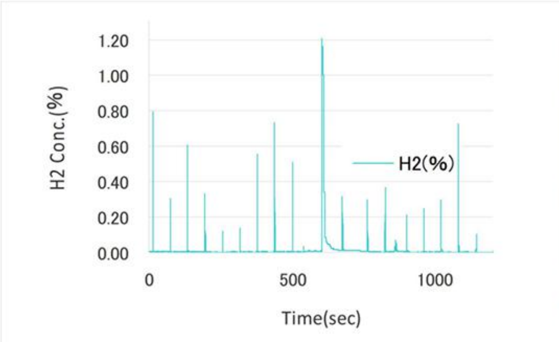
## Introduction

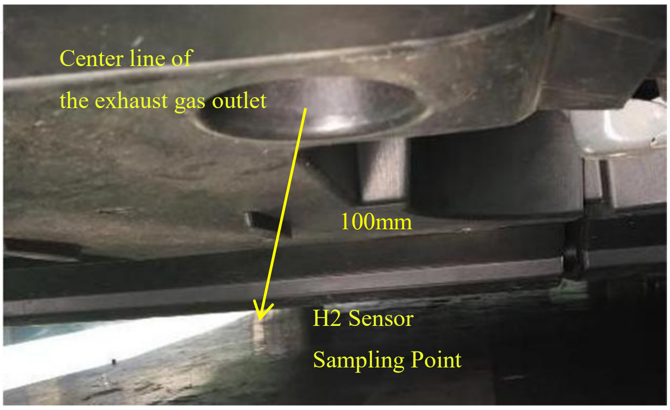
H2 clean energy source for FCV:
Hydrogen applications without CO2 emission are prospectively developing on the way of 2020 Tokyo Olympic game. Tri-generation in house and Fuel Cell Vehicles (FCV) are typical examples. From safety point of view, H2 explosion limit is 4% and according to the Global technical regulation (GTR) on FCV, fuel cell discharge system at the vehicle exhaust system`s point of discharge, the hydrogen concentration level shall not exceed 4 % average by volume during any moving three-second time interval during normal operation including start-up and shut down. Portable hydrogen sensor (Sx) is built using mass spectrometer to monitor H2 concentration in real time. Sxs are located to measure the real time images of 3D H2 concentration profile in milliseconds with high speed Schieren Photograph camera.


Exhaust gas FCV

GLOBAL REGISTRY //Global technical regulation (GTR)
For HYDROGEN POWERED VEHICLE

Fuel cell discharge system: [At vehicle exhaust system's point of discharge, the hydrogen concentration level shall not exceed 4% average by volume during any moving three-second (3sec) time interval during normal operation including start-up and shutdown.]




H2 in FCV Exhaust Gas

## H2 Sensor

Sx is 25kg and portable for the outdoor experiment. Sx has self-calibration system having certain concentration of single and mixed calibration gases for easy start up. Sx can take data in 2ms. Sampling inlet of this system is SUS capillary tube (150/250μm=ID/OD). Sample gas is introduced from capillary through dehumidifier. This system having differential pumping system, ionize by electron bombardment method (EB). To minimize the humidity influence, Sx has dehumidifier with heater. Mass Spectrometer works up to m/Z=300. Schlieren Photograph (SP) is applied to monitor for mixed gases density profile. So from gas exit we can monitor the concentration profile by Sx and density profile by SP at the same time. SP is monitored by high-speed camera in 1 msec.


Fig.1 H2 Sensor

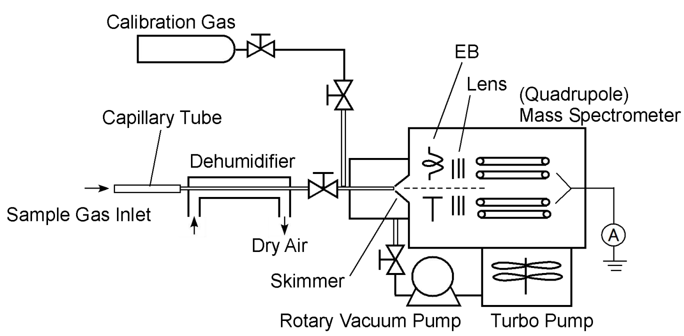



Fig.2 Schematic Diagram

## H2/N2 Mixing process by Sx

In real time monitoring of purged H2 into Nitrogen flow, under constant flow of N2 5L/min controlled by massflow controller, hydrogen is introduced by quick valve at the flow rate of about 0.2-0.5L/min by using vertical mixing with right-angle mixing head to be 4-10% concentrations. The result of H2 concentration by time is monitored in 2ms intervals. In this experiment, first hydrogen wave came with the spike head contained the highest concentration of hydrogen (Cmax) reached as a cloud by open up quick valve and then reached the equilibrium (Ceq). Hydrogen is introduced into N2 flow without diffusion and kept the concentration as H2 cloud in seconds. The concentration of spike is 1.5 times higher level than the expected concentration of Ceq. By changing the duration time of quick valve open from 1 to 100ms, the spikes change the shapes and the result are shown. The height of Spike head reached the maximum during duration time of 5-10ms and when duration time reach 100ms, the height of spike head became lowere and the width of spike became wider. This means that induration time of 100ms hydrogen volume in spike head increased compared to lower duration time data. The analysis of this spike head is also discussed in paper.

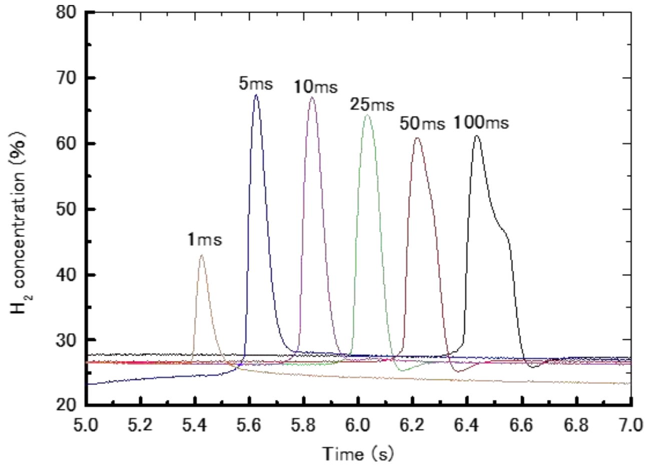



Fig.3 Spike Head by changing injection period

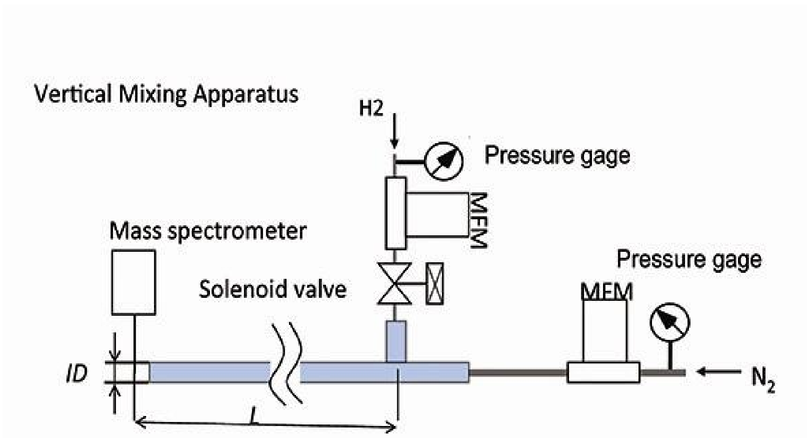


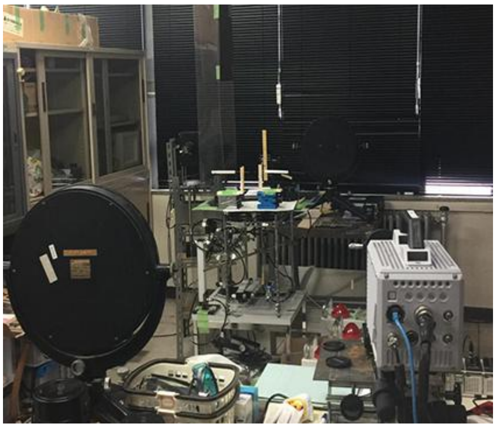

Fig.4 Schematic Diagram of Vertical mixer

## H2/Air Mixing and Combustion/Explosion process

## by Sx and Schlieren Photograph (SP)

H2/Air Mixing and Combustion/Explosion process by Sx:

Experiments are conducted using air instead of nitrogen with ignition equipment. Two tungsten wires are set the head to tale distance of 1cm for the spark where the high voltage of AC12KV is applied. So if H2 concentration is more than 4%, the ignition process is activated, monitored by SP (Schlieren Photograph )with high-speed camera at the same time 6 Sxs measure the 3D concentration changes. Explosion data are measured and analized.



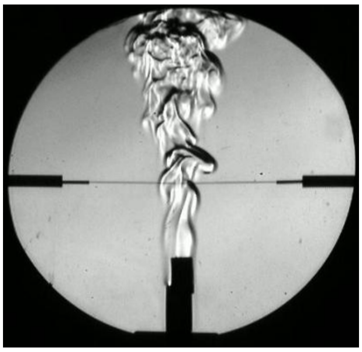


Fig.5-1,5-2,5-3 Experimental equipments with Schlieren Photograph (SP)

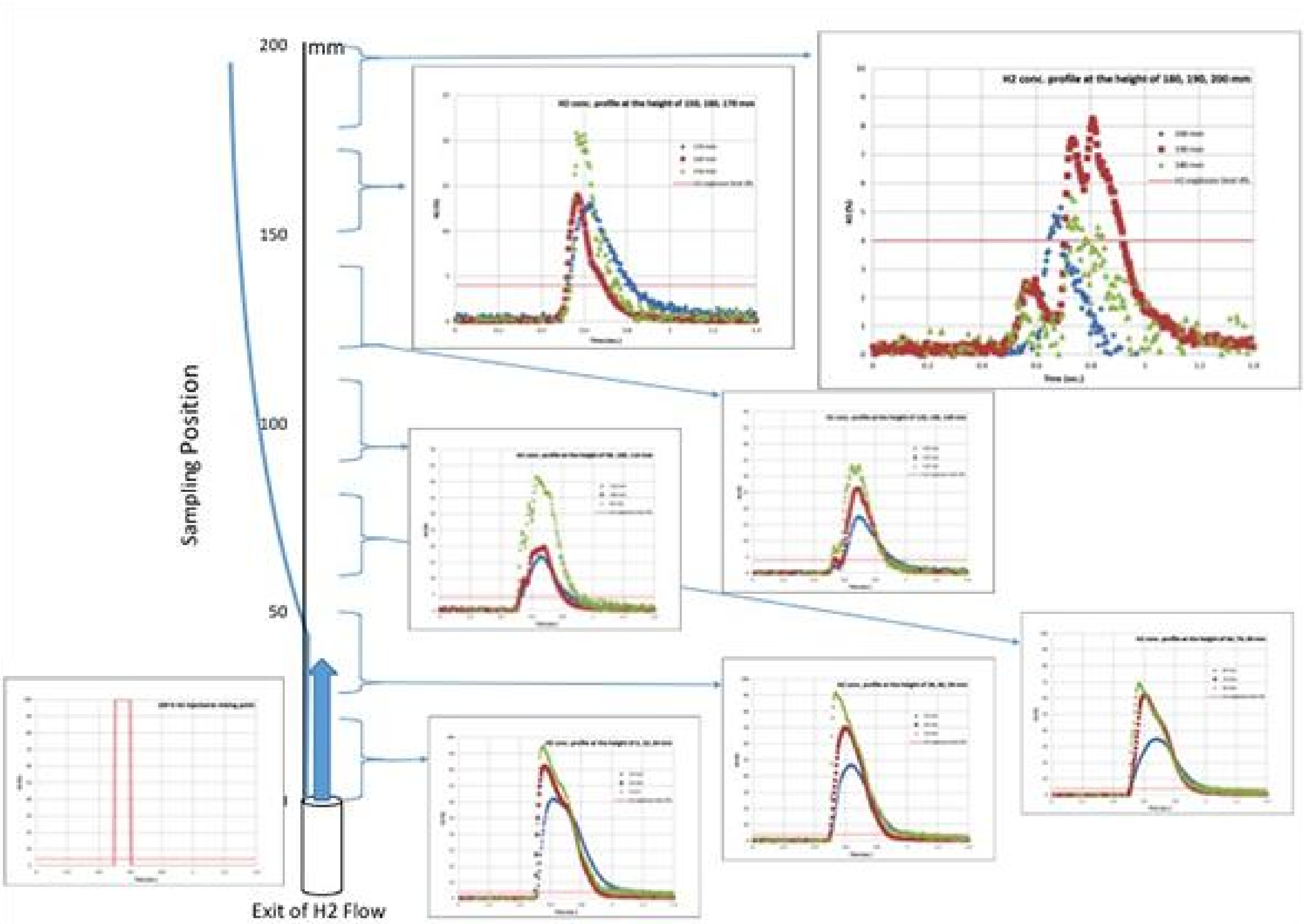



Fig. 6 H2 conc. Profile by Sampling Height of MS

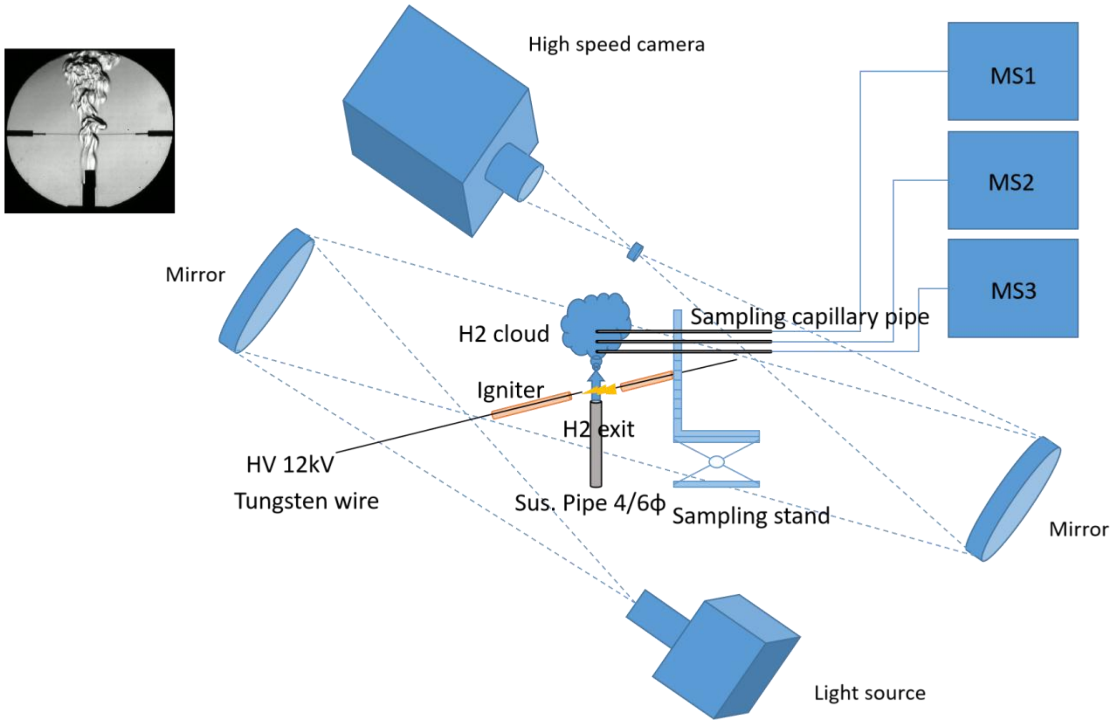



Fig. 7 Schematic diagram of Schlieren photograph and MS sampling system

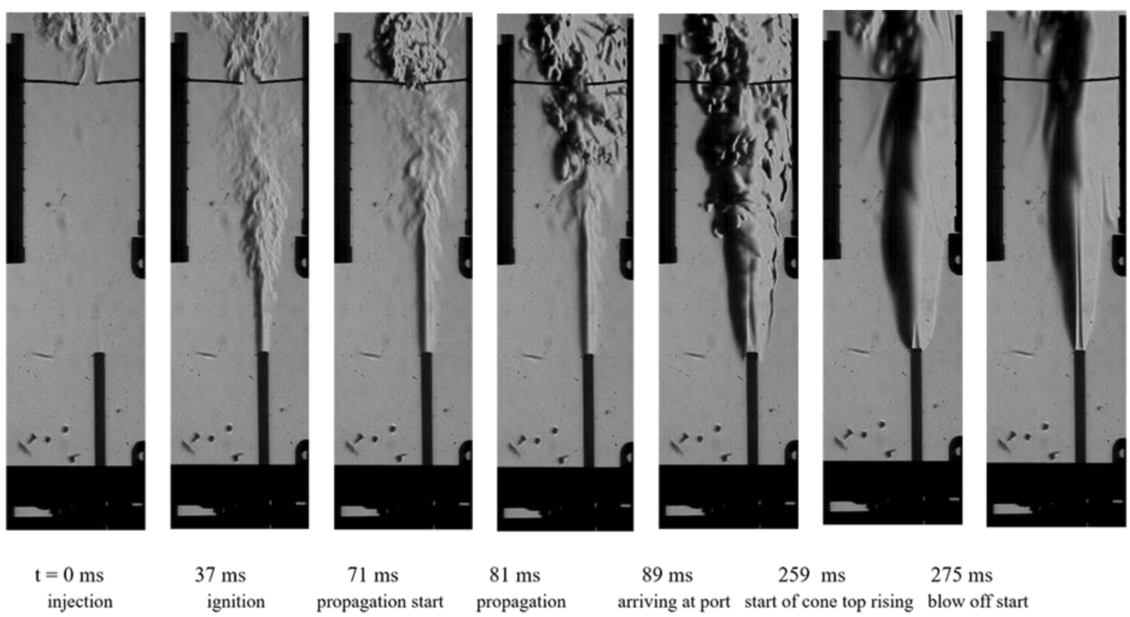



Fig.8 Schlieren Photograph (SP) of H2 combustion

## Conclusion

1:Portable H2 sensor Sx was used to detect the unintended H2 clouds.
2:Schlieren photograph and MS sampling system were applied to monitor the concentration of H2 in cloud from H2 /air mixing process.
3:In mixing process of H2 with air, before the equilibrium reached, overshooting behavior (Spike Head) was observed in the wave front .
4:The introduction of H2 into air in tube, the spike head showed the H2 concentration of 95%.
5:The combustion experiments also took place and the results were showed by the Schlieren photographs. H2 mixed with air without diffusion process created the H2 clouds.

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