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Self-ignition and flame propagation of high-pressure hydrogen jet during sudden discharge from a pipe

Toshio Mogi[a,*], Yuji Wada[a], Yuji Ogata[a], A. Koichi Hayashi[b]

[a]Research Core for Explosion Safety, National Institute of Advanced Industrial Science and Technology (AIST), 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan

[b]Department of Mechanical Engineering, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara, Kanagawa 229-8558, Japan

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ABSTRACT

Hydrogen is expected to serve as a clean energy carrier. However, since there are serious ignition hazards associated with its use, it is necessary to collect data on safety in a range of possible accident scenarios so as to assess hazards and develop mitigation measures. When high-pressure hydrogen is suddenly released into the air, a shock wave is produced, which compresses the air and mixes it with hydrogen at the contact surface. This leads to an increase in the temperature of the hydrogen–air mixture, thereby increasing the possibility of ignition. We investigated the phenomena of ignition and flame propagation during the release of high-pressure hydrogen. When a hydrogen jet flame is produced by self-ignition, the flame is held at the pipe outlet and a hydrogen jet flame is produced. From the experiment using the measurement pipe, the presence of a flame in the pipe is confirmed; further, when the burst pressure increased, the flame may be detected at a position near the diaphragm. At the pipe outlet, the flame is not lifted and self-ignition is initiated at the outer edge of the jet.

1. Introduction

Hydrogen is expected to serve as a clean energy carrier. Currently, hydrogen fuel-cell vehicles are developed extensively. However, hydrogen has extremely low ignition energy, a wide range of flammability limits, and the highest burning velocity among flammable gases. Therefore, it is important to prepare the safety regulations for hydrogen supply stations and it is necessary to obtain the data of hydrogen safety as early as possible due to the increase in a number of fuel stations that handle high-pressure hydrogen.

The sudden discharge or leakages of high-pressure hydrogen from a micro-crack, a sealed part of the connection, a safety valve, etc., are expected to occur when hydrogen is released into the atmosphere. It is well known that hydrogen ignites spontaneously after being released in air. Astbury and Hawksworth [1] (2007) reviewed the recent incidents and postulated the mechanism of spontaneous ignition of high-pressure hydrogen leakage. They found 81 cases of hydrogen ignition; however, they did not identify the source of the ignition for 86.3% of these cases.

When high-pressure hydrogen is suddenly discharged into air, a shock wave compresses the air, which mixes with hydrogen at the contact surface and results in an increase in the temperature of the hydrogen/air mixture so as to yield a possible ignition. Wolanski and Wojcicki [2] (1972) have experimentally demonstrated the self-ignition of high-pressure hydrogen jet at the contact surface with oxygen when hydrogen is released into the oxygen atmosphere using a shock tube. Tanaka et al. [3] reported in 1978

* *Corresponding author*. Tel.: +81 29 861 4449; fax: +81 29 861 8004.
E-mail address: t.mogi@aist.go.jp (T. Mogi).
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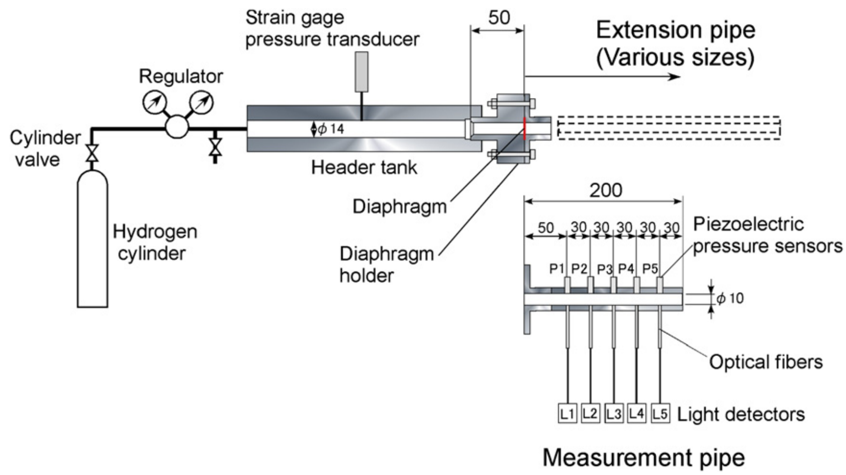

Fig. 1 – Experimental apparatus.

the self-ignition of hydrogen suddenly released into the atmosphere by using a tube with a diaphragm. Liu et al. [4] recently studied numerically a possibility of self-ignition of a hydrogen jet spouted from a 70-Mpa-compressed hydrogen tank. Dryer et al. [5] demonstrated the hydrogen self-ignition from a sudden release. They pointed out that the flow geometry downstream of a burst disk holder strongly affects the occurrence of self-ignition at the minimum burst disk failure pressure; however, the details of the experimental conditions during self-ignition are unknown. Golub et al. [6] investigated the structure of impulse jet experimentally and numerically. They presented a relationship between the burst pressure and a tube length. We also reported that hydrogen tends to ignite in the pipe as the length of the pipe increases [7]. Furthermore, we investigated the flame propagation and explosion of a hydrogen jet outside the pipe [8].

In the present study, the sudden release of pressurized hydrogen gas through a pipe into the atmosphere is investigated experimentally. In particular, we studied the ignition and subsequent flame propagation process in the pipe, at the pipe outlet, and in a hydrogen jet in detail.

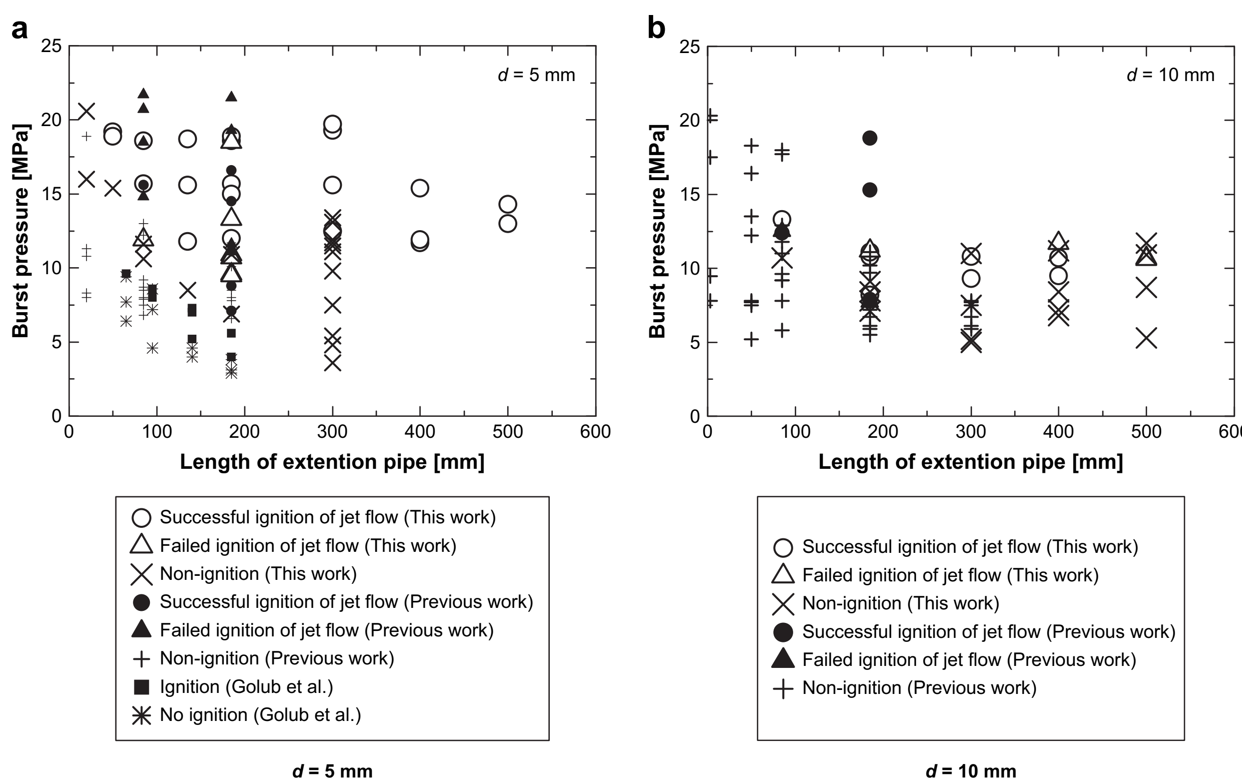

Fig. 2 – Relationship of the ignition between burst pressure and length of the pipe (a) $d = 5$ mm and (b) $d = 10$ mm.