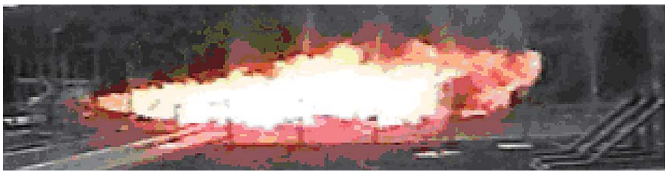

Introduction of Technology for Assessment on Hydrogen Safety

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1. Introduction

In recent years, the global warming potential of CO_2 has been taken up as a global environmental issue and therefore, the reduction of CO_2 emissions is obligated under the Kyoto Protocol. On the other hand, the local environmental problem of roadside pollution caused by car exhaust has also become a serious problem. In the meantime, exhaustion of fossil fuels are foreseen as one of the future energy problems. To solve these problems, utilization of clean hydrogen energy is anticipated. However, as hydrogen has a wide flammable concentration range, sufficient investigations on the safety are required before its introduction. To develop an infrastructure for popularization of fuel cell vehicles for which future demand is expected, the regulations related to fuel cells were already partly reevaluated in 2005 to promote introduction of hydrogen refueling stations into urban areas, and efforts are presently being made for further re-evaluation(1). Mitsubishi Heavy Industries, Ltd. (MHI), together with some relevant organizations, has so far been involved in the acquisition of data for such reevaluation of the regulations(2). In this paper, we introduce the results of our study to assess hydrogen safety and MHI's fundamental technologies supporting the assessment.

2. Investigation on the safety of high-pressurized hydrogen gas

In investigating hydrogen safety, estimation of the dispersion concentration range upon leakage, and that of flame formation and any blast wave pressure upon ignition are important. Thus, in accordance with 2 typical accident scenarios at a hydrogen refueling station (steady pinhole leakage from micro cracks in piping, etc., and unsteady, large-scale leakage such as breaking of piping, etc.), investigations relating to dispersion and explosion behaviors of hydrogen gas were carried out through field experiments together with numerical simulations. The field experiments were carried out at Tashiro Testing Facility in Akita Prefecture (the rocket combustion test facility) where a number of satisfactory results have been achieved in MHI's rocket development. Through these experiments, the useful data shown below were obtained, and using the experimental data, development of numerical simulations

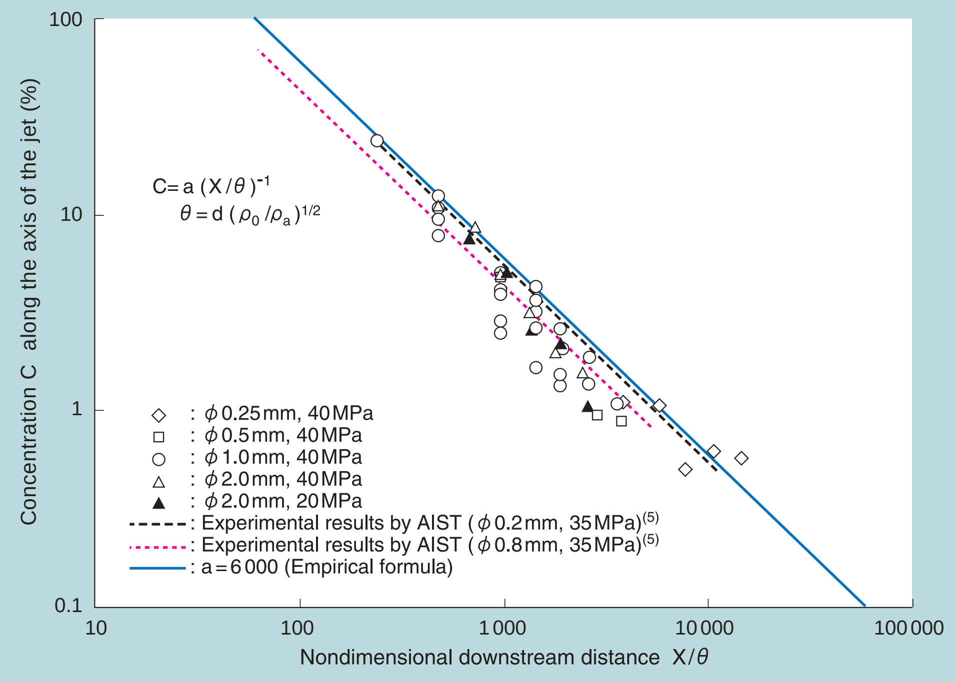

Fig. 1 Distribution of concentration toward direction of jet
Decrease of concentration relative to a nondimensional distance from the nozzle.
(θ : equivalent diameter, ρ_a: atmospheric density, ρ_0: density at outlet, d: nozzle diameter)

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has been performed for generalization so that they can be applied to various conditions.

2.1 Dispersion concentration

The field experiments on dispersion concentration were carried out with respect to steady leakage from pinholes with a diameter of 0.25 mm to 2 mm under low wind speed conditions (about 1 m/s or below). The experimental apparatus used had a structure such that hydrogen gas could be pressurized up to 65 MPa so that hydrogen gas of 40 MPa could be released as a jet into the atmosphere, and stored in five high-pressure cylinders each with a volume of 50 L(3). The test results are given in **Fig. 1** as the distribution of concentration C along the axis of the jet, together with the empirical formulae(4). The data from previous experiments conducted by the National Institute of Advanced Industrial Science and Technology (AIST)(5) are also given. When the concentration to be assessed is determined, a dispersion range with more than its concentration can be obtained from Fig. 1., that is, the distance X in the release direction down to its concentration can be calculated by giving the aperture diameter d and the density ρ (or pressure P). Thus, practically useful empirical formulae (constant a=6,000) could be obtained. However, considering the pressure loss at a nozzle, the constant a is preferably determined as 6,400(4).

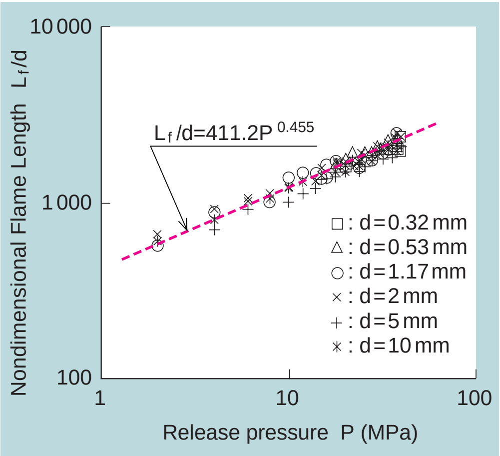

Fig. 2 Dependence of flame length on nozzle diameter and pressure
Showing that the flame length can be estimated by the nozzle diameter and pressure.

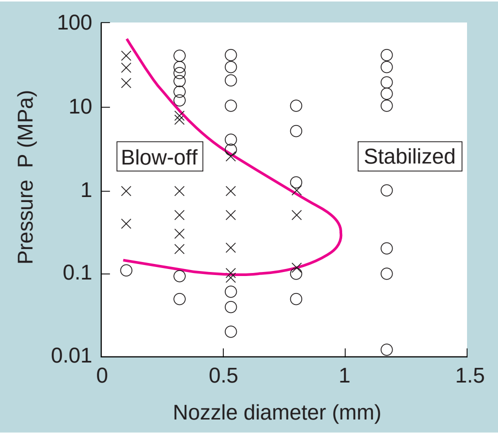

Fig. 3 Dependence of flame stabilizing range on pressure and nozzle diameter
Showing that even if there exists a source of ignition, there is a range where the flame is not stabilized.

2.2 High-pressurized jet flame

Experimental data on flame length L_f of a jet of hydrogen gas released toward the horizontal direction using a nozzle diameter of 0.12 mm to 10 mm were summarized as shown in **Fig. 2** together with an empirical formula(6). It was confirmed that when the pressure P is larger than 0.3 MPa, i.e. a condition exceeding the choke conditions, the flame length L_f is in proportion to both nozzle diameter d and pressure P with an exponent of 0.5. From these, a flame length, if formed, can be estimated. When the direction of the jet was changed from 45-degrees upward to vertical, the flame length showed no change, and thus, no influence of buoyancy was observed. Dependence of the flame stabilizing range on the nozzle diameter and pressure to release the jet is shown in **Fig. 3**, which shows that even if a source of ignition exists, there is a range where the flame is not stabilized. These are important data serving as a useful reference in assessment of hydrogen safety. Furthermore, numerical simulations of flame were carried out. **Figure 4** shows the calculated results of the effect of the fence. The flame was completely blocked by the fence and gave no effect rearwards, and this confirms that fences are very effective as a safety measure.

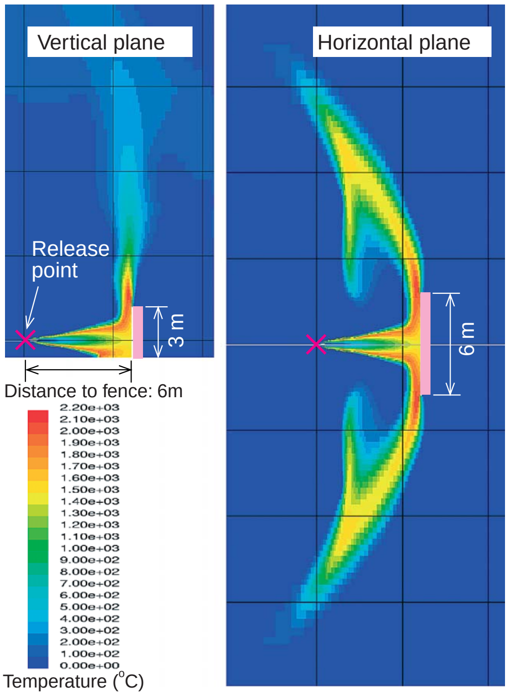

Fig. 4 The effect of fence
Temperature distribution by numerical simulation, where the position of the fence is 6 m away from the nozzle, the release pressure is 40MPa and the nozzle diameter is 10 mm ϕ.

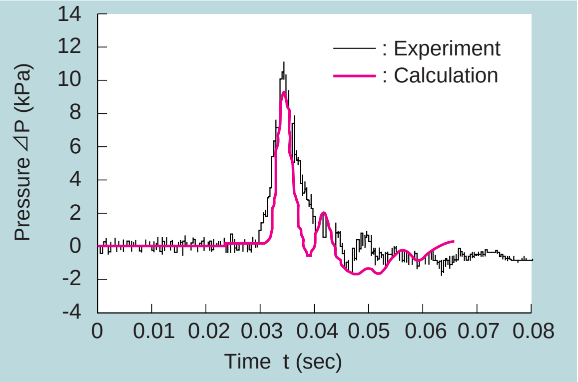

Fig. 5 Comparison of the time history of overpressure between experimental values and calculated results
Results under the conditions of a release pressure at 40 MPa, nozzle diameter of 10 mmϕ and ignition timing of 5 sec.

2.3 Overpressure

The spatial distribution of concentration just before ignition was obtained using numerical simulations, and overpressure was estimated using the calculated results thus obtained as an initial condition. The results together with the experimental data are shown in **Fig. 5**. The simulation data and experimental data agree with each other well, and this indicates that overpressure can be estimated fairly accurately by using numerical simulations with an appropriate turbulent combustion model.

3. Development of risk assessment guidance system

A framework of a guidance system for the risk assessment of hydrogen refueling stations (system configuration management module, accident sequence quantification module, hydrogen release analysis module, risk profile management module, etc.) was developed by integrating the risk assessment technologies that have been practiced for nuclear power plants and the above-mentioned experimental data relating to dispersion and explosion behaviors as well as the results of simulations. At present, we are preparing a prototype model, with the startup screen shown in **Fig. 6**. In the future, we intend to establish, via trial operations, a system that enables general designers to carry out rational risk analysis and examination of safety measures by providing information on hazard analysis and quantitative risk estimation from this guidance tool.

4. Conclusion

The experimental and numerical simulation technologies we have so far developed within our company have been applied to the acquisition of safety assessment data for the re-evaluation of the relevant regulations toward the introduction of hydrogen refueling stations into urban areas, and have been simultaneously verified. There are many products involving the handling of combustible and hazardous gases besides hydrogen gas. Therefore, the present technology is expected to be used in various areas in the future as an examination tool for further improvement of their safety.

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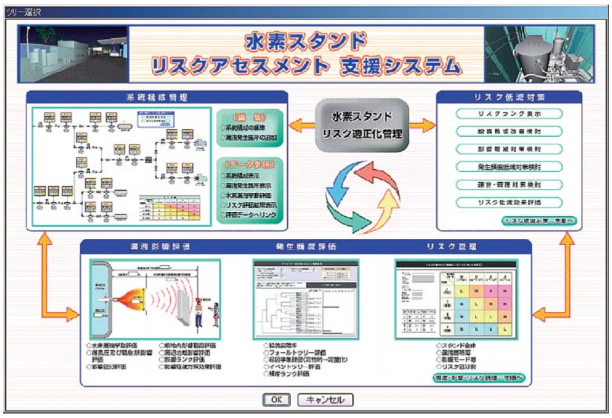

Fig. 6 Risk assessment guidance system (The startup screen)

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