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Simulation of hydrogen leak and explosion for the safety design of hydrogen fueling station in Korea

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ABSTRACT

Hydrogen has been used as chemicals and fuels in industries for last decades. Recently, it has become attractive as one of promising green energy candidates in the era of facing with two critical energy issues such as accelerating deterioration of global environment (e.g. carbon dioxide emissions) as well as concerns on the depletion of limited fossil sources. A number of hydrogen fueling stations are under construction to fuel hydrogen-driven vehicles. It would be indispensable to ensure the safety of hydrogen station equipment and operating procedure in order to prevent any leak and explosions of hydrogen: safe design of facilities at hydrogen fueling stations e.g. pressurized hydrogen leak from storage tanks. Several researches have centered on the behaviors of hydrogen ejecting out of a set of holes of pressurized storage tanks or pipes. This work focuses on the 3D simulation of hydrogen leak scenario cases at a hydrogen fueling station, given conditions of a set of pressures, 100, 200, 300, 400 bar and a set of hydrogen ejecting hole sizes, 0.5, 0.7, 1.0 mm, using a commercial computational fluid dynamics (CFD) tool, FLACS. The simulation is based on real 3D geometrical configuration of a hydrogen fueling station that is being commercially operated in Korea. The simulation results are validated with hydrogen jet experimental data to examine the diffusion behavior of leak hydrogen jet stream. Finally, a set of marginal safe configurations of fueling facility system are presented, together with an analysis of distribution characteristics of blast pressure, directionality of explosion. This work can contribute to marginal hydrogen safety design for hydrogen fueling stations and a foundation on establishing a safety distance standard required to protect from hydrogen explosion in Korea being in the absence of such an official requirement.

1. Introduction

Hydrogen is a leading fuel for a renewable and environment-friendly energy carrier. It can simultaneously reduce a country's dependence on foreign oil and significantly reduce greenhouse gases. Significant advances have been made in the use of hydrogen as a transportation fuel and a fuel for power generation. Hydrogen can be used in an internal combustion engine or a fuel cell to generate power.

Hydrogen station systems play as a key bridgehead in commercializing fuel cells and fuel cell powered vehicles. Y. Lee et al. have developed an effective operator training program providing the safety information and the public relations for the safer usage of hydrogen at hydrogen fueling

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stations [1]. The risk assessment technique for verifying the safety of hydrogen station model was employed to examine safety measures for preventing accidents [2]. Some studies related to the safety of hydrogen stations have been concerned with the diffusion of leakage, explosion, deflagration or detonation of hydrogen [3] and jet flames [4] from hydrogen fueling stations. Human errors are identified as the most frequently occurred according to accident statistics of chemical plant [5].

Hydrogen is dangerous due to its properties of low ignition temperature, small ignition energy, wide explosion limit and fast combustion speed. In a confined space, the hydrogen is dangerous, like any other flammable gas. In an open space, the probability of hydrogen explosion is lower as compared to that occurring in a confined space, as buoyancy speed is high. When hydrogen is involved in combustion, it generates water vapor by absorbing the heat from air. However, hydrogen does not generate any carbons during combustion. Therefore, its radiant heat by hydrogen explosion is significantly low [6]. Therefore, in this study, a risk factor for safety distance at hydrogen fueling stations is selected as a blast pressure instead of heat flux effect generated during combustion.

This paper aims to simulate the diffusion behavior of leak hydrogen and to identify the safe distances required to minimize damages by an explosion accident at hydrogen fueling stations, using CFD program, FLACS [7]. The simulation results for a leak jet stream of pressurized hydrogen is validated with experimental data and the simulation for identifying safety distances of hydrogen fueling station facilities is based on four explosion scenarios.

2. Experiment for leak hydrogen jet steam

The experiment on the measurement of hydrogen concentration distribution of high-pressure hydrogen leak jet stream makes an essential contribution on preventing secondary damages like ignition which can be caused by hydrogen leak from hydrogen fueling station. Houf and Shefer performed the leak experiment of hydrogen with low-pressure and large diameter [8,9].

Major experimental system comprises a cylinder full of pressurized hydrogen gas and a set of samplers for probing hydrogen jet concentrations. The cylinder is fitted with a single outlet leaking hole (an orifice) discharging to a constant external pressure of atmosphere. 5 samplers are installed along with horizontal distances from the leak point. A schematic diagram of the experimental system is shown in Fig. 1. All details on experimental work are referred to the previous study [10].

The physical points for probing hydrogen concentrations along with the centerline of leak jet stream are positioned at a set of horizontal distances away from the hydrogen cylinder; 1, 3, 5, 7 and 9 m. Hydrogen concentrations are measured from 5 samplers collected from the 5 probe points. The jet stream is tested over different diameter sizes of outlet leaking holes of 0.5, 0.7 and 1.0 mm, and different hydrogen cylinder pressures of 100, 200, 300 and 400 bar as most South Korean fueling stations are facilitated with hydrogen cylinders under pressure of 350 bar. Laser-particle-method is used to visualize the flow patterns of hydrogen jet stream. The hydrogen jet stream is viewed as symmetric diffusion along its centerline. Sampling was taken 10 s for each probe round.

3. Simulation and validation for leak hydrogen jet stream

The simulation for the diffusion behavior of hydrogen leak jet stream was performed using FLUENT in previous study [10]. In this work, the same simulation is performed using FLACS because one of the primary aims of this study is to identify safe distances in case of hydrogen explosion and FLACS, a CFD tool designed to simulate behaviors of both leak and explosion, is used to calculate the concentration profile of high pressure hydrogen in released jet stream. The simulation results are validated with experimental data and compared with those of previous study [10].

Prior to simulating the leak hydrogen jet stream using FLACS, geometrical configuration should be set up in FLACS environment as shown in Fig. 2. Fig. 3 shows one simulation result set of FLUENT, FLACS and experiment data for the conditions of 0.5 mm diameter of outlet leaking hole over a set of hydrogen cylinder pressures; 100, 200, 300 and 400 bar, respectively. Fig. 3 reveals that the hydrogen jet is dispersed in radial direction, because its concentrations decrease as the

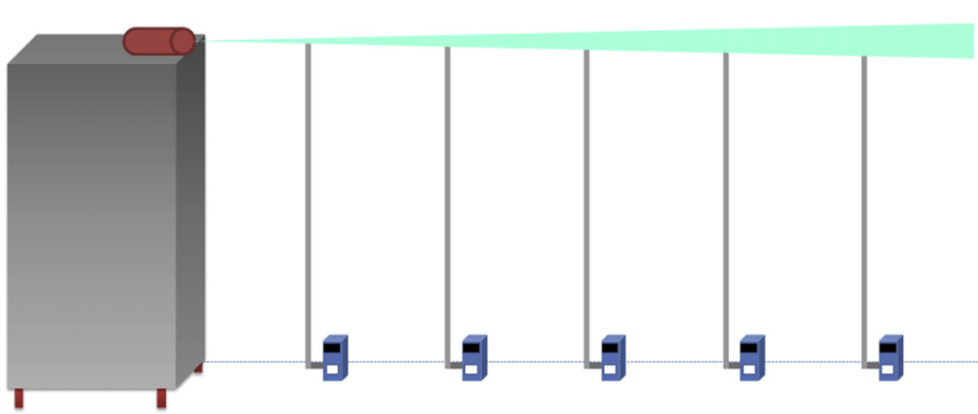

Fig. 1 – Experiment system.