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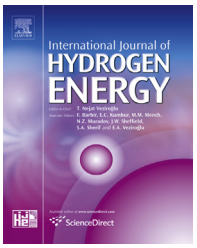

Leakage-type-based analysis of accidents involving hydrogen fueling stations in Japan and USA

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ABSTRACT

To identify the safety issues associated with hydrogen fueling stations, incidents at such stations in Japan and the USA were analyzed considering the regulations in these countries. Leakage due to the damage and fracture of main bodies of apparatuses and pipes in Japan and the USA is mainly caused by design error, that is, poorly planned fatigue. Considering the present incidents in these countries, adequate consideration of the usage environment in the design is very important. Leakage from flanges, valves, and seals in Japan is mainly caused by screw joints. If welded joints are to be used in hydrogen fueling stations in Japan, strength data for welded parts should be obtained and pipe thicknesses should be reduced. Leakage due to other factors, e.g., external impact, in Japan and the USA is mainly caused by human error. To realize self-serviced hydrogen fueling stations, safety measures should be developed to prevent human error by fuel cell vehicle users.

Introduction

Hydrogen fueling stations are essential elements for operating fuel cell vehicles (FCVs). Alazemi et al. reported that by 2013, there were 224 working hydrogen stations distributed over 28 countries and that some 43% of these stations were located in North and South America, 34% in Europe, 23% in Asia, and none in Australia [1]. In Japan, in March 2010, the Fuel Cell Commercialization Conference of Japan proposed the rollout

Abbreviations: FCV, fuel cell vehicle; HIRD, hydrogen incident reporting database; HIAD, hydrogen incident and accident database.

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of commercial FCVs and hydrogen fueling stations in 2015 and recommended ways to popularize them by 2025 [2]. In March 2016, the Japan Ministry of Economy, Trade and Industry announced its aim to construct 320 hydrogen fueling stations by 2025. Moreover, a Japanese motor corporation has been selling commercial FCVs since December 2014, and other companies are poised to enter the FCV market as well. Therefore, it has become increasingly necessary to establish hydrogen fueling stations.

Hydrogen fueling stations have the following two safety issues [3]: (i) The hydrogen pressure encountered in Japanese stations is very high at 82 MPa. (ii) Explosion and fire are very likely to occur due to hydrogen's inherent characteristics: hydrogen is likely to leak because of its low density, large flammability range, and low minimum ignition energy. In addition, hydrogen embrittlement must be taken into consideration to ensure safety. Therefore, it is very important to assess the risk of hydrogen fueling stations.

Many studies have focused on risk assessment and analyses with respect to hydrogen and hydrogen fueling stations from different points of view [3–13]. These studies include research on hydrogen explosion and fire [4–8], hydrogen compatibility of materials [9–12], and the identification and analysis of hazardous scenarios in hydrogen fueling stations using hazard and operability studies, a hazard identification study, failure mode and effect analysis, fault tree analysis, and other methods [13–28]. Serious hazards in hydrogen fueling stations have also been analyzed in depth [29,30]. Meanwhile, to improve the safety of hydrogen fueling stations by the identification of overlooked incident scenarios, the causes of the incidents have been identified and improvements to prevent such incidents have been suggested [3]. However, only few researches have focused on incident analysis with regard to hydrogen fueling stations.

Table 1 presents the incident and accident database for hydrogen and hydrogen fueling stations. Considering the data for Japan reported in the High Pressure Gas Safety Act Database, Yamada et al. [3] analyzed the incidents using the classification method [31]. The classification method was developed by the present authors. The advantage of this method is that it can categorize the causes of incidents, such as material damage, sealing part problems, human error, and others. The method was adopted as part of the High Pressure Gas Safety Act in Japan. Mirza et al. [32] selected 32 incidents involving hydrogen from the Hydrogen Incident Reporting Database (HIRD), analyzed the incident causes, and suggested safety measures. The Hydrogen Incident and Accident Database (HIAD) [33] describes two accidents involving hydrogen fueling stations in Europe. Thus, accidents involving hydrogen fueling stations in Japan and those involving hydrogen around the world are already being collected and investigated. However, no uniformity exists in the analysis of hydrogen fueling stations around the world. This is because the number of accidents involving hydrogen fueling stations is small considering that the technology is relatively new and it is difficult to compare accidents involving hydrogen fueling stations located in different areas due to regulatory differences [34].

The purpose of this study is to determine common causes of incidents and accidents involving hydrogen fueling stations. To achieve the aim, we extracted incidents and accidents involving hydrogen fueling stations in Japan and the USA from the High Pressure Gas Safety Act Database and HIRD. The method previously proposed by the authors was applied to the incidents, and we succeeded in achieving a uniform classification of incidents involving hydrogen fueling stations in Japan and the USA. Moreover, we analyzed the incidents with regard to the regulations in Japan and the USA.

Classification of incidents and accidents

Method for incident and accident classification

In this study, the incidents and accidents were classified into six categories using our method while referring to the incident response manual of the High Pressure Gas Safety Act [31]: (i) Leakage I: leakage due to the damage and fracture of main bodies of apparatuses and pipes (including welded parts). (ii) Leakage II: leakage from flanges, valves, and seals (including deteriorated nonmetallic seals). (iii) Leakage III: leakage due to other factors, e.g., human error and external impact. (iv) Explosion and fire. (v) Burst and fracture. (vi) Others.

The collected data include the incidents and accidents involving several types of hydrogen fueling stations. In Japan, the types of hydrogen fueling stations considered in this study are onsite-type hydrogen fueling stations using natural gas and other resources and offsite-type hydrogen fueling stations, which receive gaseous hydrogen and liquid hydrogen from other locations and store them. In the USA, some hydrogen fueling stations considered in this study are of the offsite type using liquid hydrogen and the type of the other stations is unknown.

It should be noted that considerable differences exist between the data for Japan and the USA, e.g., in terms of the duty of accident reporting and the standard of accidents. Moreover,

Table 1 – Database of hydrogen incidents and accidents.

Database name	Country/area of incident occurrence	Number of incidents (number of hydrogen fueling station incidents)	Database administrator
High Pressure Gas Safety Act Database	Japan (2005–2014)	(21)	High Pressure Gas Safety Institute of Japan
HIRD	USA (2004–2012)	216 (22) 2016/2/23 access	Pacific Northwest National Laboratory, USA
HIAD	Entire world	271 (2) 2016/2/24 access	European Commission's Joint Research Center, Petten, Netherlands

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