RISKS OF HYDROGEN USAGE FOR CARS WITH HYDROGEN-DRIVE ENGINE

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Introduction

Hydrogen is already being used in different ways to power vehicles [1]: to produce electricity in a fuel cell (e.g. DaimlerChrysler F-Cell, Toyota FCHV, Hyundai Santa Fe, Suzuki WagonR FCV), to replace gasoline or diesel fuel in the internal combustion engine (e.g. BMW 745H, Ford Focus C-Max, Ford Model U, Mazda RXB Renesis). To ensure that all these technologies can be used, it is important to identify as early as possible all risks associated with the use of hydrogen onboard vehicle and to succeed in mitigating them. However, only a small number of these vehicles are in operation today and that limits quite significantly the data available on safety aspects.

The Subject of the research

When introducing hydrogen-fueled vehicles, an evaluation of the potential change in risk level should be performed. The aim of the study is to identify and describe the risks associated with hydrogen explosions during the operation of a hydrogen-driven vehicle. The subject of the study is hydrogen, the object is risk associated with hydrogen usage in cars. The use of hydrogen is rising within a decentralized infrastructure. As now it is used in relatively small amounts, and increasing to a larger population, so they should be able to use it,without special training in the safety of this flammable gas [2].

Literature analysis

Hydrogen characteristics

Hydrogen is a flammable gas with a wide flammability range (4%–75% by volume) and relatively low ignition energy [3]. It has a very low density and therefore must be stored at high pressures to achieve enough mass for practical use. The ease of ignition and high storage pressure of hydrogen create a large portion of the risk associated with hydrogen usage. Hydrogen also has the ability to attack—and damage to the point of leakage—certain materials that are used for the construction of storage containers, piping, valves, and other appurtenances. This destructive capability is sometimes referred to as hydrogen embrittlement [4]. The mechanisms of hydrogen embrittlement can be complex and vary with several physical parameters including temperature and pressure. Hydrogen’s ability to escape through materials based on its destructive abilities and small molecule size also contributes to the risk associated with hydrogen usage.

Hydrogen as a Fuel for Fuel Cells

Hydrogen can be converted into electricity using a fuel cell. These fuel cells can be placed in vehicles to provide electricity for vehicles powered by electric motors or they can be used as stationary sources of electricity [3-4]. They offer advantages including no combustion emissions and, in the case of stationary fuel cells, reliable power that can be used in emergency situations such as storms or grid outages. Proton exchange membrane (PEM) fuel cells are the preferred fuel cell technology for vehicles and other new applications because of their fast start-up time and low operating temperature [5]. Hydrogen fuel cell vehicles require fueling at intervals comparable to a gasoline powered vehicle. This fueling activity will likely require vehicle owners and operators to operate fueling equipment, although in some states all fueling is conducted by fueling station personnel [4]. Fueling a hydrogen fuel cell vehicle requires approximately five minutes. This exposure of the general public to hydrogen represents a significant change in the hydrogen risk spectrum from that of trained workers in a controlled environment handling hydrogen.

General Hydrogen Vehicle Safety Research results

A large portion of the technical documents reviewed address general hydrogen vehicle safety for the entire vehicle [5-6]. General topics include:

• Fuel Cell Safety Analysis. Research has been conducted by JARI, Institute of Electrical and Electronics Engineers (IEEE) [6], and the University of Technology of Belfort Montbeliard/INRETS to investigate safety issues related to fuel cell safety in the event of a fire, safety procedures for emergency shut-down, and detection of hydrogen leaks in the fuel cell stack.

• Safety and Risk Analyses. Several papers discuss the use of formal safety analysis methods to manage the risks associated with hydrogen-fueled vehicles to support component and vehicle design, testing and codes and standards development [6].

• Vehicle Demonstration Programs. There have been several hydrogen vehicle demonstration programs. In particular, the Vancouver Fuel Cell Vehicle Program (VFCVP) is a five-year initiative designed to provide firsthand experience to demonstrate, test and evaluate the performance, durability, and reliability of five Ford Focus FCVs. were driven in real-world conditions to help generate data to determine the state of the technology and remaining challenges. To date, the program has been successful showing that the vehicles are performing with high reliability and availability as well as raising public awareness [6].

• Codes and Standards Updates. In general, the technical documents focused on the need for harmonization between countries and standards development organizations (SDOs) to develop consistent, performance-based standards for hydrogen vehicle safety [6].

Hydrogen Safety Incidents

Pacific Northwest National Laboratory, a DOE national laboratory, administers a database of hydrogen incidents called H2LL, or Hydrogen Lessons Learned 2. This database contains information about incidents that have been voluntarily reported although identifying information has been removed. These lessons learned provide information on safety issues and concerns with hydrogen technologies. Many of these entries describe events involving the industrial use of hydrogen or hydrogen usage for applications other than fuel cell electric vehicles or the infrastructure required to support these vehicles [5].

Initiating Events and Environmental Conditions

As was previously mentioned three types of initiators can be reviewed [7]:

- Crash accidents.
- Fire accidents without cash (no other cars are involved),
- Hydrogen leakages followed by ignition.

When introducing hydrogen-fueled vehicles, an evaluation of the potential change in risk level should be performed. It is widely accepted that outdoor accidental releases of hydrogen from single vehicles will disperse quickly, and not lead to any significant explosion hazard. The situation may be different for more confined situations such as parking garages, workshops, or tunnels. Experiments and computer modeling are both important for understanding the situation better. As the consequences or hydrogen ignition or explosion strongly depend on environmental conditions the following situations were taken into account [7]:

- Normal circulation (highway, country roads, suburban roads, streets),
- Circulation in a semiconfined environment (city, tunnels, gas station, parking etc.)
- Circulation and parking in a confined environment (private garage).

Risk evaluation results

The risk assessment of hydrogen-driven vehicleswas identified andsome additional risks related to hydrogen explosions were considered.

1) Five types of hydrogen explosions were identified [7]:

- the explosion in theatmosphere (open environment) – possible damage to car and injuries of individuals in the area of theincident (#1).
- the explosion in theatmosphere and in asemiconfined environment – possible damage to car and damage of other property in the accidental zone of 10 m. injuries of individuals in the area ofbeing incident (#2).
- the explosion of the car due to initial fire in combination with hydrogen releases in theinternal compartment of the car – possible destruction of the car,damageto other property in the accidental zone and possible severe injuries (#3).
- the explosion of storage tank – destruction of the car, damage to other property in the accidental zone of ~80 m and lethal casualties in the accidental zone (#4).
- the explosion of a refueling station - thedestruction of the car, damage to other property in theaccidental zone of =100 m and lethal casualties in the accidental zone (#5).

2) Estimated hydrogen explosion frequency is 5.47E-05 per car per year [7].

3) 99.8% of the risk relates to explosions in open and semi-confined environments (#1 and #2). These types of consequences are comparable with consequences of normal traffic accidents (injuries of persons, damage to cars and properties in the area of accident) [7] and represent less than 2% of traffic accidents (3.69E-03 per car per year).

4) The explosion in a semiconfined environment (#2) which represents 33% of additional risk and could lead to small damages of the surrounding property of people not directly involved in the accident (broken windows), [7] however issued as a

minor news item in the media it might create a negative impact on the public's perception of hydrogen technology.

5) Severe consequences with possible lethal casualties, damage to buildings and other properties in the area of theaccident(#3 - #5) represents less than 0.2% of additional risk ($1.15*10^{-7}$ per car/per year) [7].

6) Taking into account the population of the cars incirculation and the possible increase of vehicles on Hydrogen among the whole population [7] the frequency of severe accidents represents a non-negligible risk for a person.

7) The estimated risk of explosion at a hydrogen refueling station (#5)could he interpreted as one event every two years, which should also be considered as a hardly acceptable risk level. The risk related to the failures of equipment at the refueling station has to be added to the calculated frequency [7]. Nevertheless due to the limited information currently available the numberof incidents and consequences might be overestimated.

8) Analyseshad shown that the crash location is very important, and in particular thedamages in the rear part of the car [8]. For the consequence types (#1, #2, #3) with rear crash location contribute more than 60% to the total risk [7].

9) The scenarioswith the crash in the rear area are based on the assumption of the dependent leakage from the medium and high-pressure parts of the system caused by a crash. In order to improve the risk profile and reduce the risk the validity of this assumption has to be studied in depth.

Conclusions

Hydrogen-fueled vehicles will only be accepted by the population if all risks associated with the use of such flammable gas are completely identified and fully controlled. In fact, shouldbe taking into account that the relevant literature is relatively poor on the subject of risk evaluation. However, hydrogen technologies are controlled through codes and standards in a manner similar to other fuels. Also, the database with a lot of useful practical information exists. These documents contain references to component standards and address all key aspects of system design, construction, operation, and maintenance. Compliance with these requirements should reduce the system risk to a safe level.

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