INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 37 (2012) 5299–5306

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Safety study of a hydrogen leak in a fuel cell vehicle using computational fluid dynamics

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ARTICLE INFO

Article history:
Received 1 October 2011
Received in revised form
5 December 2011
Accepted 7 December 2011
Available online 29 December 2011

Keywords:
Hydrogen
CFD
Safety
Vehicle
Dispersion simulation

ABSTRACT

This paper analyzes safety aspects inside a Fuel Cell vehicle using Computational Fluid Dynamics (CFD) tools. The research considers an introduction of a leak of hydrogen inside the vehicle, and its dispersion for a set of typical ventilation conditions is analyzed. The leak of hydrogen has been modelled according to the properties of hydrogen and depending on the pressure difference between the hydrogen storage tank (200 bar) and the atmosphere. The parameters considered for the simulations are the flow rate of cabin ventilation air and hydrogen's leak. The results obtained for the hydrogen molar concentration are investigated in different sections of the vehicle. Significant differences between front and rear areas are observed, with higher hydrogen concentrations near the rear ventilation vents. The volume of the vehicle within ignition risk (4–75% hydrogen concentration) is also investigated. Finally, different risk mitigation measures are also proposed.

1. Introduction

Hydrogen is considered one of the future energy vectors that may present an important development and implementation within the next years. Hydrogen used in Fuel Cells presents significant advantages when compared with traditional fossil fuels, such as reduction of pollutants and CO_2 emissions, and higher efficiencies.

The activities of research and development have been developed in all areas of the so-called hydrogen technologies. All technologies related to production, storage and use of hydrogen, especially those technologies considering environmental issues, will be an object of priority attention during the next years. It is well recognized that detailed safety investigations will be necessary due to the flammable properties of hydrogen [1].

Hydrogen can be used in chemical combustion processes and in internal combustion engines. However, the application that presents higher interest is the production of electrical energy in fuel cells (electrochemical devices able to convert chemical energy contained in a fuel into electrical energy with high performance, as the conversion is not limited by Carnot's cycle). Fuel cells have a theoretical performance around 80%, with real efficiencies around 40–60% when accounting for the different voltage losses in the stack operation [2]. The type of fuel cell more suitable for the operation of a vehicle is the PEM FC due to its high power density and its low operation temperature (<80 °C) that facilitate a quick

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doi:10.1016/j.ijhydene.2011.12.046

start engine and an appropriate time response to the power demand required.

In transport applications, hydrogen storage research should focus on systems that have the capability to match the driving range of equivalent gasoline vehicles, with a necessary focus on systems that are safe. Storage systems will have to be compatible with the fuelling infrastructure, and the safety of storage systems design should be ensured through the development of codes and standards [2].

A real example of this kind of technology is the Hercules project, whose objective is to demonstrate the technical and economical feasibility of producing hydrogen from an inexhaustible, clean and high availability source in Spain as is the sunlight radiation. The project also contributes to the implantation of hydrogen in the transport sector by designing and building up a service station to dispense hydrogen to a fuel cell vehicle [3].

In all areas related to hydrogen technology, it is important to develop safety analysis due to the characteristics of hydrogen. One of the main risks of using hydrogen as fuel is the problem associated with leakages. The high buoyancy of hydrogen affects the movement of the gas even more than its high diffusivity. The buoyancy of hydrogen will create convection flows. Due to these properties, hydrogen gas will disperse quickly and it will form flammable mixtures with air when it is trapped, as is the case of fuel cell vehicles.

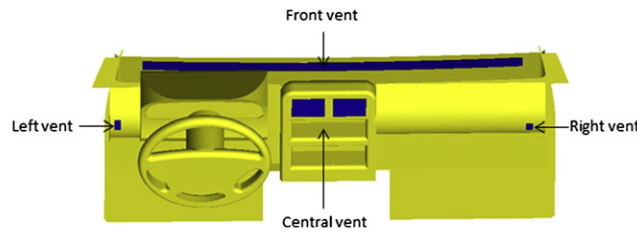

Fig. 2 – Position of the air inlet ventilation vents.

In the field of hydrogen safety there is no general detailed legislation, and each country is using different legislations, codes and standards. However, experts agree with the need to install a hydrogen detection and ventilation system.

Several authors have developed safety analysis against leakages of hydrogen in different scenarios using Computational Fluid Dynamics (CFD) tools, like a fuelling station [4], hydrogen laboratory [5], tunnels [6] and hydrogen related accidents [7–9]. All authors agree with the idea of designing a ventilation system that is capable of reducing the risk of ignition inside the enclosure. Obviously, each ventilation

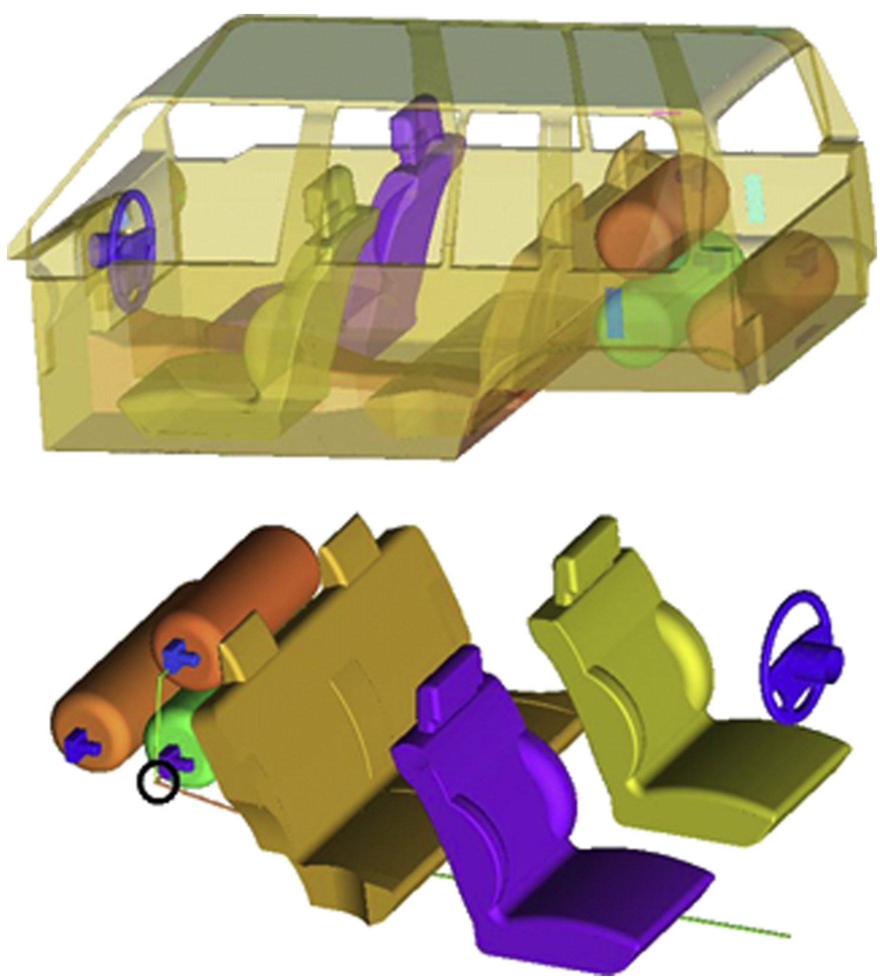

Fig. 1 – Geometry of the cabin and interior of the Santana 350.