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Dispersion and behavior of hydrogen during a leak in a prismatic cavity

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ABSTRACT

Security is recognized as one of the most important problems facing the wider use of hydrogen and the increased risk of accidental release into the infrastructure. Prismatic cavity design can be represented one of the best solutions for this problem. For this reason, dispersion and accumulation of hydrogen in a prismatic cavity with natural ventilation are computationally investigated by the commercial software FLUENT.

In this paper, the roof apex angle A and the opening ventilation of a prismatic residential garage are examined to prove their effect on the hydrogen concentration gradients and stratification. The apex angle is varied from 180° to 90° and results have shown that the hydrogen mole fraction and the flow structure are strongly influenced by A, and that the lowermost concentration is obtained for $A = 120°$.

1. Introduction

The approach in favor of sustainable development helps reduce energy consumption, pollution control and diversification of primary energy sources, development of renewable energy. Hydrogen is one of the new energy which may limit long-term releases of greenhouse gas emissions. Indeed, the hydrogen used in fuel cells or in an internal combustion engine is an energy carrier which provides electricity and heat with water as the only residue. But even the hydrogen is "extremely flammable" gas classified: it has a wide flammability range from 4% to 75%. Its ignition energy is about 10 times lower than that of classic hydrocarbons. By cons, the auto-ignition higher temperature is around 585 °C. The hydrogen combustion flame in air is almost invisible and

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extremely hot (2000 °C). He showed a very high potential explosion in confined areas. It is the lightest of all gases; it diffuses very easily in the air and has a high propensity to flee.

Various security issues were discussed until now. These especially include the fragility of hydrogen, penetration, leaks convection inflammation and explosion. In particular, research on hydrogen leaks is important to avoid accidental ignition, and set the margin of safety for leaks. Therefore, to ensure the safe use of hydrogen, it is necessary to predict and understand the characteristics of its leakage and dispersion. Recently, several researchers have investigated the dispersion and hydrogen leaks. The study subjects included an hydrogen jet through a nozzle [1], the boundary layers [2,3], the transient dispersion in a vertical cylinder [4], dispersion and natural ventilation in a garage [5–11] in a tunnel [12] and in domestic rooms [13], the effects of leakage and dispersion into the atmosphere [14]. Swain and Swain Ref. [15] reported on the building geometry influences, and on the combustible gas cloud formation when passive ventilation. They also discussed a method of classification of hydrogen leakage and proposed a risk determination for semi-open space [1]. Matsuura et al. [7] examined the effects of changes in positions of vents and ventilation conditions on the distribution of hydrogen concentration. They proposed a detection algorithm based on an adaptive risk mitigation of leaking hydrogen in a partially open space.

William Pitt et al. conducted experimental studies to characterize the behavior of helium in a residential garage at a reduced scale of 1/4 [16], the hydrogen–air mixture when it is released in a two-car residential garage [17]; they have studied the distribution of the hydrogen fraction into the garage with and without vehicle, the combustion behavior of hydrogen–air mixture resulting in damage of the garage and the vehicle.

These studies have shown that the dispersion and accumulation of hydrogen in confined spaces are examples of the most dangerous scenarios.

Kuldeep Prasad et al. [10] studied the natural and forced ventilation carrier gas released in a garage on a large scale, which they have developed a simple analytical model to predict the natural and forced mixing and dispersion of a carrier gas released partially on an opened compartment with various and multiple vents levels.

The literature review concerning natural convection in isosceles triangular cavities shows that this configuration was has been the subject of experimental and numerous numerical studies. Earlier, the flow and temperature patterns, local wall heat fluxes, and mean heat flux rates were measured experimentally by Flack [18,19] in isosceles triangular cavities with three different aspect ratios. The cavities, filled with air, were heated/cooled from the base and cooled/heated from the inclined walls covering a wide range of Grashof numbers. Asan et al. [3] conducted a numerical study of laminar natural convection in a pitched roof of triangular cross-section considering an adiabatic mid-plane wall condition in their numerical procedure.

Using hydrogen in the study requires a properly prepared system to ensure the secure execution experiments. In this regard, the CFD (Computed Dynamic Fluid) is considered a cost-effective and safe approach. If the constituent factors, such as chemical, physical, and turbulence models, boundary conditions, etc, are safety modeled, and the numerical schemes are verified [7], the methodology provides much information on the integral linkages that increase the potential hazard. This important information is required for minimizing computation.

In this study, the dispersion of hydrogen in a prismatic garage is studied by using the commercial software Fluent, considering the important factors that influence on the behavior of the hydrogen concentration and accumulation such as the roof garage apex angle and the ventilation openings positions.

2. Computational geometry

The garage having interior dimensions 6.10 m (width), 6.10 m (length), 3.05 m (height). Two 0.2 m × 0.2 m openings in the right side wall at heights of 2.3 m provided visual access to the interior. The hydrogen used in this study, entering the garage through the upper nozzle rectangular section of dimensions (0.305 m, 0.305 m, 0.15 m) respectively along (x, y, z), located in the center of the garage floor (Fig.1).

The hydrogen release scenario assumed a constant leak rate sufficient to release 5 kg (a typical amount for full tanks on current hydrogen-fueled automobiles) in 1 h. The mass flow rate of 83.3 g/min corresponds to a volume flow rate of 994 L/min for standard conditions of 1 atm and 20 °C.

In this work, the software Gambit is used to build and mesh the garage (Fig.2). Mesh quality has a great importance on the results of numerical computation. The mesh used is obtained after several tests; the cell spacing size used is 0.05 m in each one of the four geometries. The average total number of mesh obtained is 907.924 elementary cells between the four different geometrical designs. It is a tetrahedral mesh, tight. Regarding modeling, we used the 6.3.26 version of Fluent CFD software.

3. Description of the numerical model

The continuity and the compressible Navier–Stokes equations with gravitational force, as well as the energy and the transport equations for the hydrogen mass fraction are used to be numerically resolved. Gas species diffuse according to

Fig. 1 – Exterior view of the garage [17].