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Influence of the gas injector configuration on the temperature evolution during refueling of on-board hydrogen tanks

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ABSTRACT

In this article we show a refueling strategy analysis using different injector configurations to refuel a 70 MPa composite reinforced type 4 tank. The gas has been injected through single openings of different diameters (3 mm, 6 mm and 10 mm) and alternatively through multiple small holes (4 × 3 mm). For each injector configuration, slow (12 min) and faster (3 min) fillings have been performed. The gas temperature has been measured at different positions inside the tank, as well as the temperatures of the wall materials at various locations: on the external surface and at the interface between the liner and the fiber reinforced composite. In general, the larger the injector diameter and the slower the filling, the higher the chance that the gas develops vertical temperature gradients (a so-called gas temperature stratification), resulting in higher than average temperatures near the top of the tank and lower than average at its bottom. While the single 3 mm opening injector causes homogeneous gas temperatures for both filling speeds, both the 6 mm and 10 mm opening injectors induce gas temperature stratification during the 12 min fillings. The injector with multiple holes has an area comparable to the 6 mm single opening injector: in general, this more complex geometry tends to limit the inhomogeneity of gas temperatures during slow fillings. When gas temperature stratification develops, the wall materials temperature is also locally affected. This results in a higher than average temperature at the top of the tank and higher the slower the filling.

Introduction

Hydrogen fueled vehicles have the advantage of low carbon dioxide emissions when renewable energies are used for hydrogen production [1,2]. Moreover, they provide the functionality of a gasoline/diesel cars; they can be refueled in 3–5 min and they have autonomy for hundreds of kilometers before they need refueling. Expected vehicle range per full fueling is taken to be greater than or equal to 500 km (300 miles) [3–5].

For hydrogen vehicles, specific on-board storage technologies are necessary to approach typical energy densities of the traditional liquid fuels. At present, the most commonly adopted storage solution by car manufacturers is compressed

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hydrogen storage. Due to the low density of hydrogen at atmospheric conditions, high pressures are required inside the fuel tanks in order to achieve autonomy comparable to conventional vehicles. Fully wrapped carbon fiber reinforced tanks designed to work under a nominal working pressure (NWP) of 70 MPa are used in the last generation of hydrogen powered vehicles [6].

During refueling, the compression of the hydrogen inside the tank (performed in less than 5 min), heats the gas, with the risk of exceeding the +85 °C tank design temperature limit [3–5]. Furthermore, the temperature increase reduces the density of the hydrogen for a targeted pressure and this reduces the final State of Charge (SoC) of the hydrogen tank. The SoC is defined as the ratio between the hydrogen density at a given temperature and pressure and the full tank density at 15 °C and 70 MPa. If during the filling the average gas temperature increases inside the tank (up to the maximum allowed temperature of 85 °C), the target pressure has to be also increased (up to a maximum of 125% NWP) in order to reach the 100% SoC [7]. To refuel on-board hydrogen tanks within the safety temperature and pressure limits and with a reasonable level of filling, the SAE (Society of Automotive Engineers) developed a hydrogen fueling protocol SAE J2601 [8].

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) funded project HyTransfer [9] aims at developing and experimentally validating a practical approach for optimizing hydrogen refueling by means of temperature control during fast transfers of compressed hydrogen. The purpose is to meet the specified limits taking into account the thermal behavior of the compressed hydrogen storage system (CHSS) [3]. This new filling approach will be fed into the present standardization efforts. Different strategies are being studied in order to find the most practical, efficient and safest refueling for a SoC value above 95%. There are different parameters affecting the average and maximum temperature of the gas achieved during a refueling. Filling conditions as inlet temperature, filling rate, filling pattern and end pressure are important to prevent the temperature from exceeding the design temperature, to make the filling homogeneous and to achieve filling within a short time [10–13]. In addition to the filling conditions, tank characteristics (such as materials, dimensions of the tank or the configuration of the gas injector) also influence the refueling performance.

The design of the gas jetting inside a tank is an important feature which influences the temperature evolution during hydrogen refueling. In the work made by Terada et al. [14], the effect of the gas nozzle diameter on the filling of a 35 MPa type 4 tank was studied. They performed fillings with the gas axially jetted from nozzles of different sizes (4.5 mm, 7 mm, 8.5 mm and 10 mm diameter). Terada et al. related the local gas temperature rise to the low gas velocity at the injector outlet and concluded that a local gas temperature rise in the upper area of the tank during the filling tends to decrease with the reduction of the nozzle diameter and with the increase of the filling rate.

In the present article, the temperature evolution during refueling of a 70 MPa NWP type 4 tank is studied using different gas jetting configurations. Injectors with single openings of different sizes (3 mm, 6 mm and 10 mm diameter) have been tested. Moreover, an injector with 4 openings of small diameter (4 × 3 mm) has been also tested to investigate the effect of this configuration on local gas temperatures. Two different filling rates have been also considered to understand the effect of the injector on the temperature distribution inside the tank.

Experimental

Testing facility

The experiments presented in this article have been performed in GasTeF, the JRC-IET compressed hydrogen gas tanks testing facility [15]. In Fig. 1, a scheme of the facility is shown. The filling of the tanks (horizontally placed inside the sleeve) is performed in two stages; a first stage consists of a pressure equilibration with the hydrogen reservoir (which is kept at a pressure between 22 and 24 MPa) followed by a second stage by pressurizing the gas with a hydraulic compressor. The hydrogen temperature is controlled by a gas cooler and the flow is measured by a RHM03 Coriolis mass flow meter (Rheonik GmbH) placed in the gas line, 50 cm from the test vessel. Pressure and temperature sensors placed also in the gas line, 30 cm away from the test tank, were used to control de inlet gas temperature and pressure. All the facility operational data and the measurements from the scientific

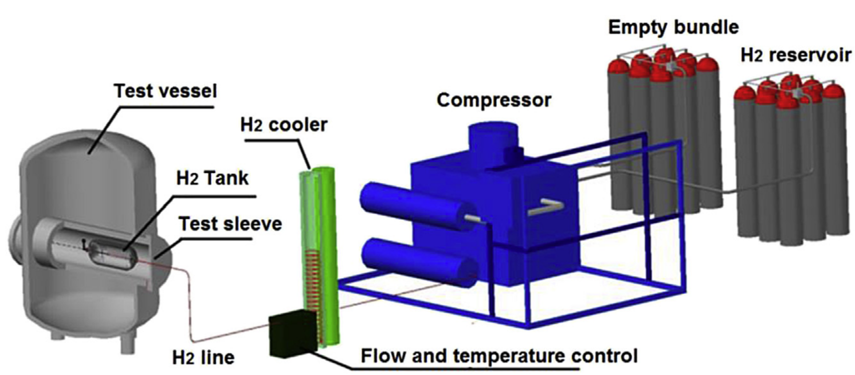

Fig. 1 – Scheme of the JRC's GasTeF facility.

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