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COMPUTATIONAL AND EXPERIMENTAL SUPPORT FOR THE DEVELOPMENT OF MOBILE HYDROGEN REFUELING STATION

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Abstract: *This paper falls within the field of applied research and focuses on emerging hydrogen technologies, particularly the use of hydrogen as a vehicle fuel in the transportation sector. The deployment of hydrogen-powered vehicles requires a network of refueling infrastructure; however, stationary hydrogen refueling stations are currently economically feasible only at selected locations. To complement this limitation, a mobile hydrogen refueling station was developed, offering relatively low initial investment costs together with flexible hydrogen delivery and dispensing capabilities. The paper outlines the main parameters of the mobile station prototype and presents the computational tools developed to determine optimal filling parameters. The final part of the paper deals with the experimental verification of the structural loading of the trailer carrying the station and with the evaluation of the driving performance of the complete vehicle–trailer combination.*

Keywords: Hydrogen, Mobile refueling station, Prototype design, CFD, Stress measurement

1. Introduction

In line with the strategy for decarbonizing the transport sector, which includes the use of hydrogen as a fuel, it is essential to ensure a sufficient number of refueling locations for vehicles using hydrogen technologies. For this reason, a prototype mobile hydrogen refueling station (see Fig. 1) was developed (Polach et al., 2025), intended to complement stationary refueling stations by providing the same service in locations that are not currently, or will not soon be, covered by the stationary network.

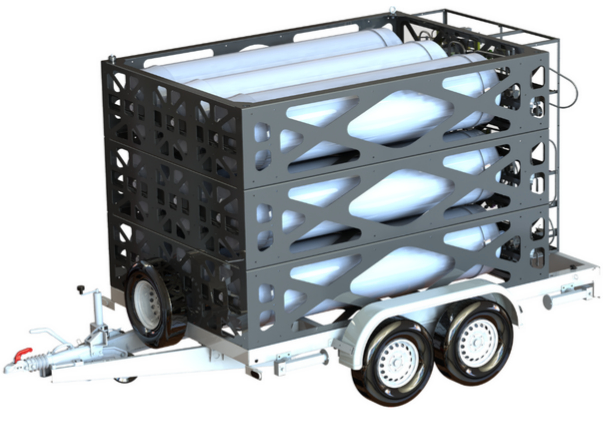

Fig. 1: Trailer with the mobile refueling station (reproduced from DEVINN, 2026).

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A representative overview of the current state of knowledge regarding hydrogen use in transportation, including hydrogen refueling stations, is presented by Genovese and Fragiacomo (2023), which reviews the latest literature on hydrogen stations, describes the global technological status, and highlights research on key components and processes, and by Genovese et al. (2023), which examines the major phenomena occurring during hydrogen refueling through analysis of relevant theory and existing modeling approaches. Pereira et al. (2024) review hydrogen's application as a fuel, summarizing the main systems involved in hydrogen refueling stations, from production to the final refueling stage. Klymovskyi et al. (2023) report that approximately 78,000 hydrogen-powered vehicles were in operation globally, supported by 1,100 publicly accessible hydrogen refueling stations. In the Czech context, Bošković et al. (2025) address the challenge of locating hydrogen refueling stations from the driver's perspective, focusing on the Pardubice region.

During the development of the mobile hydrogen refueling station presented here, it was necessary, in addition to the design work (DEVINN, 2026), to determine optimal operating parameters for refueling with non-cooled hydrogen at ambient temperatures (Polach et al., 2025), and to assess the stress levels in the load-bearing modules of the hydrogen tanks, the trailer structure carrying the station, and to analyze axle displacements and trailer accelerations (Václavík, 2023).

2. Mobile hydrogen refueling station

The developed mobile hydrogen refueling station is a system designed for the easy transport of compressed hydrogen and subsequent refueling of hydrogen-powered vehicles or other compatible devices. It enables refueling of passenger cars at a hydrogen operating pressure of 700 bar, buses (and trucks) at 350 bar, and material-handling equipment at 350 bar. The system is designed for outdoor operation.

The mobile station (Fig. 1) consists of a compressed hydrogen storage unit made up of three bundles of high-pressure cylinders with a cascaded distribution system and a unique control system for maximizing hydrogen utilization, a trailer, and a dispensing unit. The high-pressure mobile storage comprises a bundle of nine cylinders rated up to 500 bar, capable of storing nearly 100 kg of hydrogen. The bundle is mounted in a frame that ensures both the safety and proper function of the cylinders. The entire system is installed on an AGADOS cargo trailer and is designed to meet the requirements for towing behind a passenger vehicle in the up-to-3.5 t category. The station does not include a hydrogen compressor; hydrogen transfer relies solely on pressure differences between the station and the receiving device. The system can also operate at locations without connection to the electrical grid.

3. Computational support for determining optimal refueling parameters

The hydrogen refueling process, particularly for automotive storage tanks, has several specific features. Because of its very low molecular mass, hydrogen is an extremely light gas, and transferring a significant mass into a storage vessel requires very high pressures, typically on the order of tens of MPa. Both the storage tanks and the refueling infrastructure consist of one or more thick-walled pressure vessels, between which the gas is transferred either actively (e.g., by means of a compressor) or passively through pressure equalization. During refueling, rapid variations in pressure and temperature occur both within the refueling system and inside the receiving tank. These transient thermodynamic effects may result in excessive heating of the hydrogen within the tank, which can compromise the prescribed limits for safe operation of the filled system.

Existing standards could not be used for the design of the filling control system, in terms of setting the control elements of the filling cascade—such as filling rates and the timing of individual cylinders. The current version of SAE J2601 (SAE, 2020) covers only cases of filling with pre-cooled hydrogen at temperatures between –10 °C and –40 °C. For this reason, a mathematical-computational model was developed and implemented in custom software within the MATLAB environment. This model allows simulation of vehicle tank filling while considering a wide range of input parameter variations, including different tank volumes and types, ambient and tank temperatures, and varying initial pressures in the tank or the filling station cascade (Polach et al., 2025). The model is based on the conservation of mass and energy and evaluates the balance of physical quantities across four primary subsystems: the refueling station, the station supply line, the vehicle supply line, and the vehicle storage tank. The refueling station is represented as a set of independent pressure-vessel banks that can be selectively connected or switched during the refueling process. Depending on the vehicle configuration, the storage system is modelled either as a single pressure vessel or as multiple vessels being filled simultaneously. The developed software enables the evaluation of heat exchange with the surroundings across all considered subsystems. The basic scheme of the modelled thermal balance of the hydrogen refueling process is shown in Fig. 2.

Using the simulation results, control algorithms were designed to ensure the safe filling of all tanks for which the mobile filling station is intended.

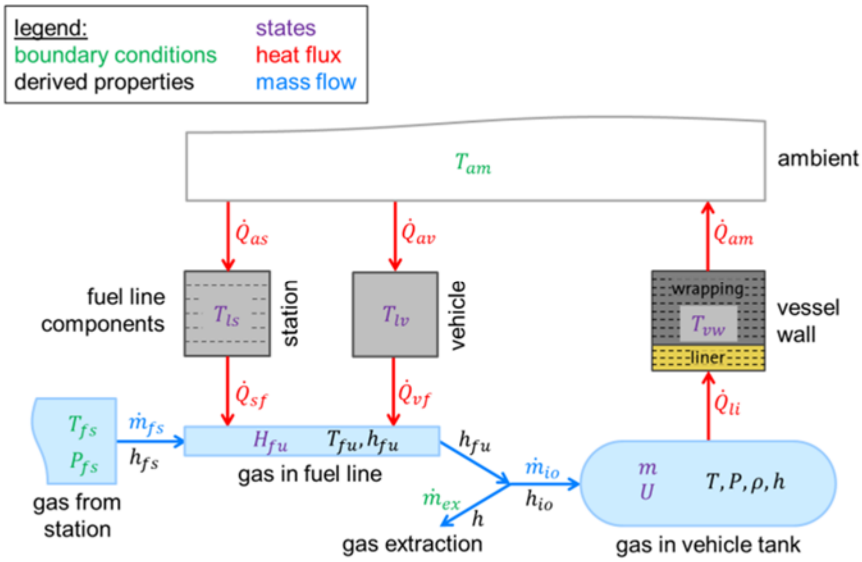

Fig. 2: Basic diagram of the modeled thermal balance of the hydrogen refueling process (T = temperature, P = pressure, H = enthalpy, h = specific enthalpy, ρ = density, $\dot{Q}$ = heat flux, m = mass, $\dot{m}$ = mass flow, U = internal energy; and subscripts according to the SAE J2601 standard: am = ambient, as = ambient-station, av = ambient-vehicle, ex = extraction, fs = fuel station, fu = fuel unit, li = liner, ls = line station, lv = line vehicle, io = inlet-outlet, sf = station-fuel unit, vf = vehicle-fuel unit, vw = vessel wall) (reproduced from Polach et al., 2025)

4. Experimental measurement of driving performance and structural loading of a trailer

The experimental measurements primarily focused on evaluating stress levels in the load-bearing modules of the hydrogen tanks and in the trailer frame, as well as on analyzing axle displacements and trailer accelerations (Václavík, 2023). Test runs were conducted with the trailer coupled to a passenger van, an Opel Combo (Fig. 3). As noted above, the objective of these tests was to verify both the structural integrity of the trailer and the driving behavior of the complete vehicle–trailer combination. For structural integrity assessment, the trailer repeatedly passed over an artificial vertical bump with a height of 58 mm during three separate test runs at speeds of 28 km·h^{-1}, 33 km·h^{-1}, and 38 km·h^{-1}. To evaluate driving behavior, a test drive was carried out on roads in the village of Spojil, including sections with pronounced road irregularities, curves, turning maneuvers, and reversing maneuvers.

Structural loading of the trailer was evaluated by measuring strain in one direction using resistive strain gauges (with a grid length of 6 mm). The strain gauges were installed primarily on the lower load-bearing module, where the highest stress levels were expected. Stress in the trailer frame was also monitored at the most critical welded joints, and their permanent strength relative to the material yield strength was evaluated based on repeated passes over the artificial vertical bump. The behavior of the entire vehicle–trailer combination was assessed by measuring axle displacements using two Panasonic laser triangulation sensors with a measurement range of ±80 mm, together with trailer accelerations in three axes and vertical acceleration at the trailer drawbar measured by four ICP accelerometers with a sensitivity of 100 mV/g.

For evaluation of the trailer frame with respect to permanent strength, a limit corresponding to 0.7 % of the material yield strength was applied, representing approximately 200 MPa. Test data were obtained from runs over the artificial vertical bump, and this limit was not exceeded at any strain gauge location. For the assessment of high-cycle fatigue strength, a stress amplitude of 60 MPa corresponding to the fatigue limit was used. This evaluation was performed using data obtained from the sample route through the village.

On the main load-bearing frame, stress amplitudes reached approximately one half of this value, whereas on the trailer subframe the amplitudes were comparable to the fatigue limit.

Based on the evaluation of all measured quantities, it was concluded that the trailer satisfies the requirements for safe operation with respect to both structural loading and the driving behavior of the vehicle–trailer combination.

Fig. 3: Trailer attached to an Opel Combo and passing over an artificial vertical bump.

5. Conclusions

The paper reports the prototype specifications, presents the computational tools for optimizing filling parameters, and describes the experimental evaluation of the trailer's structural performance and the overall driving behavior of the combination. The development of computational support for filling is currently ongoing for other design variants of hydrogen refueling stations.

Acknowledgement

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