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# MOBILE HYDROGEN REFUELING STATION AND CALCULATION SUPPORT FOR DETERMINING OPTIMAL REFUELING PARAMETERS

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**Abstract:** *This paper focuses on applied research in the currently highly supported field of hydrogen technologies. Specifically, it addresses the use of hydrogen as a fuel for transportation to reduce emissions in the sector. For this use of hydrogen, it is necessary to build a network of stationary hydrogen refueling stations. However, their construction is time-consuming, financially demanding, and feasible only in specific locations. To complement stationary stations, a solution combining low initial costs with the flexibility of hydrogen distribution and dispensing has been developed: a mobile hydrogen refueling station. This paper summarizes the key parameters of the mobile hydrogen station prototype and presents computational support for determining optimal refueling parameters.*

**Keywords: Hydrogen, Mobile refueling station, Design prototype, Numerical modeling, Thermal balance**

## 1. Introduction

One approach to reducing greenhouse gas emissions in the transportation sector is to enable the seamless operation of vehicles using hydrogen fuel cells for their propulsion. With regard to the decarbonisation strategy of the transport sector, it is essential to ensure a sufficient number of refueling locations for hydrogen-powered vehicles. For this reason, a prototype of a mobile hydrogen refueling station was developed (Polach et al., 2022). Its purpose is to complement stationary refueling stations—providing the same service in areas that currently lack or will not soon have access to a network of fixed hydrogen stations. The developed station can be used both for refueling vehicles, and for refueling mobile power stations with hydrogen fuel cells, which subsequently can perform the function of mobile charging stations for electric cars or an independent source of electricity.

The overview of the current state of knowledge on hydrogen use in the transport sector, including the topic of hydrogen refueling stations, is presented e.g. in the papers Genovese and Fragiacomo (2023), with more than 300 references to relevant literature, and Genovese et al. (2023), with more than 150 references to relevant literature. The review of the technology of hydrogen refueling stations is introduced in Pereira et al. (2024).

During the development of the mobile hydrogen refueling station, it was necessary to determine optimal refueling parameters for the operation of the station on uncooled hydrogen at ambient temperatures. It was not possible to use existing standards for the filling control design (in terms of setting the cascade system's control elements, such as refueling speed and the activation time of individual tanks). The current version of the SAE J2601 standard (SAE, 2020) covers only refueling scenarios involving precooled hydrogen at temperatures between -10 °C and -40 °C. For this reason, a mathematical computational model was created and implemented in an in-house software using MATLAB environment. This model allows for simulations of vehicle fuel tank refueling while considering a wide range of input parameters, including different tank sizes and types, varying ambient and tank temperatures, and differing initial pressures in both the tank and the refueling station cascade system (Bělohoubek et al., 2023). The simulation results were used to develop control algorithms that ensure safe refueling for all devices intended to be refueled by the mobile station.

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## 2. Mobile hydrogen refueling station

The developed mobile hydrogen refueling station (see Fig. 1; Polach et al., 2022) is a device designed for the convenient transport of compressed hydrogen and the subsequent refueling of hydrogen-powered vehicles or other compatible equipment. It enables the refueling of passenger cars with an operational hydrogen pressure of 700 bar, buses (or trucks) with an operational hydrogen pressure of 350 bar, and material handling equipment with a pressure of 350 bar.

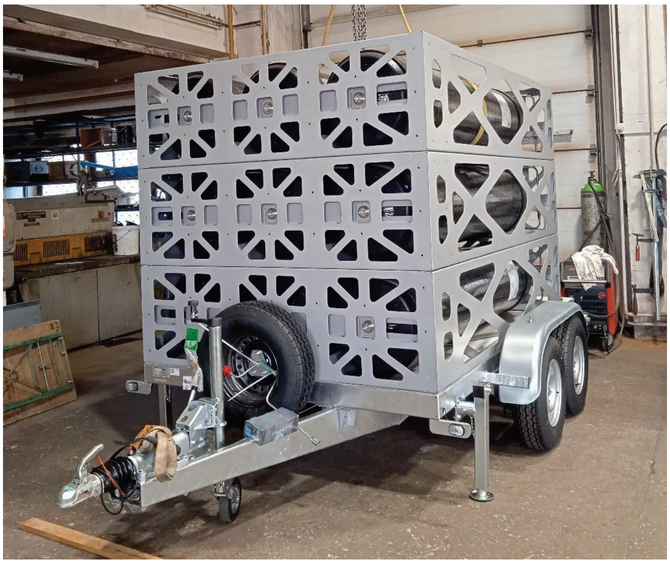

*Fig. 1: Trailer with the mobile refueling station.*

The mobile station consists of:

- a compressed hydrogen storage system composed of a system three bundles with pressure cylinders with a dimensioned cascade distribution system and a unique control system to maximize the utilization of hydrogen from the storage (see Fig. 2),
- a trailer,
- a dispensing unit.

The high-pressure mobile storage is implemented with a bundle of nine pressure cylinders capable of holding up to 500 bar, allowing for nearly 100 kg of hydrogen storage. The bundle is mounted in a frame that ensures the safety and proper functionality of the cylinders. The entire system is designed to meet the requirements for transport behind a passenger vehicle. The station does not include a hydrogen compressor; only overflow is used based on the different pressure levels in the refueling station and in the refueled equipment.

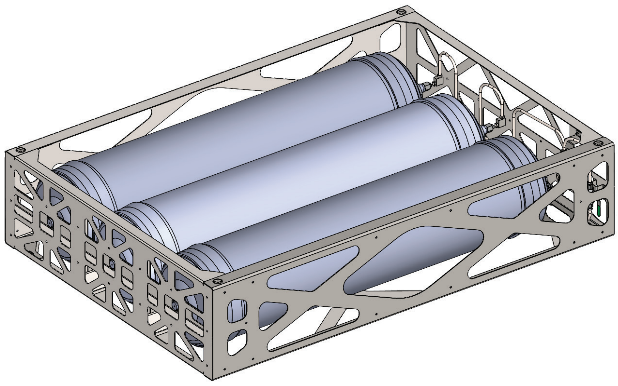

*Fig. 2: Bundle of pressure cylinders.*

One kilogram of hydrogen provides approximately 33 kWh of usable energy. Assuming a conversion efficiency to electrical energy of around 50%, a single mobile hydrogen refueling station can deliver up to 524 kWh of electrical energy.

## 3. Computational support for determining optimal refueling parameters

The hydrogen refueling process, especially for automotive tanks, has specific characteristics. Due to its low atomic number, hydrogen is an extremely light gas, and delivering a larger mass into the tank requires high pressure (typically up to several tens of MPa). Both the tanks and refueling stations are equipped with one or more thick-walled pressure vessels, between which gas is transferred either forcibly (e.g., using a compressor) or passively (based on pressure equalization).

During the refueling process, significant changes in temperature and pressure occur within the refueling station and the receiving tank. This can lead to excessive heating of hydrogen inside the tank, potentially violating the conditions for the safe operation of the filled device. The conditions for safely refueling hydrogen vehicles are defined by the SAE J2601 standards (e.g. SAE, 2020; Will, 2014), which are issued for various tank sizes, ranging from motorcycles to heavy-duty trucks and buses. These standards specify four criteria that must be met to ensure safe refueling:

1. The maximum temperature during refueling must not exceed 85°C.
2. The maximum pressure must not exceed 1.25 times the nominal tank pressure (87.5 MPa or 43.75 MPa for the most common tanks).
3. The tank's maximum capacity, referred to as “State of Charge” (SOC), must remain below 100%.
4. The maximum mass flow rate must not be exceeded throughout the refueling process. For the most common tank types, this is limited to <60 g/s or <120 g/s, depending on the tank type.

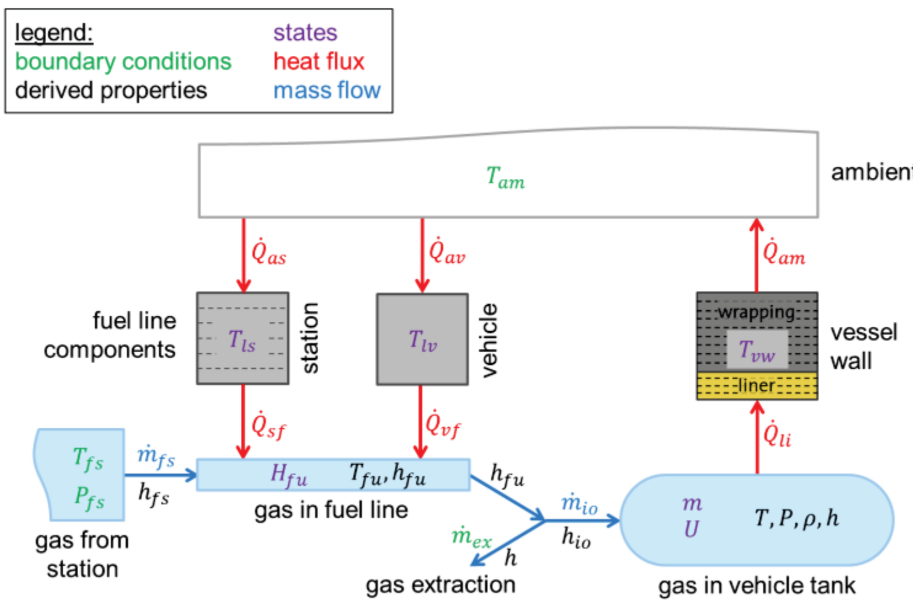


*Fig. 3: Basic diagram of the modeled thermal balance of the hydrogen refueling process ($T$ = temperature, $P$ = pressure, $H$ = enthalpy, $h$ = specific enthalpy, $\rho$ = density, $\dot{Q}$ = heat flux, $m$ = mass, $\dot{m}$ = mass flow, $U$ = internal energy; and subscripts according to the SAE J2601 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).*

The model is based on a combination of 0D modeling (mass and energy balance within individual geometries) and 1D modeling (heat exchange with the surroundings through the walls of individual geometries), including the incorporation of the Joule-Thomson effect in the area of the transfer valve (e.g. Moran and Shapiro, 2006). The model balances physical quantities across four primary geometries: the refueling station, the fuel line station, the fuel line vehicle, and the vehicle tank. The refueling station is defined as a set of independent bundles of pressure, between which it can be switched at will during refueling. The vehicle tank, depending on the vehicle’s specifications, is modeled as either a single pressure vessel or multiple vessels being filled simultaneously. The developed software enables the calculation of heat exchange balance with the surroundings across all these geometries. The basic scheme of the modeled head balance of the hydrogen refueling process is introduced in Fig. 3.

The implementation of the developed mathematical-physical model is realized through four fundamental physical modules:

- **Thermal balance during gas transfer between geometries.** The thermal balance of the transferred gas between geometries balances two fundamental quantities: mass and energy.
- **State model of hydrogen.** This model defines the variable physical properties of hydrogen as a function of temperature and pressure. In thermodynamics, a state model refers to equations or a set of equations that describe the relationships between variables characterizing the state of a given thermodynamic system.
- **Heat dissipation to the surroundings.** According to the formulated energy conservation law and the state description, introducing a specific amount of gas into a pressure vessel increases the gas's energy and, consequently, its temperature. Under certain refueling conditions, this may pose a risk to the safety requirements for refueling. Heat dissipation through the pressure vessel walls plays a critical role in mitigating this risk.
- **Local phenomena in specific parts of the geometry.** A significant physical phenomenon included in the heat balance calculations is the local process known as the Joule-Thomson effect. This effect occurs during the adiabatic expansion of fluid through a barrier between regions of differing pressure, causing a change in the fluid's temperature.

The solution was validated based on the literature Woodfield et al. (2008).

## 4. Conclusions

The paper presents the basic parameters of the mobile station prototype and introduces computational support for determining optimal refueling parameters. The development of computational support for refueling is ongoing, including for other design variants of hydrogen refueling stations.

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