Using Absorption Refrigerator and Metal Hydrides in Hydrogen Fuel Cell Trains: Draft Design Process and Feasibility

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HVAC installations on trains are the 2nd largest consumer of energy after traction. For long-distance trains this can be 15% to 20% and for regional vehicles up to 40% of the total energy requirement [1, 2]. An annual energy demand for heating, ventilation and air conditioning (HVAC) of 54.7 MWh in a local tram train was described for a specific project [3]. For fuel cell trains with an efficiency of appr. 50 %, this number would lead to an additional hydrogen consumption of 3.2 t H_2 per year, if HVAC is performed with electrical power only. To reduce this energy demand, we investigate the feasibility and benefits of Hydrogen Powered Air Conditioning (HyPAC) and absorption AC in a simulation study. Both technologies use the energy which is already on board. The HyPAC exploits the pressure difference between hydrogen tank, while the absorption AC relies on waste heat from the fuel cell system.

Introduction

Within the project FCH2Rail, a hydrogen fuel cell regional train will be demonstrated and to outline future efficiency improvements, the feasibility of two heating, ventilation and Air-Conditioning (HVAC) systems (example in Figure 1) will be investigated in a simulation study. The energy consumption through state-of-the-art HVAC systems impose a higher power demand on the drivetrain of railway applications. For overhead line independent technologies such as diesel powered, battery electric and hydrogen-based drivetrains, the coverable range will therefore be reduced, if HVAC systems are used. To provide a comfortable riding experience, air conditioning (e.g. cabin cooling or heating) is indispensable. Thus, it is necessary to investigate in more efficient concepts to fulfill the need of air conditioning in order to reduce the train's overall energy consumption [4]. Therefore, novel HVAC concepts will be investigated to reduce energy consumption while still meeting the required passenger comfort. The study will be focused on two technologies for hydrogen trains.

Figure 1. Rooftop Air-Conditioning System for Train applications

Metal Hydride Refrigerator

The HyPAC utilizes the pressure energy between pressure tank and fuel cell to generate a heating and cooling effect with exothermic absorbing and endothermic desorbing hydrogen in metal hydrides. Weckerle already demonstrated that metal hydrides filled in two plate reactors can provide a quasi-continuous cooling and heating flow with using suitable hydrogen and heat transfer (HTF) valves in a valve switching process [5].

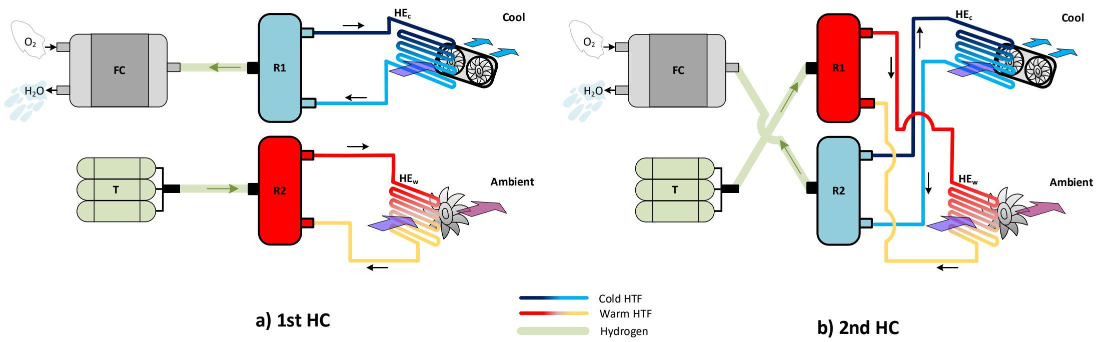

Figure 2. Metal Hydride Two Reactor Concept with half cycle 1 a) and half cycle 2 b) [6].

Figure 2 shows a schematic of these two reactors, which are connected to the fuel cell (FC) and hydrogen tank (T) as well as to a cooling loop and an ambient loop. In the first half cycle (a), reactor 1 desorbs hydrogen and directs it towards the fuel cell and the cold heat transfer fluid will be directed to a heat exchanger that cools down the supply air for the train's saloon. Meanwhile rector 1 absorbs the hydrogen from the hydrogen tanks, the aforementioned exothermic reaction than heats up the HTF. If equilibrium state is nearly reached, the HyPAC controller switches from first half cycle to the second half cycle by triggering a switching mechanism for the hydrogen and HTF valves. Now the reactor 1 absorbs the hydrogen and recools towards the ambient and rector 2 desorbs hydrogen and provides a cold flow for the saloon in our case. Half cycle 2 switches to half cycle 1 again, when the pressure of the desorbing reactor decreases.

The cooling power is limited by the desorbing hydrogen mass flow towards the fuel cell system and the reactor size, as switching between absorbing and desorbing reasons the main losses in the system and smaller reactors switch more often than bigger reactors at the same hydrogen mass flow rates. In previous simulation studies, the benefit on Fuel Cell Hydrogen Electric Vehicles has already been investigated and an increased vehicle range by 6 to 15 % has been observed [7]. However, the hydrogen mass flow in this study was relatively low with 0.075 g/s and thus the cooling power was limited. In train applications a higher hydrogen mass flows are expected between approximately 0.3 g/s and 1.3 g/s due to higher fuel cell powers. In this way, the cooling power could also be increased even further.

Absorption Refrigerator

The absorption refrigerator (ABR) uses the waste heat from the fuel cell system to provide cabin cooling with a thermal driven compressor, which consists of two vessels and a recirculation pump (Figure 3). In these two vessels the ABR process is driven by a thermally stimulated dissolution process. In the first vessel (Absorber), the solvent absorbs the vapor refrigerant by cooling it against the environment. Afterwards, this solvent can be pumped in a second vessel (Generator), where the refrigerant is desorbed by heating the solvent with the waste heat from the fuel cell system. The refrigerant is handled in the condenser as for classic vapor cycle. In that way pressure will be increased in the Generator and decreased in the absorber with just a pump system and no electrical driven compressor. For this technology, the application fuel cell train has its main advantage in providing the main portion of waste heat through the coolant loop of the fuel cell system in contrast to systems with internal combustion engines, where 18 % of heat losses come from exhaust enthalpy stream.

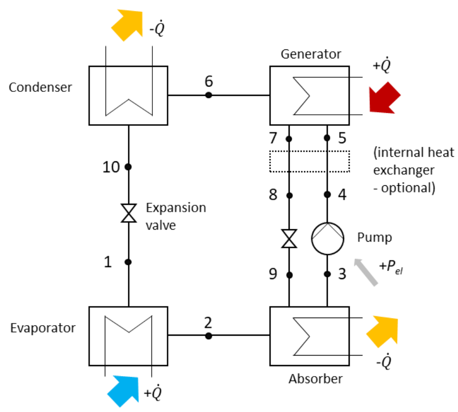

Figure 3. Absorption Refrigerator Concept.

However, state-of-the-art ABR systems with lithium-bromide water need heat source temperatures above 90 °C to provide the low temperature level for the Air conditioning system of the vehicle. The heat source temperature level between 65 – 75 °C of the investigated low temperature poly-electrolyte-membrane fuel cell demand strategies to adapt the system for providing the required cooling capacity. For this study, a conventional vapor compression refrigeration system will be used as a lower stage of a cascade system.

Technology Comparison

In order to calculate comparable and reliable simulation results, it has been decided to compare HyPAC and ABR technology in two independent models with test cases defined in EN 50591-2021. As the fuel cell's mass flow and waste heat defines the providable cooling power, these values have been utilized out of simulations of two typical driving pattern. Furthermore, generic thermal body parameters have been used, as these values are intended to map a standardized carriage for multiple units.

This presentation focuses on design parameters and processes to adjust the two HVAC concepts for hydrogen fuel cell trains. Moreover, the simulation and validation strategy will be shown and key performance indicators will be introduced to proof feasibility of the system.

Acknowledgements

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No. 101006633. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.

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