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This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 6: Stationary Applications / Transportation Applications
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-6
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-656-9

Potential of Hydrogen-Oxygen Fuel Cells in the Transportation Sector

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1 Introduction

To cope with the increasing demand on individual mobility the efficiency of the powertrain of the car has to be increased significantly compared to the state of the art. At the same time the energy demand of the vehicle has to be lowered by mass reduction and by lowering the resistances (air drag, rolling resistance).

In this context the application of an electric motor (EM) within the powertrains opens a large potential for efficiency improvements and the availability of a new torque characteristic which leads to a wider range where the nominal power is available.

To provide the energy demand of the EM electricity has to be released from an onboard storage device (battery) or has to be generated (fuel cell, auxiliary power unit APU) based on a chemical energy carrier. The design of the adequate energy-storage-device or a mix of several storage devices is among other factors a question of the required autonomy and performance of the vehicle, requested emissions level of the vehicle operation, the costs and also from the available infrastructure for fuelling.

For the electricity supply of the board net via APU hydrogen as well as hydrocarbon-based fuels can be considered as fuels. For HC-based fuels a reformer is needed or the application of a direct methanol fuel cell is another option. If the FC is considered as propulsion unit for the vehicle direct stored hydrogen can be seen as the only appropriate option.

For both option the refill time of the tank is not a limiting option given that the fuel for some 100 km range can be transferred with a few minutes to the vehicle.

2 Powertrain Based on a PEFC

An electrical powertrain comprising only a fuel cell is a possible configuration and there has been some vehicles running, demonstrating the feasibility of such a concept. In the last years the majority of the solutions for passenger cars were combinations of an energy storage device and a fuel cell. The main advantages are (i) the power demand of the vehicle can be split in a continuously available power and a peak power which has to be provided only for a limited time. (ii) If an energy storage device in form of a battery or a supercapacitor unit is available braking energy can be recuperated. (iii) The dynamic requirements to the fuel cell system can be partially decoupled from the power demand of the driver.

Plug-in concepts can be realized for these hybrid-kind powertrains where the battery can be charged from the grid as well as from the fuel cell.

3 Use of Pure O_2 Compared to Air as Oxidation Media in a PEFC

The operation of a PE-FC-system, which is using direct H_2, is mainly influenced by the selection of air or pure O_2 as oxidation media. The differences are manifested on the cell respective the stack level, at the level of the auxiliaries for the system and in the integration and characteristics of the system in the vehicle integration.

We are looking at the three levels in the following:

3.1 Cell/stack level

Within the cathode side the gas flow in the case of pure is lower because the nitrogen is not present. For every mol of O_2 consumed by the reaction a mol of product gas (H_2O) is produced. In case of liquid water the product gas volume will shrink further.

Consequence: Gas channels n the cathode side can be made less high, resulting in the potential to reduce the thickness of the bipolar-plate on the cathode side.

With the pure O_2 the reaction-resistance on the cathode is diminished. The characteristics of the voltage –current curve is more flat over a large area.

Consequence: There exists a potential for increased power density at higher voltage. To realize this potential the heat transport and the electricity resistance has to be in line with the increased specific power density.

Since the conflict of transporting the gaseous educts and the product-gases is less severe in the case of pure O_2-usage, the requirements of the porosity and structural composition of the gas-diffusion layer (GDL) is less demanding.

Consequence: Cheaper materials can be use for the GDL on the cathode-side.

Using air as oxidation media face the challenge that at specific locations the air is polluted with unknown molecules at varying concentrations. Therefore the absence of air, the pollutant concentration at the electrode-interface, or in the GDL can be reduced in a large extend. The only source of pollutants could be impurities carried by the oxygen.

Consequence: Pollutant based degradation on the cathode side can be limited significantly by using pure O_2.

3.2 Fuel cell system (auxiliaries) level

Since the oxygen content of air is approximately 21%, the air is often compressed to gain enough O_2 for the reaction. Using pure O_2 enables to reduce or avoid entirely some of the auxiliaries. No air compressor is needed. The compressed O_2 can be fed directly from the pressurized O_2 tank.

In combination with the avoidance of a compressor also no charge air cooler is needed, which reduce the total heat-exchanger area required in a vehicle.

The output O_2 can be recirculated and combined with fresh gas. Since the cathode-exhaust is in most cases in a saturated state. Therefore there can be designed a system without an additional humidifier of the oxidation gas.

Using pure O_2 helps to reduce the volume of the air ducts. The pressure level of the O_2 can be chosen higher than air. Consequently further reduction of the pipe diameters can be achieved. A significant volume is attributed to the air filter which is not required in the O_2 case.

Consequence: Reduced volume and mass of the auxiliaries (no compressor incl. its electrical motor, no oxygen humidifier, charge-air cooler, air ducts, air filter).

The absence of an air compressor reduces the noise level dramatically at least in the cases of a high pressure compressor. The compressor is normally the source of the highest noise level and defines significantly the noise reduction efforts towards the environment and the passenger compartment. Beside the noise, also the vibration level of the fuel cell system is heavily influenced by the characteristics of the compressor.

Consequence: Less effort to spend to separate noise and vibrations from the fuel cell system to the passenger compartment and the environment.

The fact that H2 and O_2 are both stored as pressurized gases in the vehicle in case of pure O_2-application the pressure level of operation can be varied in a much wider range than in case of air. This can be used to increase the efficiency for a specific requested power (higher voltage level with higher pressure level).

Consequence: Wider power range > 1:20 by application of a variable system pressure range.

The power output of an H_2 - O_2 fuel cell system is not disturbed by operation at variable altitude. In high altitude the air based system has to provide more compression energy for the same O_2 output resulting in a lower net-power output of the fuel cell system

Consequence: No adaptation for high altitude operation is required for O_2 – systems.

The lower resistance on the cathode side for the O_2 operation leads to higher efficiencies and therefore the cooling requirements for the total system can be reduced for the same net-output power.

Consequence: Lower heat-exchanger needed in the vehicle.

The absence of an electrical driven air-compressor as a large mechanical inertia in the gas supply path leads to a much higher dynamic behaviour of the FC-system. The nominal power output can be reached within < 100 ms.

3.3 Vehicle level

The increased efficiency of the stack as well as of the system the fuel demand for a specified range is reduced significantly compared to an air system. Since efficiencies above 60 – 62% are possible for a wide range this reduction can be as large as 15 – 20%. In comparison with the air system an additional pressurized tank is needed for the O_2. This tank is in principle half the size of the H_2 storage. In particular this has to be adjusted depending on the maximum pressure as well as in relation of the real gas properties. In fact at a pressure level of 200 bar the gas properties of O_2 favour a smaller tank.

In vehicle applications short start-up times are important. The fuel cell system based on O_2 favours minimal starting time. The gases can be provided out of the storage tanks at a required pressure level nearly without delay. In addition the simplicity of the fuel cell system can be used for smallest gas volumes outside the stack as well as for low thermal capacity of the auxiliary components. Together with the low thermal heat capacity of the stack, based on its high power density, the heat-up time of the system from start-temperature to the nominal temperature can be kept reasonable short.

3.4 Infrastructure level

It is true that at the logistic side two gases are needed to be fed to the vehicle. If we take into account that most of the low-CO_2-emitting energy paths are transported via electricity the use of an electrolyses-process offers an option to produce H_2 and O_2 at the same time in the needed quantities. In case of harvesting intermittent renewable energies like wind or sun via PV, the use of decentralized electrolysers offers a way to transmit larger amounts of this energy into fuels without the explicit need to install reserve capacity in the grid.