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System Technology Aspects for Light Traction Applications of Direct Methanol Fuel Cells

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1 Introduction

Due to extended driving range and quick refuelling time the Direct Methanol Fuel Cell (DMFC) is advantageous for special niche applications compared to the traditional battery propulsion technology. The system setup is adapted to the boundary conditions of the particular unit. Usually there are guidelines for maximum space, weight and of course costs. Additionally technical rules are given concerning gaseous and noise emissions. Safety requirements for the electric drive system and the fuel must be fulfilled.

In this contribution the results of a system analysis on the basis of a first prototype system for the energy supply of a horizontal order picker (see Figure 1) will be discussed.

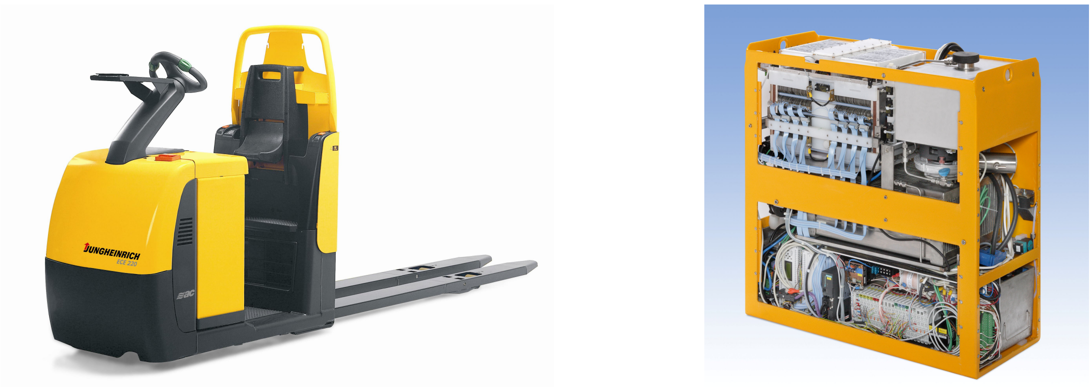

Figure 1: Horizontal order picker (Jungheinrich AG, Germany), first prototype DMFC V3.1 of the energy supply system with DMFC technology.

As reported two years ago [1] an industrial project was initiated to commercialize the DMFC technology for light traction as an alternative to battery systems. The first project phase focuses on technical R&D topics as performance enhancement and cost reduction, durability, water autonomous operation at elevated temperatures and packaging of sub components and development of prototypes.

2 Advances in the System Setup

The energy system of the horizontal order picker consists of a DMFC system hybridized with a battery. Setup and control of the energy fluxes within the active serial hybrid are described in [2].

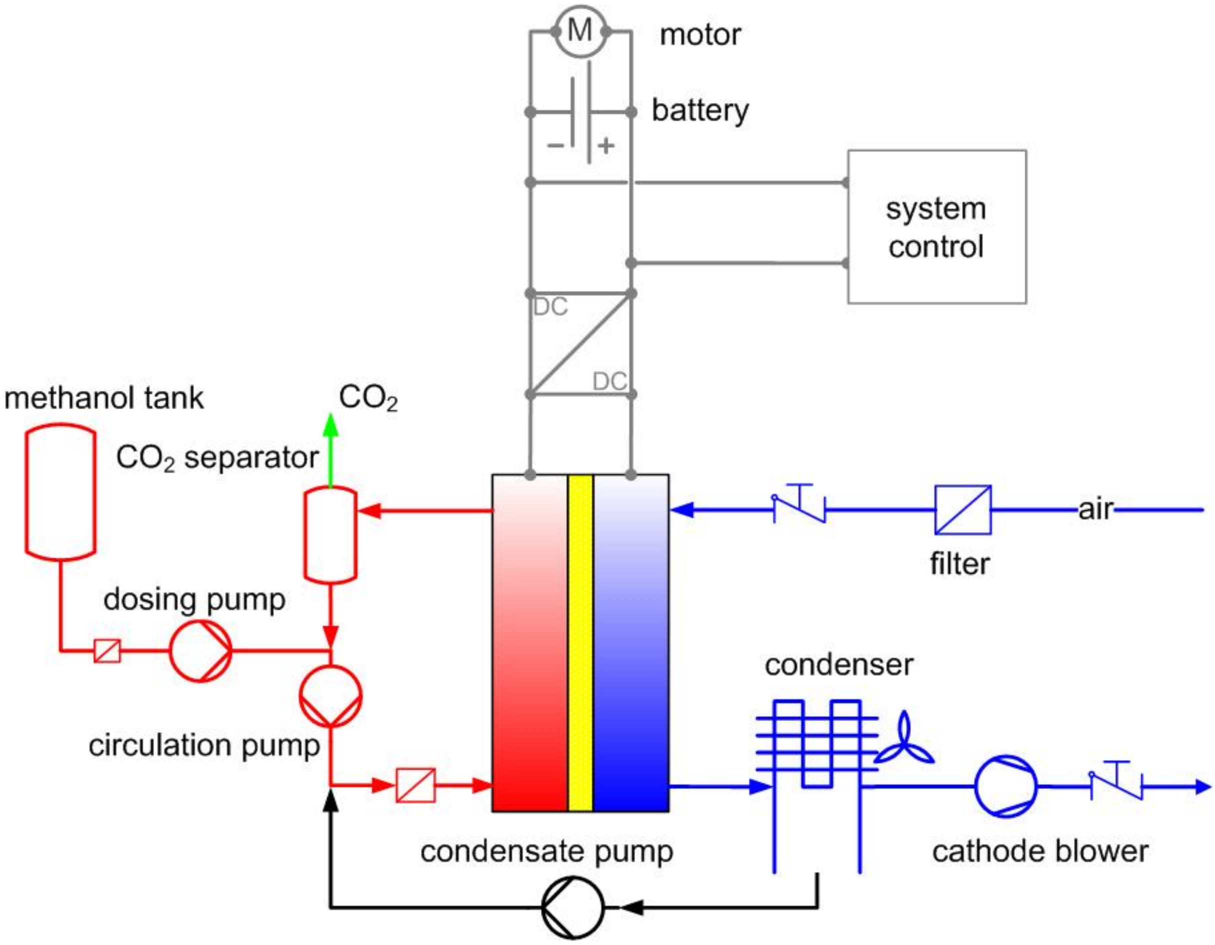

Figure 2: Flow chart and basic electric setup.

Figure 2 shows the general setup of the first prototype from Forschungszentrum Jülich called DMFC V3.1 (2007). The complexity of the DMFC system is quite low. Air and Methanol are the only operating fluids coming from outside the system boundary. The system operates at atmospheric pressure; the stack temperature is in the range 65...75 °C. Additionally the system consists of a closed water cycle. On the one hand water is consumed by the anode reaction and permeates through the membrane from the anode to the cathode side. On the other hand water is produced at the cathode side. By realizing internal water recycling a water autonomous operation is possible. Actually the water will be recovered by cooling the exhaust gas, condensing a part of the water content and pumping the liquid phase to the anode side.

The aim is to accommodate the complete energy system for the forklift truck in the battery tray. Figure 1 shows the implementation of the first DMFC V3.1 system. In addition to the main components DMFC stack (maximum power: approx. 1.5 kW), methanol tank (volume: 12 l, range: approx. 12 h), condenser (water autonomous up to an external temperature of 35 °C) and hybrid battery (capacity: approx. 1 kWh), a large amount of space was required for the electrical control system and data logging.

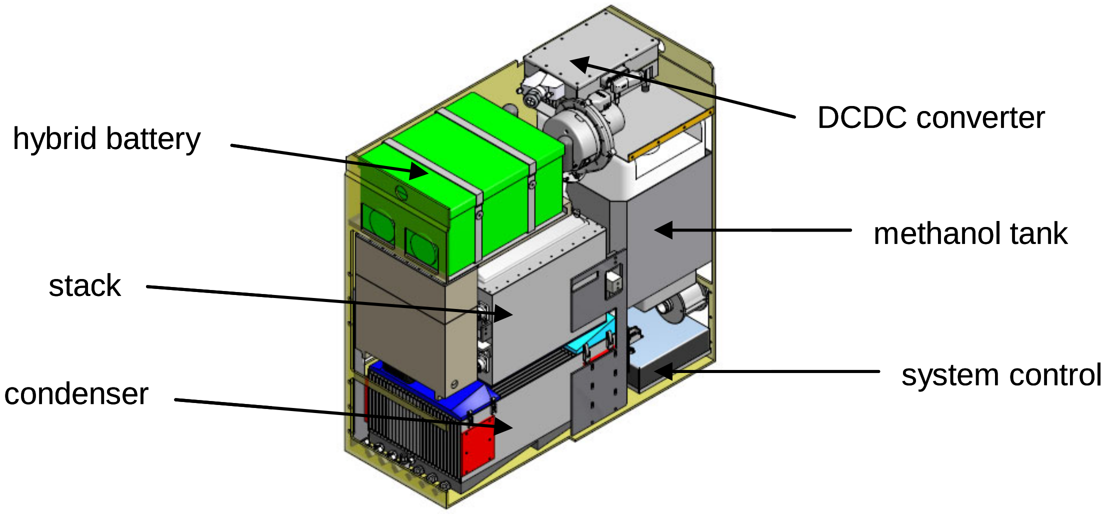

Figure 3: CAD sketch of DMFC V3.3.

The successor system DMFC V3.3 (see Figure 3, completed in 2009), which represents the further development of DMFC V3.1 in cooperation with an industrial consortium, comprises the following major changes:

- Increase in tank volume to 20 l. This brings us closer to achieving the goal of being able to operate a forklift truck for three full shifts in a warehouse on one full tank. This represents a significant advantage in comparison to conventional battery systems.
- Improvement in the temperature distribution in the battery tray. By means of a suitable air circulation system, the process heat created in the tray is directed to the outside.
- “Tailor-made” electronic components (control system with integrated data logging, DC/DC converter, cell voltage monitoring unit) developed for a compact setup.
- Concepts for reducing degradation in the stack when it is shut down (system for closing the cathode feed line, cyclical back-feeding of methanol).
- Improved control system and monitoring unit. The use of additional sensors for air mass flow, methanol concentration and temperatures should allow more robust and reliable system operation.

3 Heat and Water Management

In the actual system design DMFC V3.3 the rejected heat from the stack operation is transferred to the exhaust gas by water evaporation. This leads to a compact and simple system design, because no further cooling device on the anode side is needed. To cope with the heat extraction edge conditions regarding air and water quantities at the cathode side have to be fulfilled. The results from the thermodynamic calculations are shown in the following diagrams (Figure 4). By the definition of stacks with different power densities, the variation of the average cell voltage and the presetting of the fuel utilization a characteristic map of stacks regarding electrical and thermal economy can be calculated. In the first step the mass flow of evaporated water is determined whose energy content is equal to the energy content of the rejected heat. For different stack temperatures Figure 4 (left) shows the air/fuel ratio which is sufficient for the heat extraction according to the described concept. As an assumption the exhaust gas is fully saturated.

In the next step the condenser for the water recovery from the exhaust gas must be sized. The DMFC system is in water balance if the exhaust gas contains exactly the water coming from the inlet air humidity and from the methanol oxidation. In Figure 4 (right) the dewpoint temperature of the exhaust gas after the condenser is plotted against the air/fuel ratio.

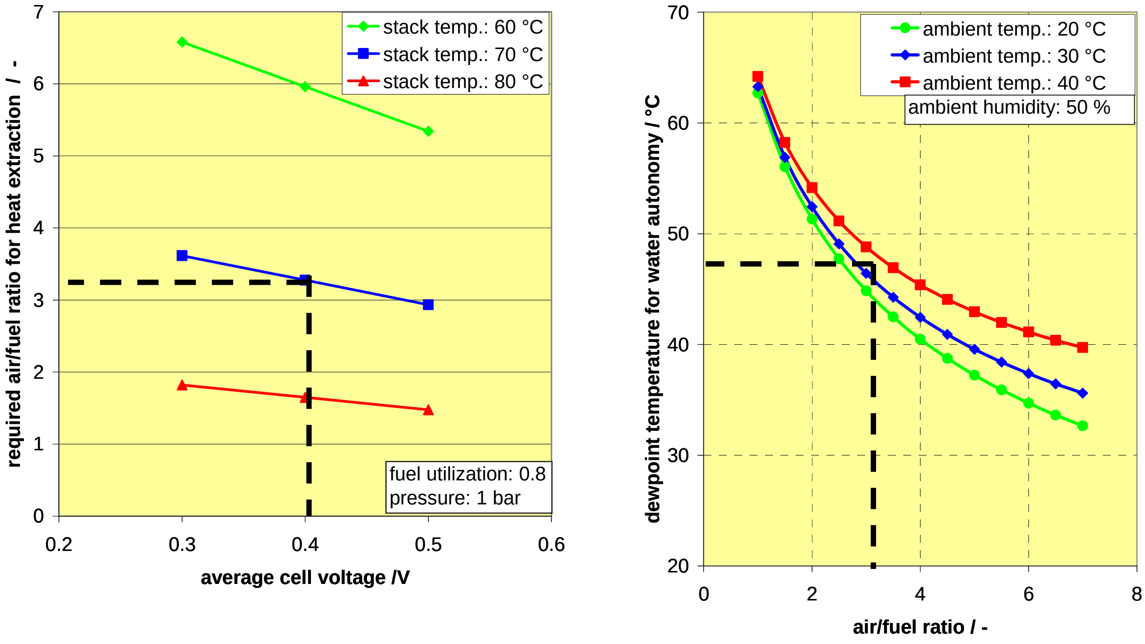

Figure 4: Sizing diagrams for heat extraction and water recovery.

The following Table 1 gives the sizing parameters for the condenser of DMFC V3.3. The dotted lines in Figure 4 represent the design point of stack and water management. Figure 5 shows the construction which is done in cooperation with AKG Thermotechnik, Germany. The condenser is made from stainless steel at the condensing side. Aluminium is used for the cooling fins. To minimize the condenser size the general setup is cross-counter-flow. That means the cooling air is directed horizontally from the left side to the right side through the cooling fins. The exhaust gas coming from the stack enters the condenser at the top side. Internally the exhaust gas will be deflected three times before it leaves the condenser via two pipes at the left top side.

Table 1: Sizing parameters for the condenser.

Stack power	1.3 kW
Air mass flow cathode	23.2 kg/h (air/fuel ratio ~ 3)
Maximum exhaust gas inlet temperature condenser (~ stack temperature)	70 °C
Maximum ambient temperature	35 °C
Condenser outlet temperature for water autonomy	47.5 °C (see Figure 4)

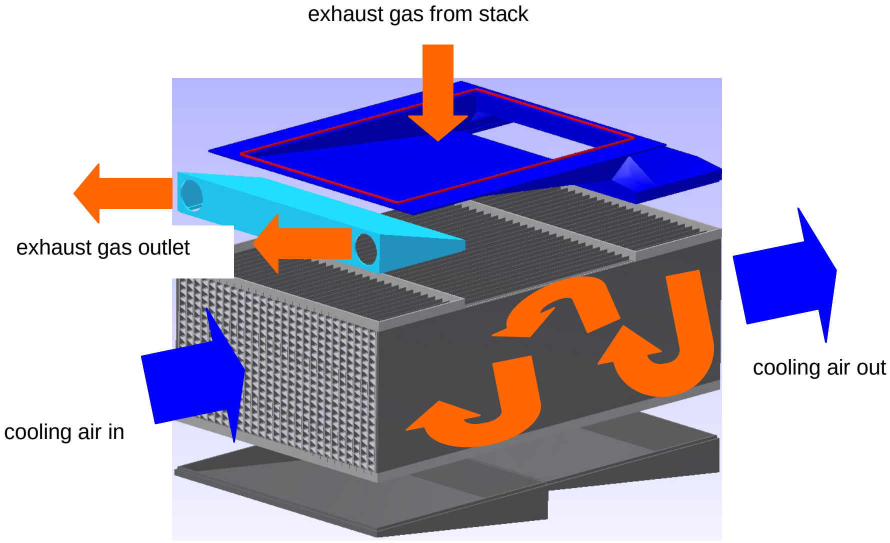

Figure 5: **Condenser design for DMFC V3.3.**

4 Stack Integrated Anode System

Main target of the new anode system development is the reduction of installation space for the complete DMFC system [3]. The packaging considers the integration of the system in a battery tray. In Figure 6 a cross-sectional view of the construction and the stack integration is shown. In addition to the main components like CO_2 separator and containers for level fluctuations of the anode fluid all actuators and sensors for the anode sub system are installed. The dotted line in Figure 6 represents the pathway of the anode gas (primary CO_2) beginning from the separator inlet to the condenser inlet which is located under this unit. For a better orientation the cross-section in Figure 6 is also shown as an isometric drawing.

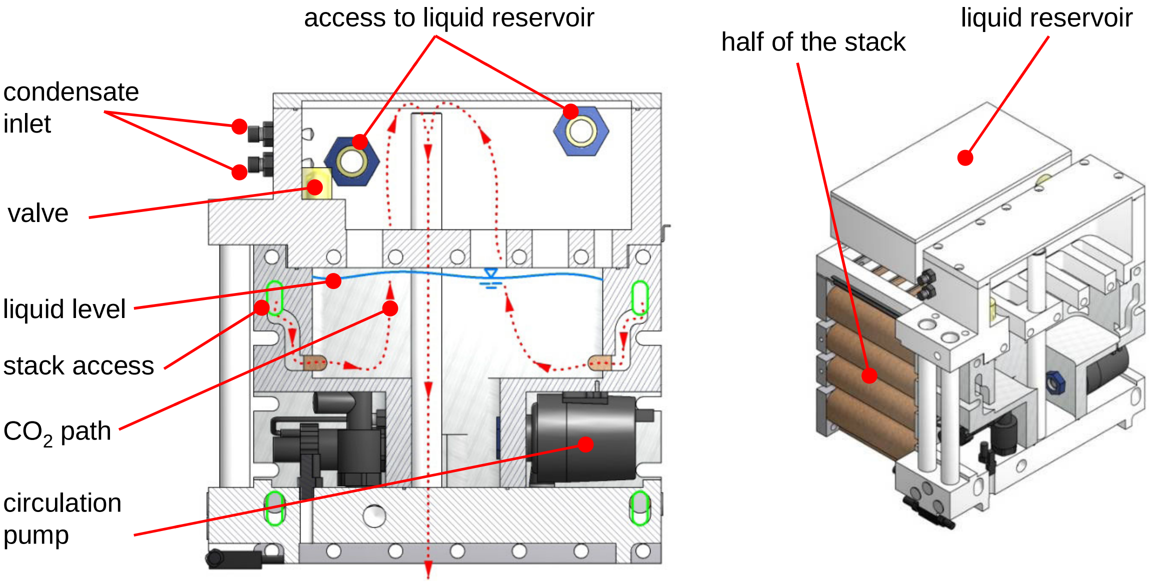

Figure 6: **Construction details of the stack integrated anode system.**

5 Conclusions

It could be demonstrated that it is possible to replace the original energy system of a horizontal order picker by a DMFC hybrid system without installation space modifications. There are lots of ideas for technical improvements which have the focus to increase the robustness and the advantages against battery systems, like operating time and operating costs.

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