The impact of tar contaminants on SOFC performance under high fuel utilization condition

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Introduction

The operation of solid oxide fuel cells with biomass-derived syngas would provide convincing solutions for combined heat and power production from renewable sources. Due to their fuel flexibility, SOFCs could be operated with unsaturated or aromatic hydrocarbons, which are contaminants in bio-syngas. However, the impact of tar on SOFC anodes is not coherent in literature and still requires further investigation.

Test set-up and methodology

The test rig (Fig. 1) is able to feed commercial planar 5 x 5 cm² Ni-GDC/3YSZ/LSCF electrolyte supported single cells with tar-loaded fuel gas. The concentration of tar components is controlled by the volume flow rate of N_2 through tar bubbler at certain temperature. To prevent the carbon deposition, the gas mixture is humidified by a temperature-controlled water bubbler with a high S/C>3. The gas composition before and after entering the SOFC's anode chamber is measured by different methods to obtain the tar conversion rate. The fuel utilization (U_f) is defined as

$$U_f = \frac{I}{2F \cdot \dot{n} \cdot x_{H_2,inlet}}$$

Where F is the Faraday constant, I is the current, $\dot{n}$ is the total molar volume flow of the anode gases, and $x_{H_2,inlet}$ is the molar proportion of H_2 in the anode gas. U_f could alternatively be derived from the measured concentration of H_2 at the gas inlet and outlet. To investigate the impact of tars on cell voltage, the open circuit voltage (OCV) is measured and compared with the theoretical Nernst voltage. I-V curve measurements were taken to characterize the cell performance.

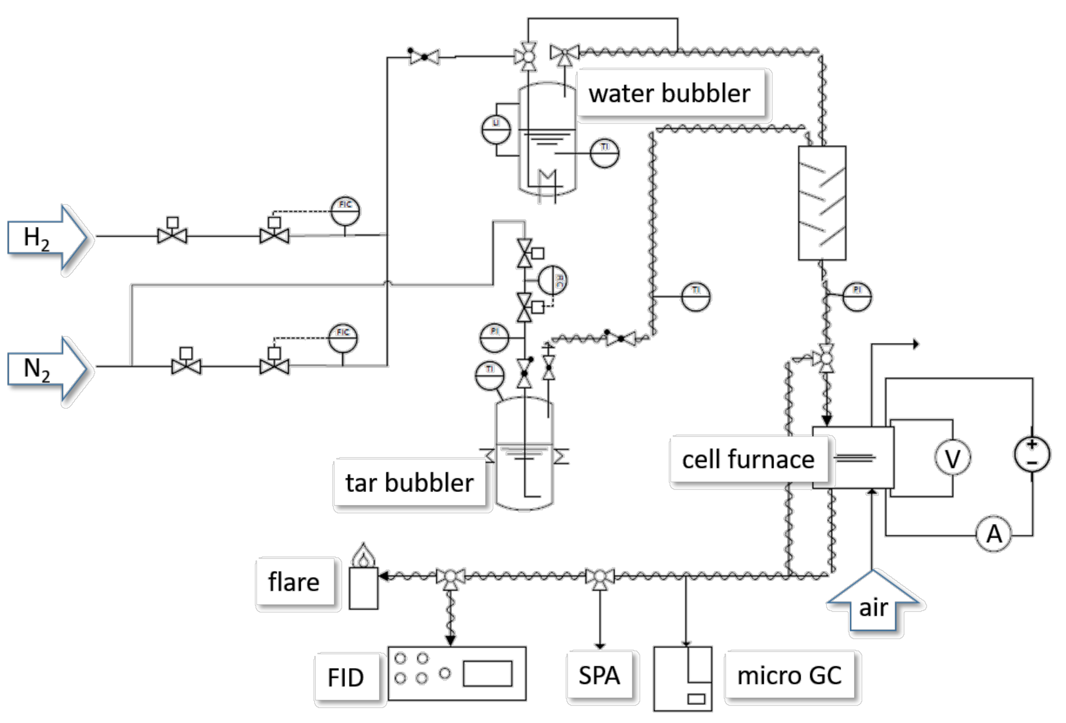

Fig. 1: Experimental setup

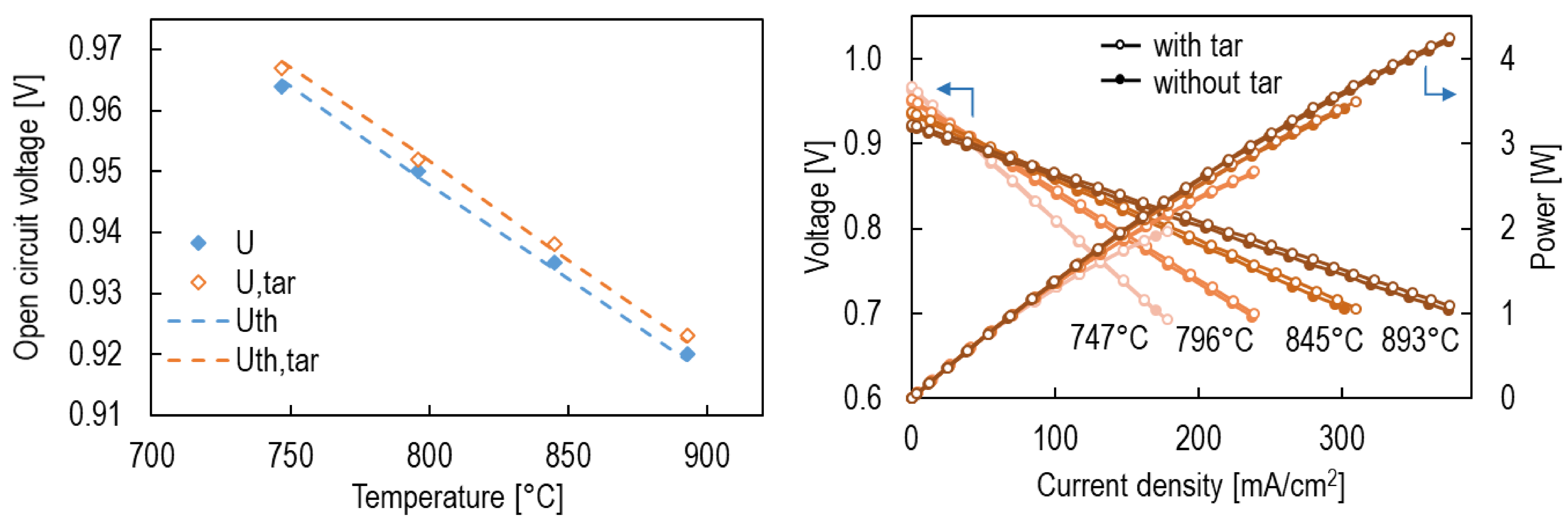

Fig. 2: left: OCVs with/without toluene compared with Nernst voltage; right: I-V curves and cell performances with/without toluene (35%H_2+30%H_2O+35%N_2+5g/Nm³ (dry) C_7H_8)

Reforming of toluene on SOFC

After addition of 5 g/Nm³ toluene into the humidified H_2/N_2 gas mixture, the OCVs of SOFC increased immediately about 2-3 mV at different temperatures. Compared to the Nernst voltage which premises a full reforming of toluene, the measured voltages suggest a complete conversion of toluene at each temperature (see Fig. 2 left). The gas composition measurements at the anode exit also show that the conversion rate of toluene reaches already 99% at 747°C.

Fig. 2 right shows the I-V characteristics with/without toluene at different temperatures. The ionic resistance of YSZ-electrolyte is reduced with increasing temperature, which leads to better performance at higher temperatures. The cell performance increases with the addition of toluene due to the additional hydrogen produced by means of the steam reforming.

Effect of toluene at higher fuel utilization

To achieve high fuel utilization above 60%, the volume flow of H_2 is significantly reduced. Fig. 3 demonstrates the I-V curve (left) and U_f-V curve (right) with/without toluene respectively. The calculated Nernst voltage varying with U_f is also shown in Fig. 3 right. When U_f exceeds the value at which the critical Nernst voltage (0.701V at 843°C) is reached, the reducing atmosphere at anode cannot be ensured and the re-oxidation of Ni could occur. This would result in performance degradation and even irreversible mechanical damage.

The I-V curve with/without toluene showed a parallel tendency at lower current. Under high current conditions, the effect of concentration polarization plays a more important role. With steam reforming of toluene, more H_2 is available on the anode side, which reduces the obstacle in the diffusion process of H_2 to the active side of the anode. Therefore, the fuel cell could be operated at higher current density before entering diffusion area, where the voltage drops more rapidly. This also means a lower possibility of Ni re-oxidation (lower U_f) while maintaining the same voltage output (Fig. 3 right).

In reality, local oxidation of Ni takes place already at lower fuel utilization, especially for cell stacks. The lower diffusion resistance of electrolyte-supported single cells with thin anodes enables operation with a high fuel utilization of over 80%. However, in order to determine the critical fuel utilization for the safe operation of the fuel cell, long term tests are required.

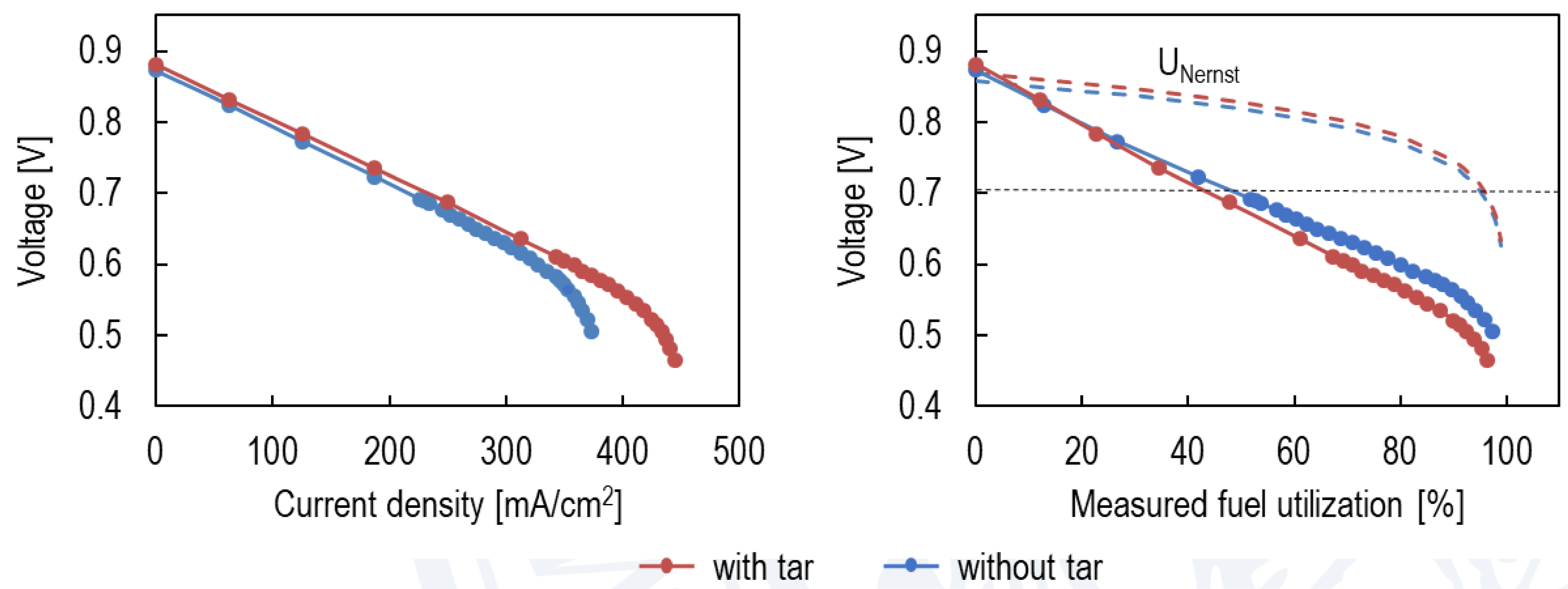

Fig. 3: Influence of the steam reforming of toluene on cell voltage (left) and fuel utilization (right) (T=843°C, 7%H_2+30%H_2O+5g/Nm³ (dry) C_7H_8, rest N_2)

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