

Development and Test of a Solid Oxide Fuel Cell Subsystem with a Low Temperature Anode Off-gas Recirculation

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Introduction

In recent years, several SOFC systems spanning a wide power range, from a few watts into the several hundred kilowatt range, have been developed and demonstrated. Most of these are operated with hydrocarbon-containing fuels, with methane favored. At the JÜLICH, an SOFC subsystem was built and operated. This subsystem consists of the well-established Integrated Module, combined with a low temperature off-gas recirculation loop. The off-gas recirculation loop has two general advantages. Firstly, part of the unconverted fuel at the outlet of the stack is returned to the stack inlet and reused during the operation. Secondly, a proportion of the electrochemically-produced steam is simultaneously recirculated and can be used for the steam reforming process.

Experimental Setup

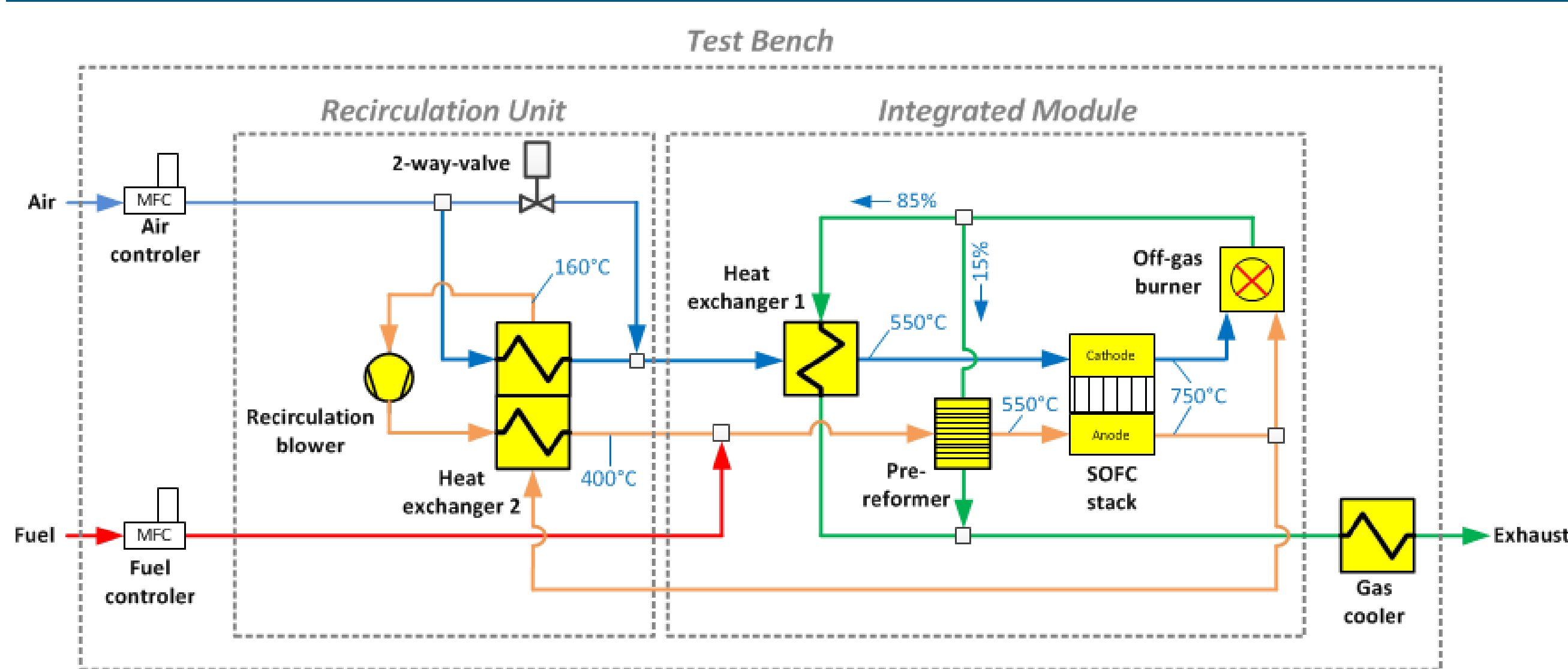


Fig. 1: Flow scheme of the SOFC subsystem

Within the test bench, almost the entire SOFC system is implemented, except air blower and power electronics.

Recirculation loop → The recirculated anode off-gas is cooled down in heat exchanger 2 using the cold anode off-gas stream and the partial air stream. Thereby, the amount of air is controlled and adjusted to ensure a blower inlet temperature of approximately 160°C. Downstream of the recirculation blower, the recirculate is reheated above 400°C with heat exchanger 2.



Fig. 2: Test Bench

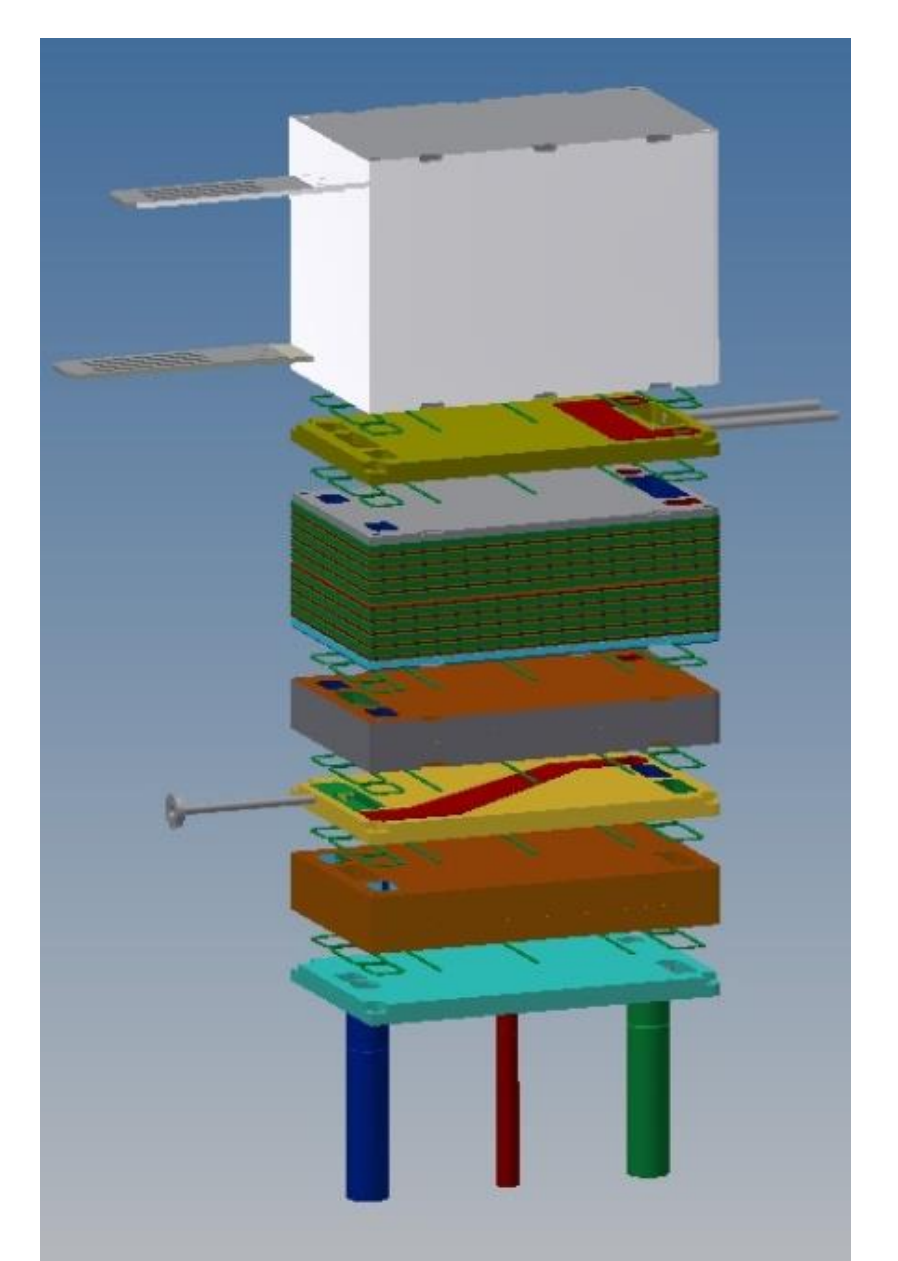


Fig. 3: Integrated Module



Fig. 4: Side Channel Blower
→ VacuVane GmbH
→ Temp. < 200 degC

Boundary conditions of the system test.

Cell Type	Anode Supported Cell
Cells per System	36
Active cell area	0.0361 m ²
ASR at 750°C	480 mΩ/cm ²
Test duration	< 2000 h
Pre-reformer catalyst	Nickel
Fuel	Methane
Recirculation blower	Side channel blower

Results

Test sequence	1	2	3	4	5	6	7	8
RR [%]	80	77	74	77	78	82	74	73
uf Stack [%]	63	66	69	66	73	69	69	71
uf System [%]	90	90	90	90	93	93	90	90
Current [A]	90	90	90	90	90	90	144	155
Lambda [-]	1.9	1.9	1.9	1.9	1.9	1.9	2	2.3

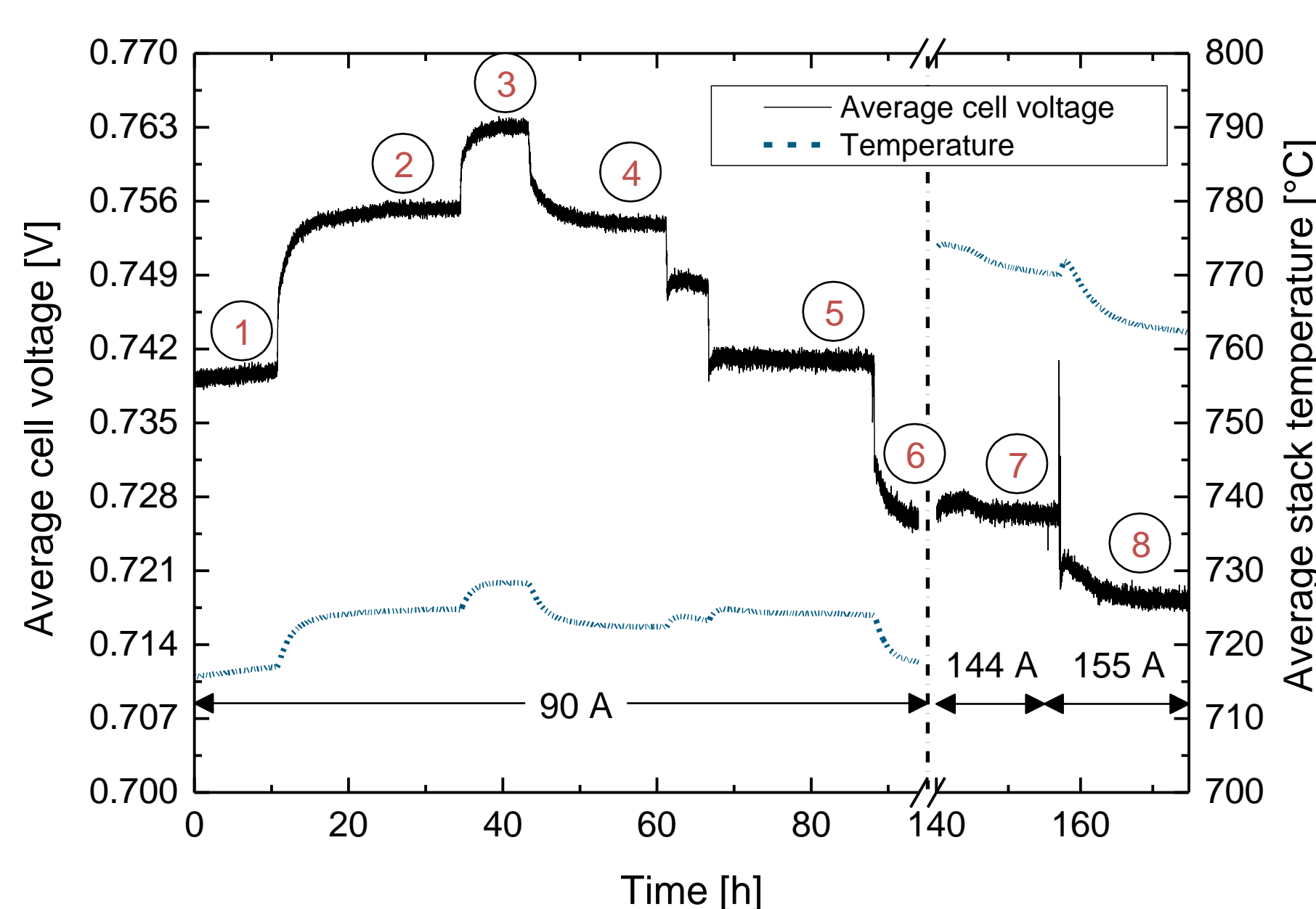


Fig. 5: Average cell voltage and temperature at 90, 144 and 155 A and different recirculation rates

The solid lines and dots represent the measured power output of the stack and the measured power demand of the recirculation blower. The dashed lines and open dots show the efficiency of a complete system, including the air blower (assumed efficiency, 27%), the electrical power demand of the system (assumed with 50 W) and inverter (assumed efficiency, 94%).

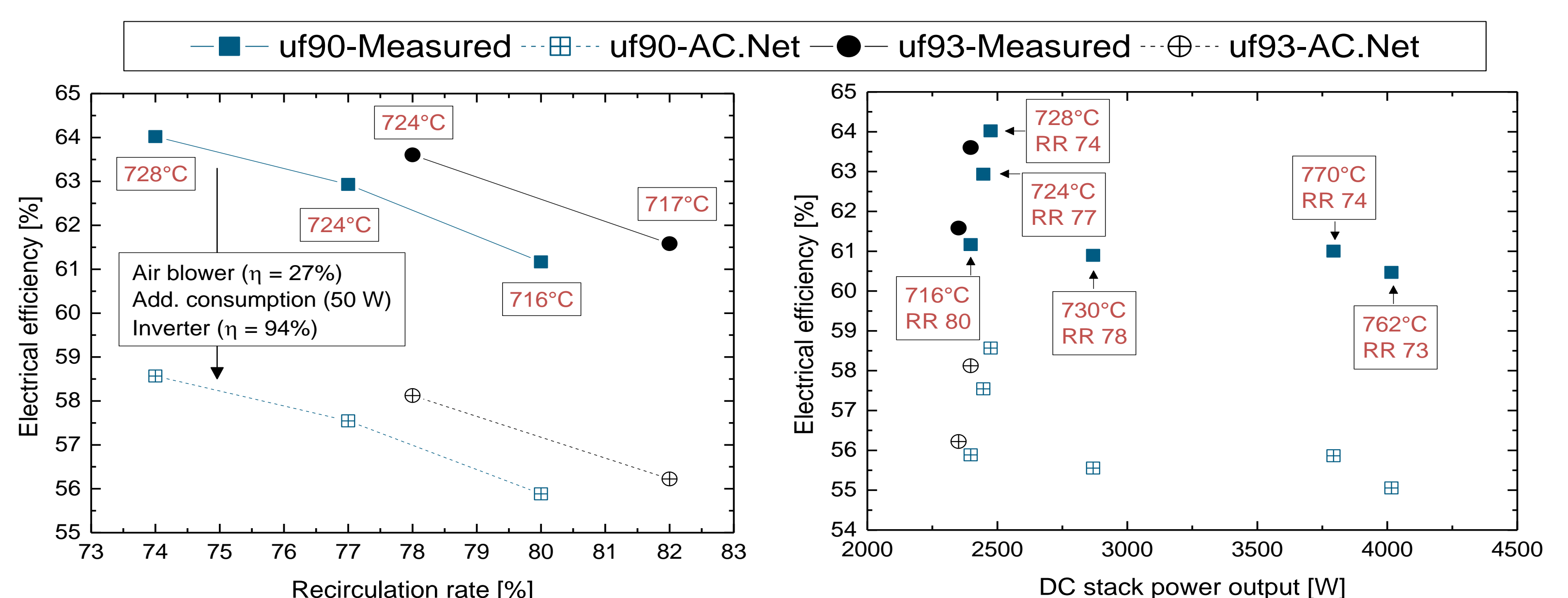


Fig. 6: Electrical efficiency at different recirculation rates and a current of 90 A (left) / electrical efficiency at different DC stack power output and recirculation rates (right)

Conclusions

- An anode off-gas recirculation in combination with JÜLICH's "Integrated Module" is realizable and successfully operated.
- High recirculation rates lead to a reduced cooling air demand of the stack (lambda < 2).
- The stack can tolerate inlet gas temperatures of 500°C at anode side and 550°C at cathode side.
- The highest electrical efficiencies can be reached at high system fuel utilizations in combination with low recirculation rates.
- Electrical net efficiencies above 60% are achievable.
- The setup was up to 2.000 h in operation.