Battery Ageing • Battery Models • Battery Diagnostics • Battery Pack Design • Electromobility • Stationary Energy Storage • Energy System Analysis

Water Consumption Testing and Analysis

AABC Europe
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Dirk Uwe Sauer, Jonathan Wirth

Chair for Electrochemical Energy Conversion and Storage Systems

ISEA Power Electronics and Electrical Drives | RWTH AACHEN UNIVERSITY

Motivation

- CO_2 reduction in automotive applications needed
- Carbon-enhanced batteries (EFB+C) show high potentials for higher dynamic charge acceptance
- Water consumption in hot climate is still an important issue

→ How do parasitic reactions in batteries with carbon additives compare to those in common batteries in dynamic microcycles?

Overview

- Motivation

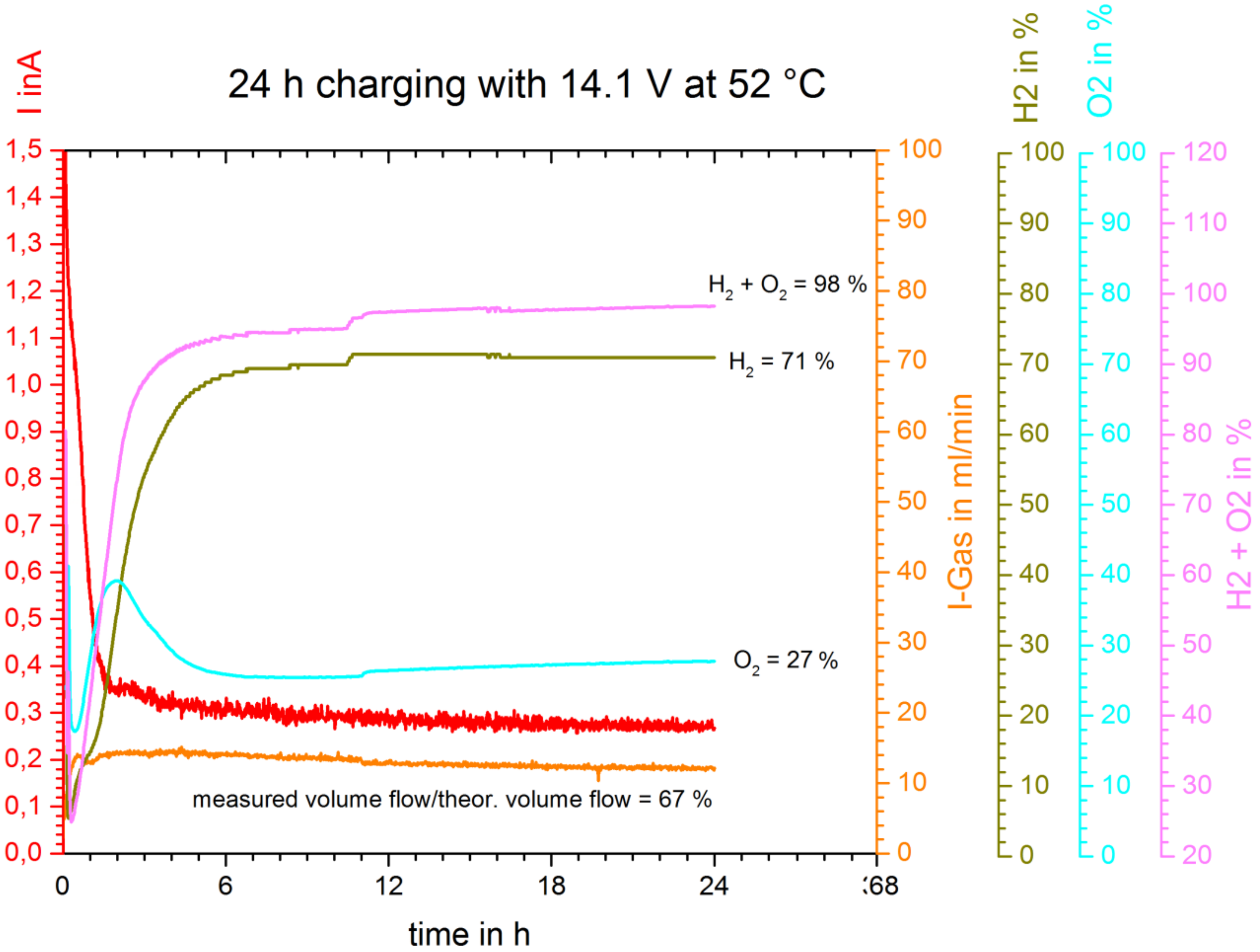
- Dynamic overcharge
  - Measurement
  - Drive cycle
  - Results
  - Discussion

- Summary & outlook

Measurement methodology

Example for steady-state overcharge measurement

(70 Ah EFB+C)



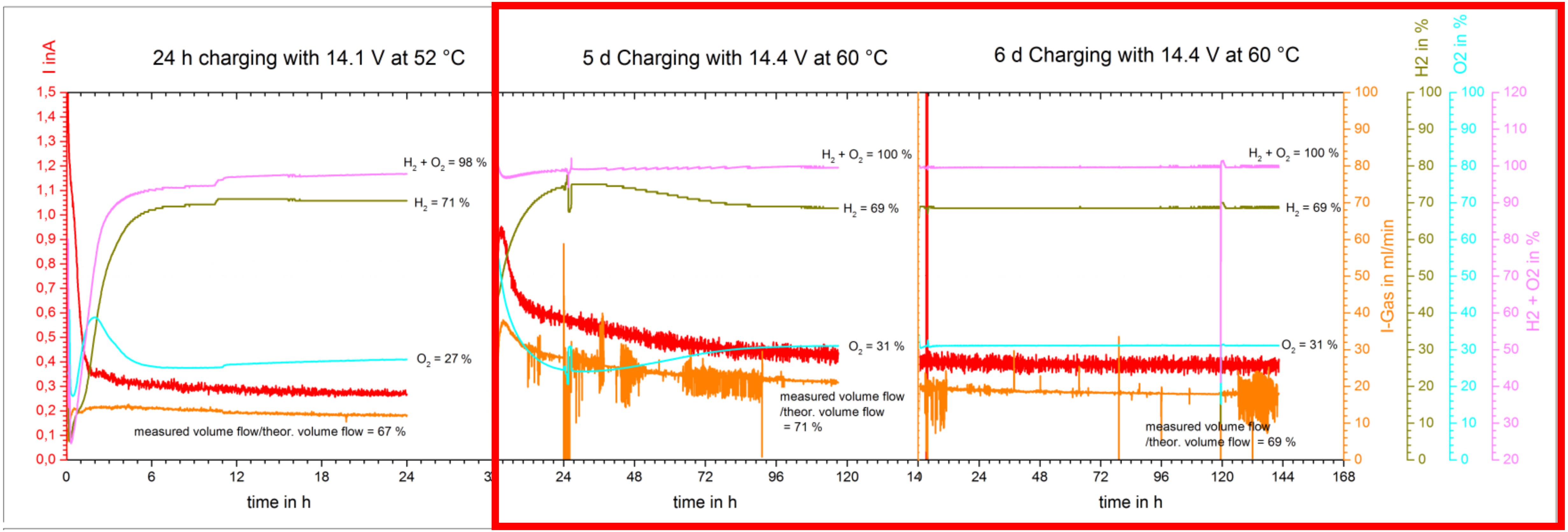
Measurement methodology

- Gas flow measurement with electronic gas analysis device (eGAS)
  - hydrogen-proof flexible connecting tube
  - gas is dried by silica gel
  - 2 flow sensors for high and low gassing rates
  - hydrogen and oxygen concentration sensors
- Weekly weight loss and internal ac resistance (Hioki) measurements

● (a) SLI	1 type
◆ (b) EFB	1 type
▲ (c) EFB+C	10 types
■ (d) AGM	3 types

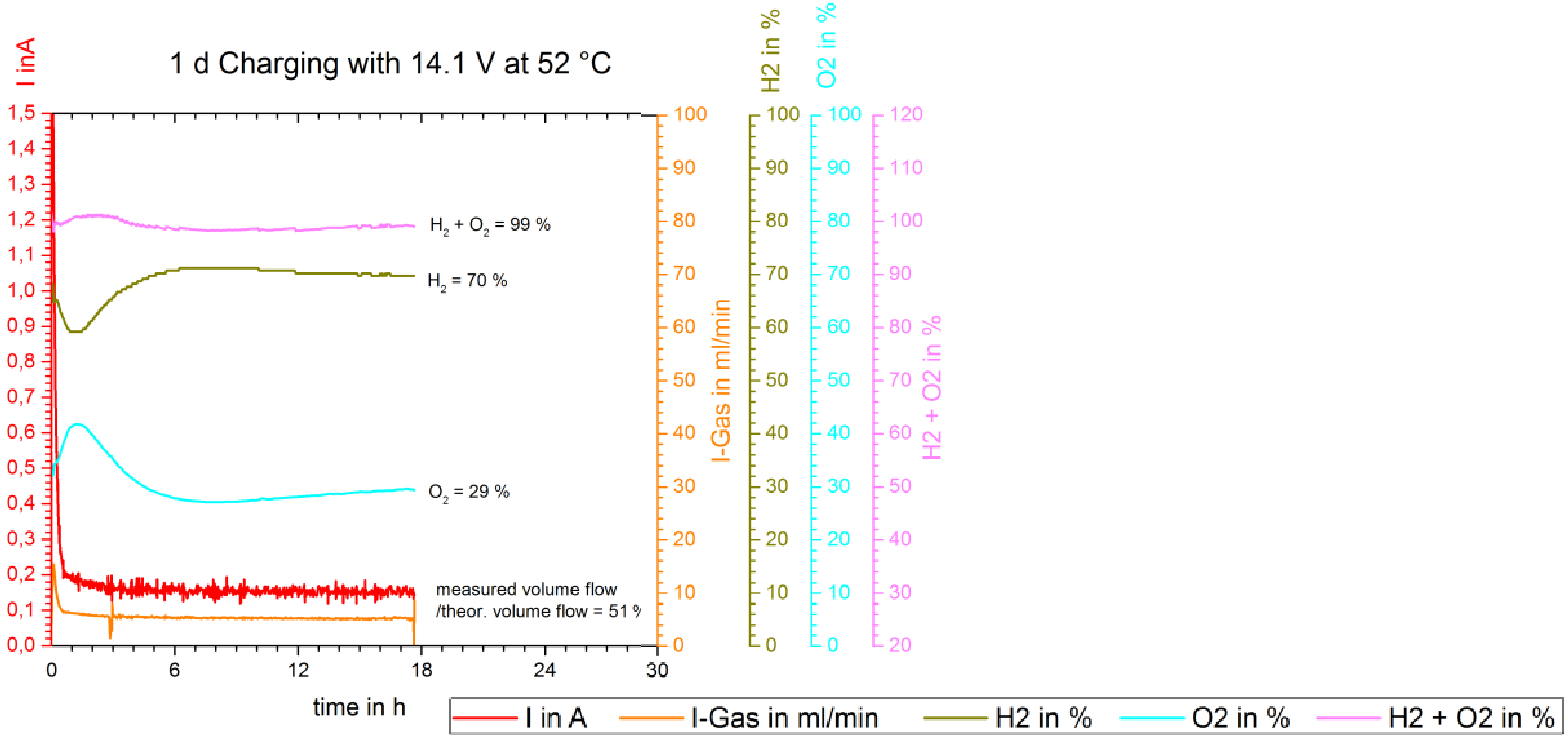
Ford Research Center, Aachen

Steady-state overcharge: Test sequence

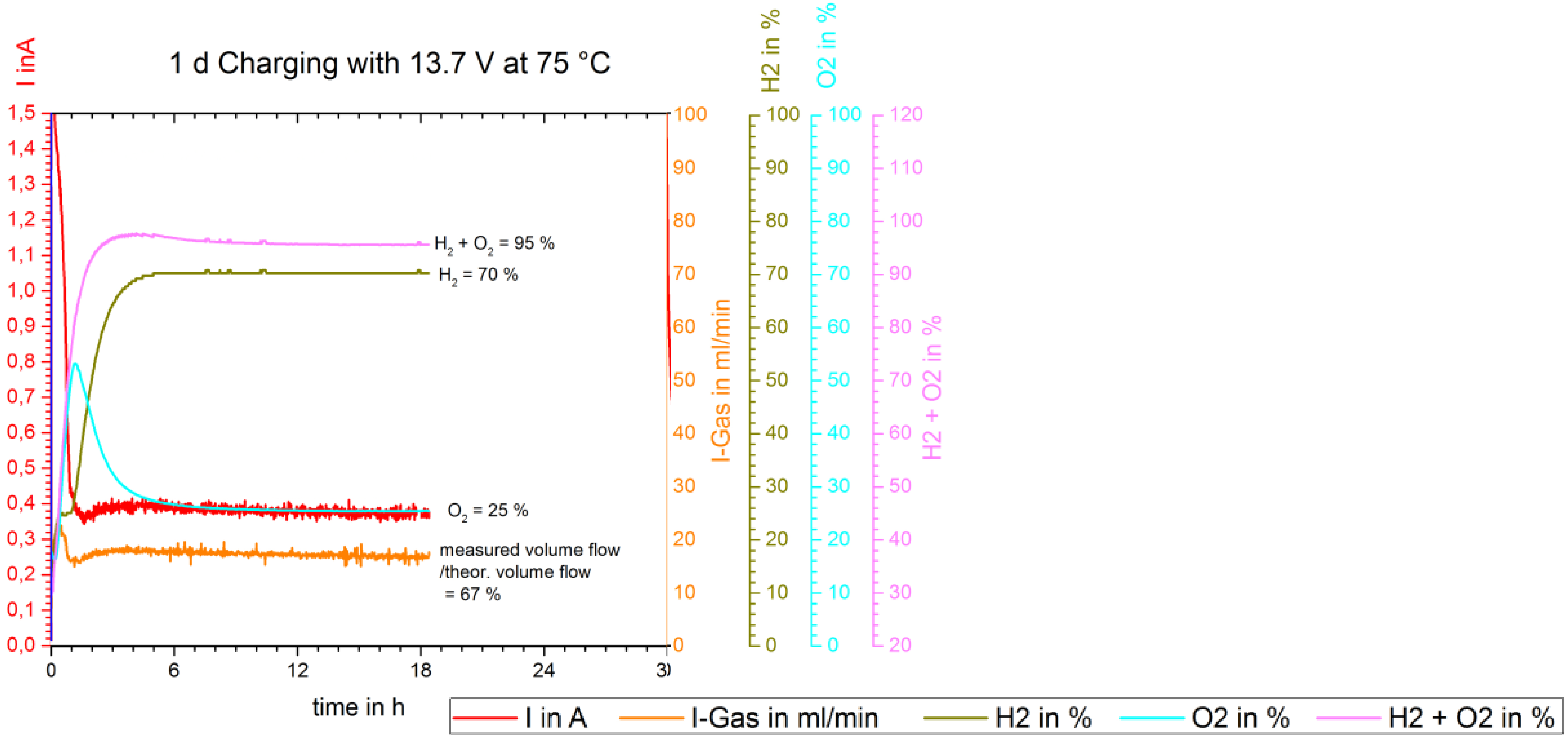


- Initial cycles (1/2)
  - RC, CHA 15.4 V/24 h
  - CCA SAE, CHA 15.4 V/16 h
- 24 h overcharge at 14.1 V/52 °C (cf. BCIS-04)
- 11 to 13 d overcharge at 14.4 V/60 °C (cf. EN 50342-1) ➔ extrapolation to 42 d

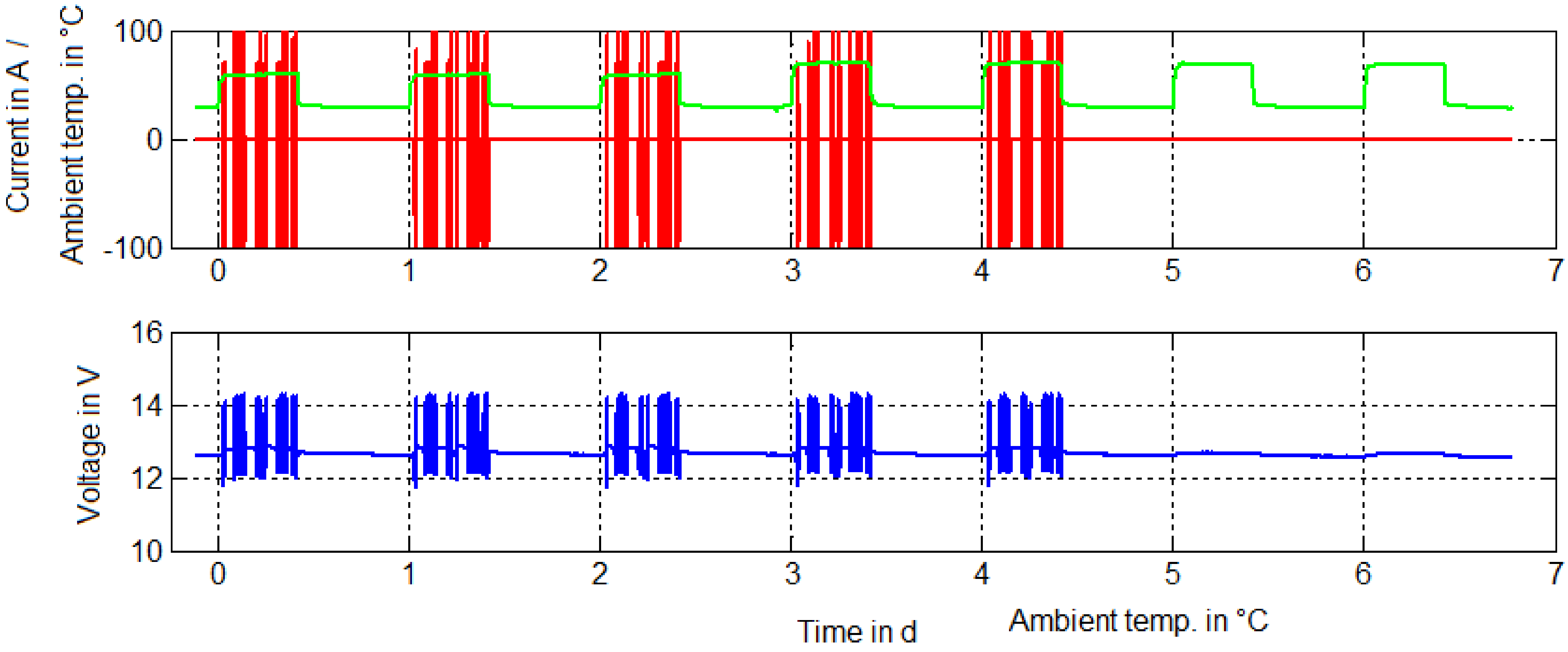
Steady-state overcharge: Test sequence with further overcharge for 18 hours



Steady-state overcharge: Test sequence with further overcharge for 18 hours

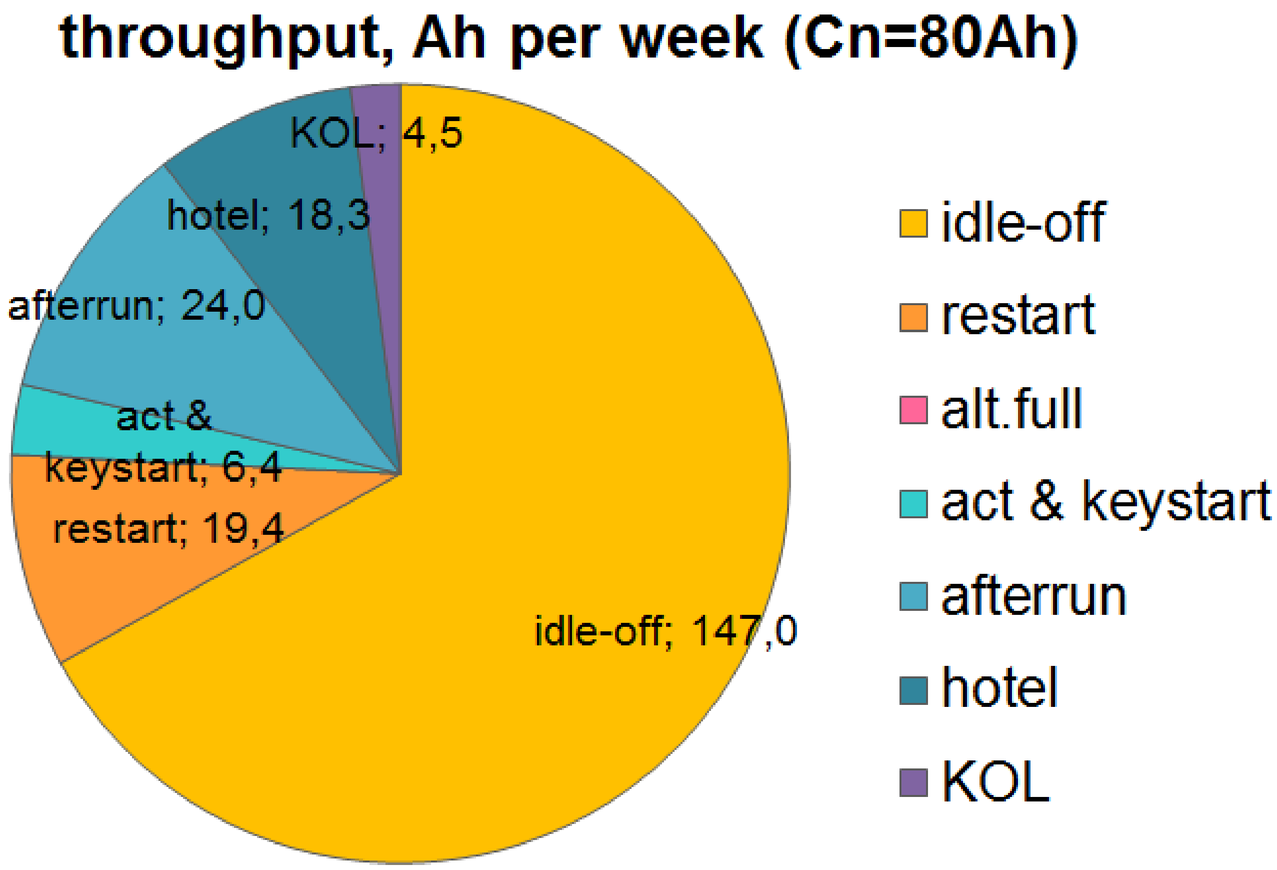


Charging during dynamic microcycles: Test definition



Charging during dynamic microcycles: Test definition

- Drive cycle with stop/start
  - 6 trips/day with 10…80 min, 4 h/day in total (3.5 h charging time incl. regenerative braking)
  - 5 driving days, 2 days week-end
  - external resistance as quiescent load (0.8 %C_n/day)
  - 3.5 h charging with two different strategies:
    - conventional charging with 13.75 V
    - float charging with 13.2 V
    - 10% regenerative braking always 13.75 V
- Temperature profile
  - Tests performed in automated climate chamber
  - Ambient 75/30 °C day/night cycle



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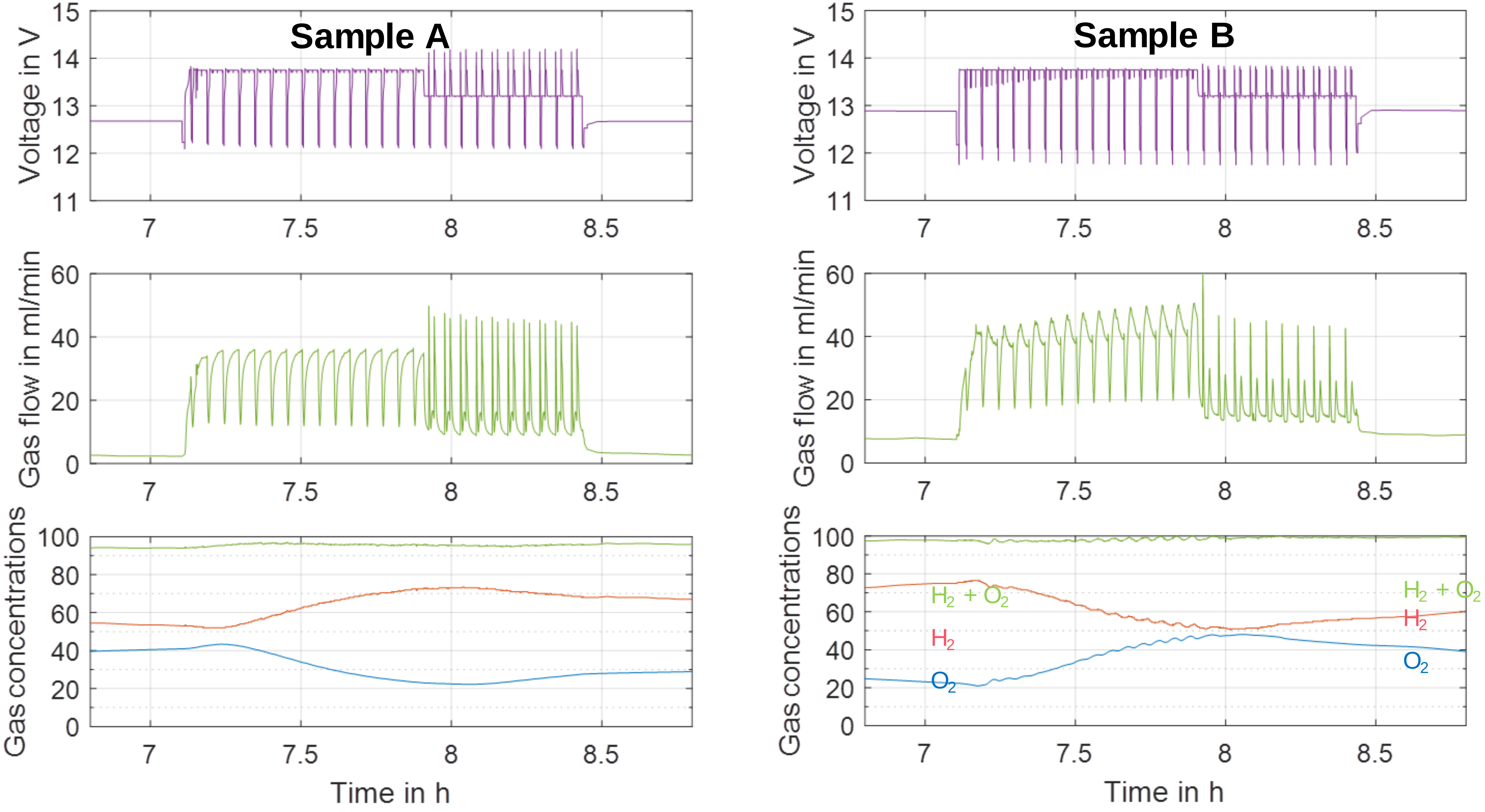
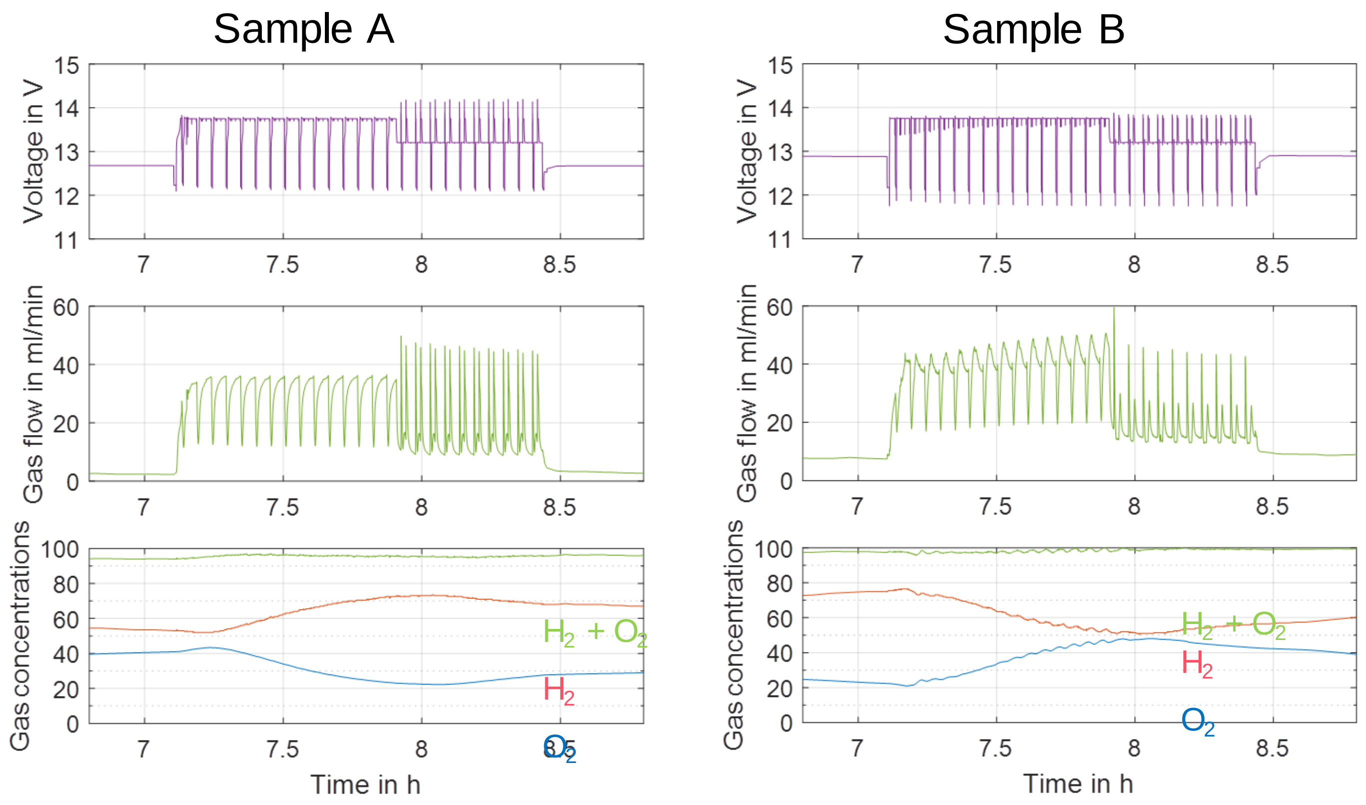
Charging during dynamic microcycles (EFB+C): Exemplary results with different gassing behavior



Charging during dynamic microcycles (EFB+C): General observations

- Oxygen and hydrogen concentrations are not static during the day
- Measured concentrations are low-pass filtered by battery headroom volume
  ➔ Increasing trend of H_2 indicates that almost exclusively H_2 is being formed
- Depending on charging strategy (conventional/float charging), concentrations vary significantly
- Differences might be explained with different polarization of electrodes due to different design or composition

Exemplary results with different gassing behavior

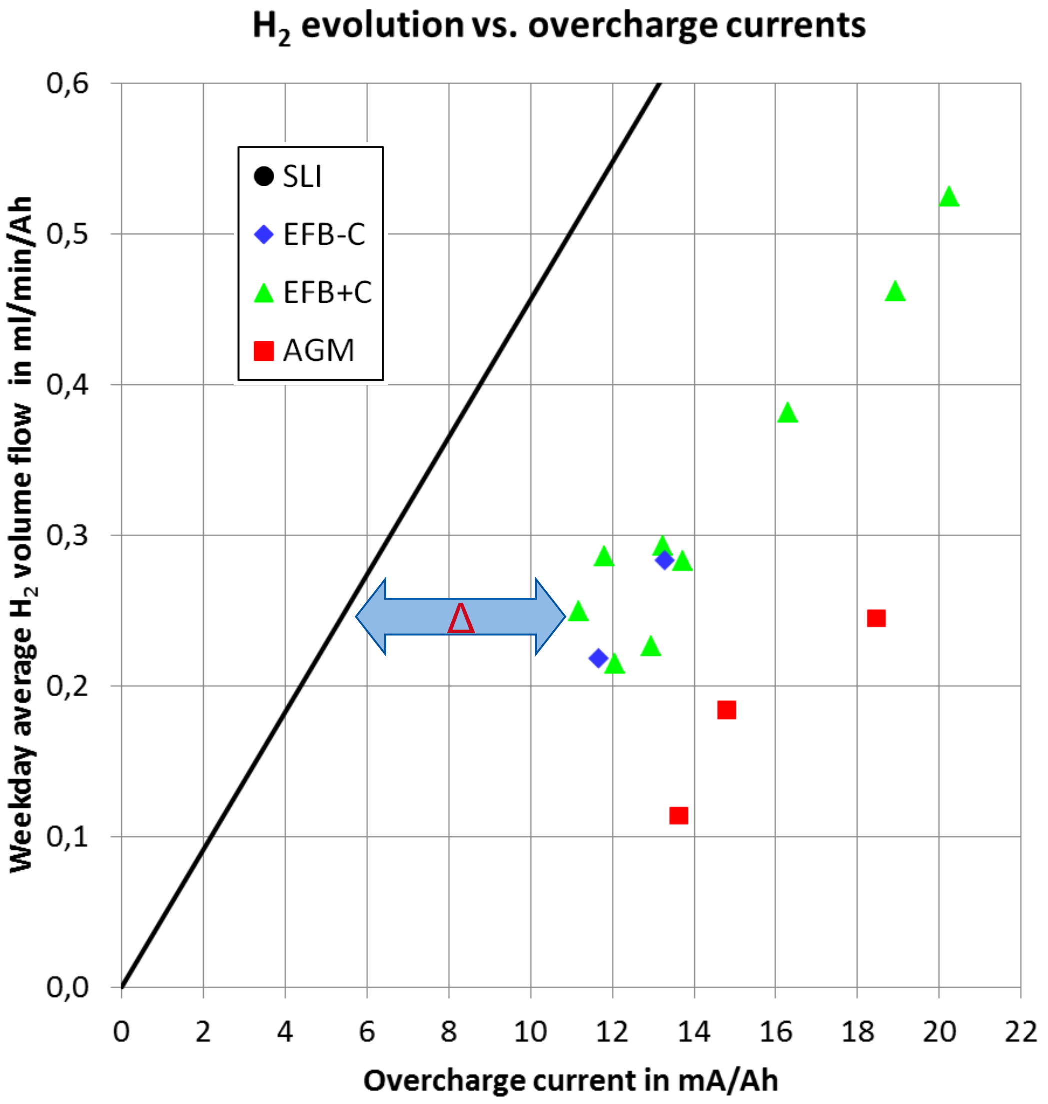


Charging during dynamic microcycles: Hydrogen evolution vs. overcharge current

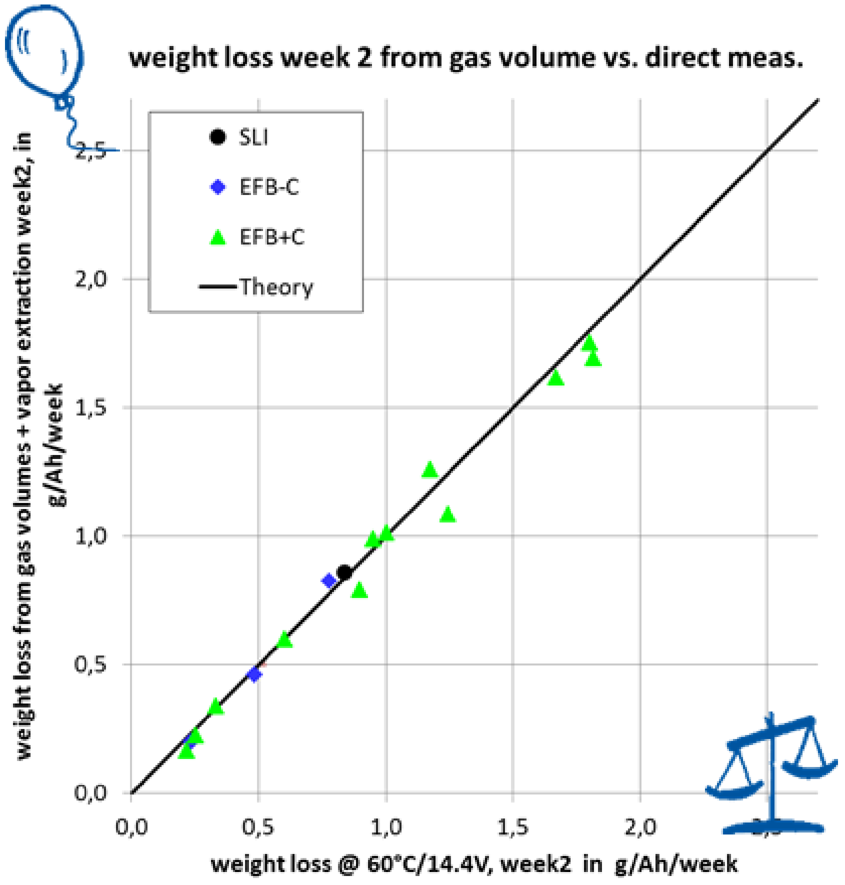
- Effective overcharge current during Partial SoC (PSOC) microcycle operation calculated from daily charge balance:

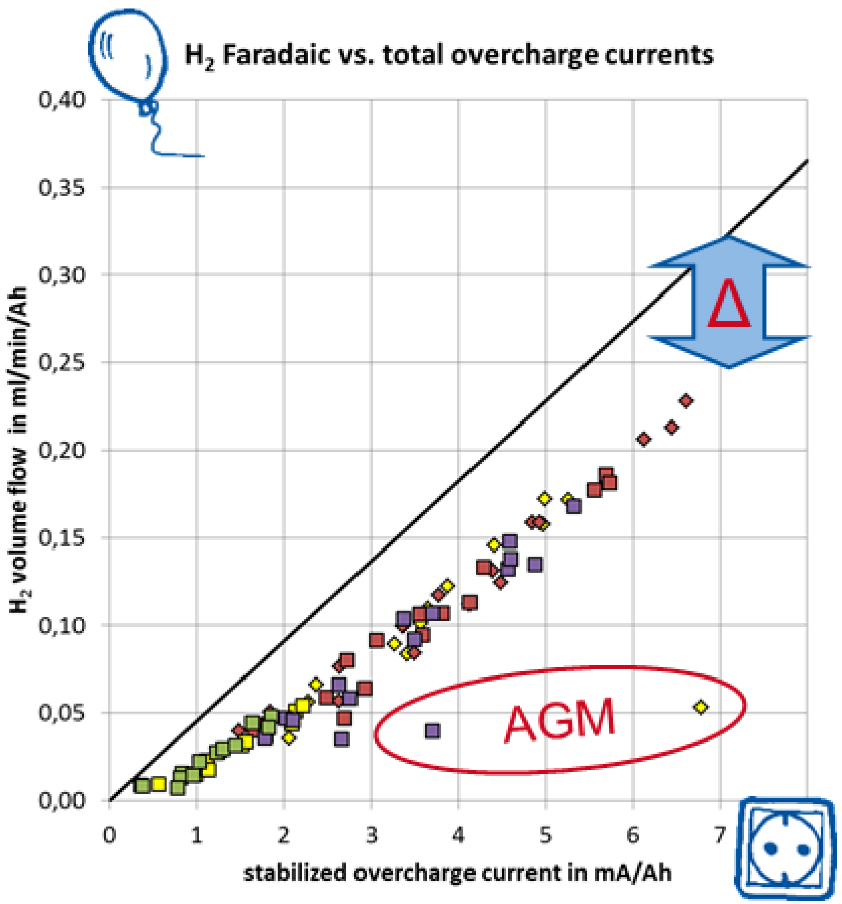
$$\sum Q_{charged} - \sum Q_{discharged}$$

- Electrolysis of water only partly accounts for overcharge current
  - Unknown side reaction(s) taking place: Oxygen recombination cycle?
  - Side reaction(s) higher for AGM batteries



Results: Gassing during steady-state overcharge





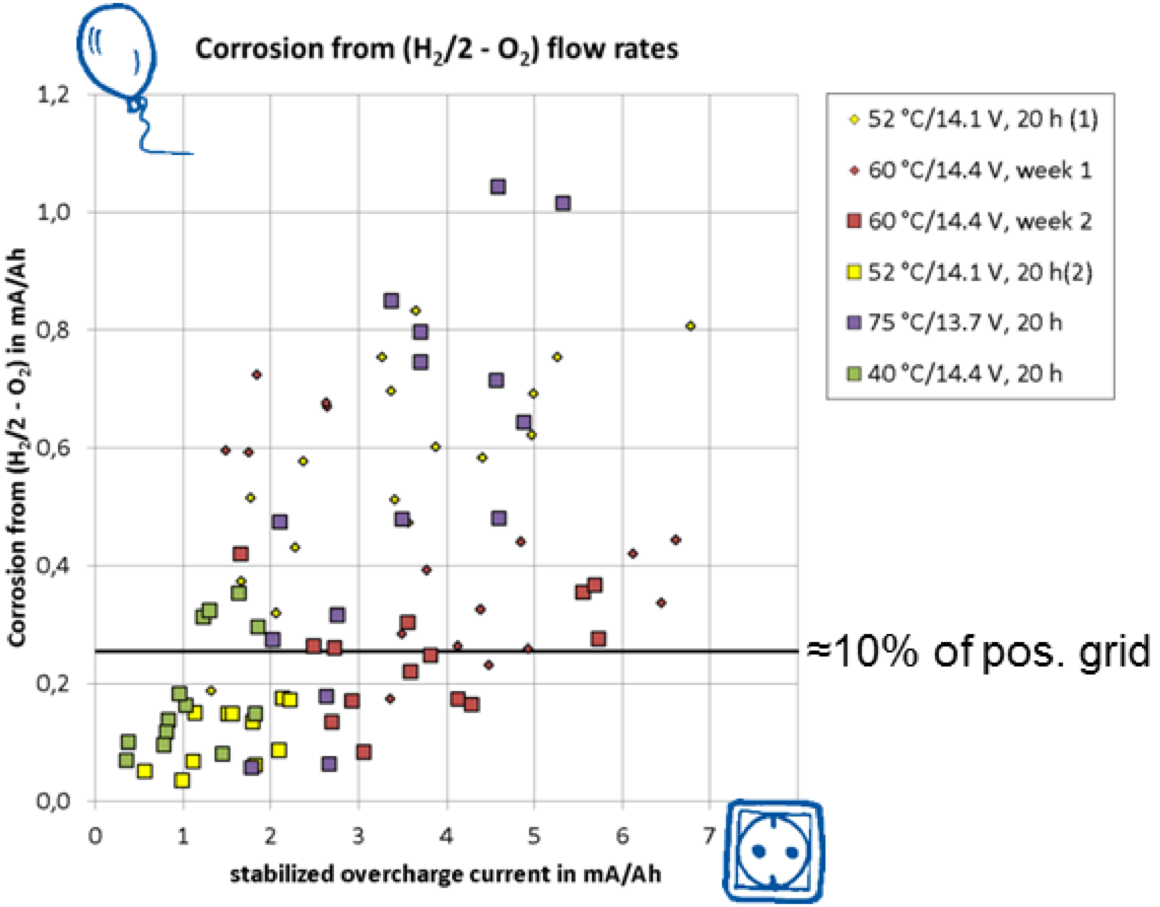
Sanity check for eGAS

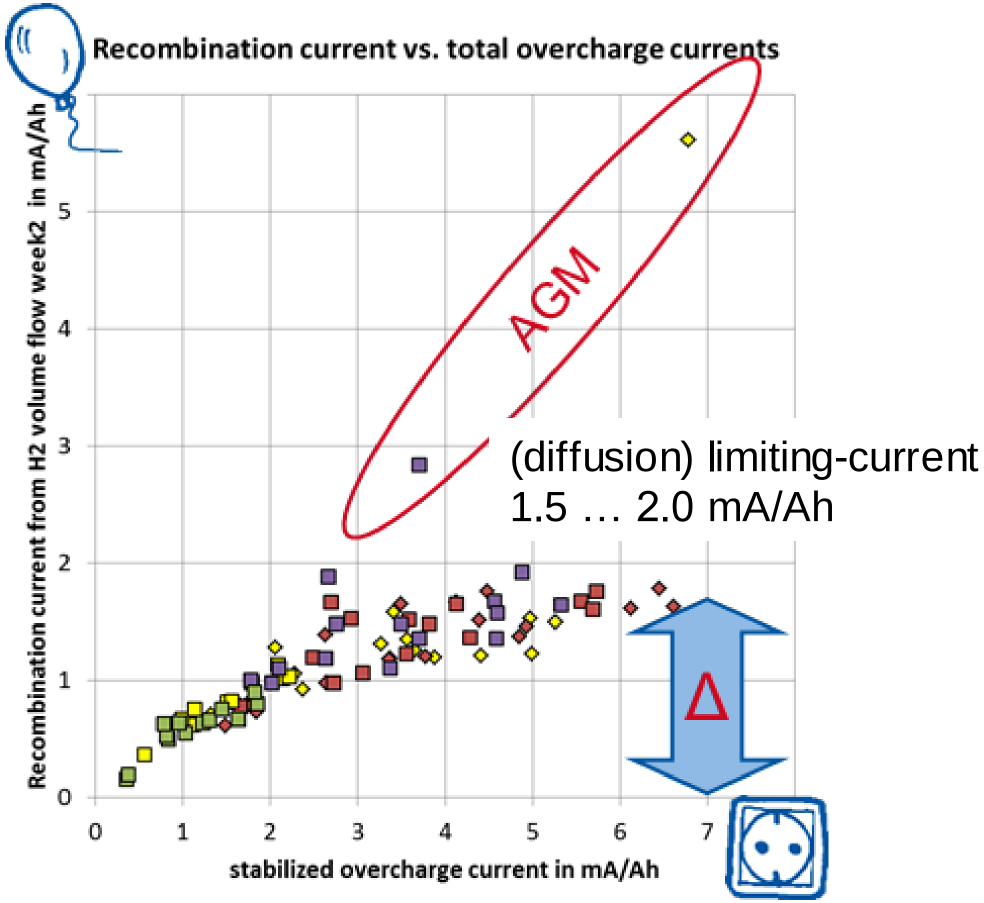
- Vapor extraction effect: 15 %vol ≙ 23 %wt
- Weight loss and extracted gas volume correlate well

H_2 gas flow vs. electric current

- Electrolysis of water only partly accounts for overcharge current ➔ other side reaction(s)?

Results: Gassing during steady-state overcharge





Corrosion analysis

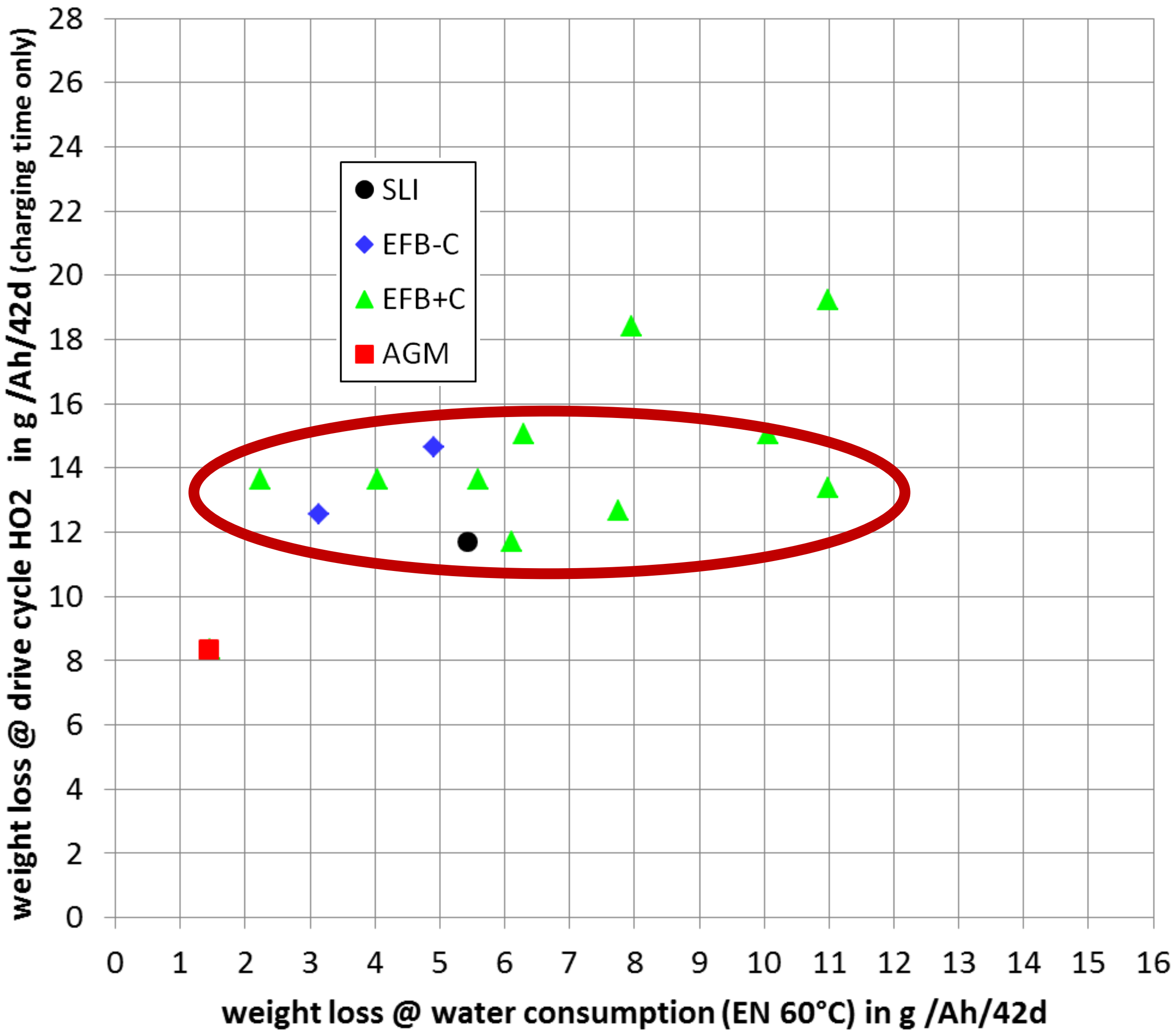
- Subtract Faradaic equivalents of H_2 and O_2 gas flows
- Can be explained with positive grid corrosion

Oxygen recombination cycle?

- Flooded & EFB, independent of battery design, carbon, voltage, temperature

Charging during dynamic microcycles: Test results – Comparison to steady-state overcharge

- Water loss in dynamic microcycles shows lower variation than in steady-state overcharge
- Higher water loss in dynamic microcycles test, despite the lower voltages applied (13.75 vs. 14.4 V)
  - Values are normalized to charging time ➔ water loss also occurs during pauses, e.g. due to self discharge
- Most of EFB+C show very similar results in dynamic overcharge test, but vary by a factor of 5 in static overcharge test
  - Which result does reflect real-life behavior better?
  - How sensible are the results to assumptions made?



Summary and outlook

- Realistic dynamic microcycles lead to significantly different gassing behavior compared with steady-state overcharging tests
- Very weak correlation between water consumption in dynamic vs. steady-state condition

- Influences of different parameters have to be analyzed:
  - Higher or lower loads
  - Voltage control, steepness of voltage changes
  - Alternator strategy

- Which high-temperature durability tests can improve correlation, yet be kept simple?

➔ **New test procedures are urgently needed for realistic estimation of water loss**

Thank you
for your attention

Contact

Dirk Uwe Sauer
Tel.: +49 241 80-96977
dsa@isea.rwth-aachen.de
batteries@isea.rwth-aachen.de

Chair for Electrochemical Energy Conversion
and Storage Systems
Univ.-Prof. Dr. rer. nat. Dirk Uwe Sauer
RWTH Aachen University

Jaegerstrasse 17/19
52066 Aachen
GERMANY

www.isea.rwth-aachen.de

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