

Water consumption 24/7 at different temperatures and charging voltages

Discussion: 24/7 Backup battery & normal mode ?!

Why would we go away from **normal mode**?

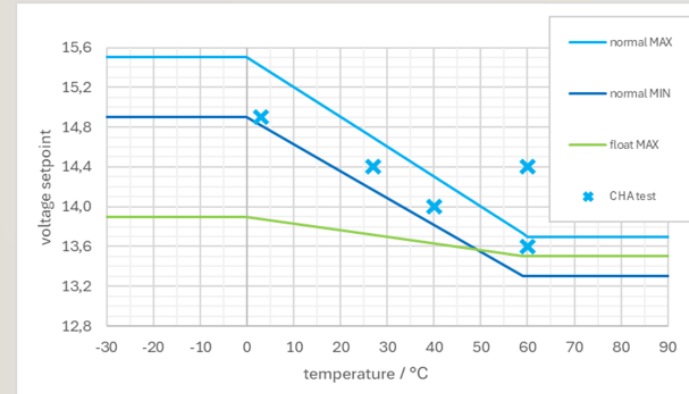
- 👉 Remember AUX batteries fail with sulfation and cycling, but not corrosion and water loss – even in Southern China.
- 👉 The higher float curves are in the “normal” region for $T > 50^{\circ}\text{C}$
- 👉 Do we expect massive corrosion or water loss at $T < 50^{\circ}\text{C}$? Or why would we reduce voltage there but not in hot?

Benny's Challenge: Try it.

- put 5 batteries into the usual water baths and overcharge 3, 6 or 12 weeks at “normal” Z curve voltages (examples see crosses in diagram)
- at least for AGM, do some initial capacity tests first (e.g., RC-RC-C20)
- observe stabilized current, weekly weight loss, power test ever 3 weeks
- if possible, measure half-cell potentials and gas flow (rate & composition)
- tear down after test and search for corrosion

	Z curve	steeper Z curve	float charging
temperatures	0-21 days	21-42 days	42-63 days
3°C	14,9 V	15,5 V	13,8 V
27°C	14,4 V	14,6 V	13,7 V
40°C	14,0 V	14,1 V	13,6 V
60°C	13,6 V	13,3 V	13,5 V
75°C	13,6 V	12,8 V	13,5 V

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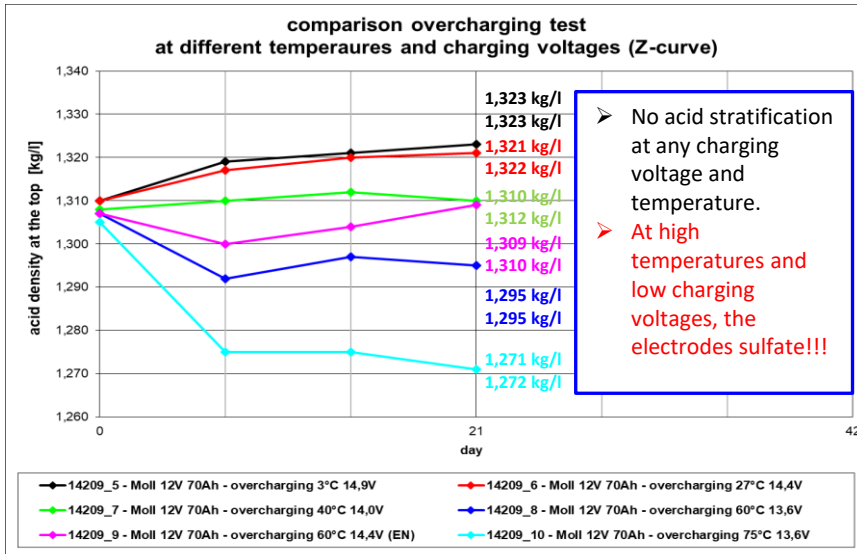
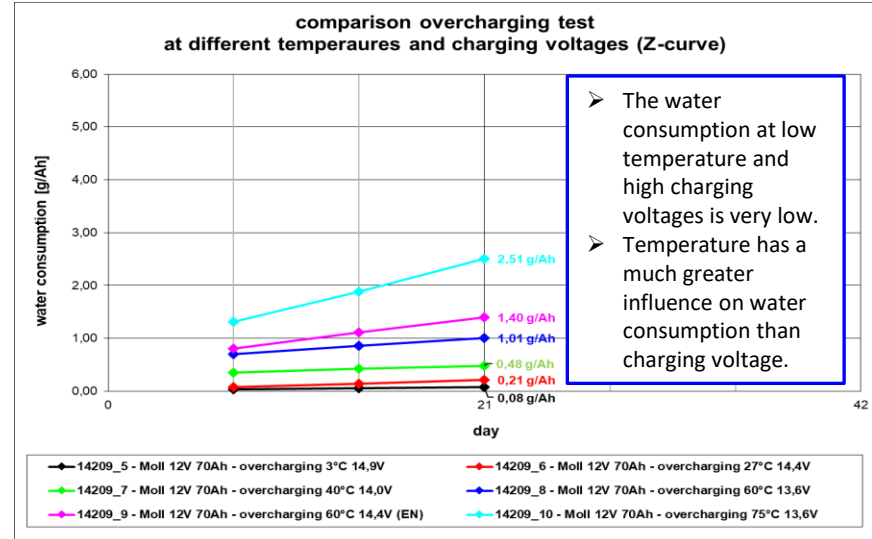
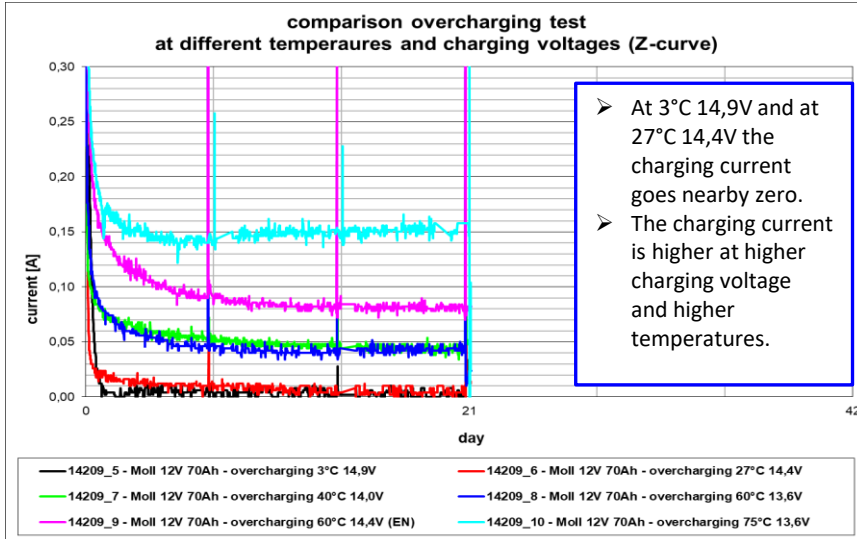


backup battery 24/7

- ❑ assume permanent 12V supply out HV battery via low-power low-loss dc/dc converter (or normal dc/dc when needed)
- ❑ 12V battery for backup (comfort and/or safety) only
- ❑ additional battery discharge tests may be actively performed for battery monitoring or diagnostic purposes

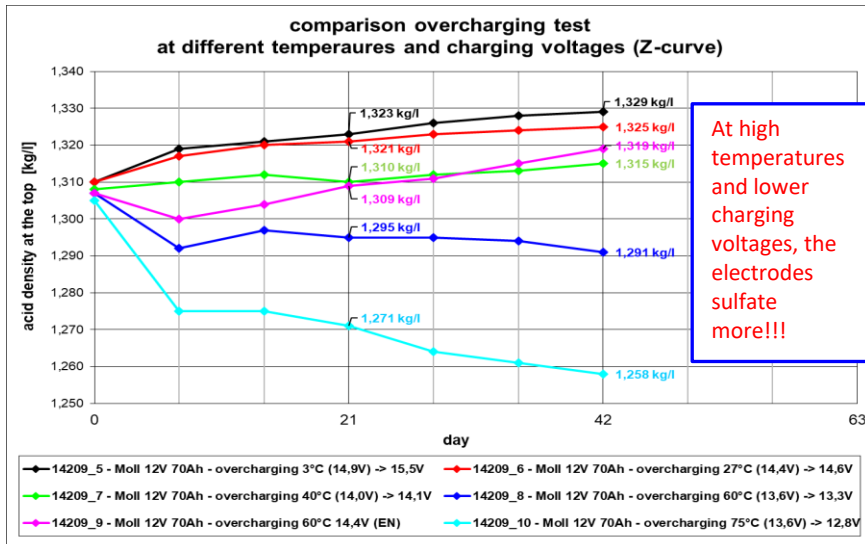
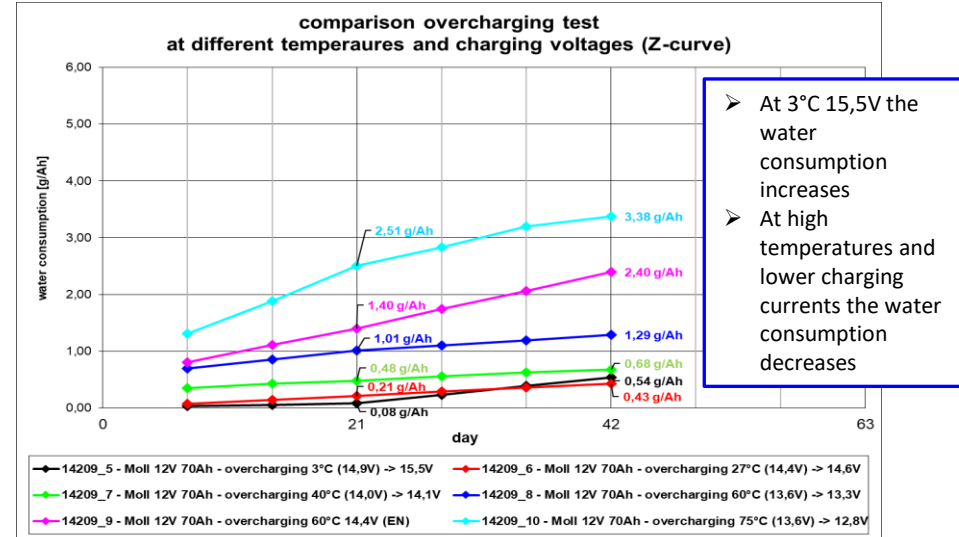
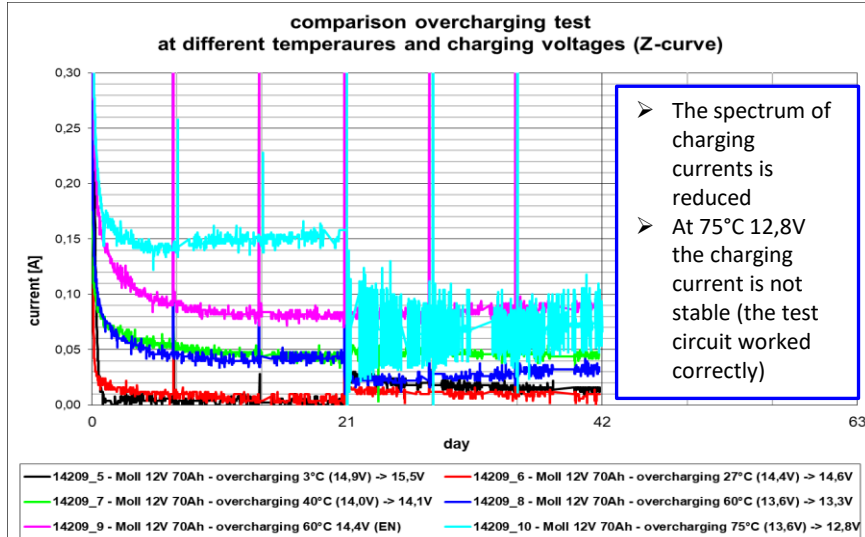
→ **low mode** may support battery durability
→ **boost mode** equalization is **then** mandatory

Water consumption 24/7 at different temperatures and charging voltages day 0-21



temperature [°C]	charging voltage [V]	charging current (without week 1) Ø [A]	waterloss per week (without week 1) Ø [g/Ah]	acid density at starting point [kg/l]	acid density at the top Ø [kg/l]	acid density at the bottom Ø [kg/l]	Acid stratification did not occur in any measurement series
3	14,9	0,003	0,02	1,310	1,322	1,323	very low charging current; very low waterconsumption; increasing acid density
27	14,4	0,008	0,07	1,310	1,321	1,322	very low charging current; very low waterconsumption; increasing acid density
40	14,0	0,04	0,08	1,308	1,311	1,312	low charging current; very low waterconsumption; stable acid density
60	13,6	0,042	0,18	1,307	1,295	1,295	low charging current; low waterconsumption; slightly decreasing acid density
EN 60	14,4	0,083	0,32	1,307	1,309	1,310	"normal" charging current; "normal" waterconsumption; stable acid density
75	13,6	0,150	0,60	1,307	1,271	1,272	high charging current; high waterconsumption; strong decreasing acid density

Water consumption 24/7 at different temperatures and charging voltages day 21-42



temperature [°C]	charging voltage [V]	charging current (without week 1) Ø [A]	waterloss per week (without week 1) Ø [g/Ah]	acid density at starting point [kg/l]	acid density at the top Ø [kg/l]	acid density at the bottom Ø [kg/l]	Acid stratification did not occur in any measurement series
3	(14,9) 15,5	0,018	0,15	1,322	1,329	1,330	low charging current; low waterconsumption; increasing acid density
27	(14,4) 14,6	0,011	0,07	1,321	1,325	1,327	very low charging current; very low waterconsumption; increasing acid density
40	(14,0) 14,1	0,042	0,08	1,311	1,315	1,316	low charging current; very low waterconsumption; stable acid density
60	(13,6) 13,3	0,024	0,10	1,295	1,291	1,291	low charging current; low waterconsumption; slightly decreasing acid density
EN 60	(14,4) 14,4	0,085	0,32	1,309	1,319	1,320	"normal" charging current; "normal" waterconsumption; increasing acid density
75	(13,6) 12,8	0,030 - 0,110	0,30	1,271	1,258	1,258	charging current not stable; "normal" waterconsumption; strong decreasing acid density

Summary and next steps

➤ Summary

- Z - curve (no acid stratification in any test series)
 - Low temperatures: **charging current goes nearby zero; water consumption is very low**; no sulphation;
 - Middle temperatures; low charging current; low water consumption; no sulphation;
 - High temperatures: high charging current; high water consumption, **sulphation of the electrodes**

- Steeper Z - curve (no acid stratification in any test series)
 - Low temperatures: **low charging current; low water consumption**; no sulphation;
 - Middle temperatures; low charging current; low water consumption; no sulphation;
 - High temperatures: charging current not stable; **normal water consumption, massive sulphation of the electrodes**

➤ Next Steps

- Change the charging voltage after 42 days to float charging values (float MAX)
- What will happen if we charge a discharged battery at these temperatures and charging voltages?

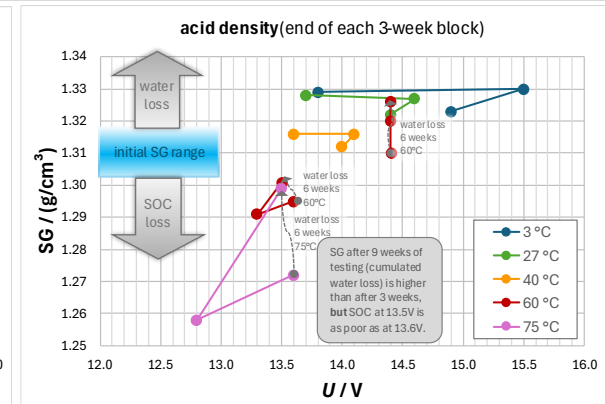
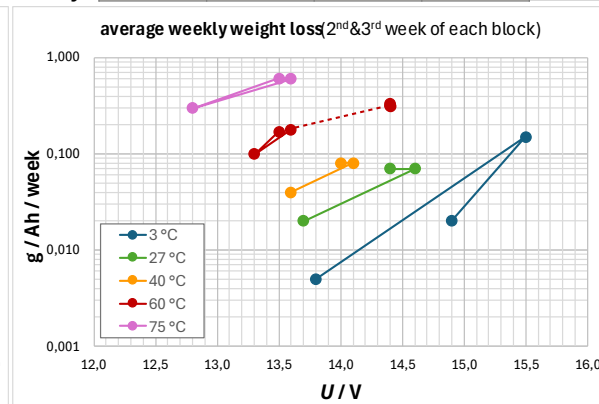
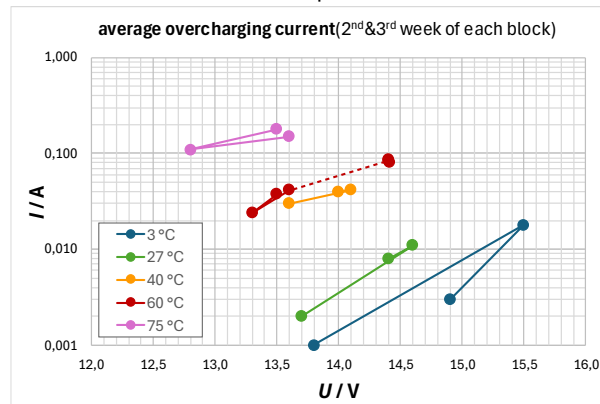
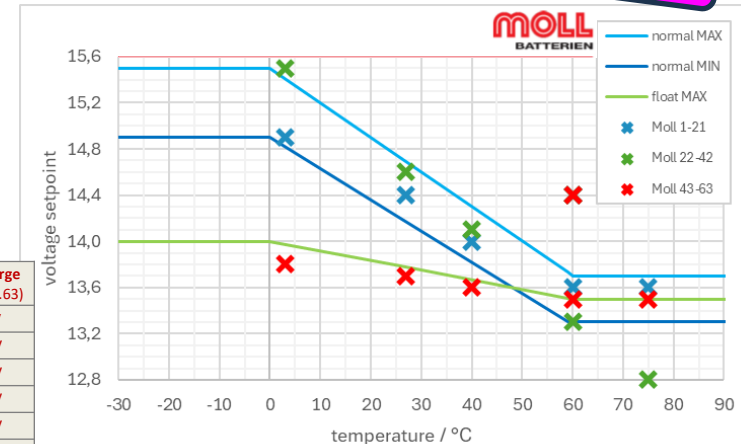
	Z curve	steeper Z curve	float charging	Proposed testing procedure
temperatures	0-21 days	21-42 days	42-63 days	
3°C	14,9 V	15,5 V	13,8 V	a) Discharge C20 at 27°C
27°C	14,4 V	14,6 V	13,7 V	b) Conditioning the battery to the respective temperature for at least 12 hours
40°C	14,0 V	14,1 V	13,6 V	c) Charging the battery at the respective temperature and charging voltage for 24 hours.
60°C	13,6 V	13,3 V	13,5 V	d) Conditioning the battery to 27°C for at least 12 hours
75°C	13,6 V	12,8 V	13,5 V	e) C20

Constraints for Z curves – experimental study

modified “water consumption” test

- ❑ 6 identical samples: Moll EFB (EN W4), after EN initials and fully charged
 - 5 samples, each in one water bath, overcharged at 3 voltages 3 weeks each
 - 1 sample = control: EN/IEC “water consumption” at 60°C for 9 weeks
- ❑ stabilized (over)charging currents and weight loss per week (semi-log plots) reproduce expected “Tafel” behavior
 - water-loss and its reduction at “float” voltage are insignificant at 27 °C and below
- ❑ acid density indicates that SOC cannot be kept “full” even with $U \approx 13.5V$ at high temperature
 - 2nd kink of Z curve provides trade-off with durability

water bath temperature	base Z curve (days 1...21)	steep Z curve (days 22...42)	float charge (days 43...63)
3 °C	14.9 V	15.5 V	13.8 V
27 °C	14.4 V	14.6 V	13.7 V
40 °C	14.0 V	14.1 V	13.6 V
60 °C	13.6 V	13.3 V	13.5 V
75 °C	13.6 V	12.8 V	13.5 V
control: 60°C	14.4 V	14.4 V	14.4 V



Recommendations for Z curves – Discussion

Charging voltage setpoints for lead batteries must be adjusted with temperature

- Recommended parameterization (blue curves) in this document represent expert consensus and long (ICE) experience.

“Normal Mode” voltage control is preferred from LAB perspective

- Evidence-based optimum trade-off between undercharge / sulfation and overcharge / gassing / corrosion
- Charging should be invoked in parking BEVs to avoid deep cycles (→wear) and long periods at low SOC (→sulfation):
The dc/dc converter should be activated based on high-load condition and 12V-battery SOC.
- Wide field data demonstrate that undercharge, sulfation, and excessive cycling drive 12V battery failures in HEV & BEV, but **not** water consumption and corrosion (not even in hot climate) -
- “Float” voltage 24/7 is insufficient to maintain (or even restore) high SOC and avoid undercharge / sulfation.

OEMs may still require Low Charge Mode for energy management reasons only.

- examples: brake energy recuperation in 12V micro-hybrid, power consumption of 12V resistive loads
- In such cases, make sure that equalization charge is applied regularly, preferably applying **Boost Charge Mode** !