Pool-boiling Experiments

dr. ir. Rob van Gils
Technologist Thermal
Mechatronics Technologies
Philips Innovation Services

High Tech Campus 7, 2.B.007,
5656 AE Eindhoven, the Netherlands
Tel: +31 6 4684 8367
Email: Rob.van.Gils@philips.com
www.innovationservices.philips.com

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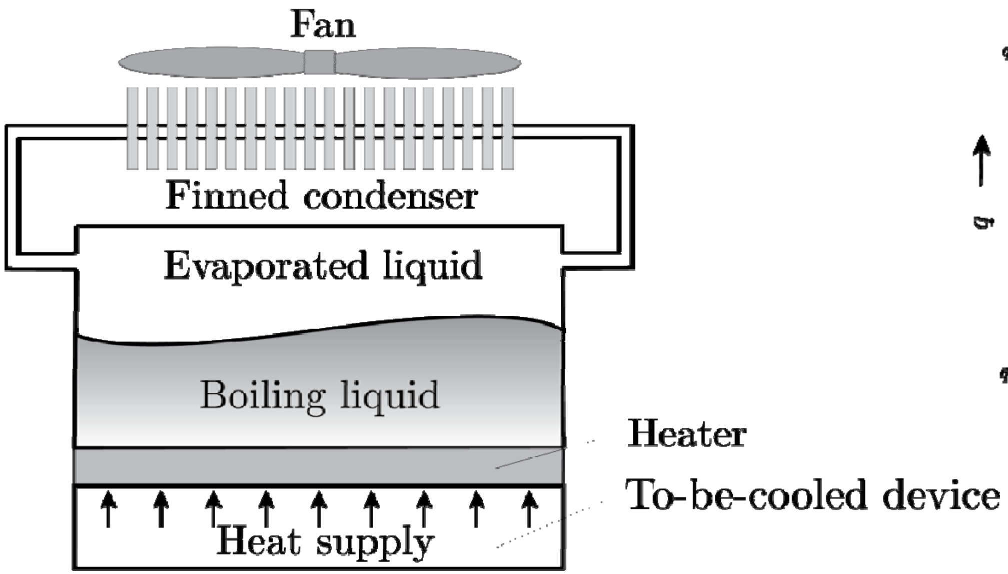
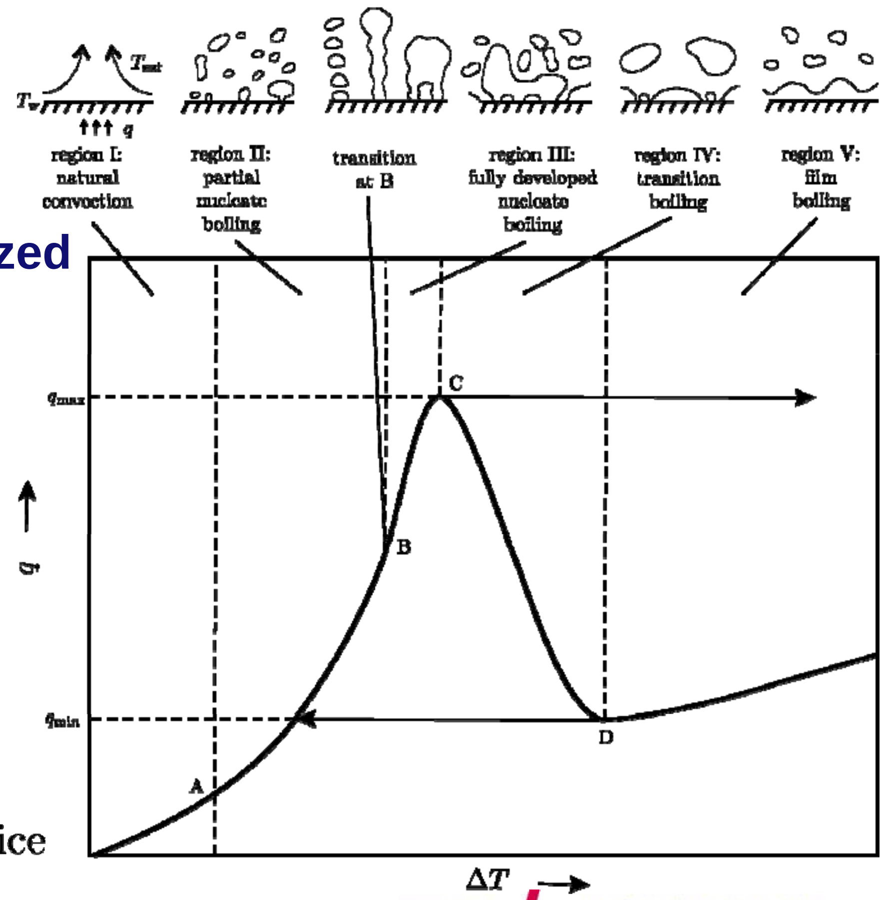
Introduction

- **Can theoretical phenomena be observed in a practical setup?**
  - **Experiments**
- **Pool-boiling plant:**
  - **Heater submerged boiling liquid**
  - **Heat transfer to liquid characterized by global boiling curve**





Objective

Can theoretical phenomena be observed in a practical setup?

- **Field of application: EVs**
- **Start small scale: submerge 1 battery in boiling liquid**

Objective:

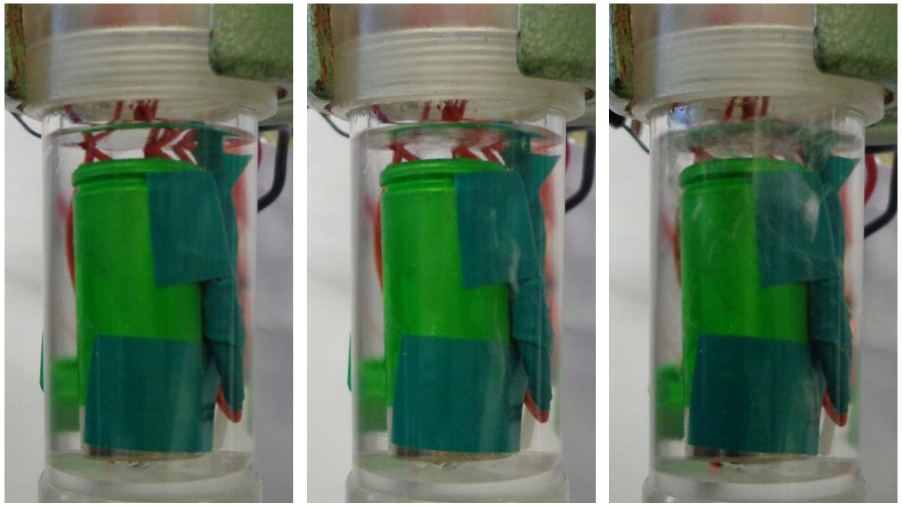
- **Experimental investigation of the ability of pool boiling for thermal conditioning of batteries in EVs**

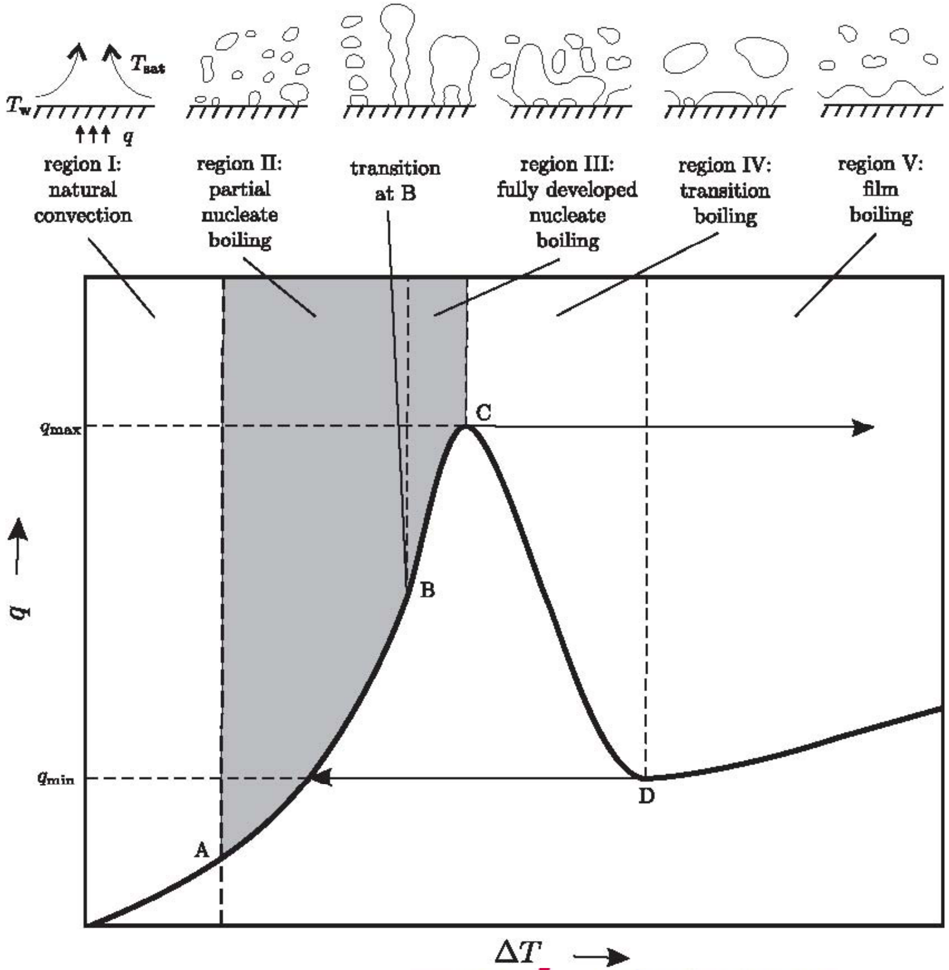
First exploratory experiments are carried out to investigate:

- **The electric interaction between battery and cooling liquid**
- **The cooling capacity of the proposed cooling liquid**
- **The ability of the boiling process to thermally homogenize batteries**
- **The controllability of the boiling process**

Background

- **Due to limited heat generation by battery only small region of boiling curve will be touched**
  - **Region I: Natural convection**
  - **Region II: Partial nucleate boiling**
  - **Region III: fully developed nucleate boiling**





Experimental setups

Two setups are utilized for the experiments

- **In cooperation with dept. of Chemical Engineering and Chemistry**
- **Battery testing system (Maccor 2300, USA)**
- **Battery: Sony US18500VR (d = 18mm, h = 49mm)**
  - **1Ah Li-ion battery**
- **Working fluid: Novec7000**
  - **3M, USA, chemical composition: 99.5 weight percentage of $C_3F_7OCH_3$ (1-methoxyheptafluoropropane)**
  - **Boiling point @ atm pressure = 34 ºC**
- **The first setup (setup 1) is used to investigate:**
  - **the dielectric properties of the fluid.**
  - **discharge experiments at atmospheric pressure.**
  - **pulse-charge-discharge (PCD) experiments at atmospheric pressure**
- **The second setup (setup 2) is used to investigate:**
  - **pressure variations on the boiling process**

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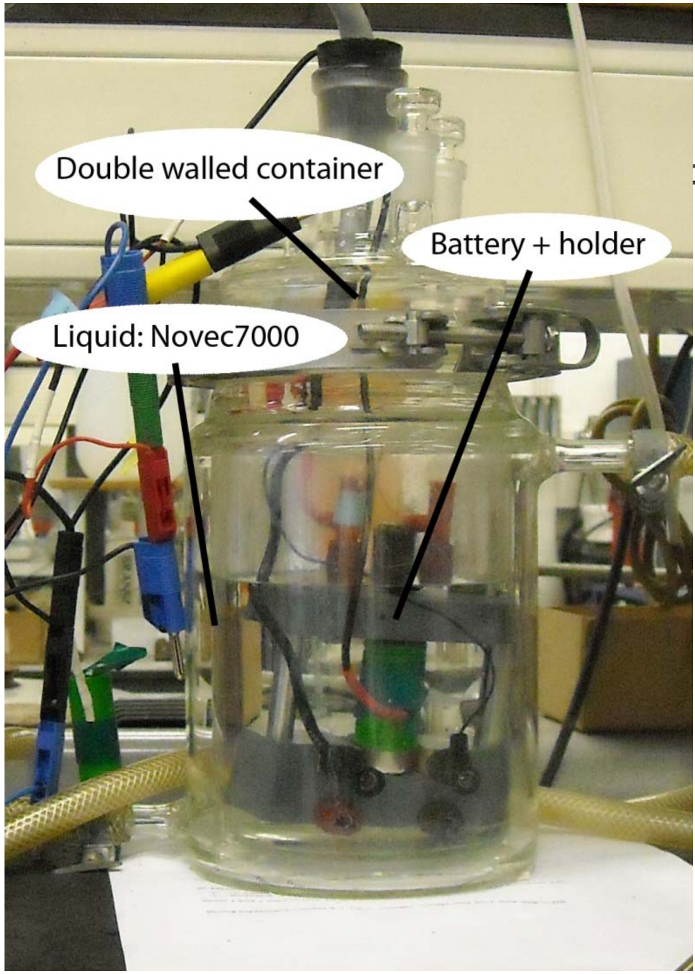
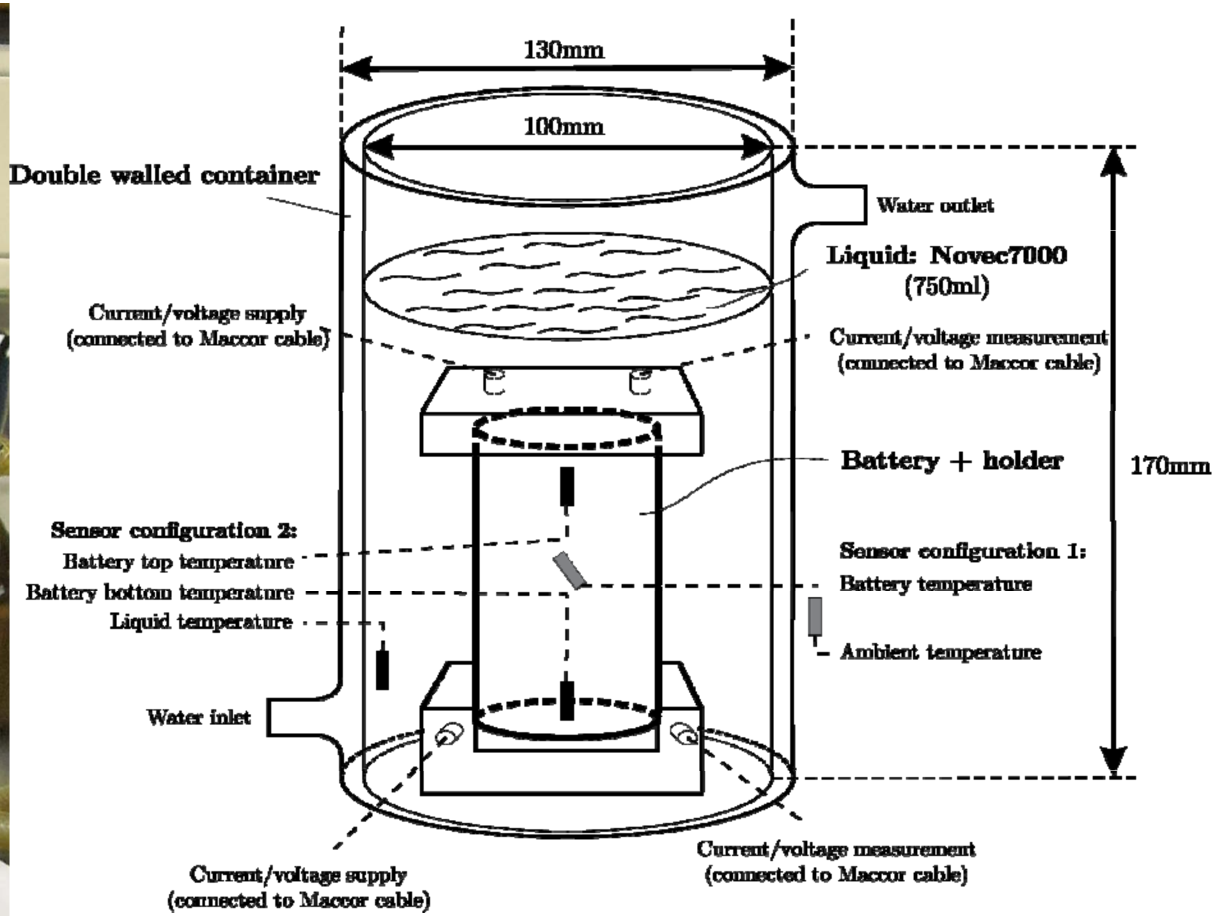
Setup 1





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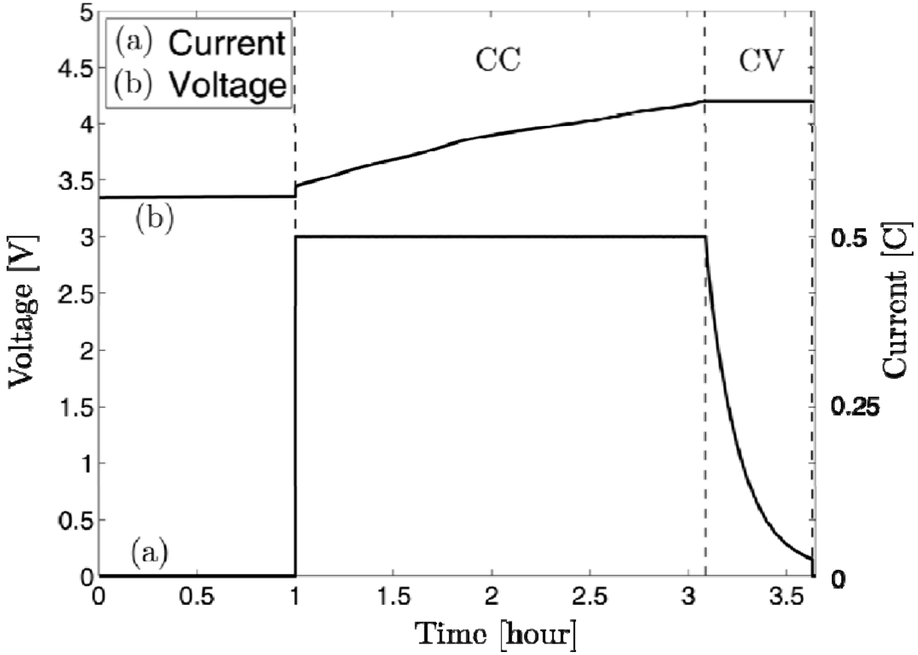
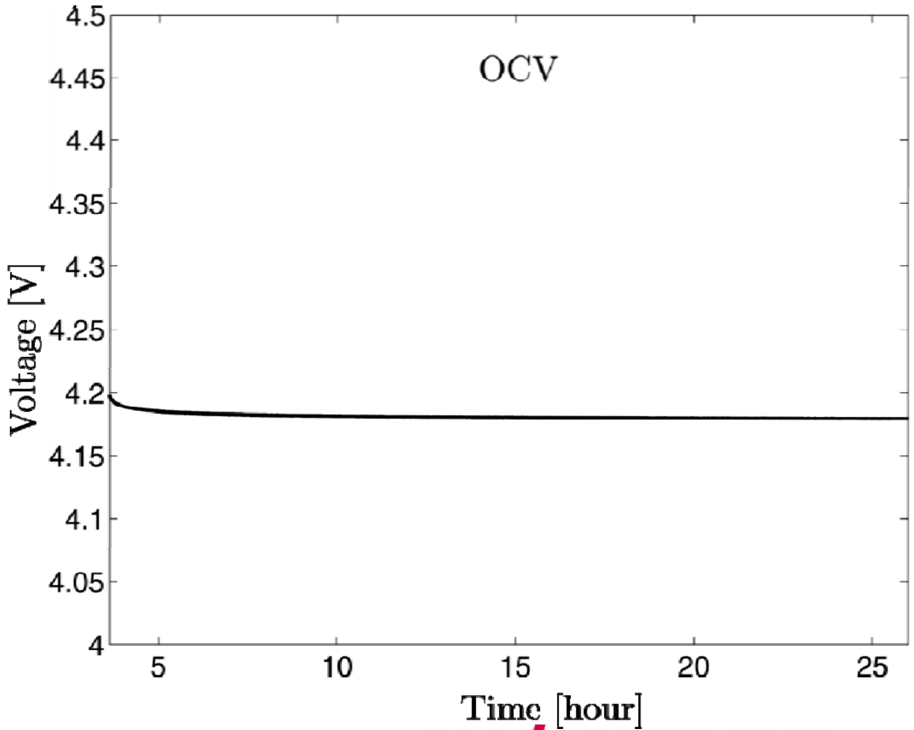
Experiments: Dielectric property of the working fluid

- **Submerge battery in liquid**
  - **Fully load battery**
  - **Monitor voltage for 24h**





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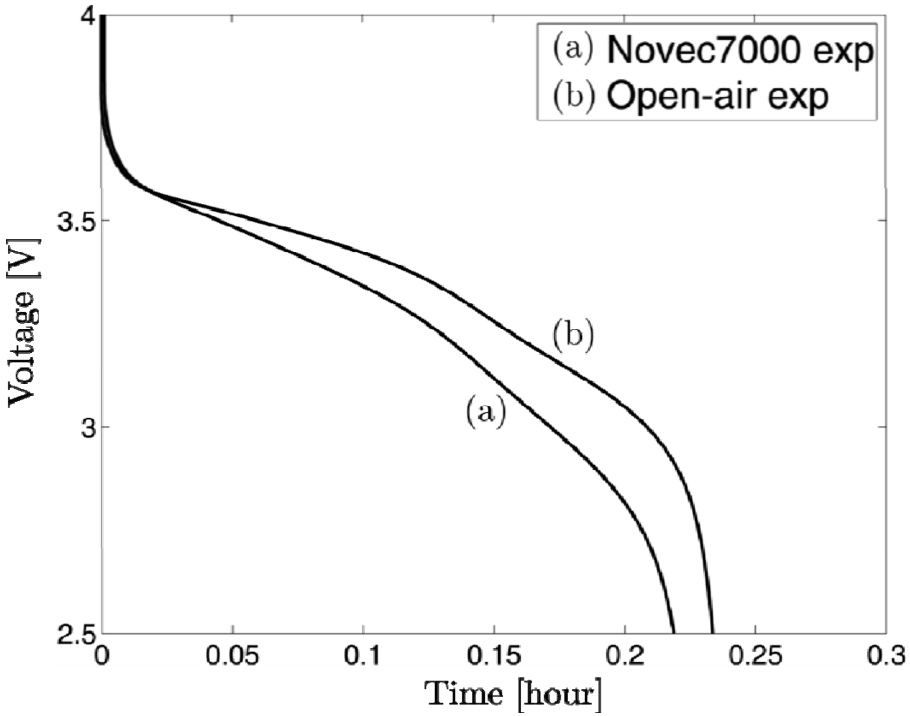
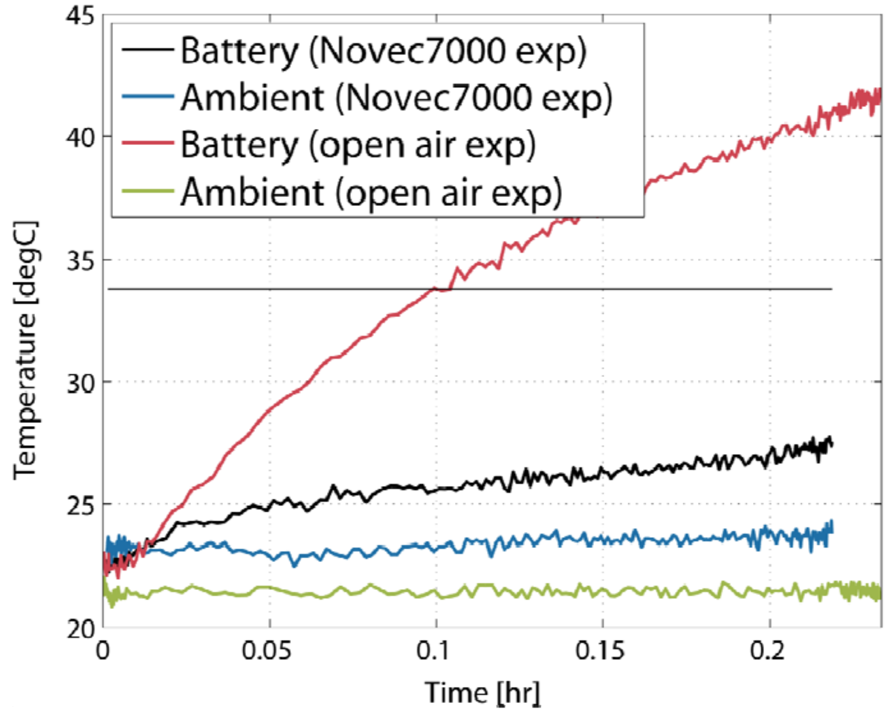
Experiments: Submerged discharging

- **Discharge @ 5A (maximal current by Maccor system)**
  - **submerged in liquid vs in open-air**





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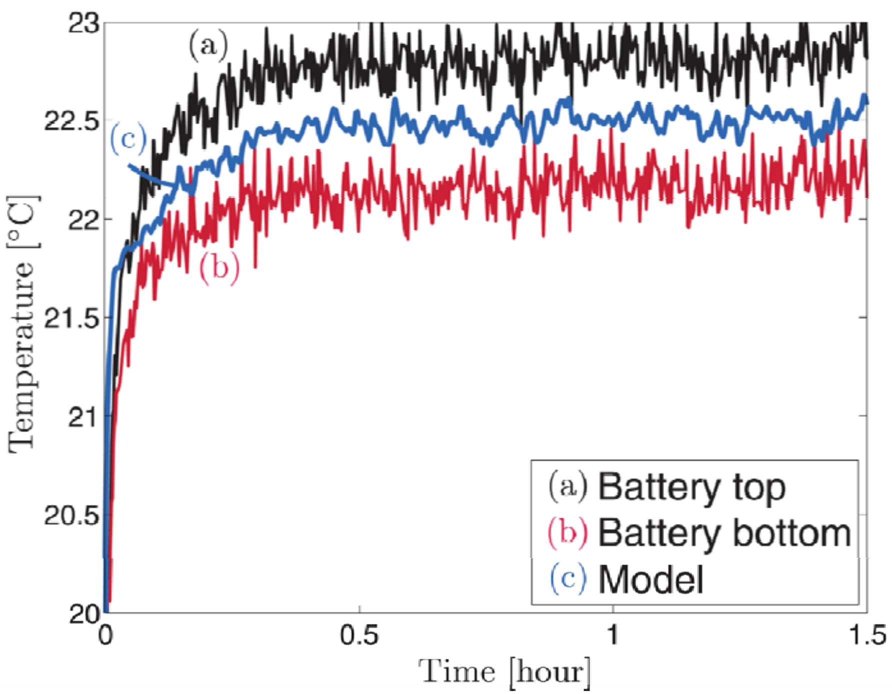
Experiments: Pulse Charge Discharge cycles

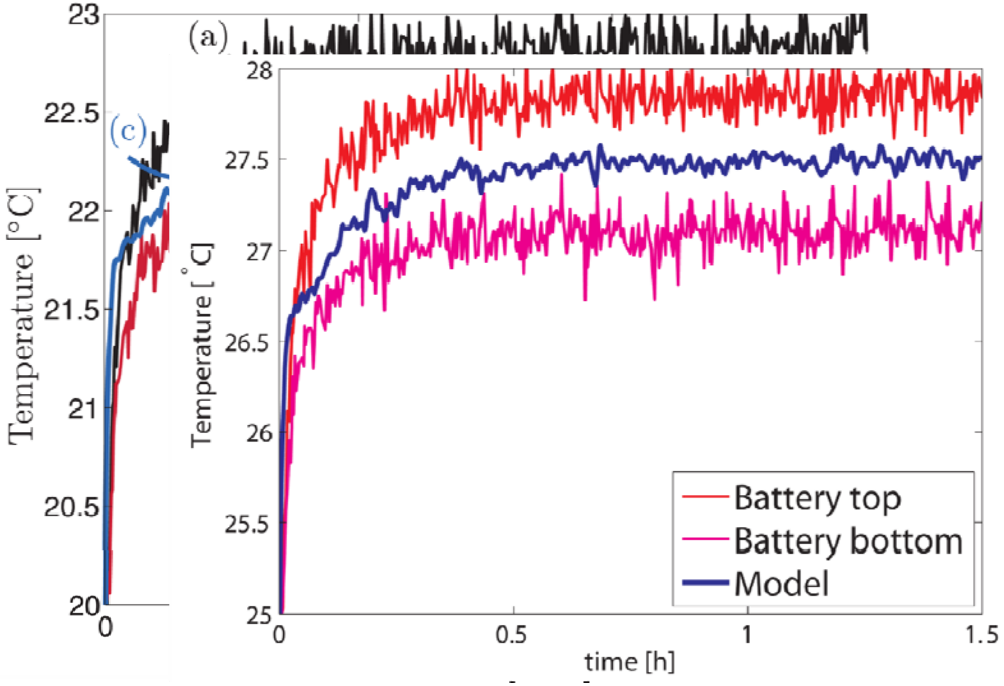
- **Non boiling regime**
  - **T_{wall} = 20 ºC**



- **Boiling regime**

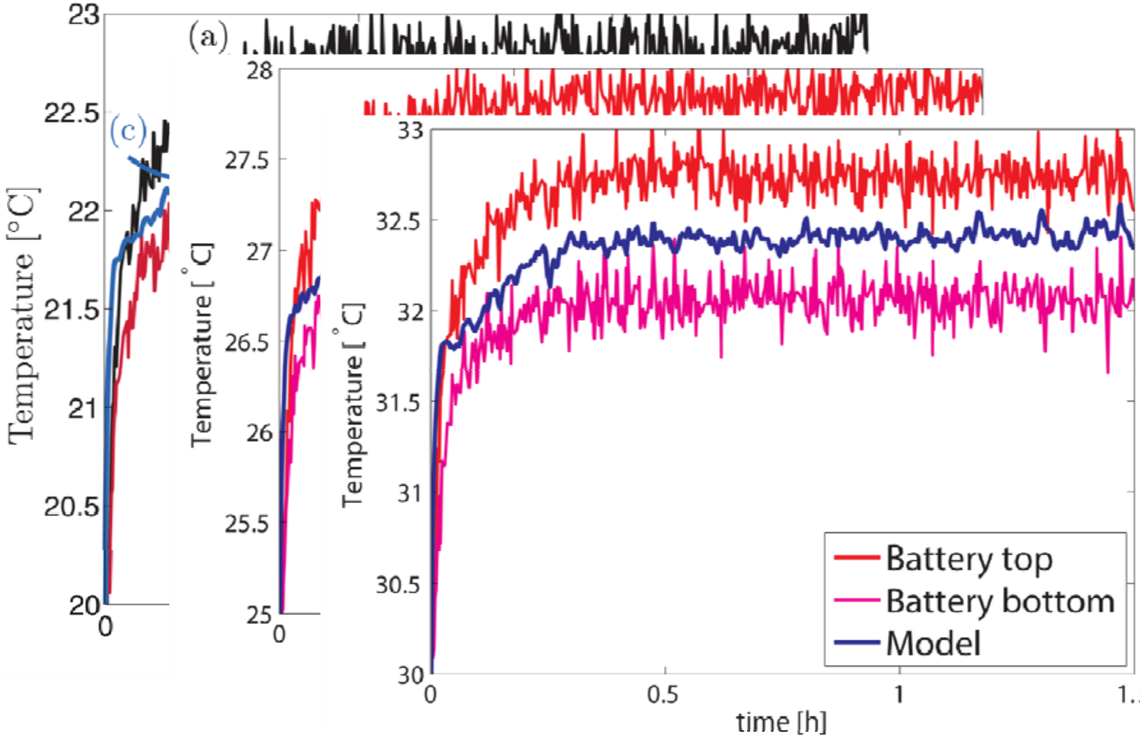
Experiments: Pulse Charge Discharge cycles

- **Non boiling regime**
  - **T_{wall} = 25 ºC**
- **Boiling regime**



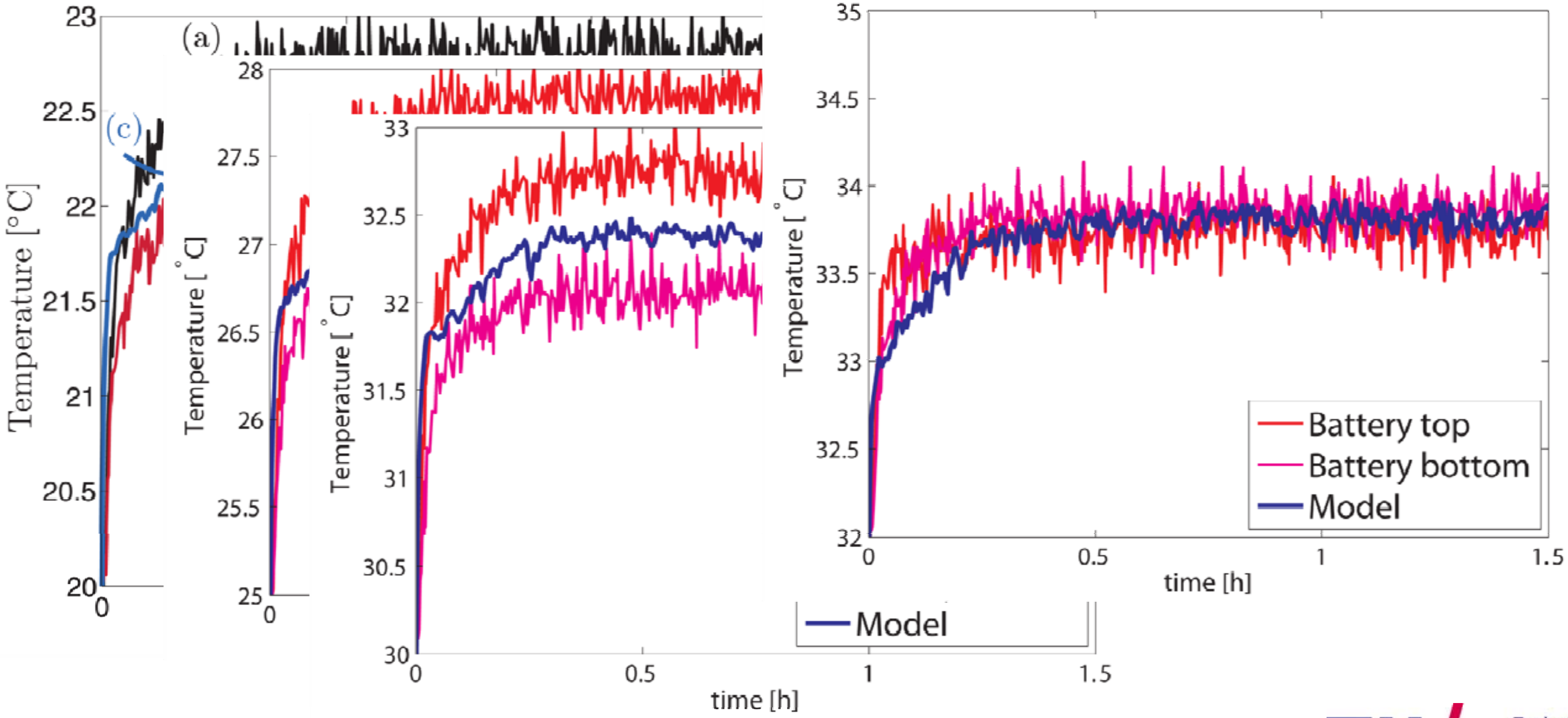
Experiments: Pulse Charge Discharge cycles

- **Non boiling regime**
  - **T_{wall} = 30 ºC**
- **Boiling regime**



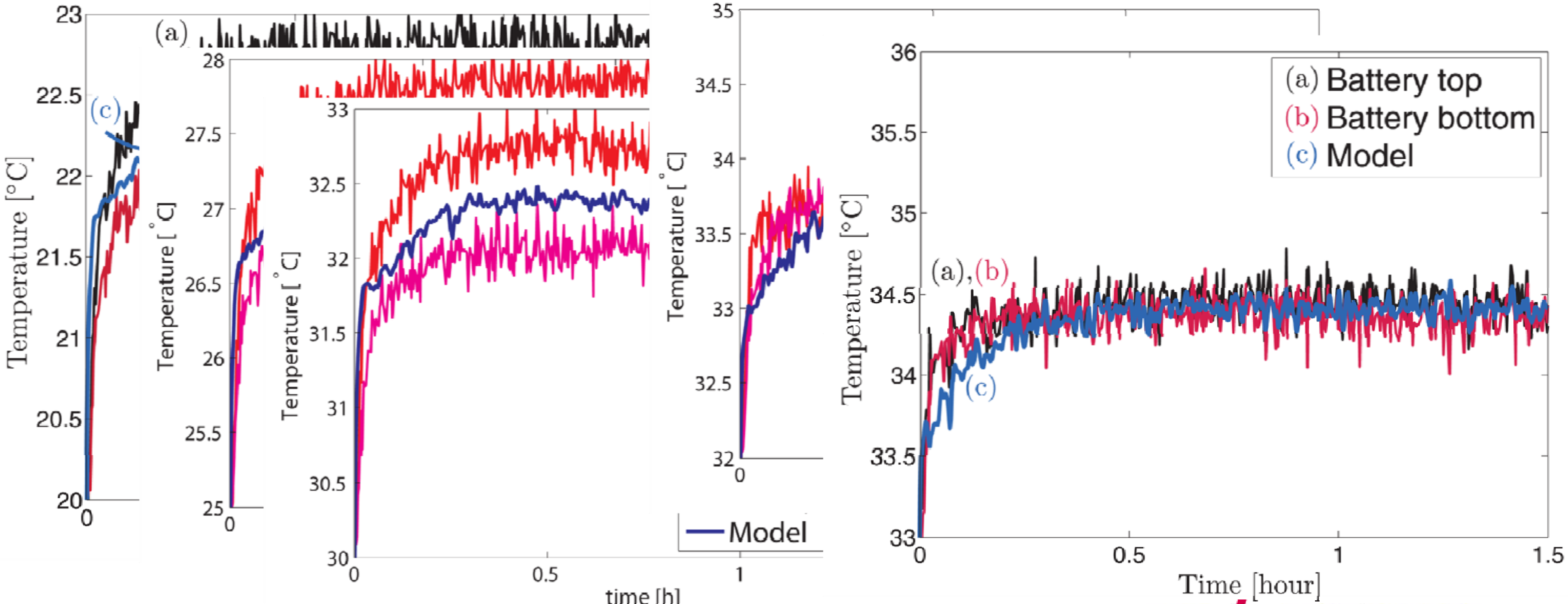
Experiments: Pulse Charge Discharge cycles

- **Non boiling regime**
  - **T_{wall} = 30 ºC**
- **Boiling regime**
  - **T_{wall} = 32 ºC**



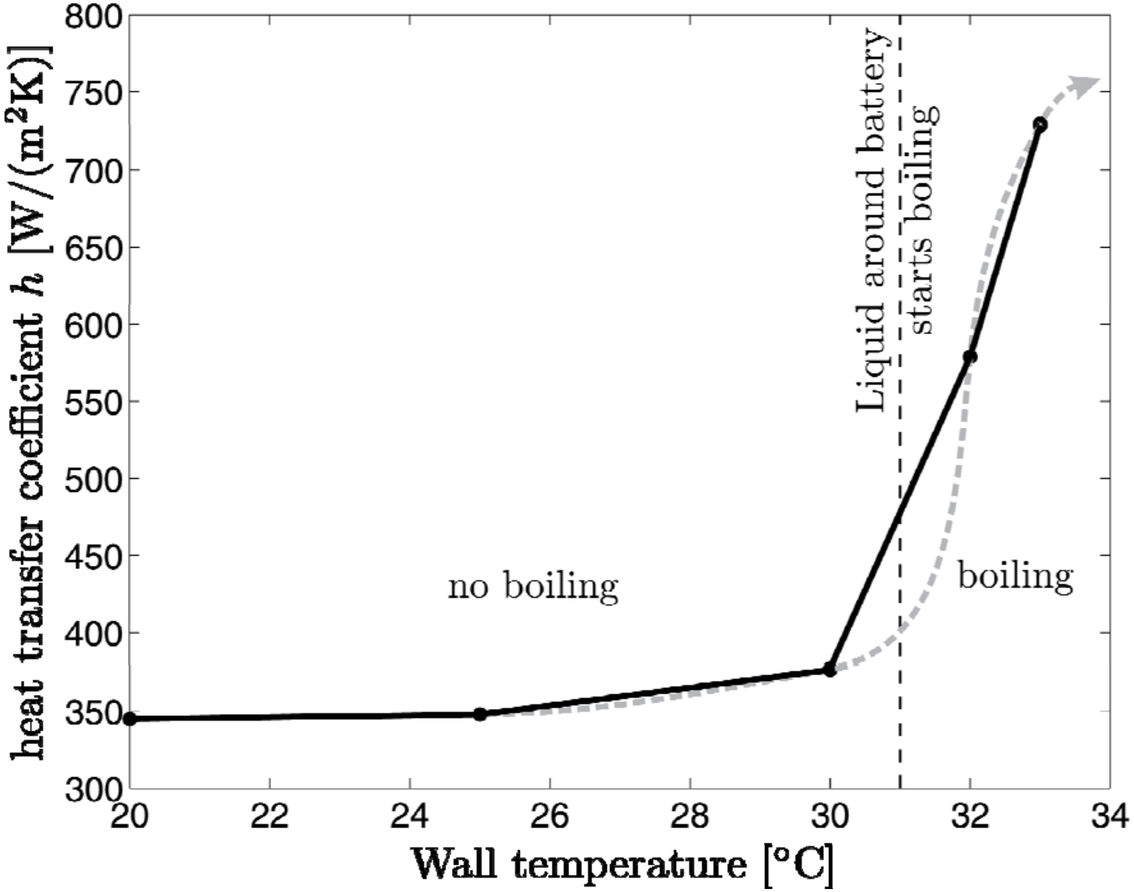
Experiments: Pulse Charge Discharge cycles

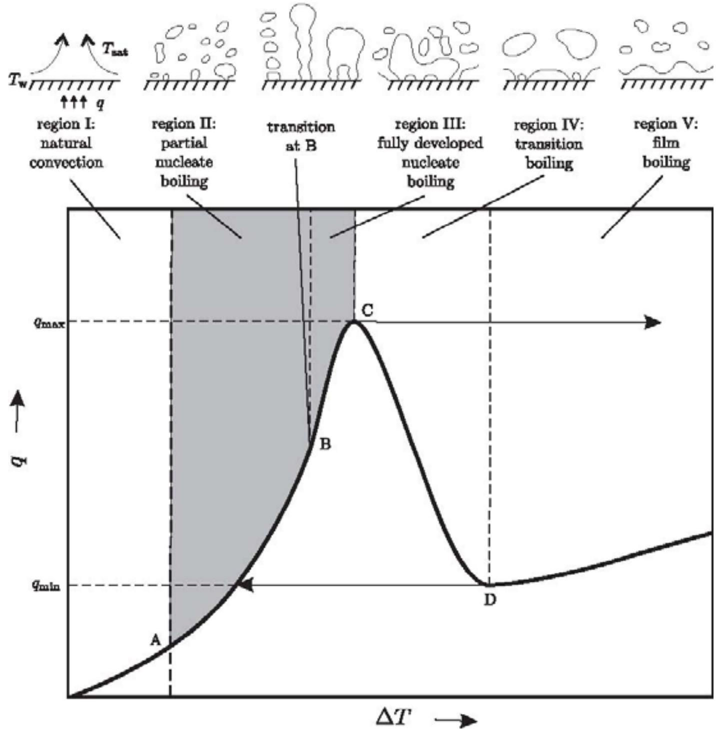
- **Non boiling regime**
  - **T_{wall} = 30 ºC**
- **Boiling regime**
  - **T_{wall} = 33 ºC**



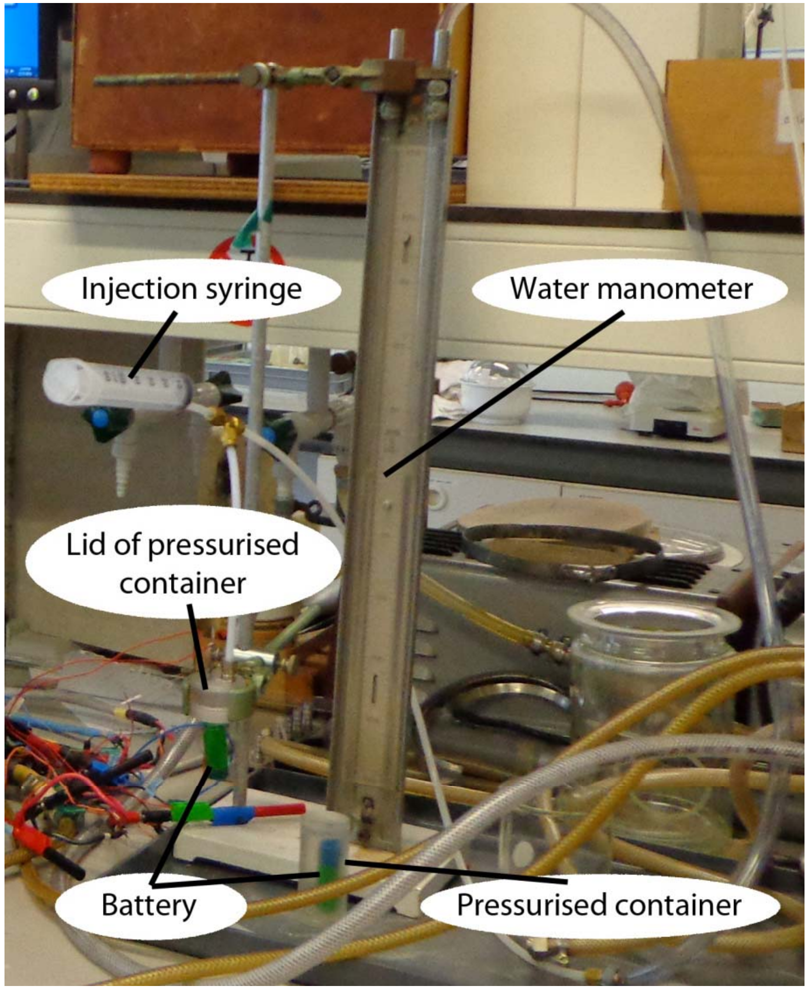
Experiments: Pulse Charge Discharge cycles

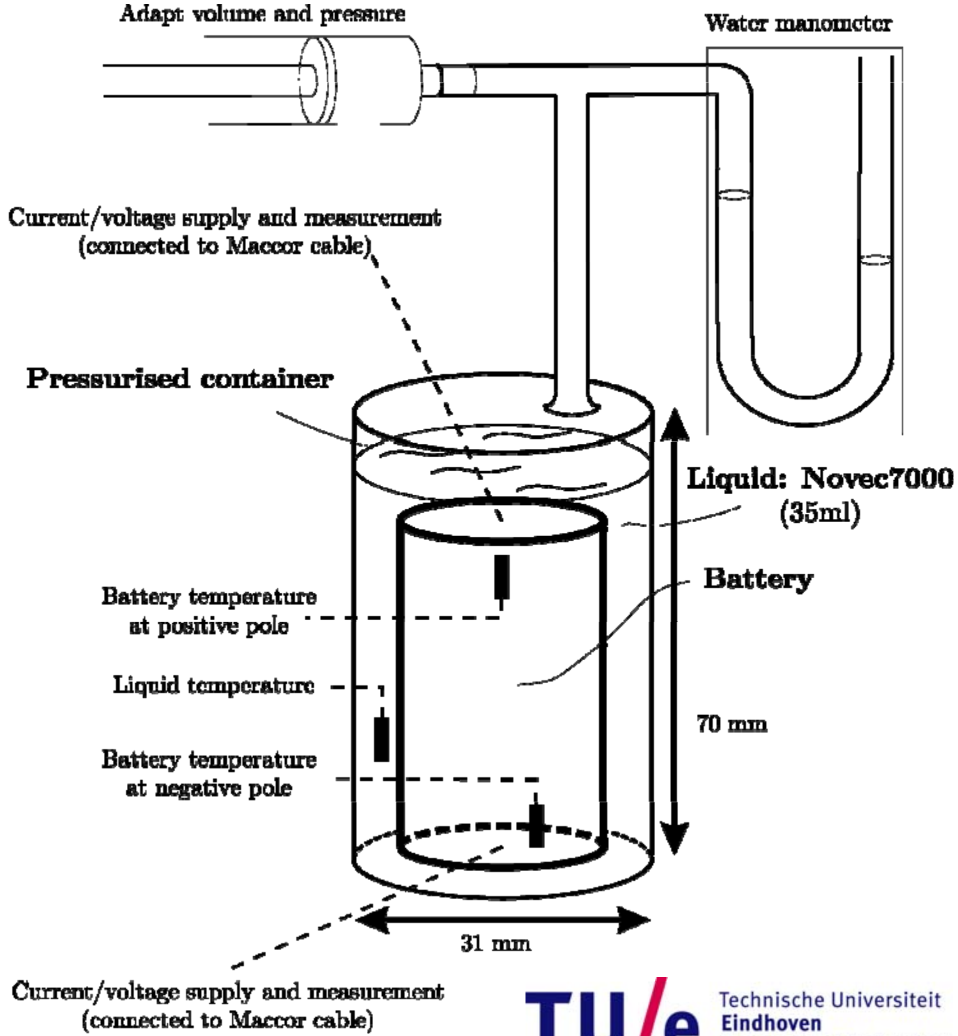
- **Heat transfer coefficient from battery to liquid**





Setup2


Injection syringe
Water manometer
Lid of pressurised container
Battery
Pressurised container

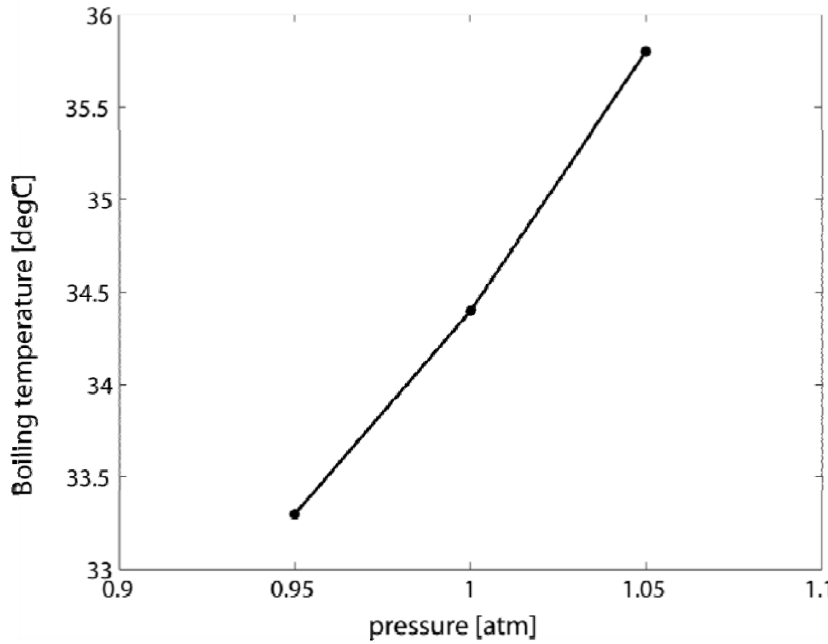

Adapt volume and pressure
Water manometer
Current/voltage supply and measurement (connected to Maccor cable)
Pressurised container
Liquid: Novec7000 (35ml)
Battery
Battery temperature at positive pole
Liquid temperature
70 mm
Battery temperature at negative pole
31 mm
Current/voltage supply and measurement (connected to Maccor cable)

Experiments: Boiling process control via pressure

- **Requirement for application in Evs:**

  Actively and rapidly control the boiling process via the pressure:

  - **Boiling temperature changes with pressure**
  - **Best results obtained directly after pressure change**
  - **Then the effect wears off due to the new thermal equilibrium the liquid and battery take**



Experiments: Boiling process control via pressure

1 Ah Li-ion cell
submerged in
Novec7000 (3M)
(BP @ 1 atm: 34C)
PCD at 4.5A

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Conclusions

- This study investigates the ability of thermal conditioning by boiling
- Principal results are:
  - The working fluid (Novec7000) can be applied directly on the battery due to dielectric property
  - Its cooling capacity greatly exceeds that of air
  - When boiling, the liquid can thermally homogenise the battery
  - Pressure can regulate the boiling process
    - Change pressure, instanteneously affects the boiling process
- Experimental proof of principle for thermal homogenization of battery packs in Evs
- Follow-up experiments are required