

Single Phase Static Immersive Cooling of Cylindrical Battery Insight of Measuring Methods and Result

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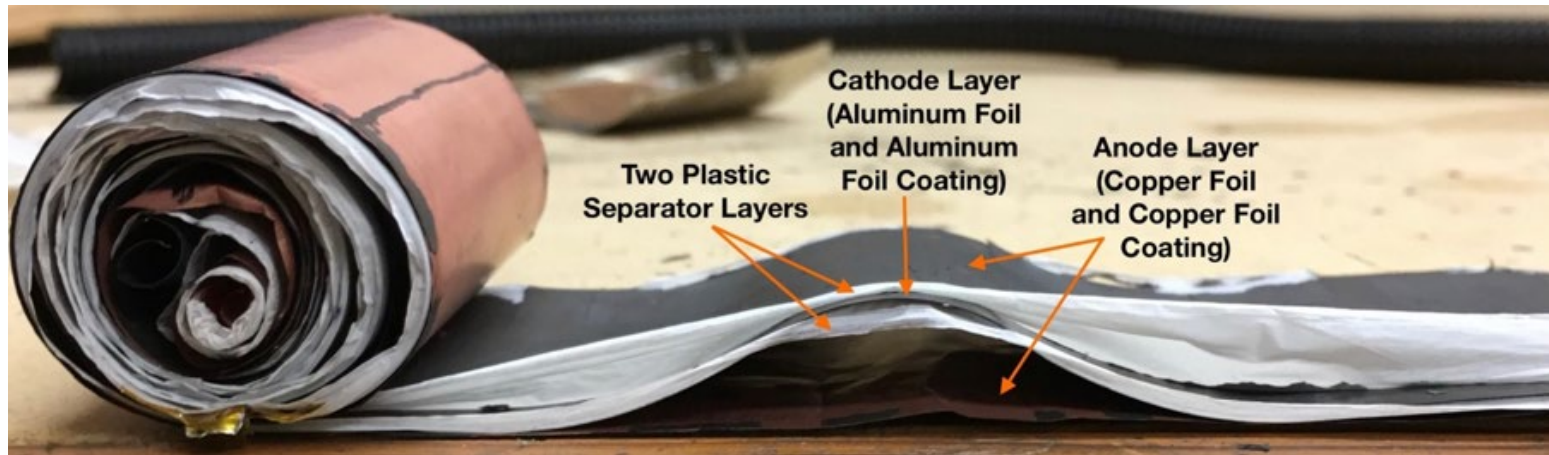
Introduction *Li Battery* Heat Generation

Sources of Heat:

- Cathode intercalation
- Anode intercalation
- electrical resistance within battery (IR drop)
- Collision between Li^+ , electrolyte particles, and electrodes (activation / ohmic, & concentration polarization)



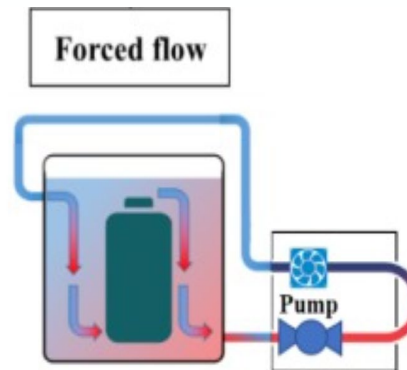
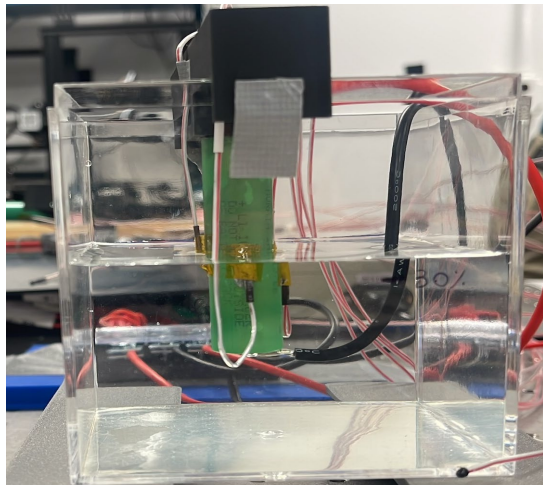
*Fire and Thermal Runaway Propagation Challenges in Electric Vehicles [1]



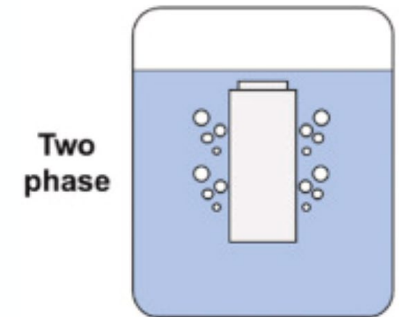
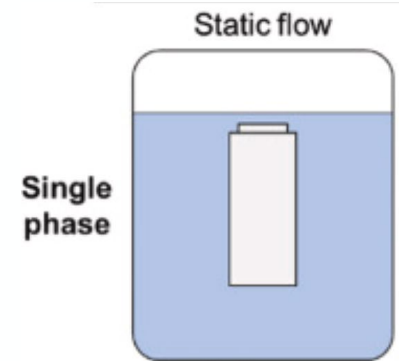
Radial thermal conductivity measurements of lithium-ion battery cells [2]

Introduction **Single Phase Static Direct Immersive Cooling**

- **Single Phase:** Coolant remains as a single form
- **Static:** No external force is used to move the coolant
- **Direct:** Fluid is contacting the battery's body
- **Immersive Cooling:** parts of / whole battery is inside the coolant for heat transfer

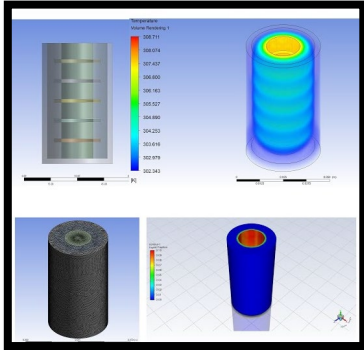


Performance evaluation of a hydrostatic flow immersion cooling system for high-current discharge Li-Ion Batteries [4]



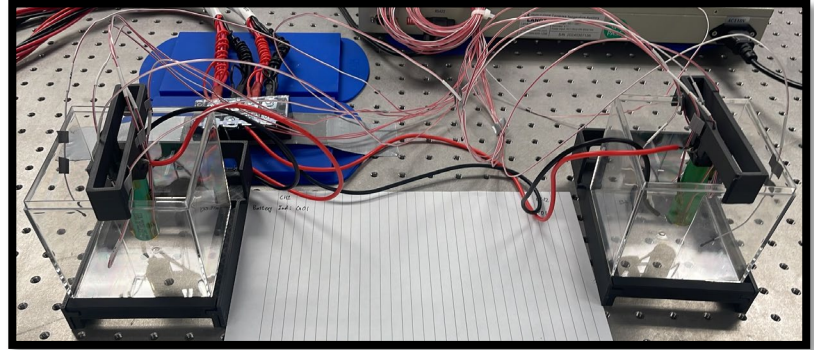
Immersion cooling for lithium-ion batteries – A Review [3]

Objective Milestones & Current Agenda

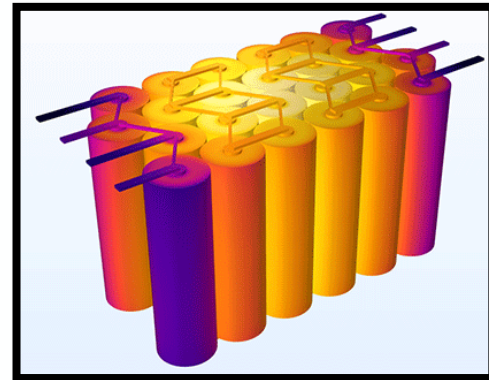


CFD simulation of Single Cell Lithium Ion Battery with fins, PCM & enclosure with heat generation [5]

1. Create Accurate Battery Model



2. Validate and Tune the Model with Experimental Data



How to accurately simulate batteries from detailed electrodes to the pack thermal management scale [6]

3. Use the model to optimize the battery configuration

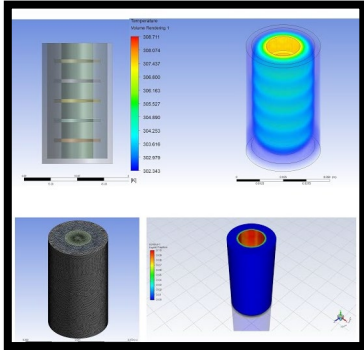


Electric Vehicle Li-ion Battery Pack [7]

4. Validate the result from step 3

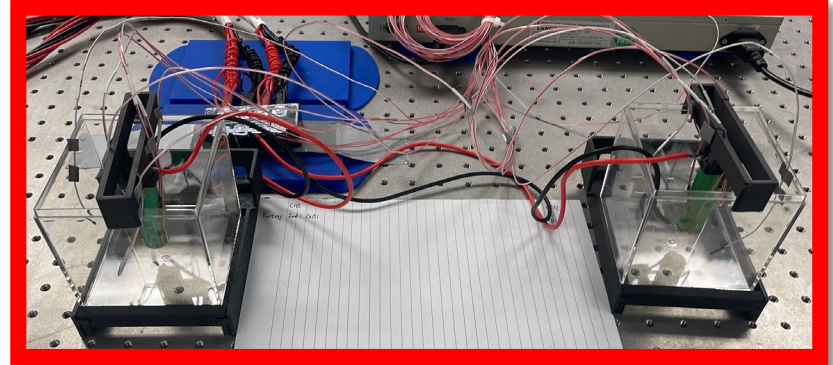


Objective Milestones & Current Agenda



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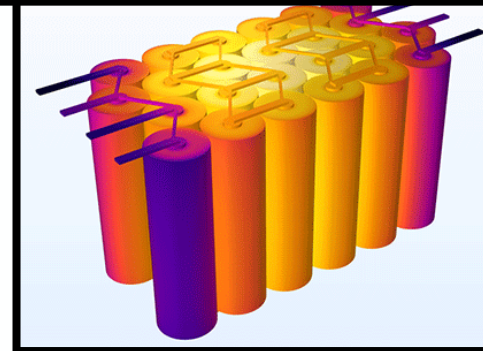
2. Validate and Tune the Model with Experimental Data

Main Objective for this SURF Research



Electric Vehicle Li-ion Battery Pack [7]

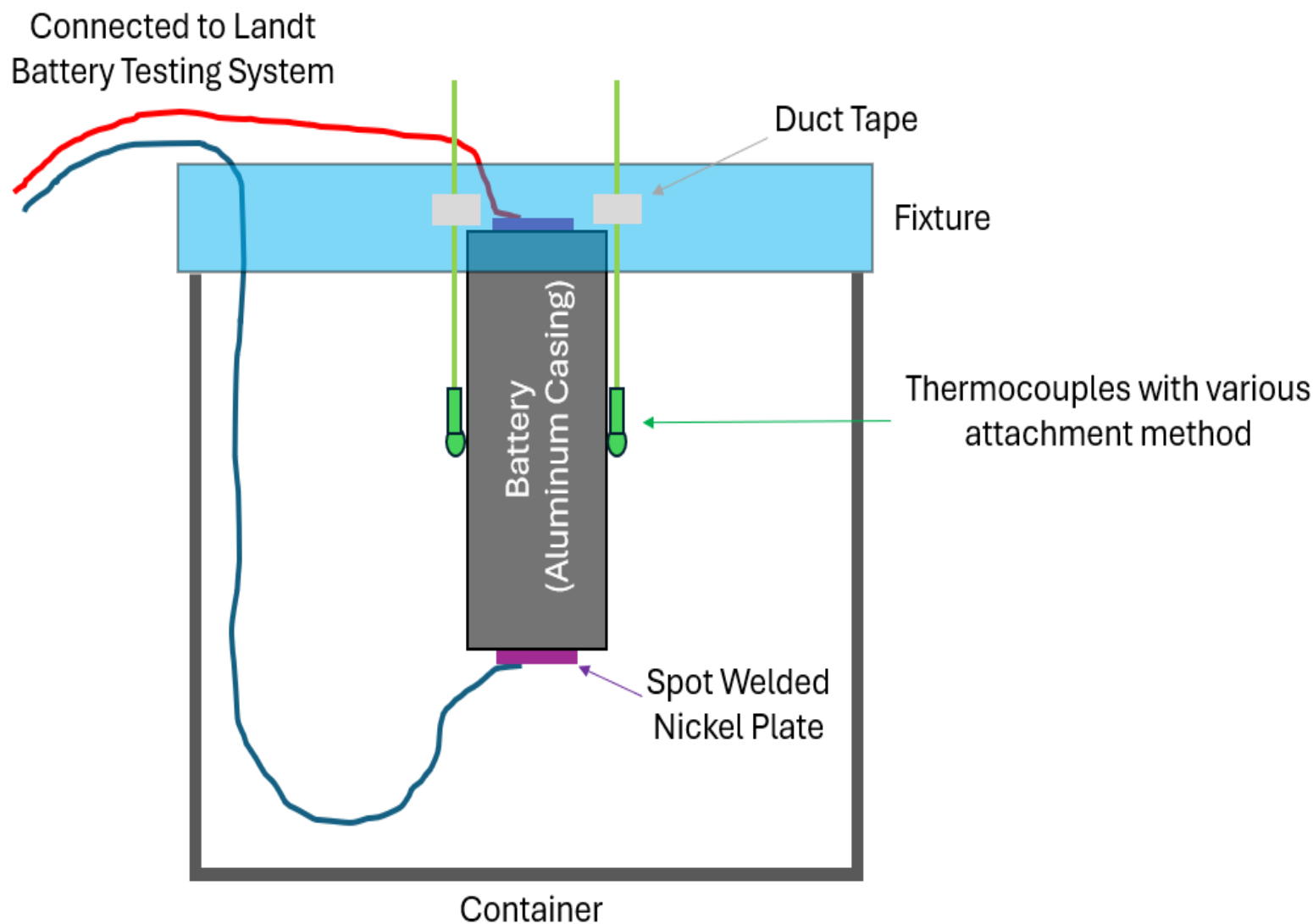
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How to accurately simulate batteries from detailed electrodes to the pack thermal management scale [6]

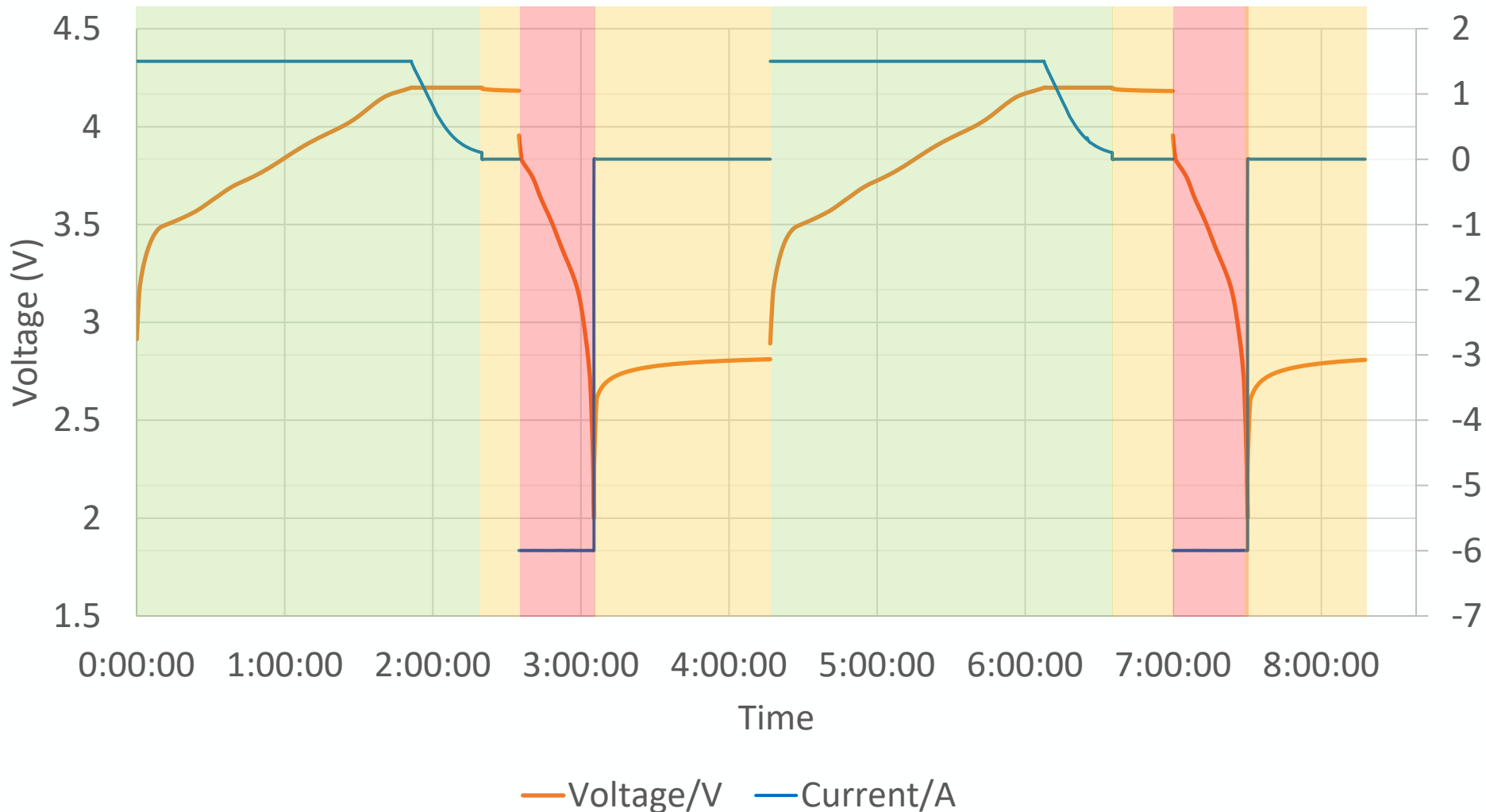
3. Use the model to optimize the battery configuration

Method I. Preliminary Measurement



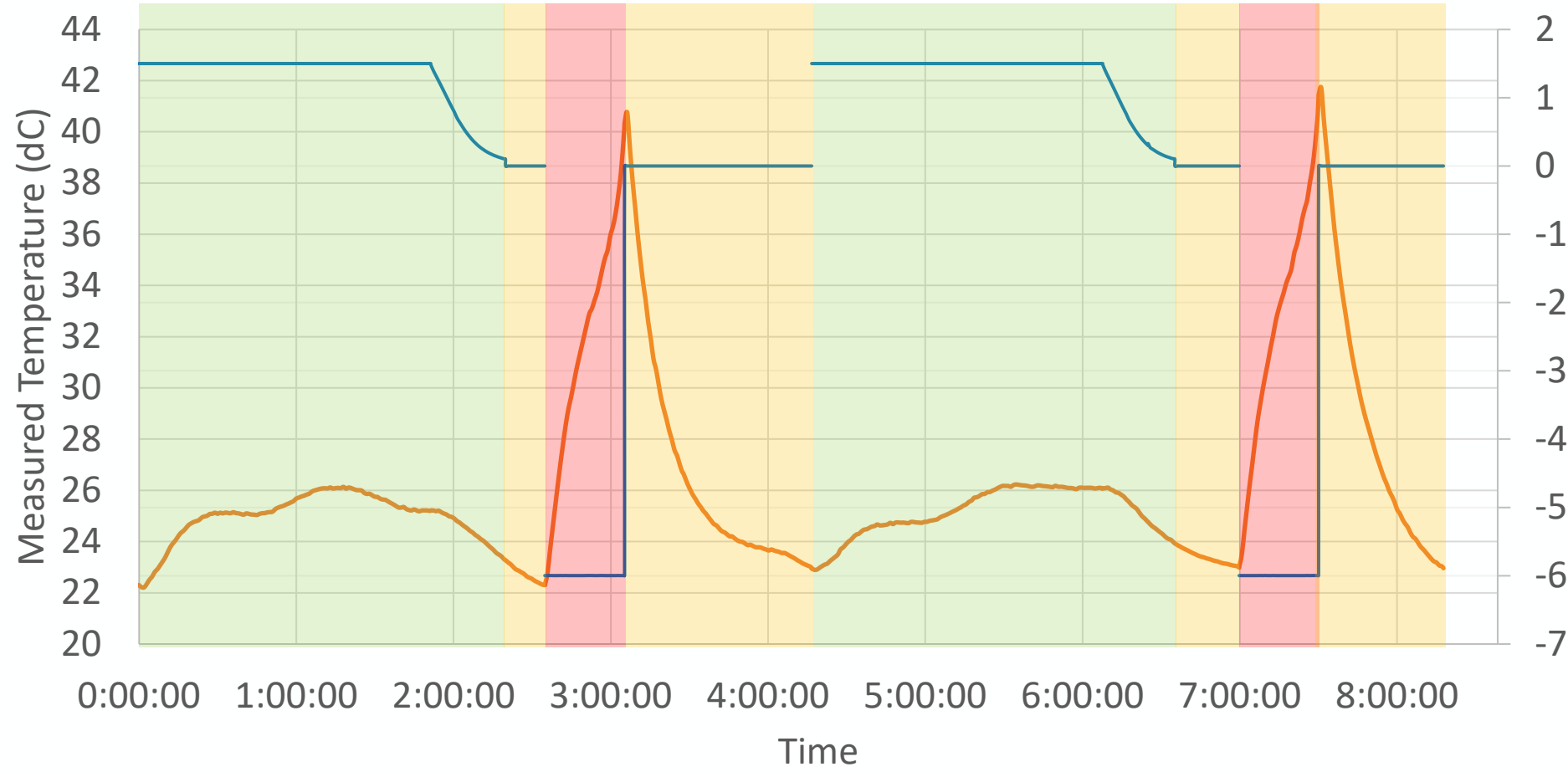
Result I. Preliminary Measurement

Standard Charging Profile; 0.5C (2hr/cycle) Charging and 2C Discharge (0.5hr/cycle)



Result I. Preliminary Measurement

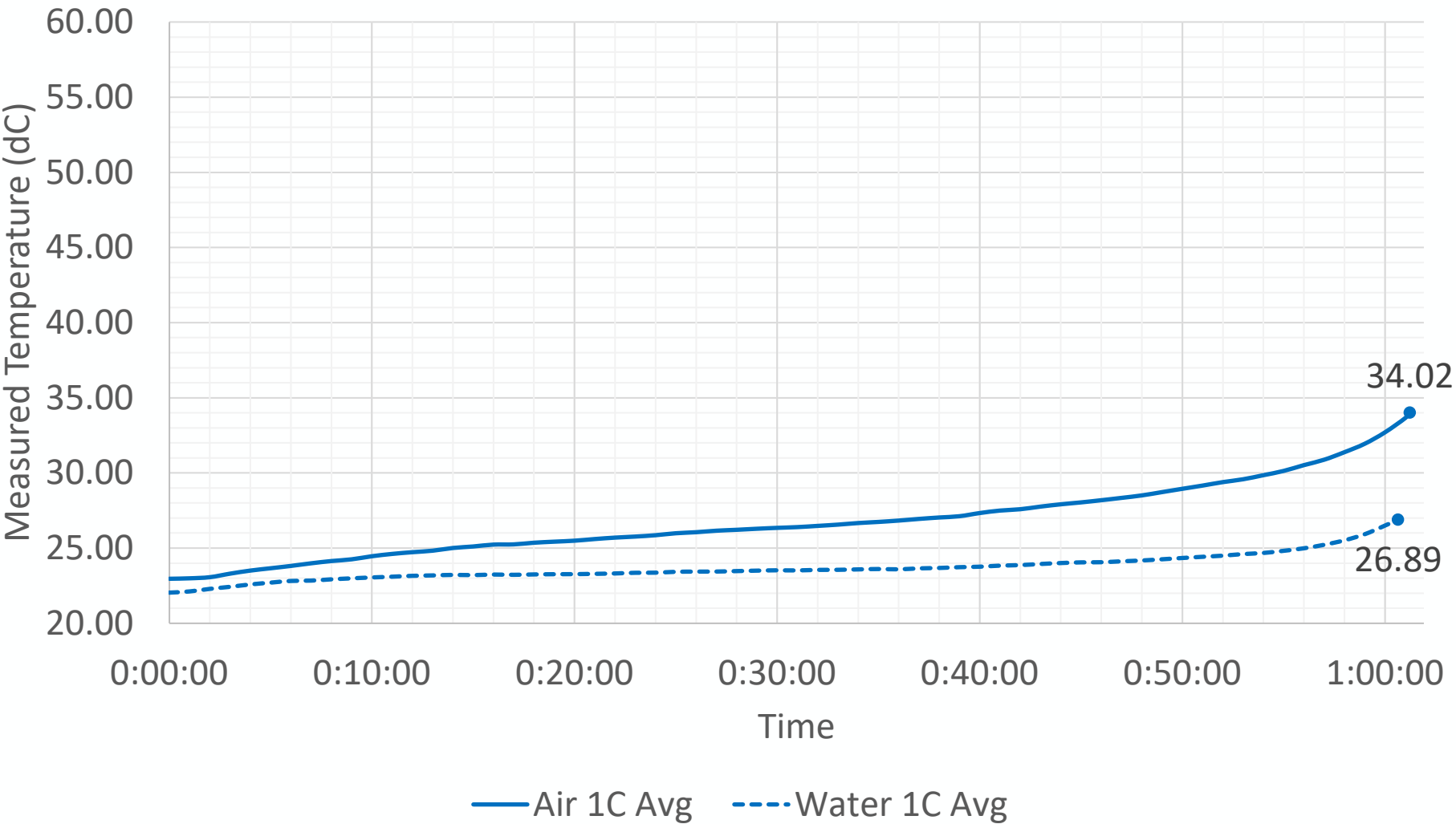
Measured Temperature and Current Evolution Curve Over Time during 0.5C Charging and 2C Discharge



— Avg Temperature/dC — Current/A

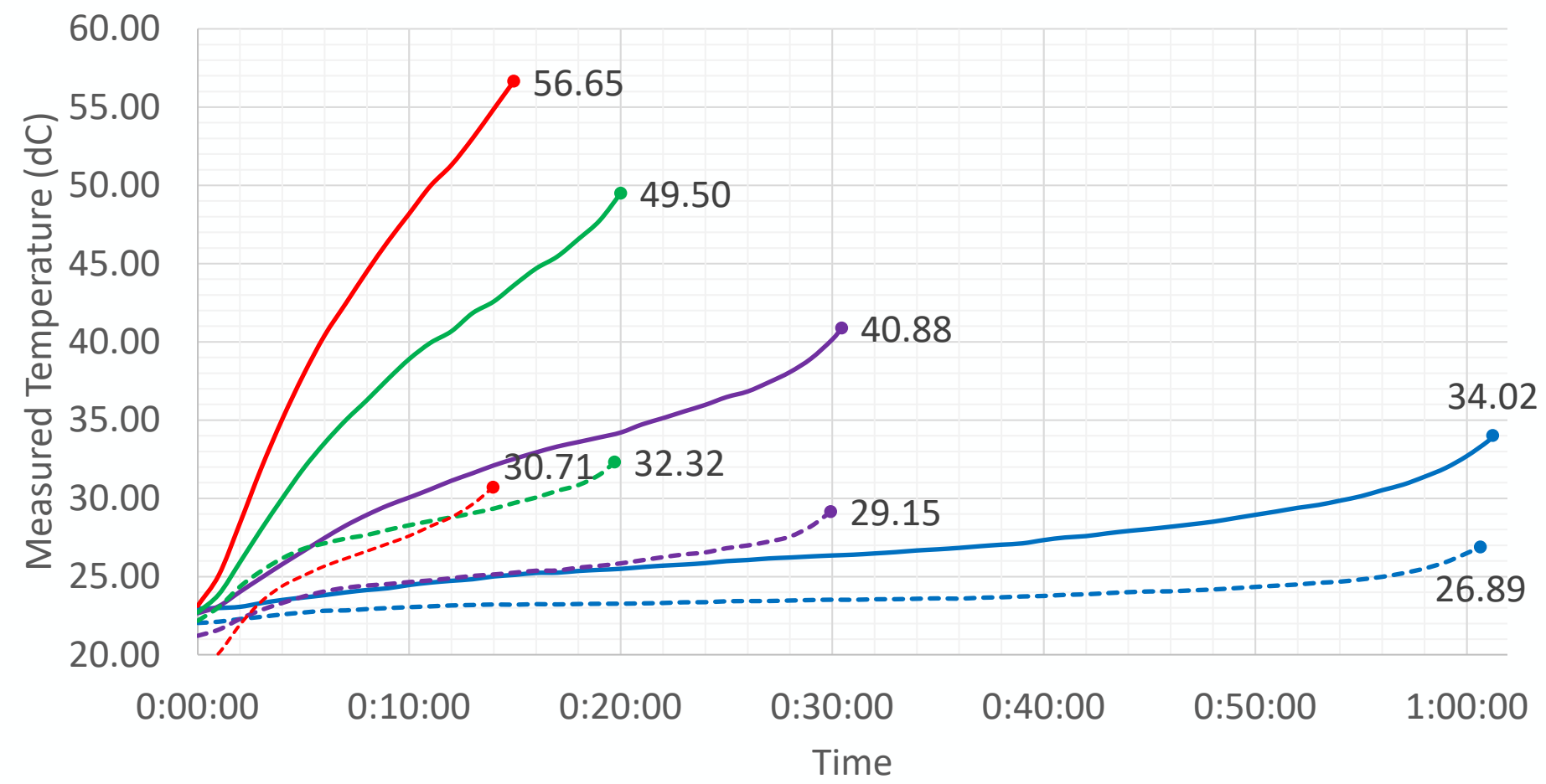
Result I. Preliminary Measurement

Discharge Evolution Under Air and 30% Water for Sony Battery



Result I. Preliminary Measurement

Discharge Evolution Under Air and 30% Water for Sony Battery

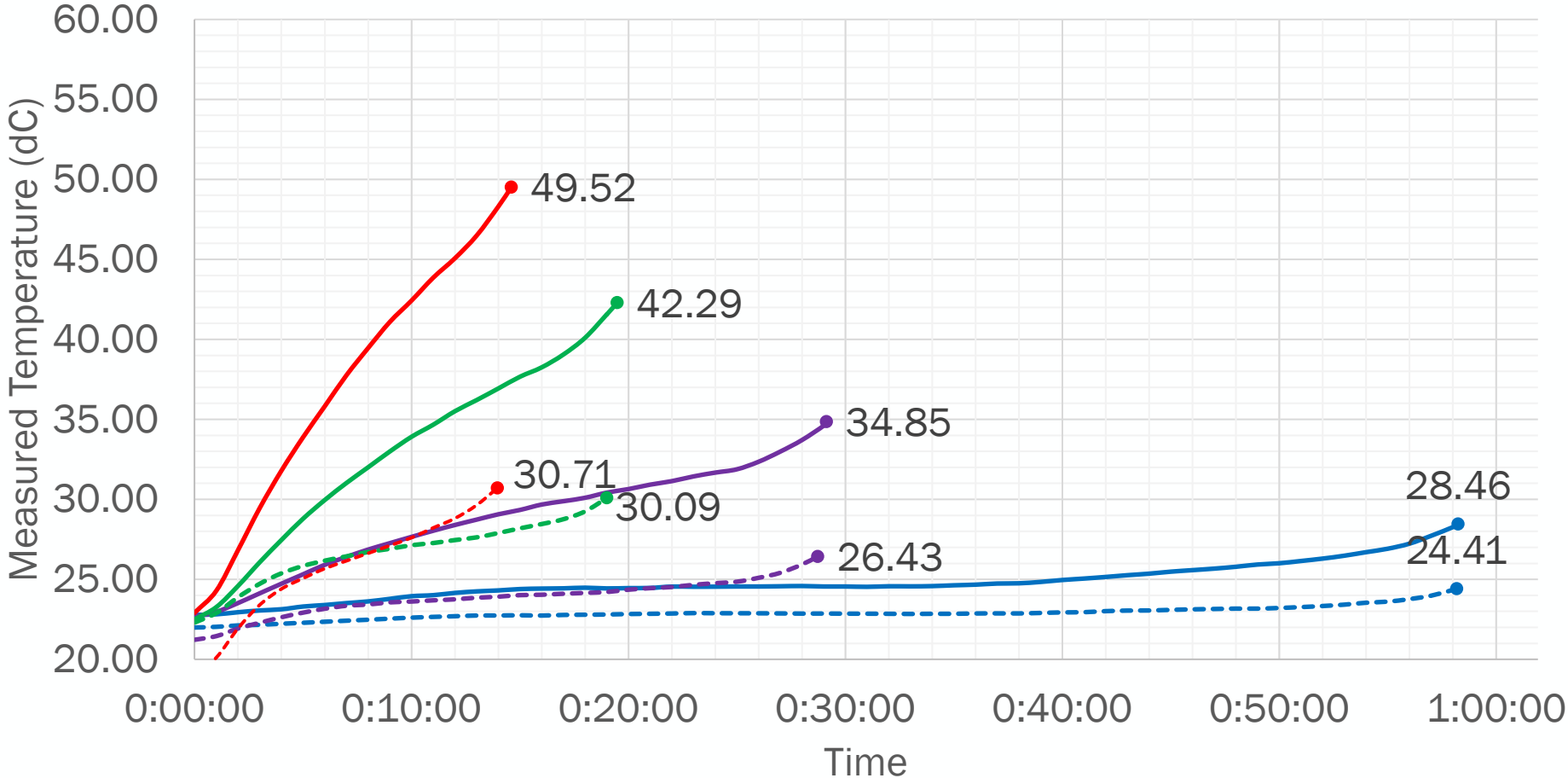


- Air 1C Avg
- Water 1C Avg
- Air 2C Avg
- Water 2C Avg
- Air 3C Avg
- Water 3C Avg
- Air 4C Avg
- Water 4C Avg



Result I. Preliminary Measurement

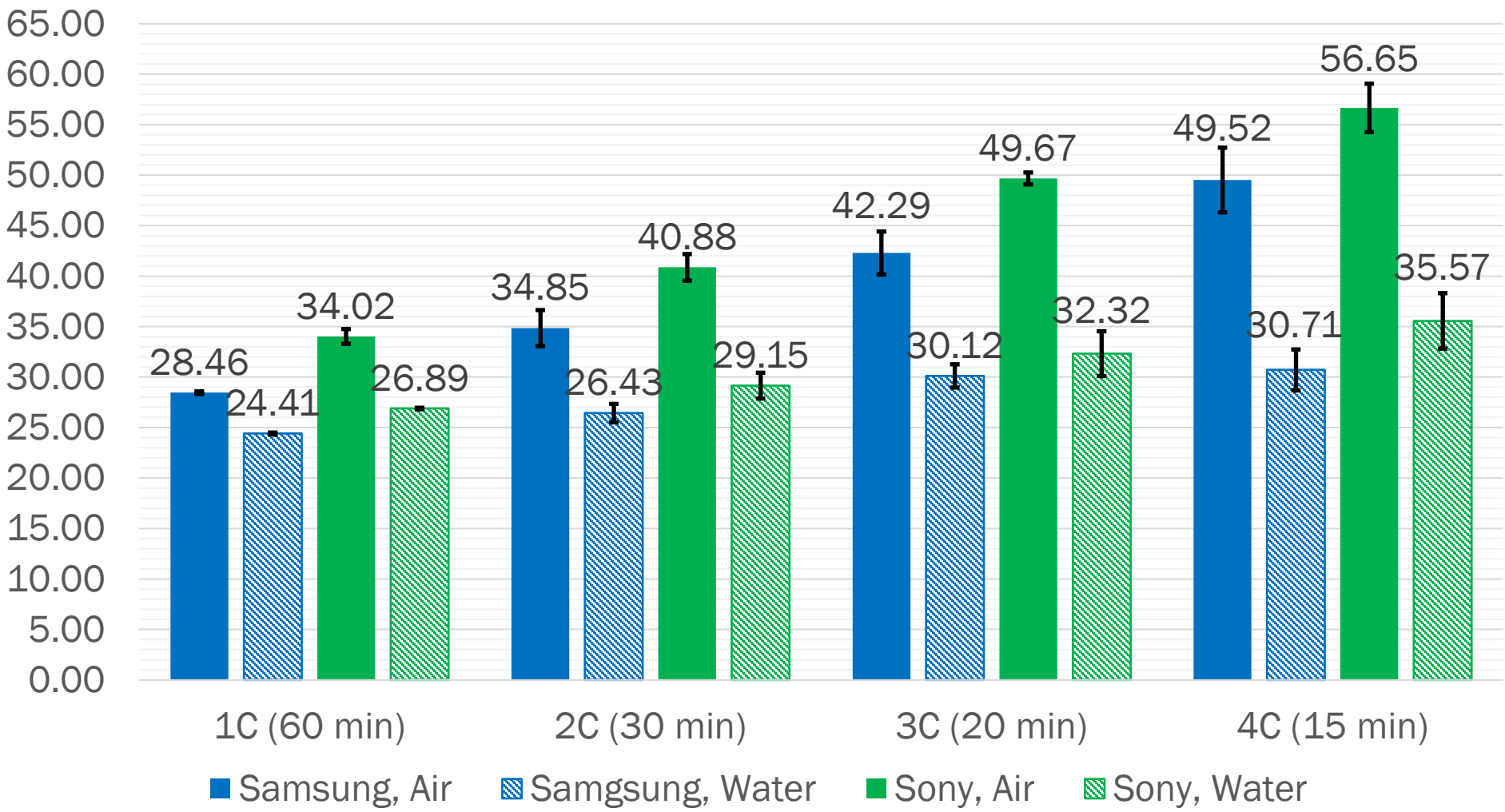
Discharge Evolution Under Air and 30% Water for Samsung Battery



Air 1C Avg Water 1C Avg Air 2C Avg Water 2C Avg
Air 3C Avg Water 3C Avg Air 4C Avg Water 4C Avg

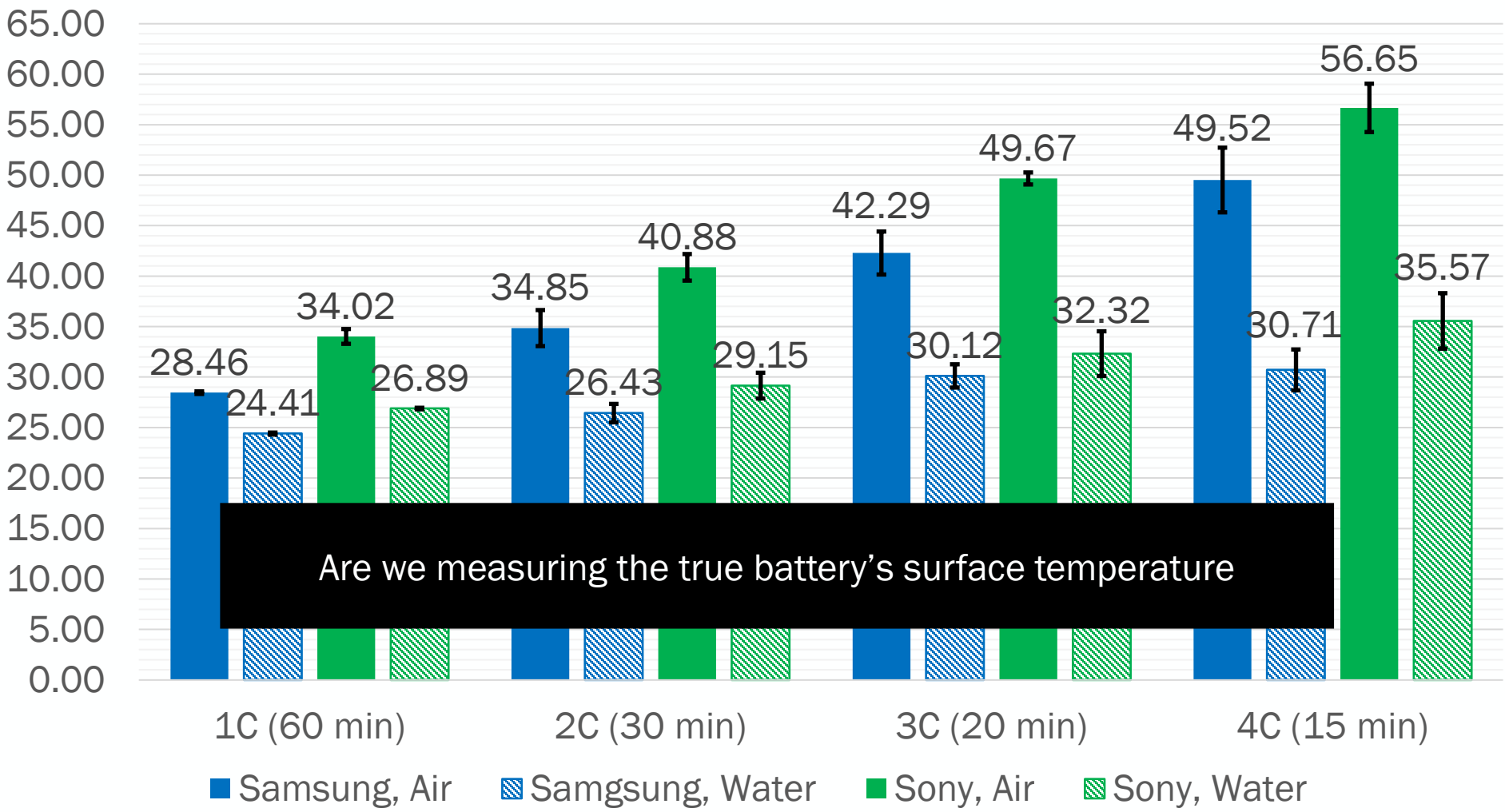
Result I. Preliminary Measurement

Average Maximum Temperature for Battery Discharge Under different Parameters



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Average Maximum Temperature for Battery Discharge Under different Parameters



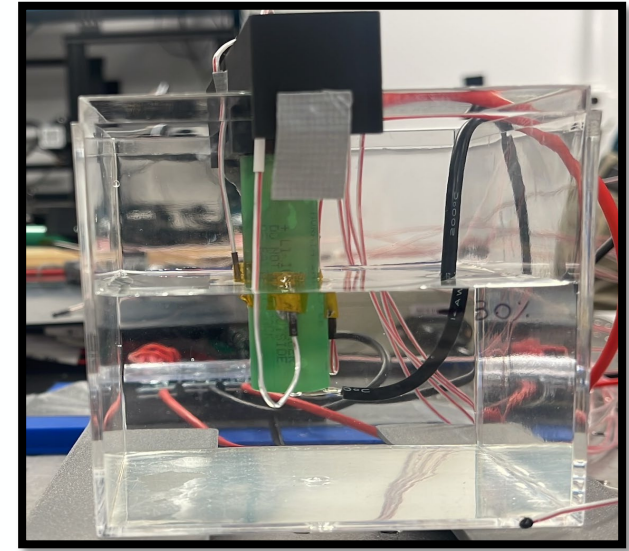
Objective II. Seeking Ideal Thermocouple Attachment Me

- New Objective:** Identify the most accurate and precise measurement method

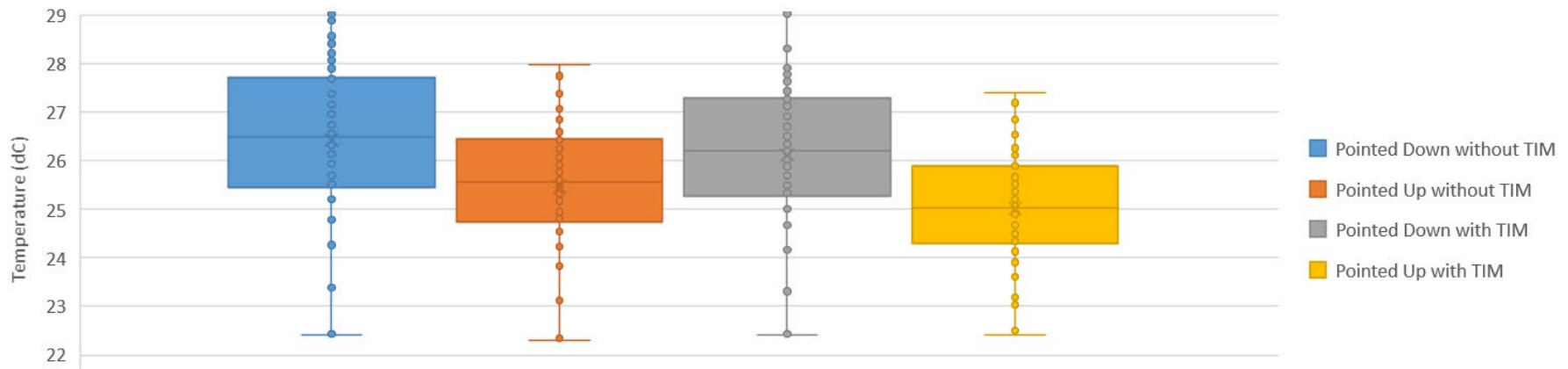
Pointed Down
Without TIM



Pointed Up
With TIM



Box Chart of Temperature Measured During CCD



Method II. Validating Assumptions

Is the battery temp uniform on the same altitude?

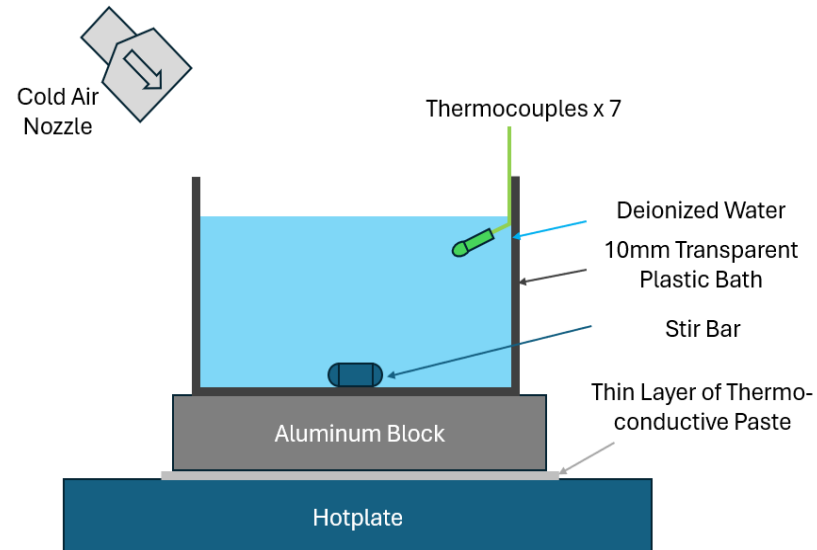
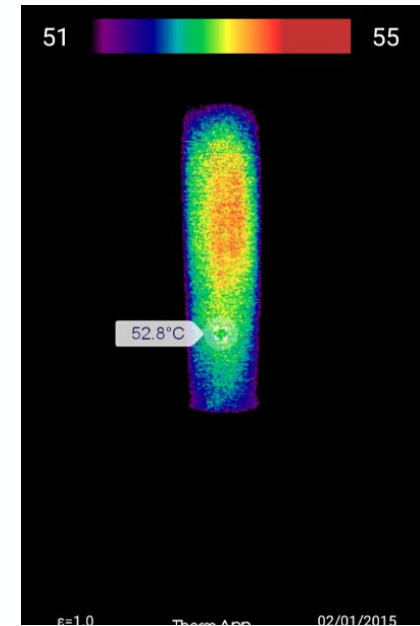
- IR Camera is used to validate the homogeneous horizontal heat generation

Are thermocouples calibrated?

- Water bath is used to validate the accuracy and precisions of the thermocouple

Are the thermal hotplate generating uniform temp?

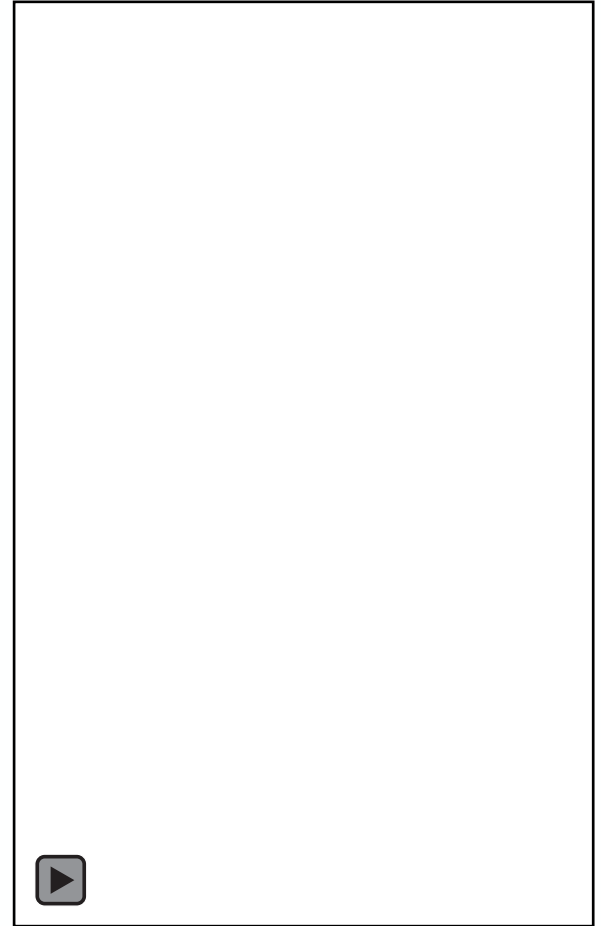
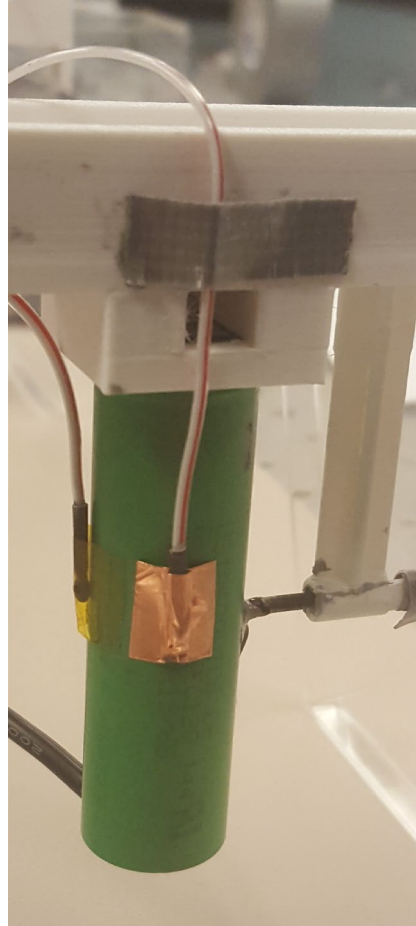
- IR Camera is used to validate homogeneous temperature across the top surface of the aluminum block



Result II. Is Battery Providing Uniform Temperature

Verified:

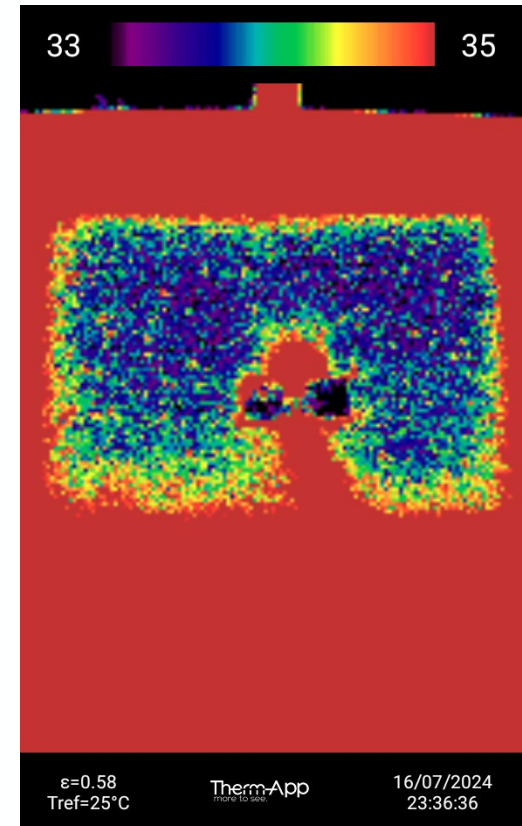
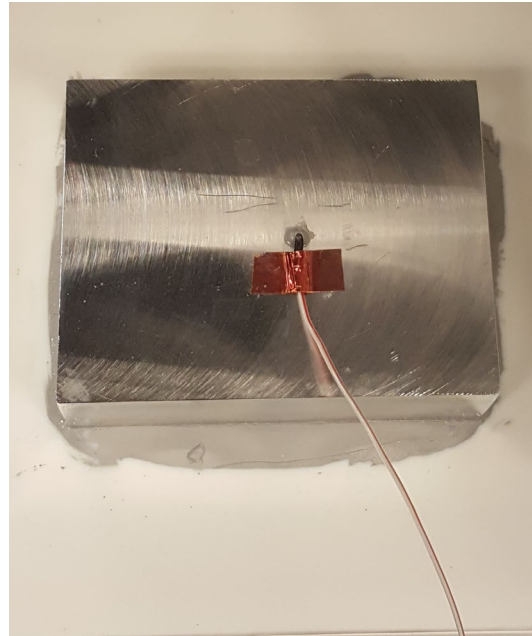
- Homogeneous horizontal heat generation of the battery



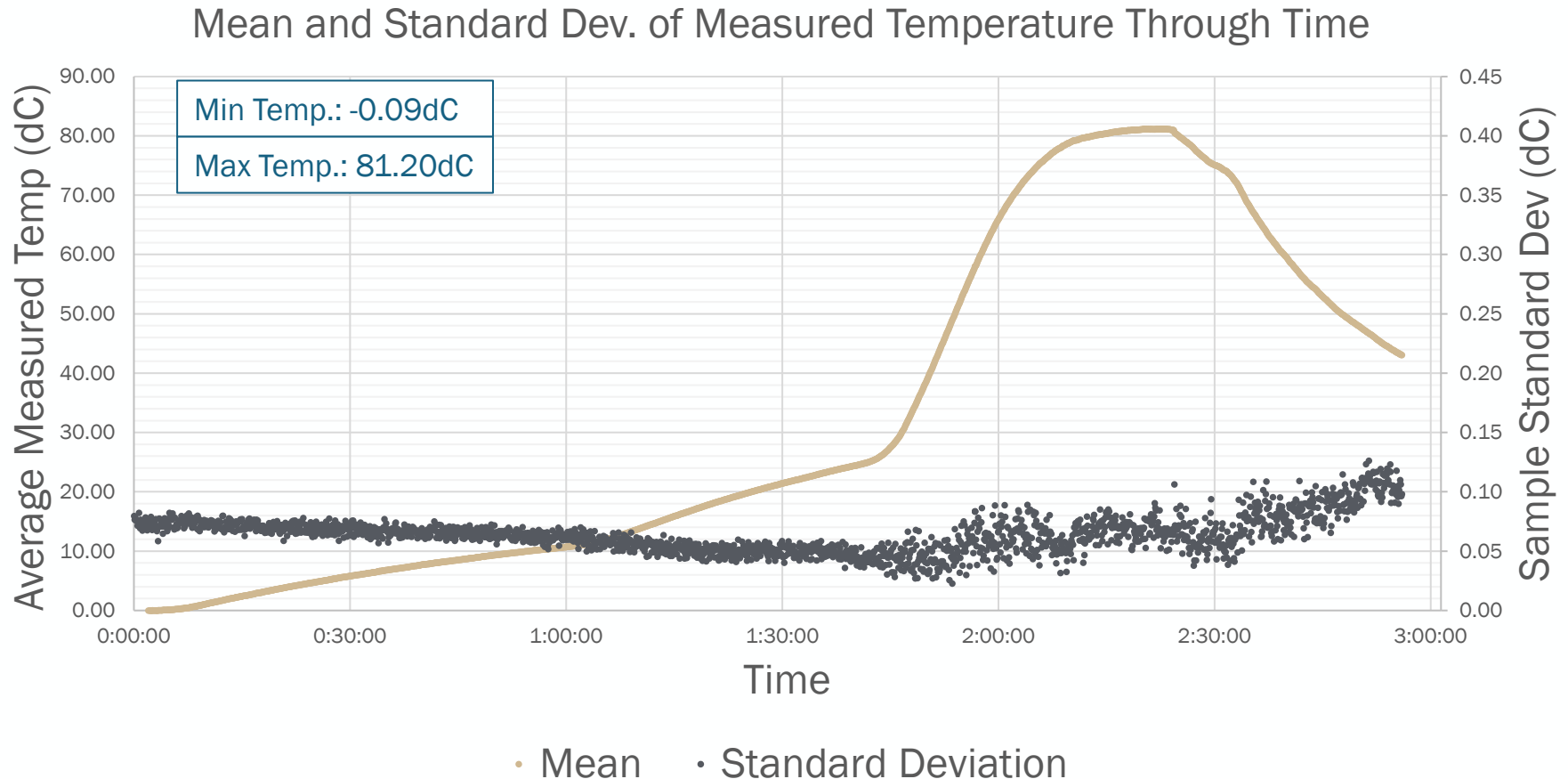
Result II. Is Test Bed Providing Uniform Temperature

Verified:

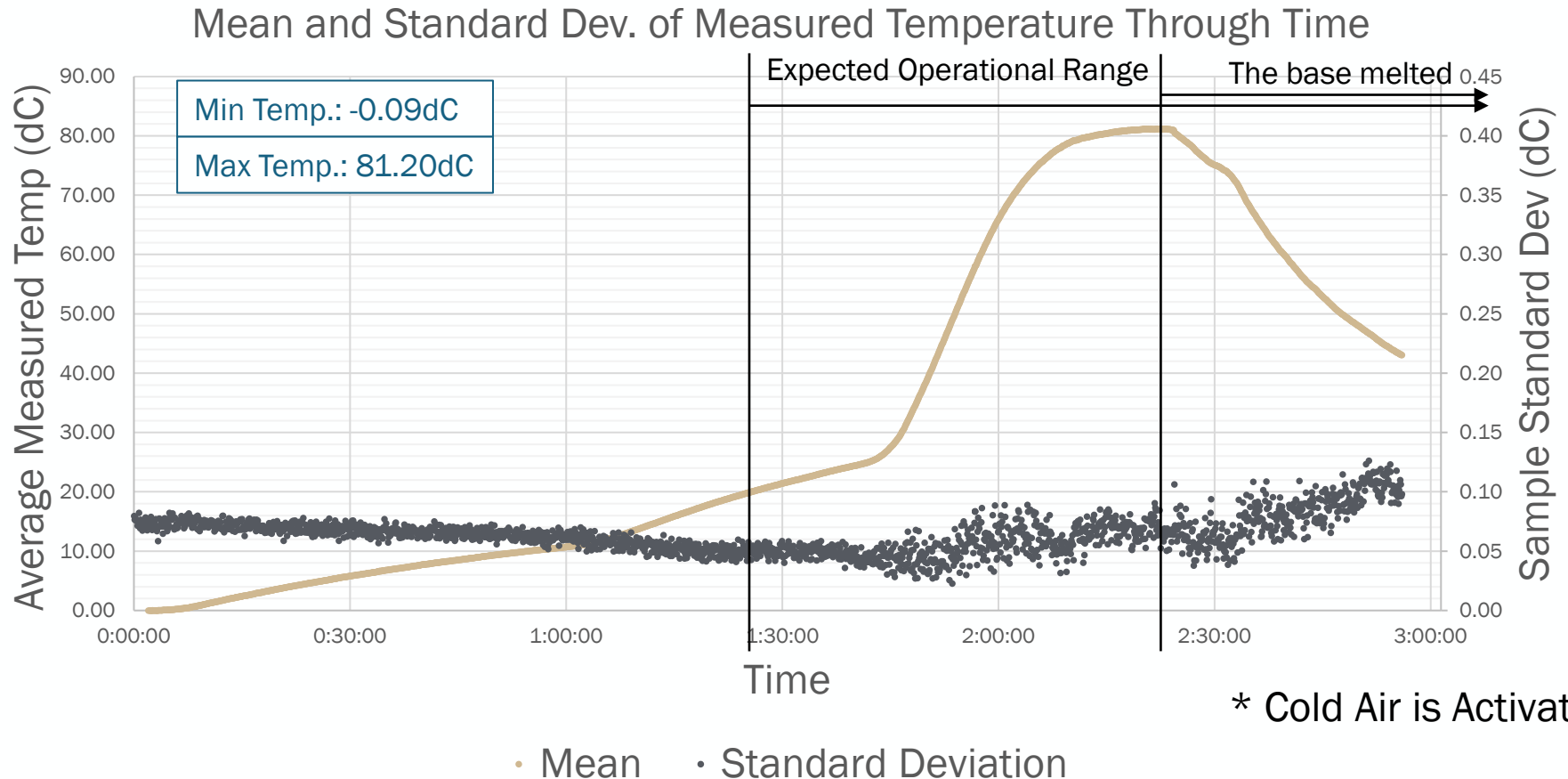
- Homogeneous horizontal heat generation of the battery
- Homogeneous temperature across the aluminum block surface



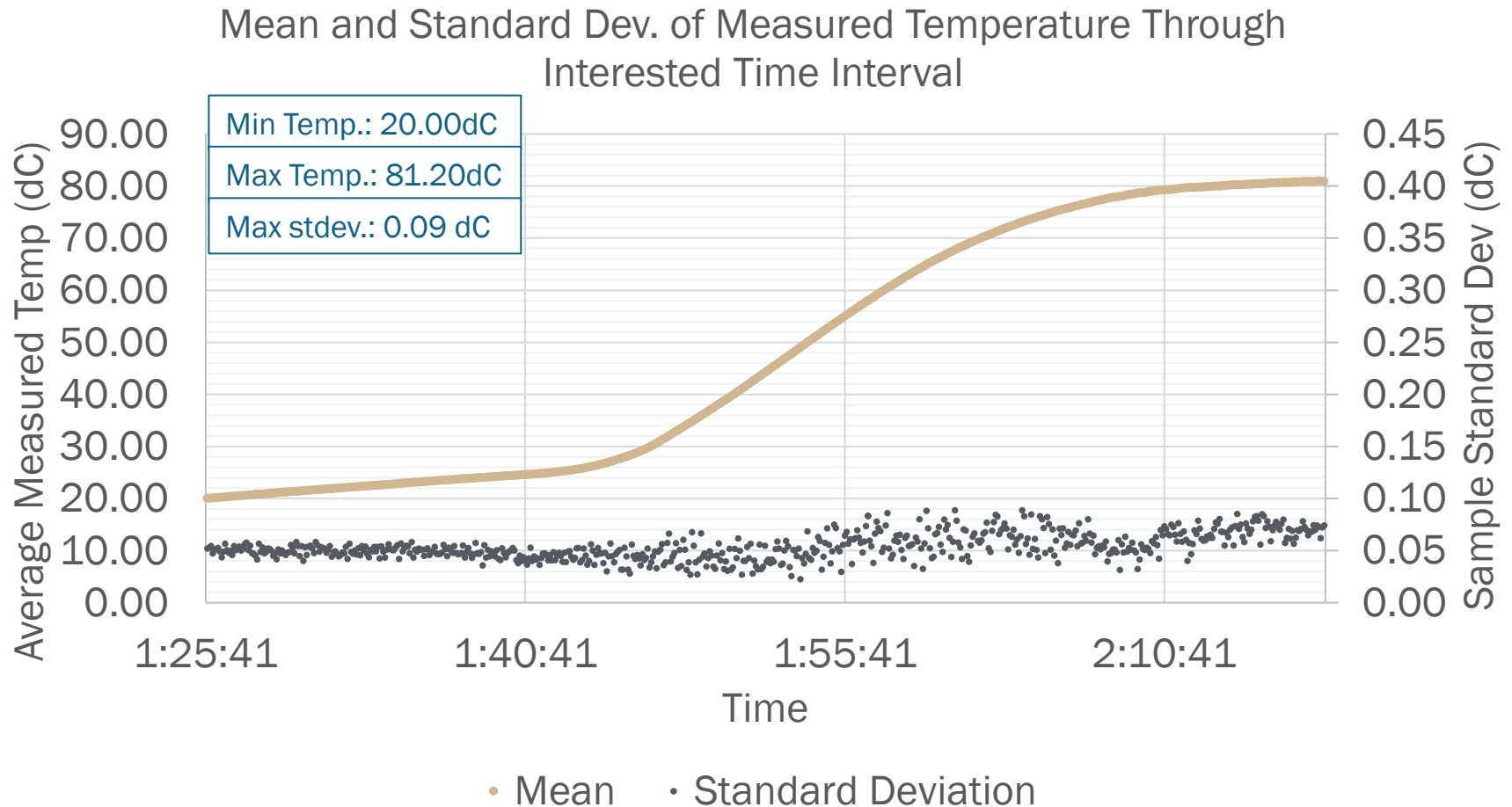
Result II. Are Thermocouples Calibrated



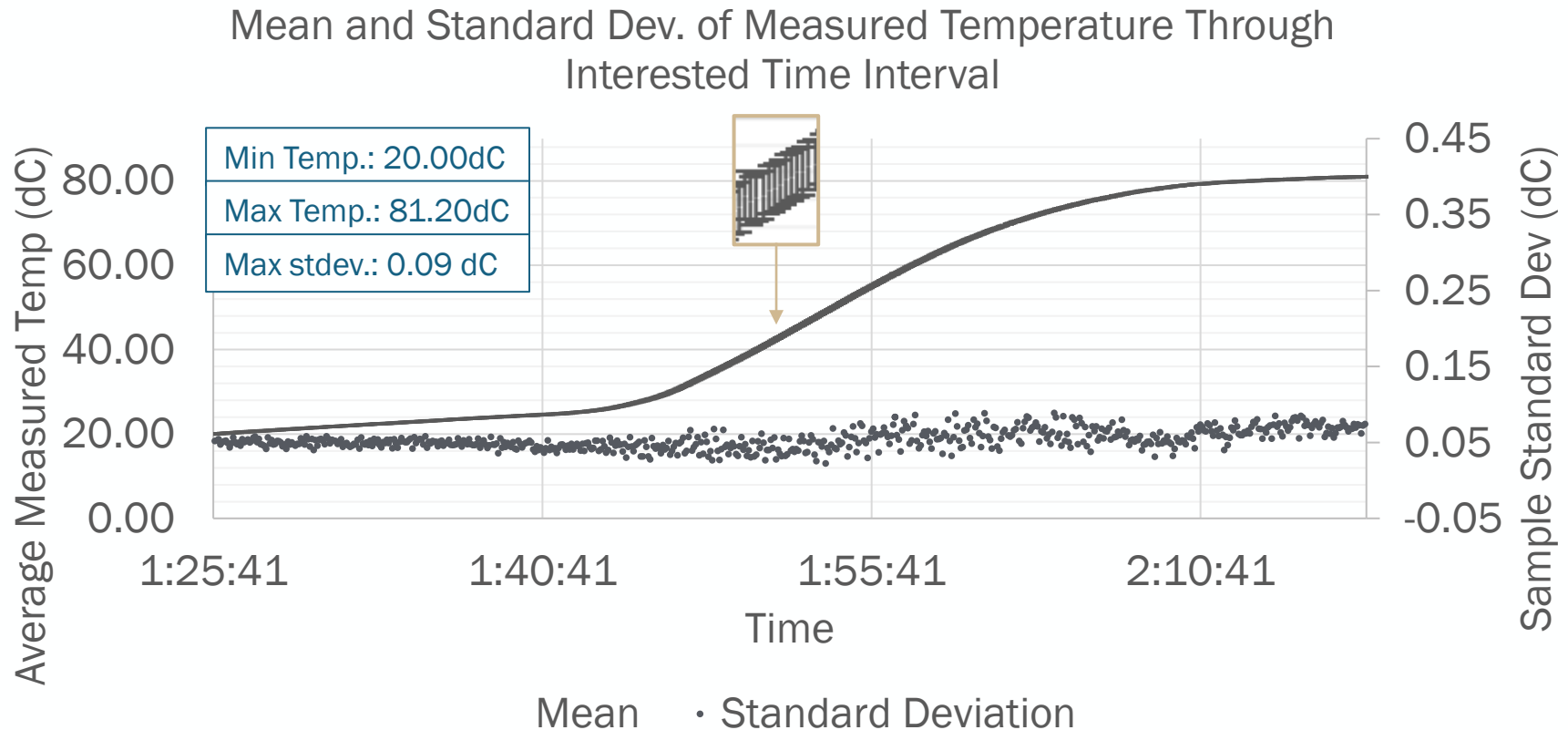
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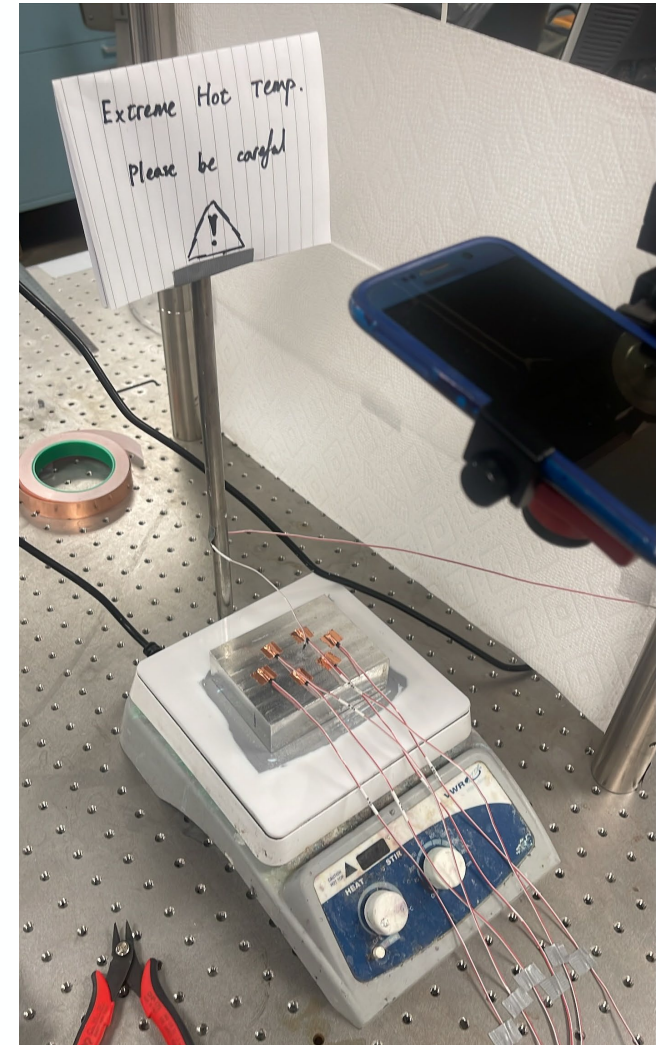
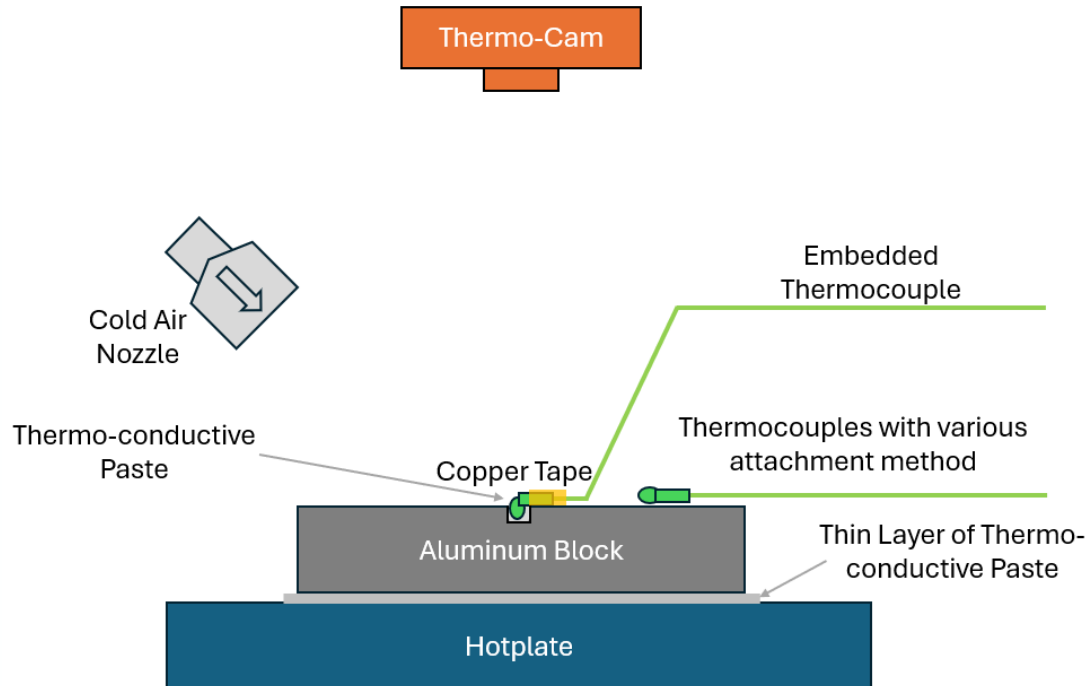


Result II. Are Thermocouples Calibrated



Assuming normal distribution, we have 95% confidence that the actual temperature is within ± 0.176 dC of the measured temperature

Method III. Finding Ideal Thermocouple attachment Meth



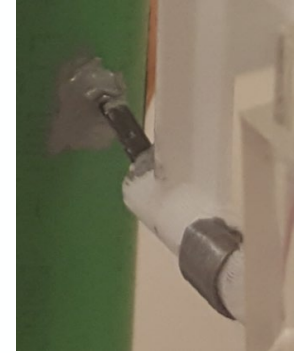
Method III. Finding Ideal Thermocouple attachment Meth



Kapton Tape without TIM



Kapton Tape with TIM



Perpendicular with TIM



Copper Tape without TIM



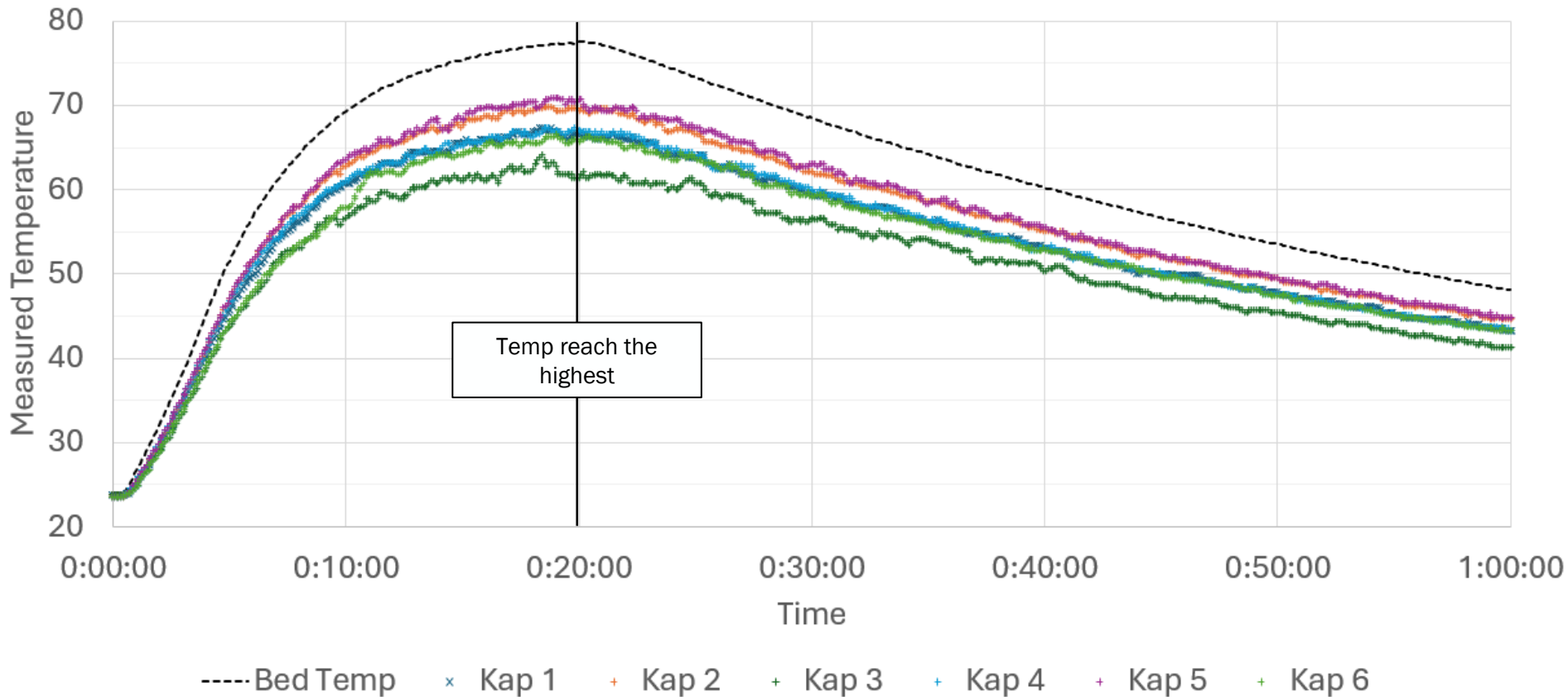
Copper Tape with TIM



Embedded Method &
Embedded with TIM

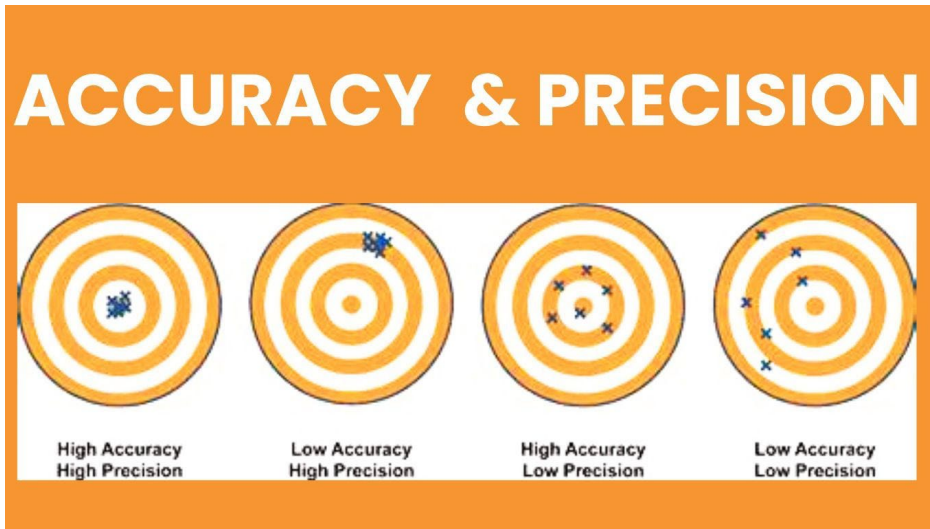
Method III. Finding Ideal Thermocouple attachment Meth

Temperature Measured Using Kapton Tape vs Time on the Horizontal Test Bed

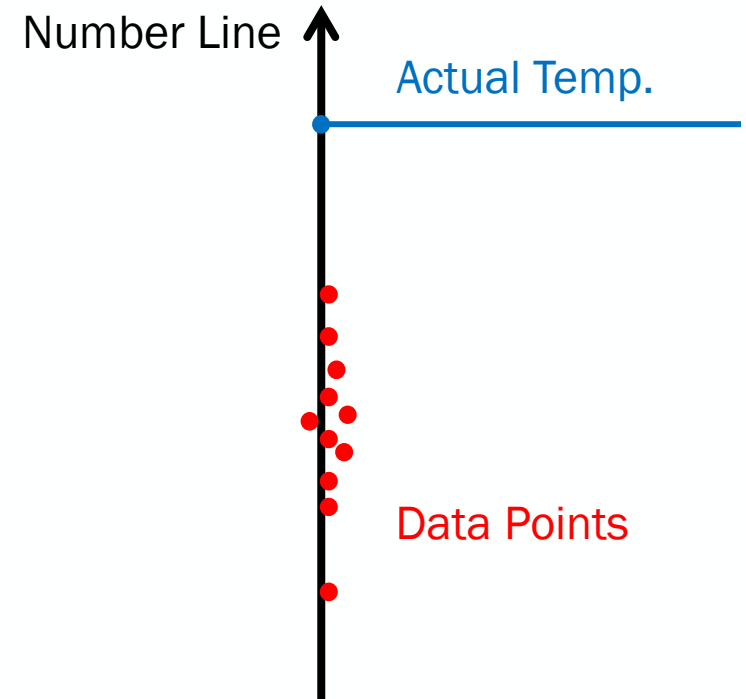


Method III. Finding Ideal Thermocouple attachment Meth

* Assume Normal Distribution

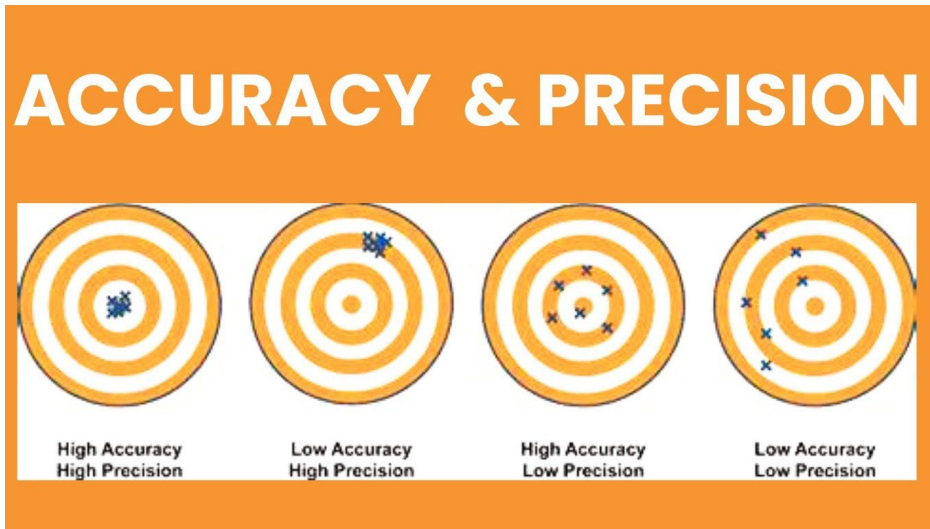


* What Are the Differences between Accuracy and Precision? [8]

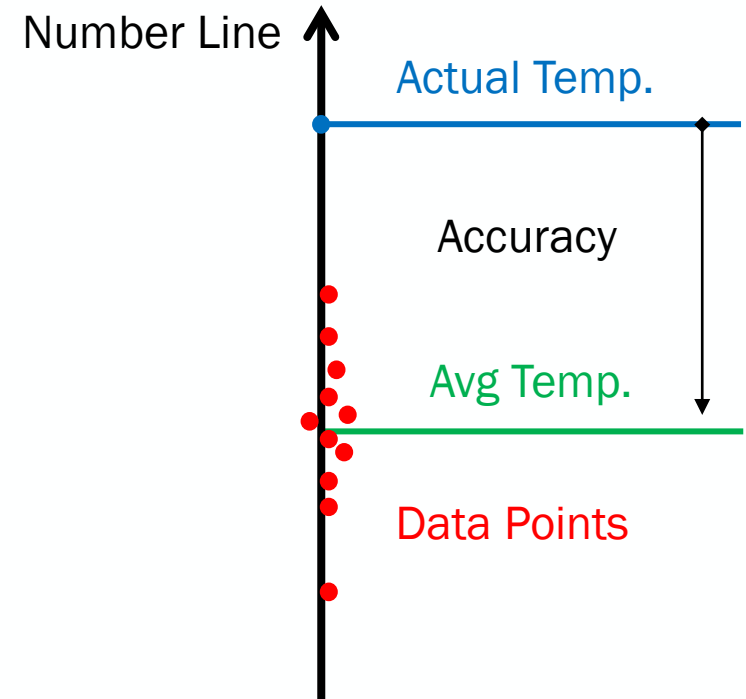


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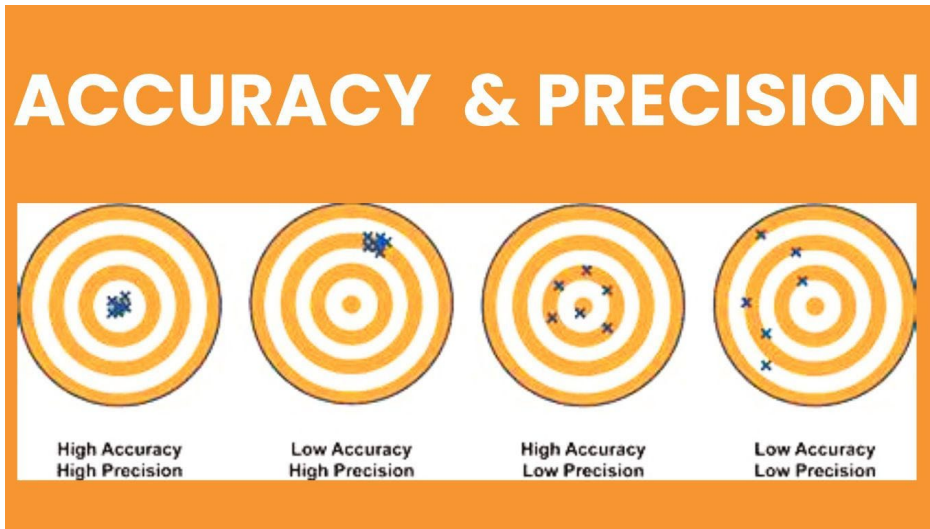


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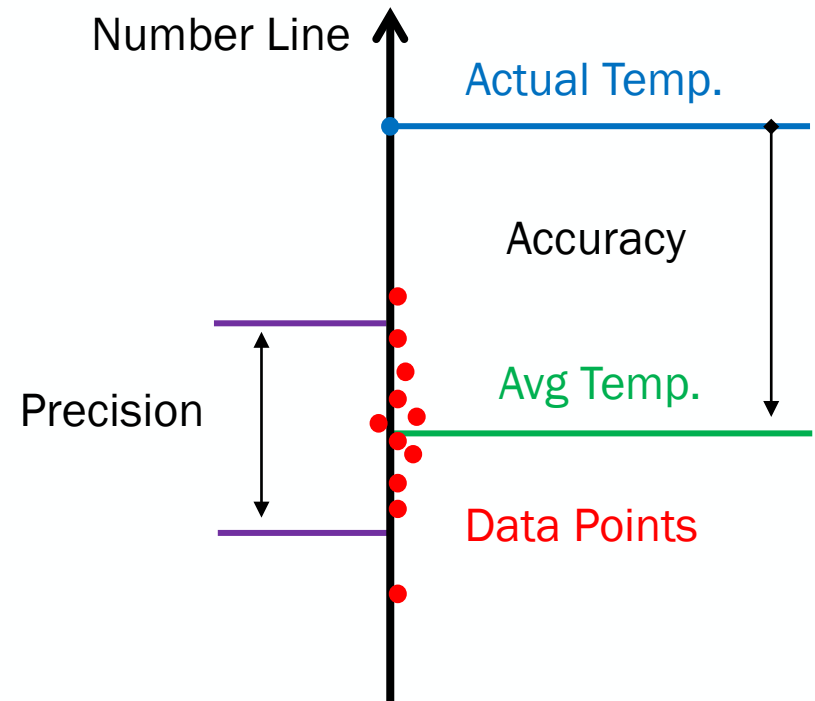


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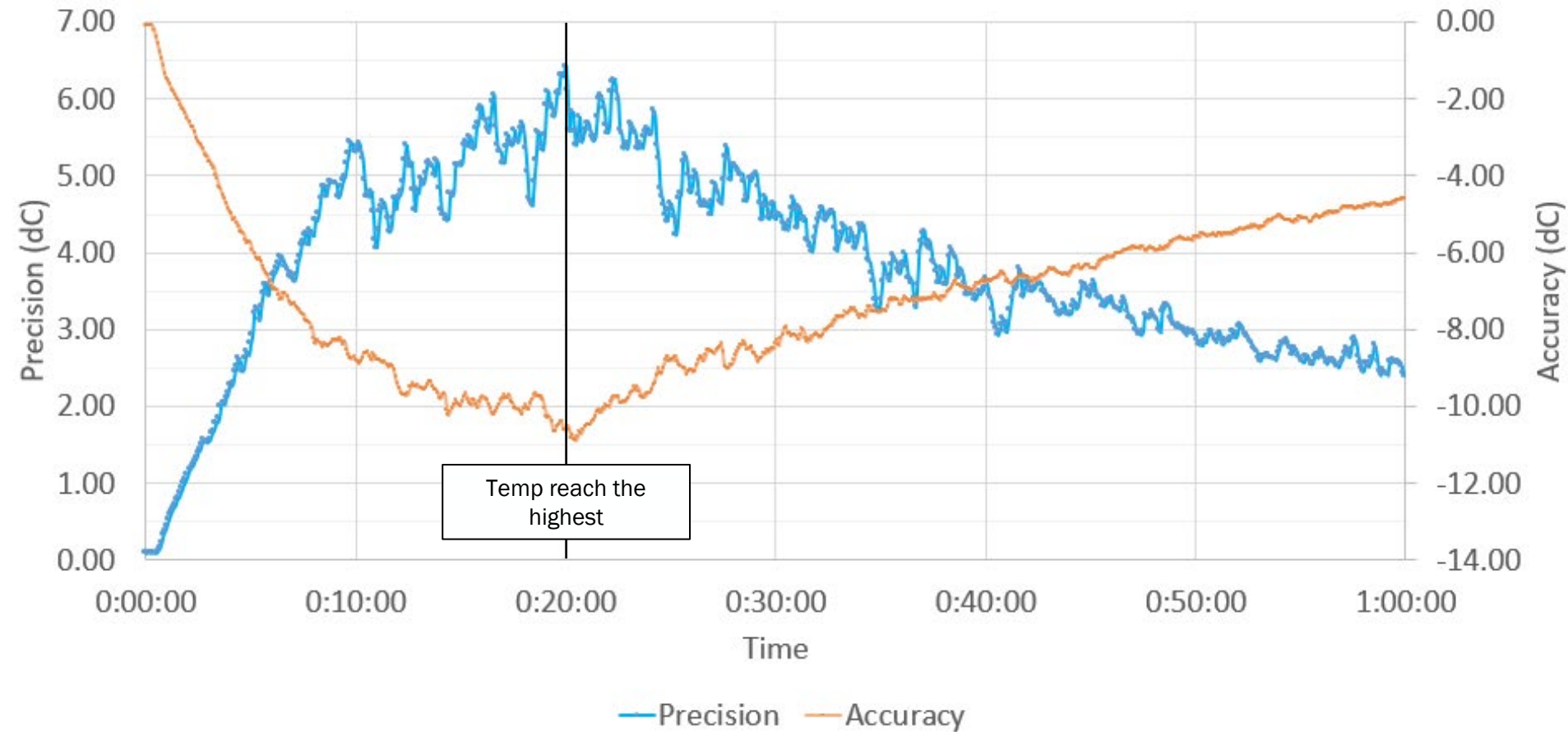


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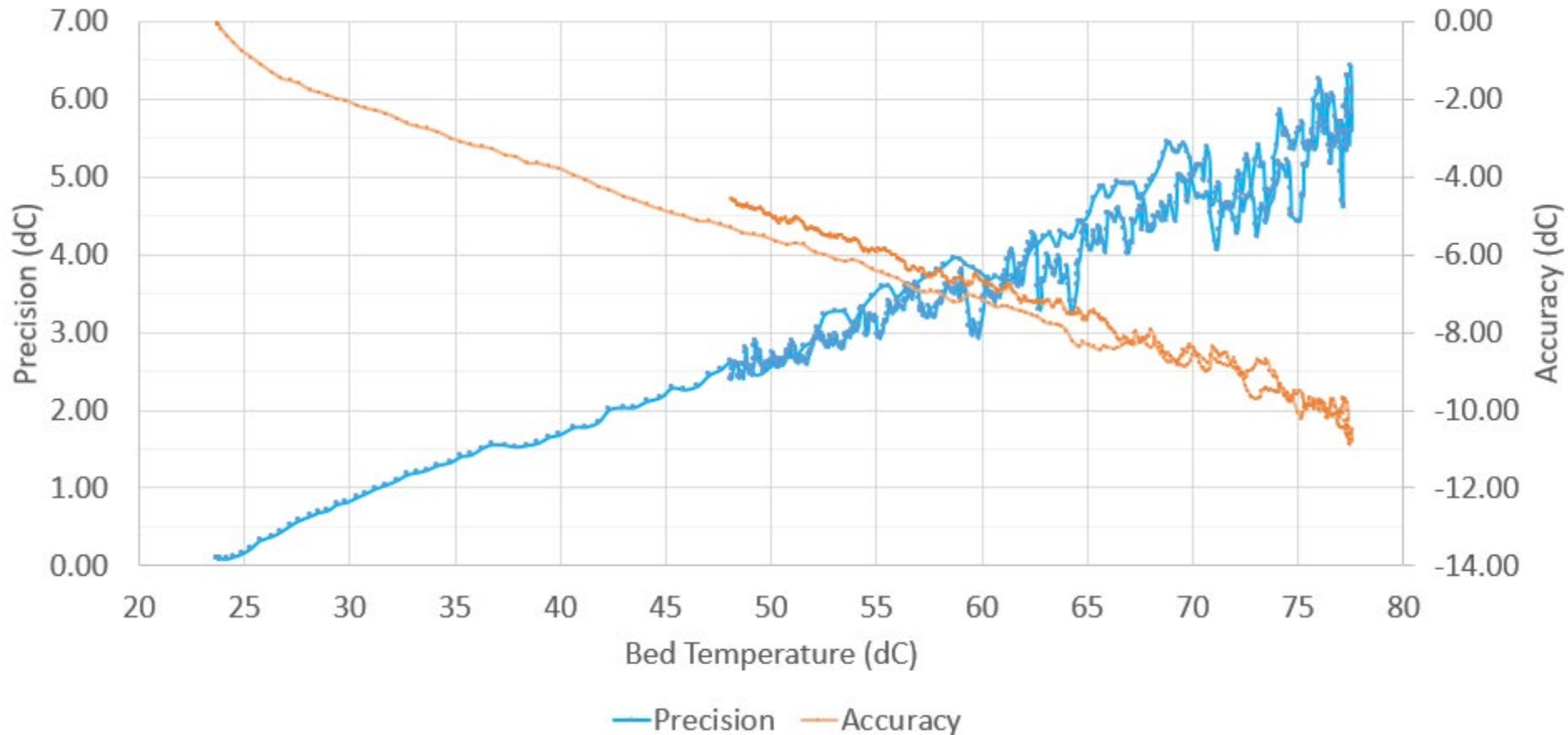
Result III. Finding Ideal Thermocouple attachment Method

Accuracy and Precision of the Measurement vs Time when using Kapton Tape vs Time on the Horizontal Test Bed



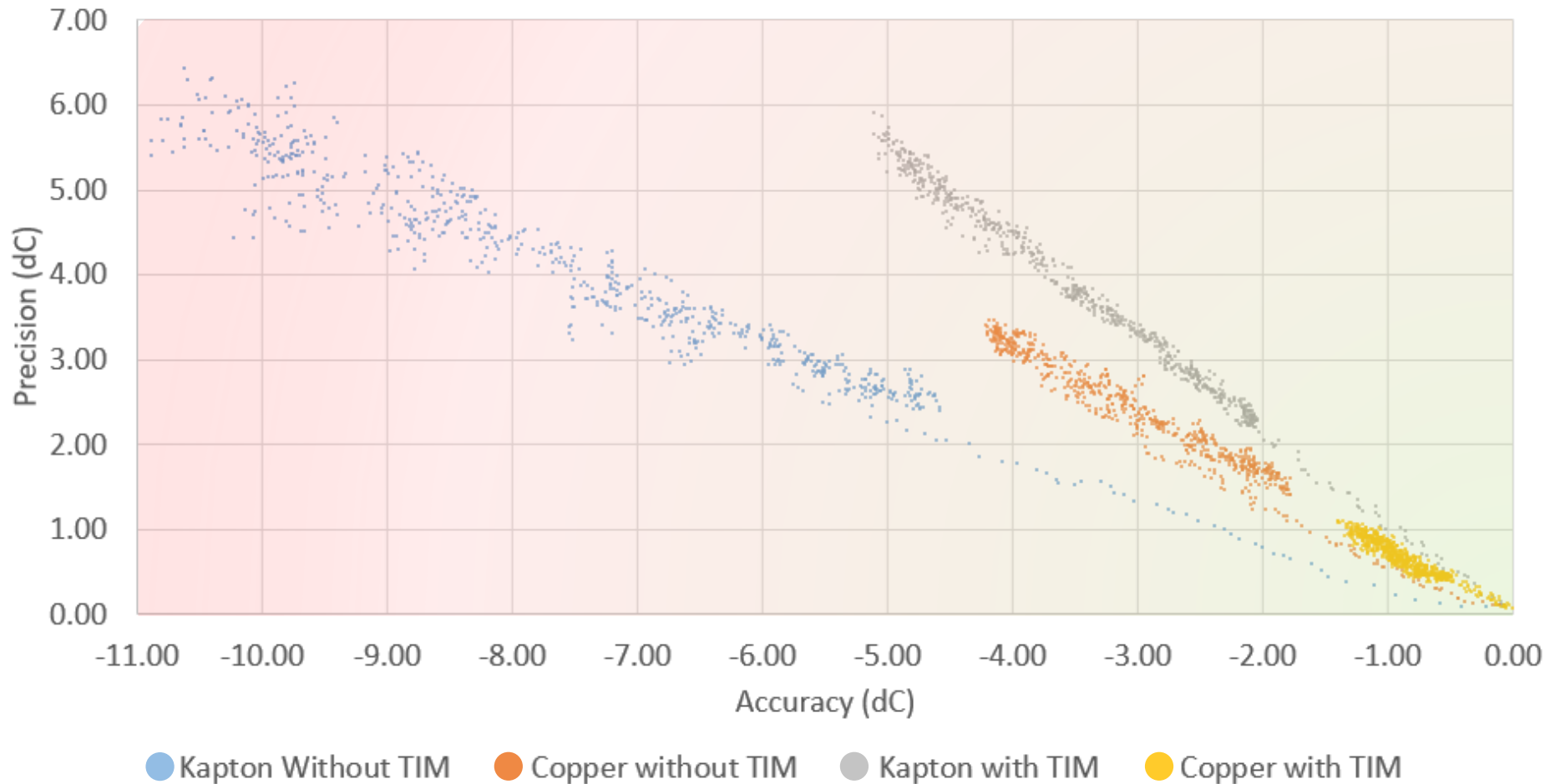
Result III. Finding Ideal Thermocouple attachment Method

Accuracy and Precision of the Measurement vs Bed Temperature when using Kapton Tape vs Time on the Horizontal Test Bed

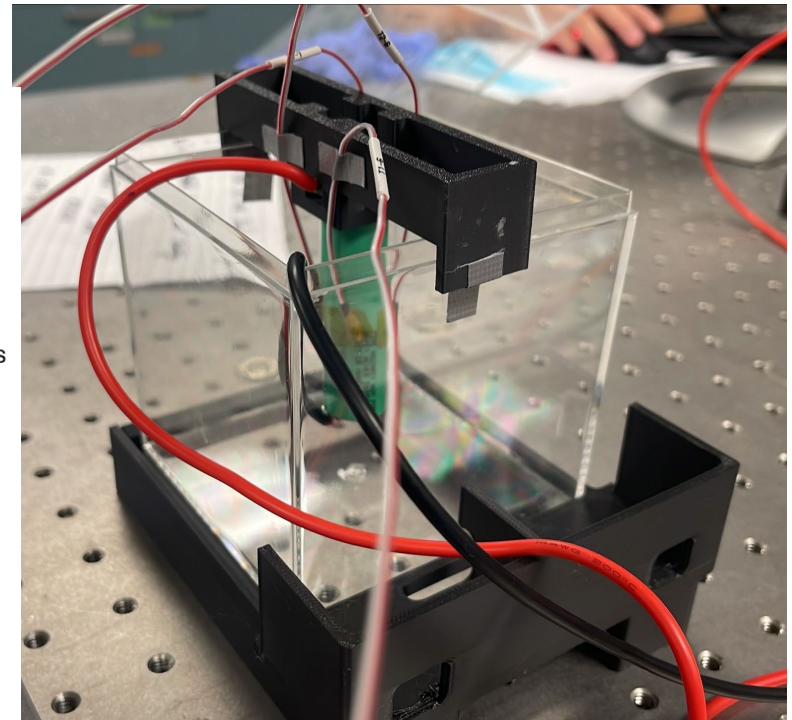
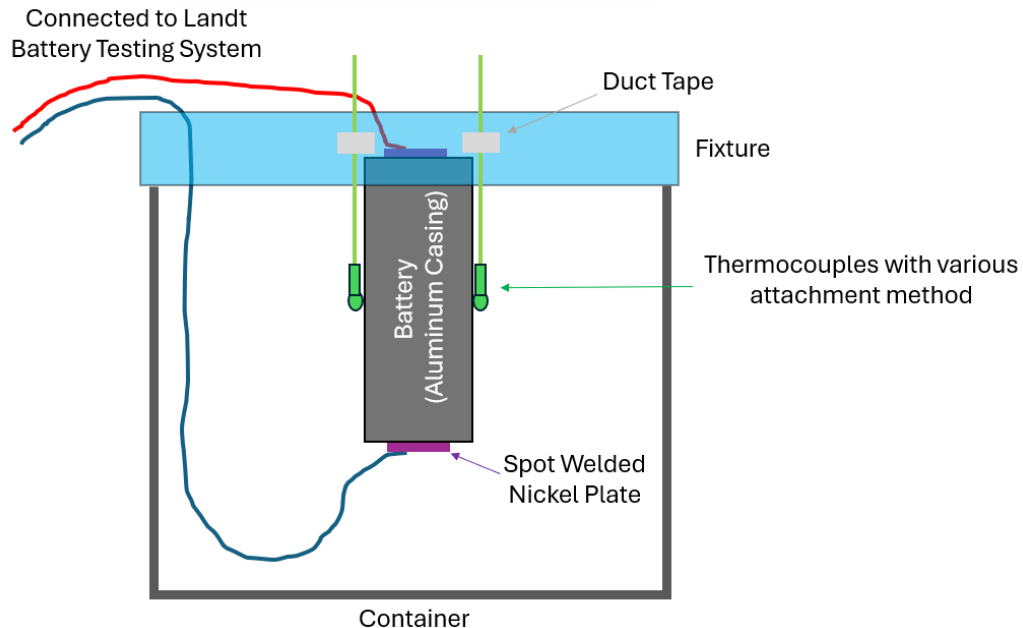
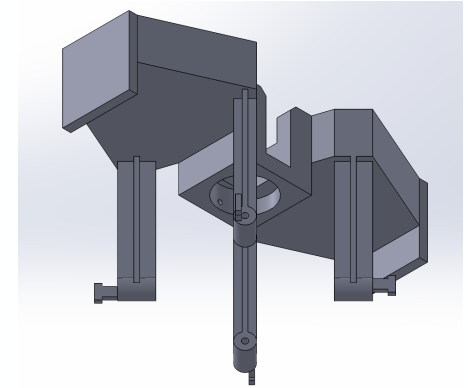
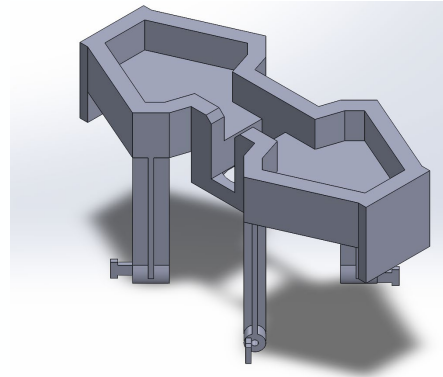
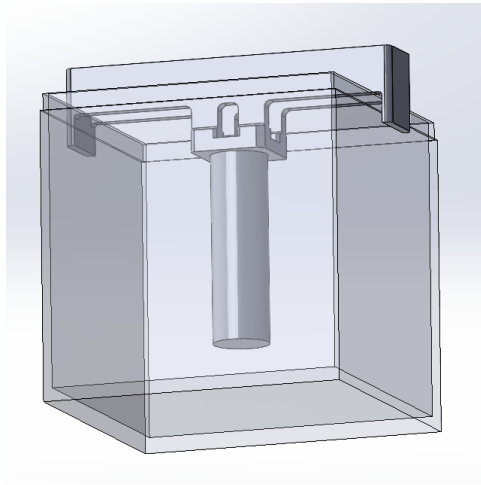


Result III. Finding Ideal Thermocouple attachment Method

Precision vs Accuracy of Four Different Thermocouple Attachment Methods

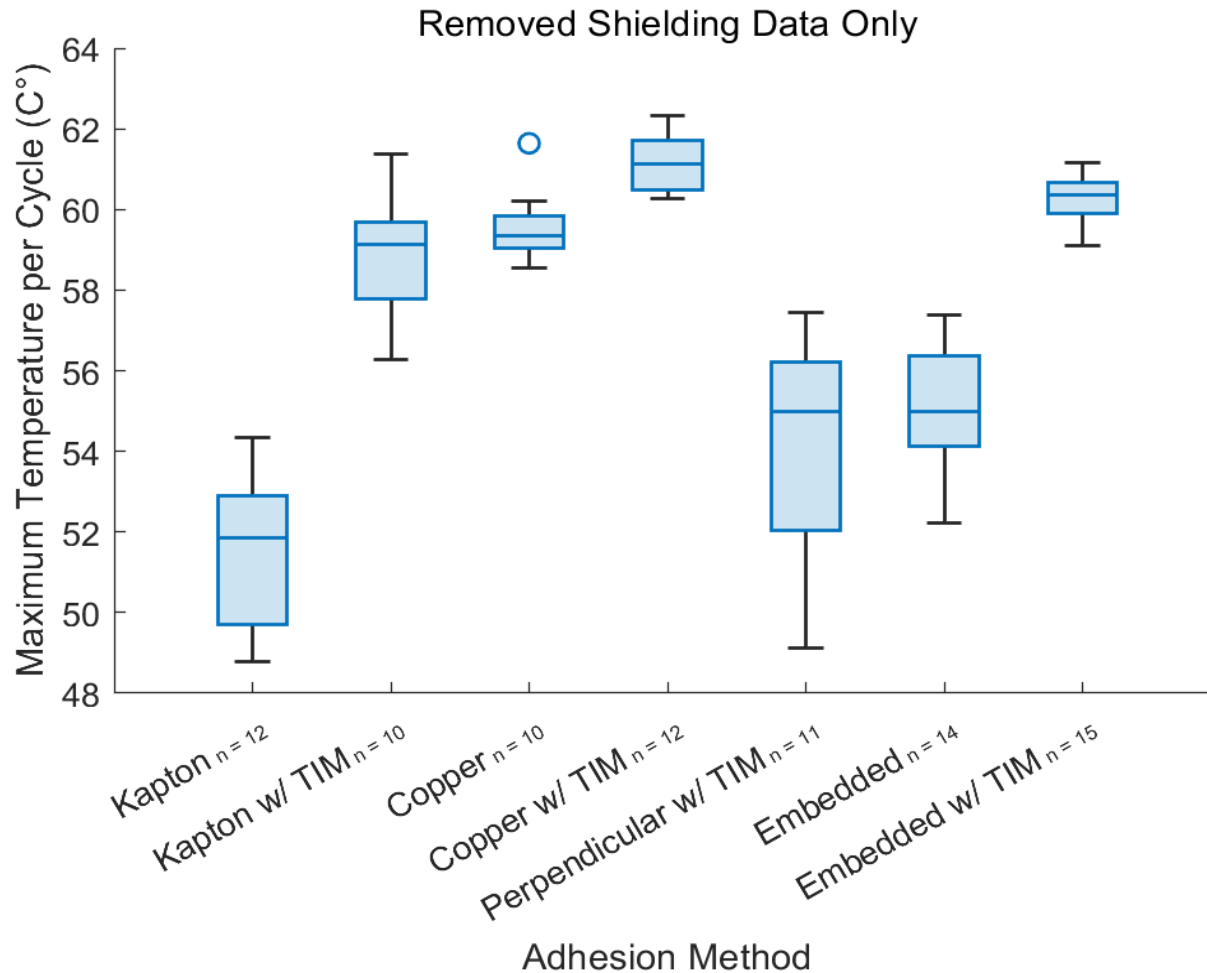


Method IV. Finding Ideal Thermocouple attachment Met



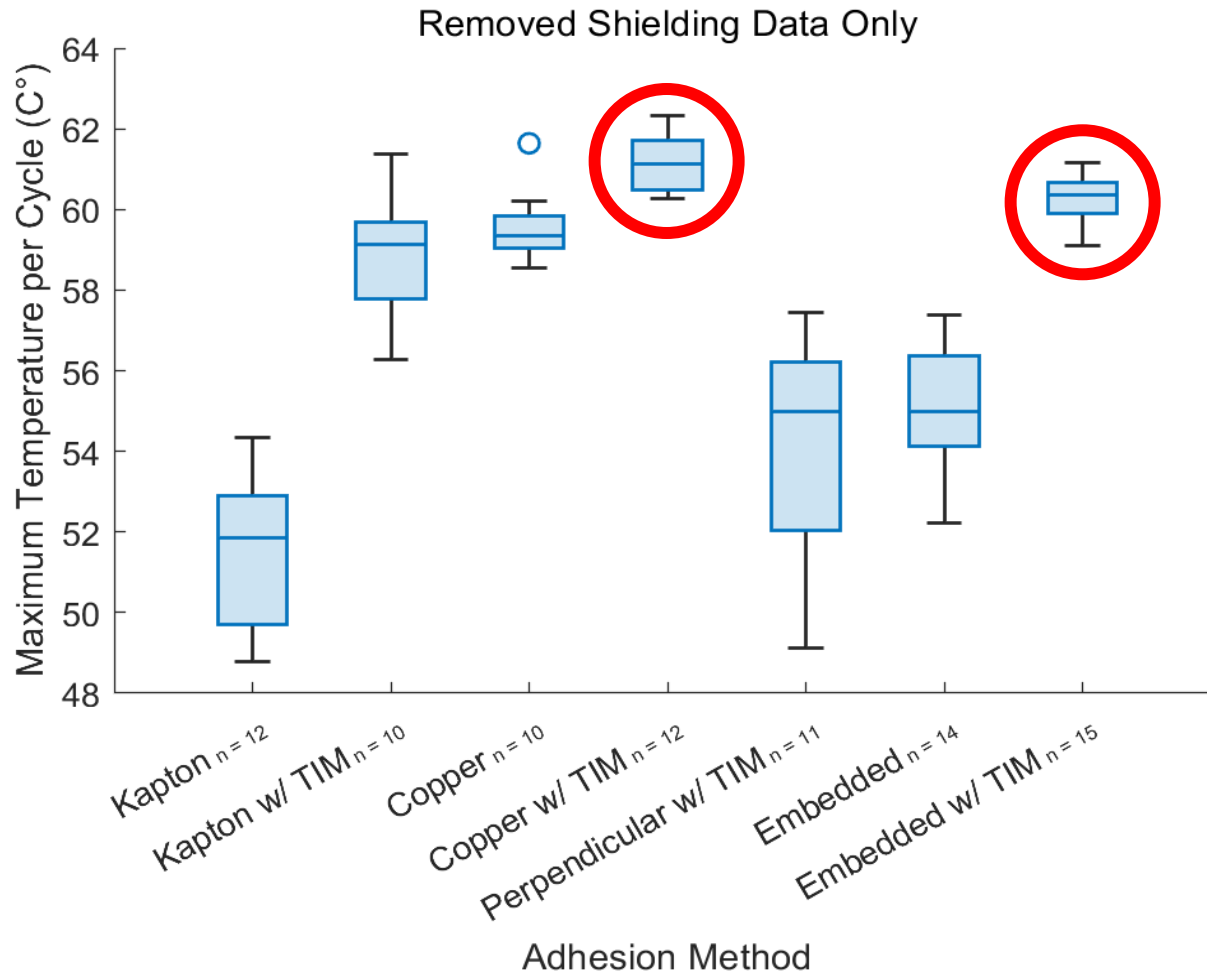
Method ~~IV~~ Finding Ideal Thermocouple attachment Method

Performance and Consistency for Thermocouple Adhesion Methodology



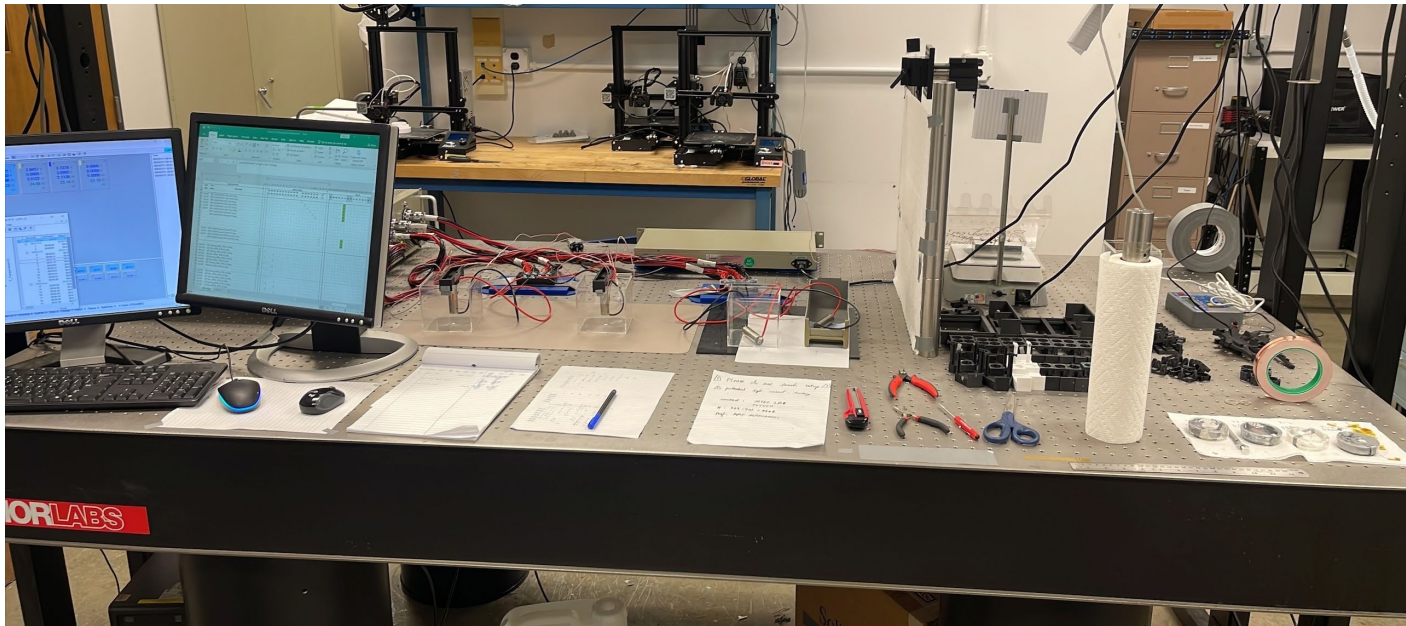
Method ~~IV~~ Finding Ideal Thermocouple attachment Method

Performance and Consistency for Thermocouple Adhesion Methodology



Future Direction

- Complete Testing different Battery's Measurement
- Construct battery simulator to access accurate performance of thermocouples
- Innovate better thermocouple attachment methods (ex. Silicon)
- Compare battery measurement with IR camera in air
- Devise fixtures or tools that assist attaching the thermocouples



Learning Experience

bottom - top bottom LEB : also compare to N-C (3rd cell, metal cathode) and N-PH (solid metal, high) battery
 → higher specific energy; power density; natural discharge voltage; low self-discharge rate

among all LEBs, N-C (bottom cell, metal cathode) and N-PH (solid metal, high) have high specific energy and deliver high voltage.

LEB construction

main structure

discharge : porous materials that allow H_2 to generate electric current; as both electrodes are sealed & covered with discharge, discharge being porous allows the oxygen from between electrodes and discharge is sufficiently exchanged (H_2 diffusion rate)

anode : the electrode that houses the H_2 and red energy to remove H^+ from the lattice; anode will release a H^+ into the electrolyte when an H^+ leaves
 → to be more stable relative to free ions, when calculated in metal lattice, so free state H^+ will naturally form H_2 and structured in metal lattice of possible; ex. graphite

cathode : the electrode that houses the H^+ and large energy to remove H^+ from the lattice; cathode will release a H^+ into the electrolyte when an H^+ leaves
 → to be more stable relative to free ions, when calculated in metal lattice (depending on free state & metal intercalation rate), so free state H^+ will naturally form H_2 and structured in metal lattice of possible; ex. solid metal (cathode)

seal collector : metal plate that would be from a cluster point to allow H^+ to pass through with low resistance (which decreases chance for penetration), allowing H^+ to directly collect by current collector with low resistance
 → typically Cu cathode (copper) is used as the current collector for anode and Al ribbon (aluminum) is used as the current collector for cathode; different materials are used as the conductivity of the cathode and anode material that they can bond & not crack

discharge : material (liquid or polymer) that can move H^+ between cathode and anode, but not H^+ ; consists of following material
 → there are two major types of electrolyte: liquid (which requires about 10% water) or polymer; liquid electrolyte when comparing to polymer type has higher ionic conductivity (ion more easier, more faster changing & discharging rate with less heat generation), but after from long operating temperature range, safety concern, degradation, discharge fluctuation, and thermal shock stability
 → for the replacement of wet electrolyte, one will use liquid electrolyte to replace

separator : a nonconductive, porous material that allows discharge to range H^+ but not H^+
 → did you remember how water discharge table rate (60/100)? Basically H_2O molecules break H_2O 's main bond quickly, and H_2O from a mixture shell due to the discharge (60/100) (better conductive force)

to note : bottom cell is done with the discharge; as the discharge will contain between ions (since the solvent will break apart between cell from the cell from ions from due to the ion-discharge 100% between bottom cell and multiple solvent, more detail up phase of (bottom - discharge page 19)
 → ex. one common material used as the bottom cell is lithium hexafluorophosphate ($LiPF_6$)

addition : a material inside the discharge that helps creating a solid discharge electrolyte (SEI) at the anode surface (also equal to the discharge) during the first time charging; it also helps creating cathode discharge electrolyte (CEI) that is solid/bound at the cathode surface (also equal to the discharge)
 → ex. one used material for addition is vinylene carbonate (VC)

separator : material that separates cathode and anode physically; preventing external short circuit that build up from; it is porous to allow H^+ ions from one side to another

discharge is an systematic way - between the layers of



due to both natural current and attraction from between H^+ and ions being toward the lattice
 get between the lattice layer
 distance between H^+ ion and H^+ (from lattice) is the shield the lattice get shorter, eventually the attraction force and for

when the interaction energy is result from the attraction
 → between ions H^+ and release H^+
 as H^+ is the same, therefore lower the interaction energy - then

how much inside (in the lattice structure) is in H^+ reaction
 → interaction with the oxygen ions (in the H^+), therefore both in structure, the H^+ is slightly bound in the oxygen lattice, the cathode lattice, therefore between cathode ions have a high H^+ bond, please review "Frederick Chemistry note page 11"

discharge energy between each carbon in the graphite lattice ions review "Frederick Chemistry note page 12", where shows
 → the reason H^+ from graphite lattice, resulted in low interaction phase reaction "Frederick Chemistry note page 11" of graphite

get, most (~70%) H^+ ion in the LEB are intercalated in H^+ as the anode has a small quantity of water H^+ when an anode, only a tiny portion (~5%) of H^+ ions left in the solid structure of H^+ ions inside the LEB that

1 and another current collector (negative), also release a electron when an electron from the H^+ inside the cathode that is in a high level H^+ energy; therefore the H^+ in the cathode get released which partially charged; some cathode lattice have a higher energy is actually more H^+ from the cathode
 → the cathode will and the H^+ in the cathode current collector bound at negatively charged, then the separation of H^+ ions cathode in the in the already applied electric field
 → current collector

→ but also H^+ ion in from the same bond, therefore due to other 1. the not positive charge of the cathode, just like in the discharge due to the discharge ion intercalation from of due to the natural movement caused by temperature/attraction

in general attracted toward the anode; when H^+ does it from from the not negative made lattice, so the flow H^+ ions get pulled in between the negatively charged anode

→ the discharge; anode: shifting from discharge side H^+ → the release of H^+ ions intercalating into the anode being H^+ 's potential energy into kinetic, releasing each other (graphite shell); accordingly kinetic energy is lost; say in the energy/rate than by the voltage source
 → as quite small, least the "interaction energy" action and much to attraction, this is caused by current the major release, increases the concentration of H^+ in cathode, cathode ions drops in 100% from the cathode to anode's discharge power

present in the discharge anode inside, the concentration of H^+ is more H^+ to be released with other particles & not other less possible releasing due to the decrease of H^+ ion they cathode but toward the discharge anode cathode; therefore a way that the speed of diffusion for H^+ is toward from product; before the H^+ concentration in the discharge is larger number of H^+ to move toward to anode / less time means more activation on both sides, multiplying the of H^+ , increasing the rate of H^+ toward toward the

rate of H^+ intercalating from the cathode and the rate but discharge toward the cathode, as well as the H^+ negative charge of H^+ inside the discharge toward the anode due and anode side will produce an electrical field pointing
 → charge as the 1. concentration of H^+ from the H^+ the concentration of H^+ toward the anode inside from from the cathode in the anode through the discharge

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discharge rate will not itself - however, during H^+ discharge, when H^+ from the anode that
 → discharge at get get up first, during the H^+ is released and drops from the discharge from the anode, when it is the larger for H^+ demand of H^+ ion most of the H^+ ions of demand of cathode side, therefore the in called "concentration polarization"
 → one consider this battery is fresh discharge

ability
 → capacity of battery, what have the charge
 (100%) : it can be negative
 → polarization (a activation forces of rate after releasing) of the voltage of the system; then one realize 1. some

and release, increase the battery rate to increase discharge
 → because the distance that H^+ need to travel as well as more more potential energy of the H^+ in stay such to increasing the resistance; decreasing the useful potential rate
 → and since the voltage that due to the resistance increases release will greatly increase when current actually increases
 → this 100 drop in called "IR drop", and in present through

→ space for electrode materials to increase its requirements
 → and the electrode shell (as H^+ inside the first more in to the cathode relative to the anode cathode)

the charge on which any suggest H^+ which more suggest
 → the negative charge, the there is no way of H^+ and the cathode toward in the region of cathode; during a very slow layer of type and cathode in energy H^+ ; however, more ions in the cathode, which more a concentration of H^+ in the cathode, which polarization; this polarization does not as more more H^+

1 first in order to attract H^+ , which is the same H^+ get that

→ H^+ → then will be more H^+ on the anode side and due to the cathode side, primarily due to the difference between H^+ between H^+ concentration toward toward discharge
 → cathode's first energy, when will be more H^+ accordingly the 100 drop more the battery is called "charge polarization" enough to increase the H^+ when diffusing from the anode will have more in the not flow of H^+ get faster, so there polarization enough H^+ flowing toward the cathode, easily distributed in H^+ more of the discharge, concentration polarization decrease the of H^+ and cathode demand in H^+ , and then one more enough H^+ on H^+ and possible, so the discharge polarization 100% energy drop

discharge rate will not itself - however, during H^+ discharge, when H^+ from the anode that
 → discharge at get get up first, during the H^+ is released and drops from the discharge from the anode, when it is the larger for H^+ demand of H^+ ion most of the H^+ ions of demand of cathode side, therefore the in called "concentration polarization"
 → one consider this battery is fresh discharge

ability
 → capacity of battery, what have the charge
 (100%) : it can be negative
 → polarization (a activation forces of rate after releasing) of the voltage of the system; then one realize 1. some

and release, increase the battery rate to increase discharge
 → because the distance that H^+ need to travel as well as more more potential energy of the H^+ in stay such to increasing the resistance; decreasing the useful potential rate
 → and since the voltage that due to the resistance increases release will greatly increase when current actually increases
 → this 100 drop in called "IR drop", and in present through

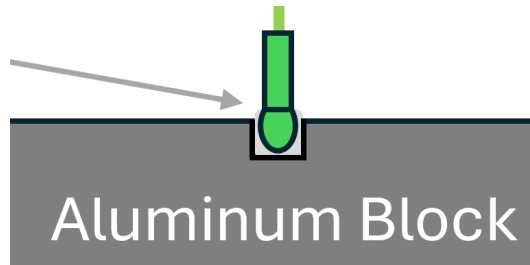
→ space for electrode materials to increase its requirements
 → and the electrode shell (as H^+ inside the first more in to the cathode relative to the anode cathode)

the charge on which any suggest H^+ which more suggest
 → the negative charge, the there is no way of H^+ and the cathode toward in the region of cathode; during a very slow layer of type and cathode in energy H^+ ; however, more ions in the cathode, which more a concentration of H^+ in the cathode, which polarization; this polarization does not as more more H^+

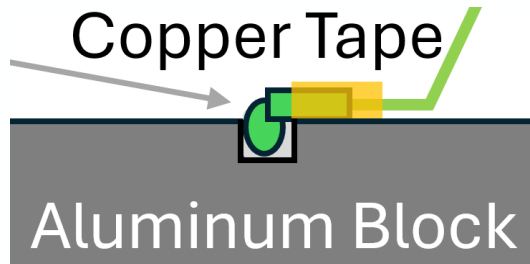
1 first in order to attract H^+ , which is the same H^+ get that

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Learning Experience

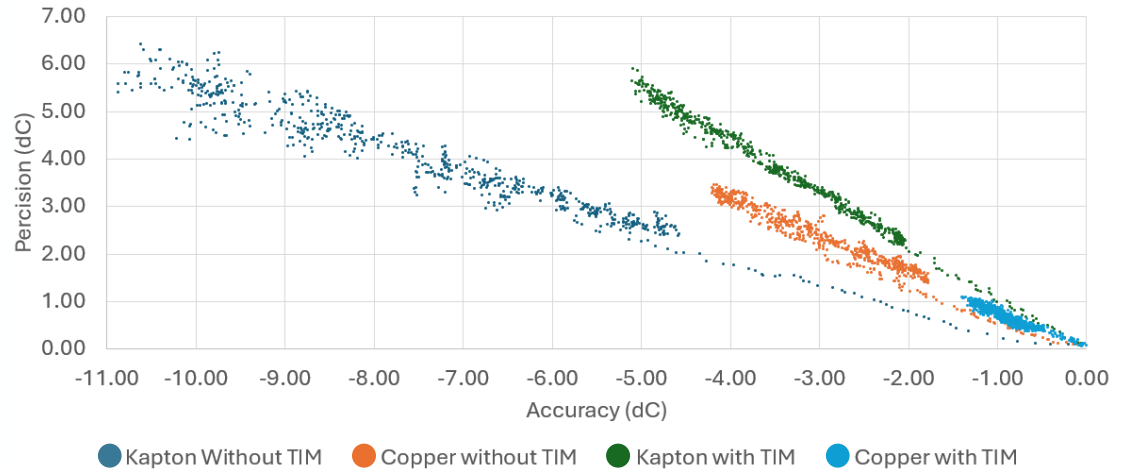


Old Method

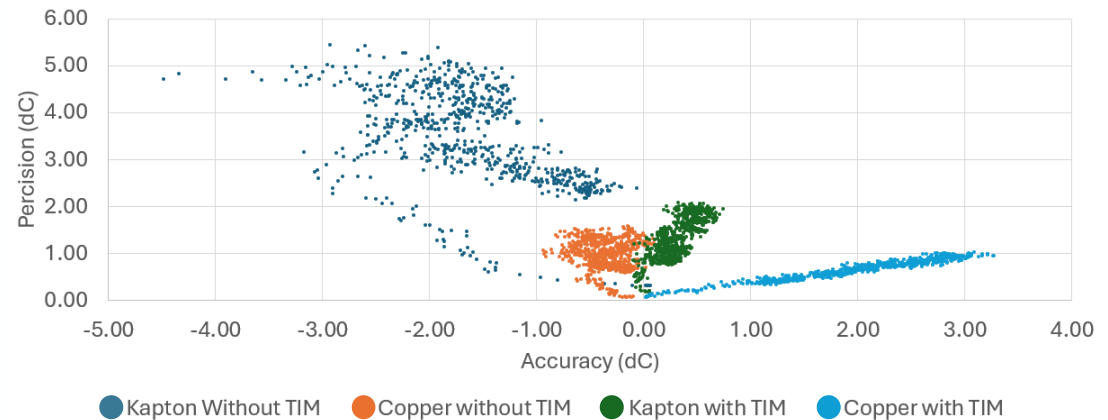


New Method

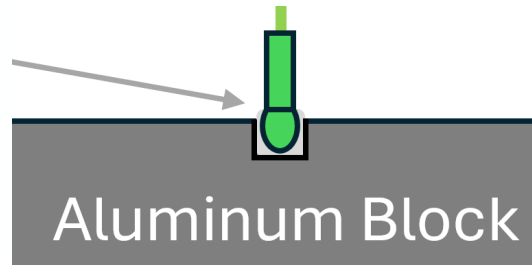
Precision vs Accuracy of Four Different Thermocouple Attachment Methods



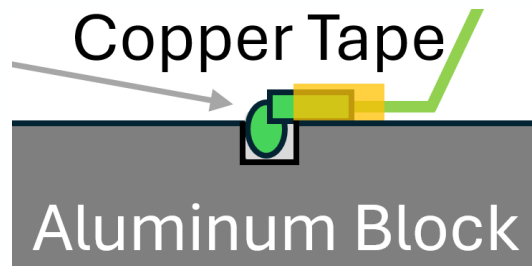
Precision vs Accuracy of Four Different Thermocouple Attachment Methods



Learning Experience

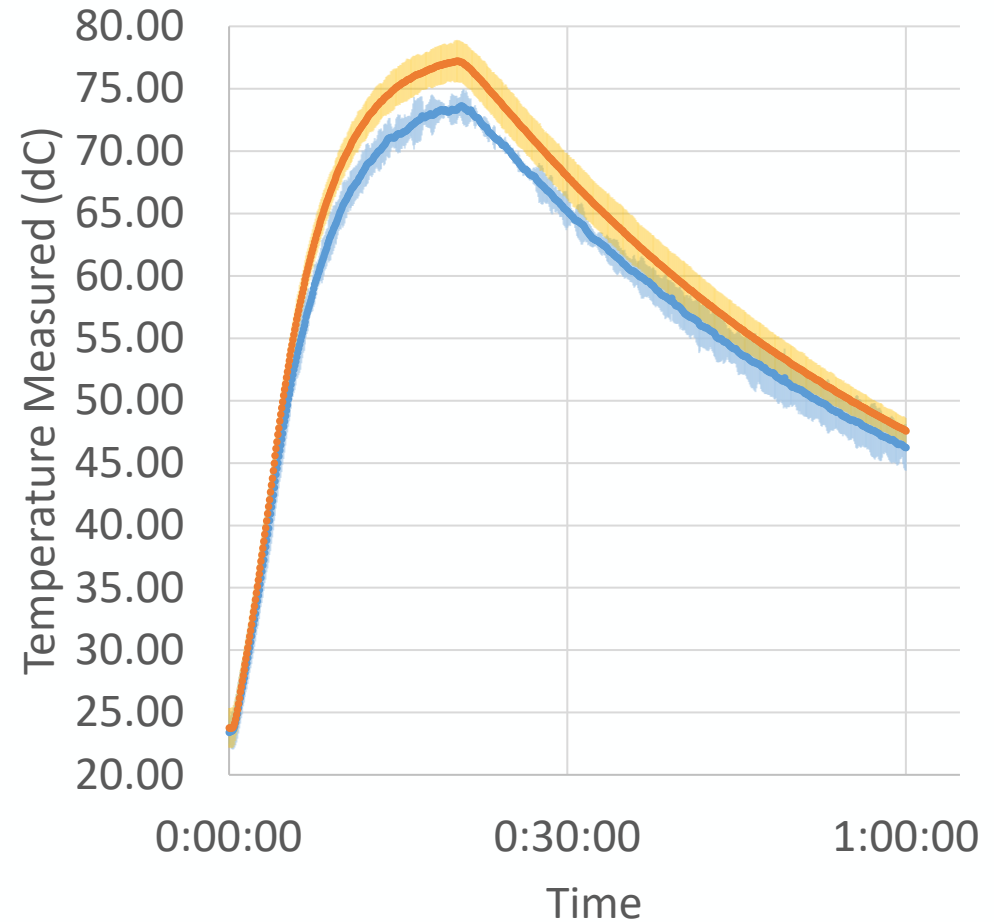


Old Method



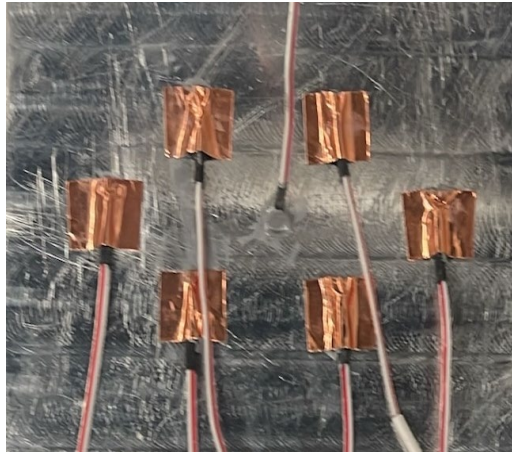
New Method

New and Old Bed Measuring Methods vs Time

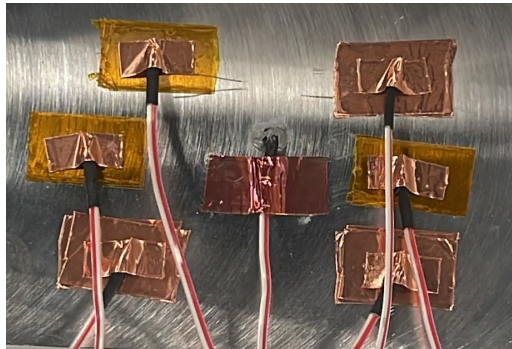


● Old Avg ● New Avg

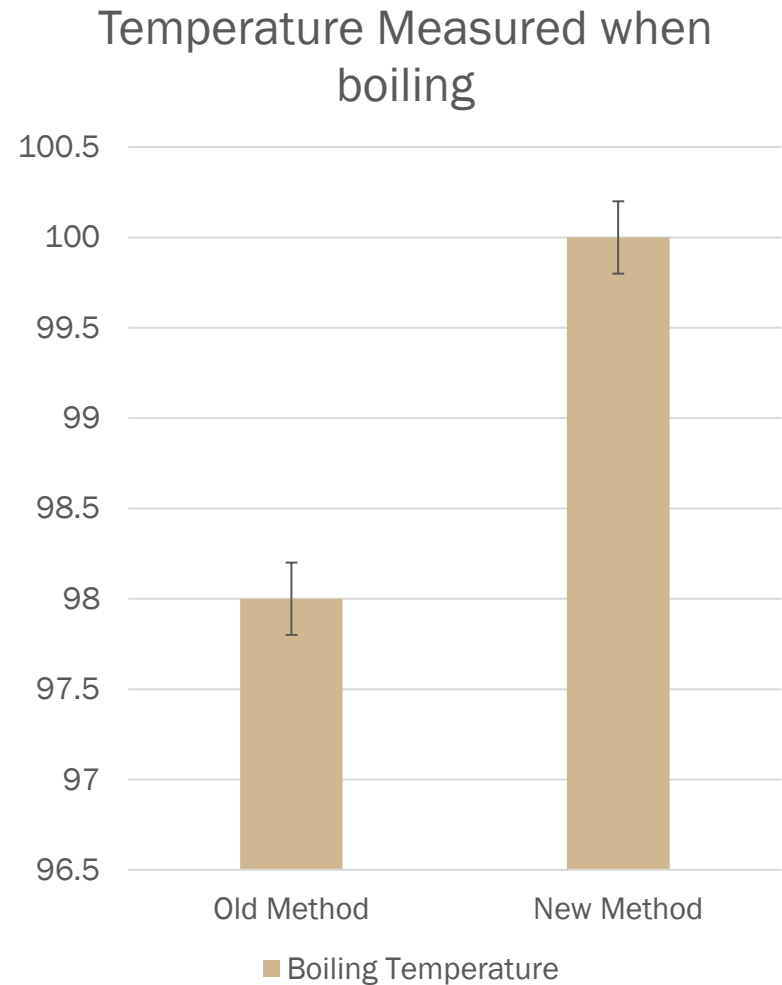
Learning Experience



Old Method



New Method



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Q & A

Thank You



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