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Is It Hot In Here (Or Is It Just Me?): Temperature Control and Uniformity

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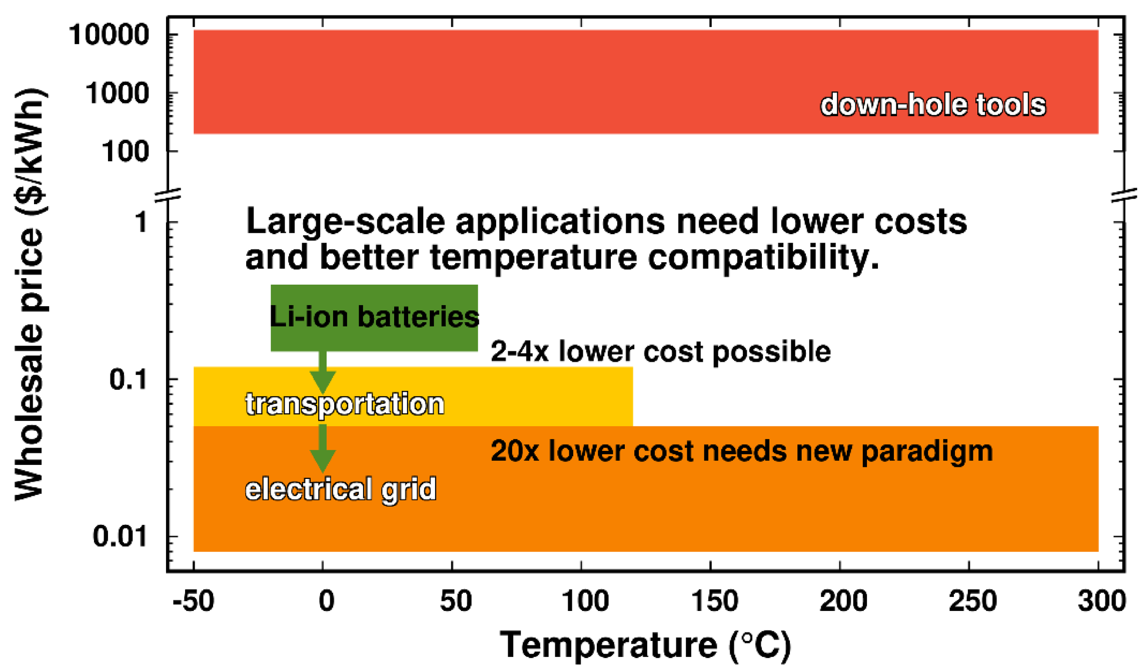
OVERVIEW

Electrochemical energy storage (e.g. lithium-ion batteries) currently only function in 'Goldilocks' conditions – not too hot, and not too cold. Our development efforts are focused on making electrochemical energy storage work in more places. Here we describe our temperature measurement and control system.

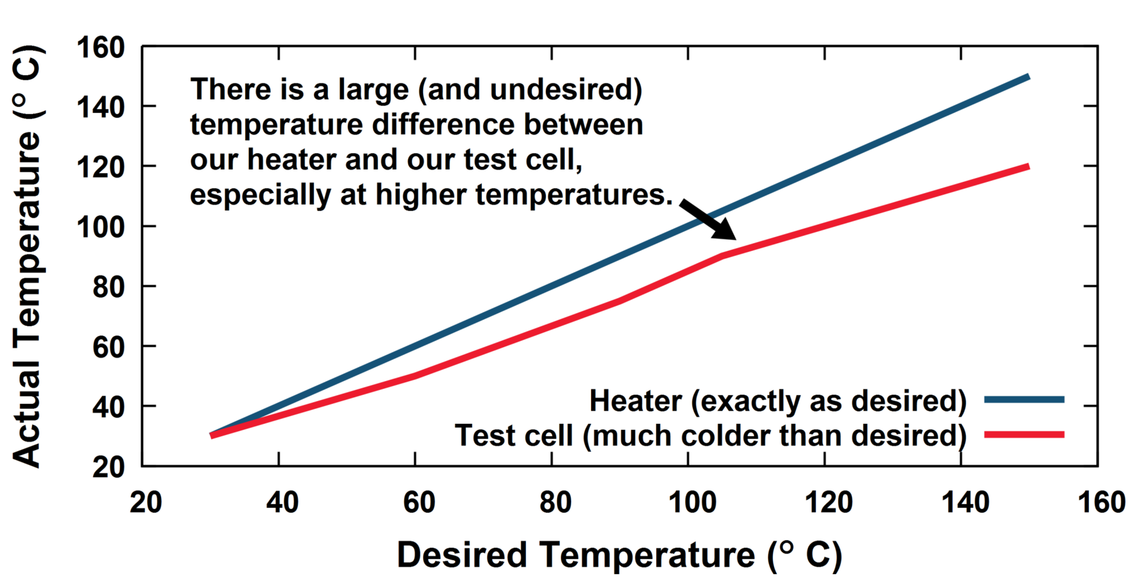


OUR OLD DESIGN

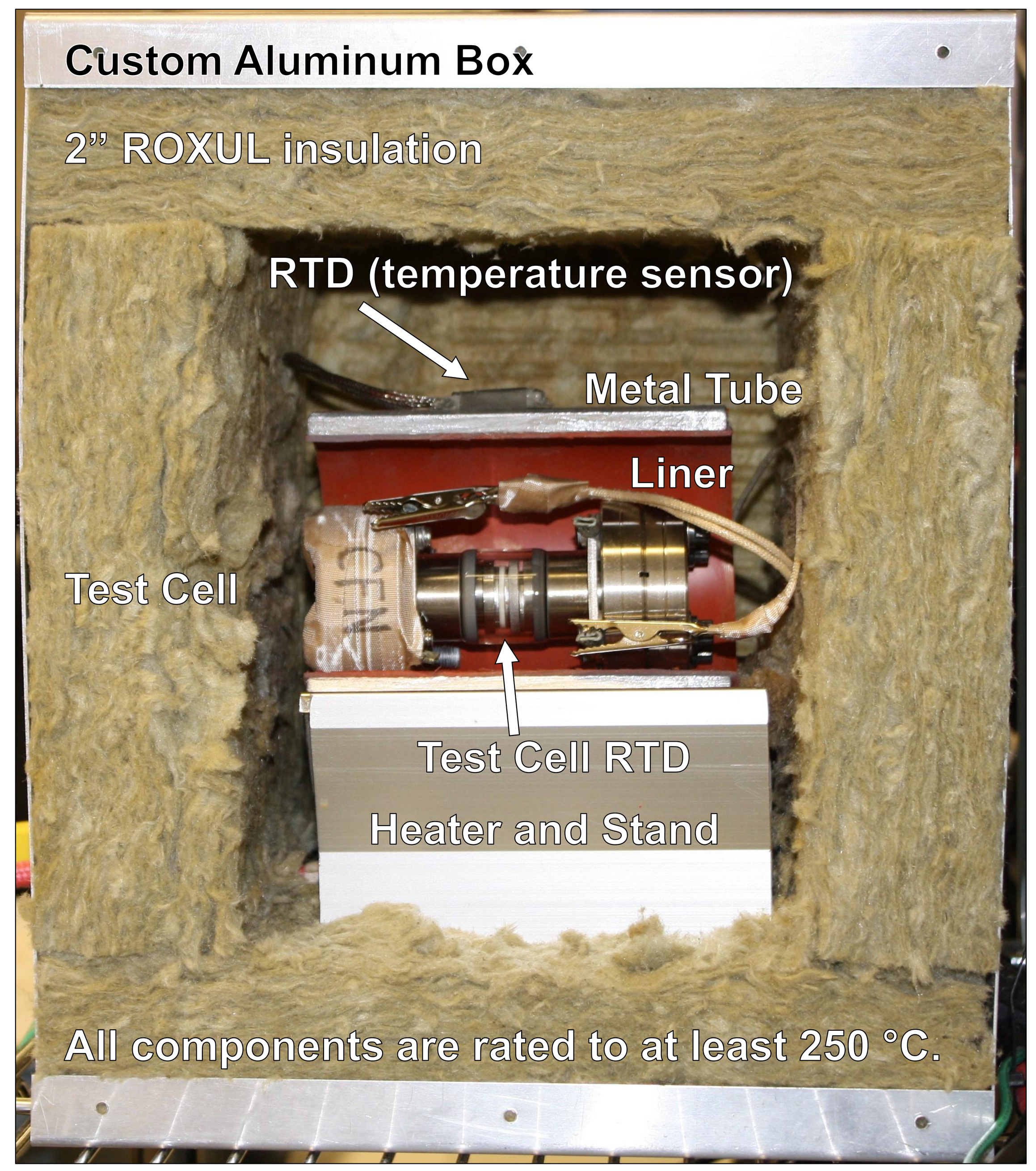
Each cell was housed in a steel box with ½" of glass wool insulation.

TEMPERATURE DIFFERENCES WERE A PROBLEM

Test cells previously rested directly on the heating element. Cell temperatures were inconsistent. We needed better temperature control.

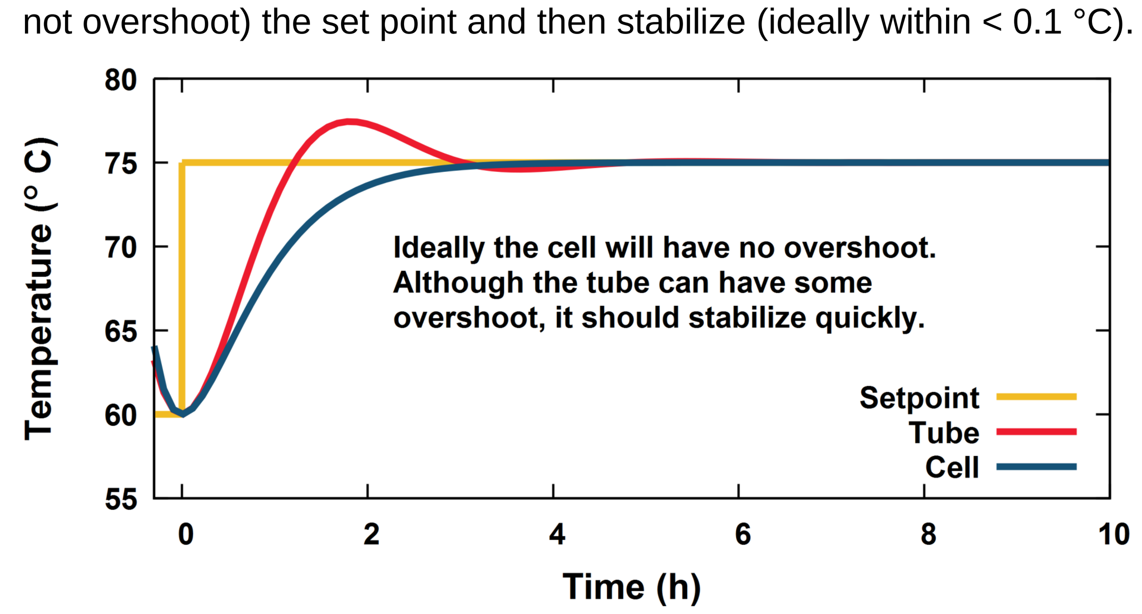


OUR NEW APPROACH – RTDs, TUBES, LINERS



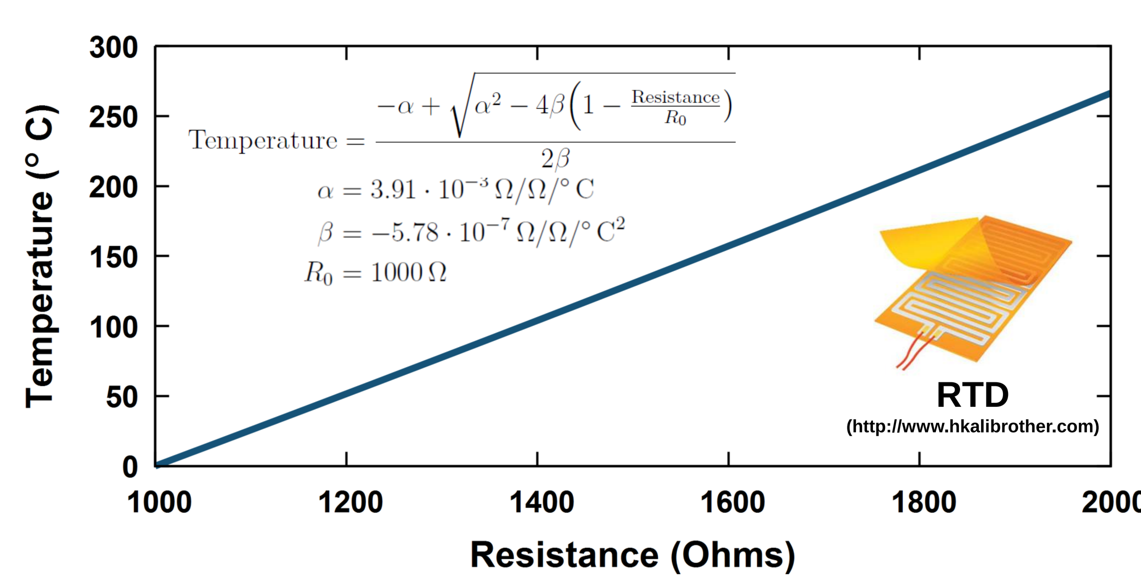
IDEAL TEMPERATURE CONTROL

The tube and cell should respond quickly when the temperature set point changes. This may mean that the tube temperature needs to overshoot the set point in order for the cell temperature to reach (but not overshoot) the set point and then stabilize (ideally within < 0.1 °C).



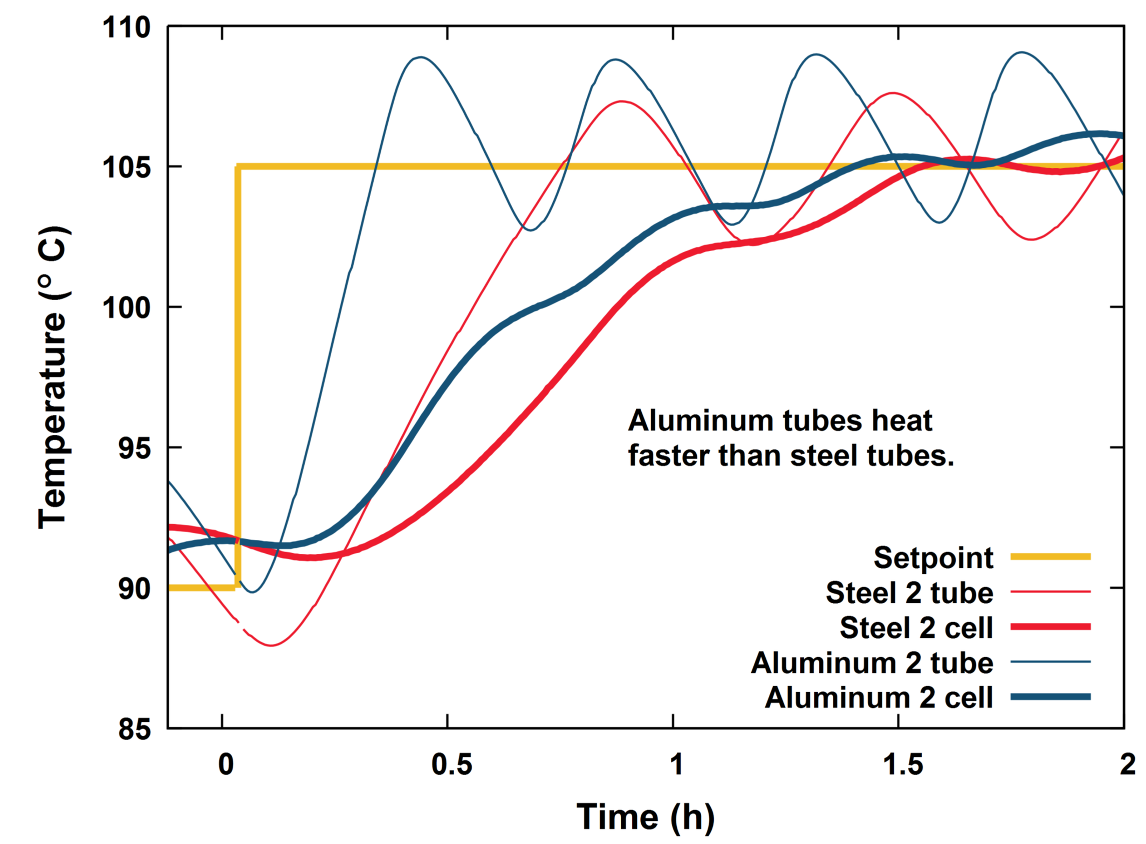
WE USE RTDs TO MEASURE TEMPERATURE

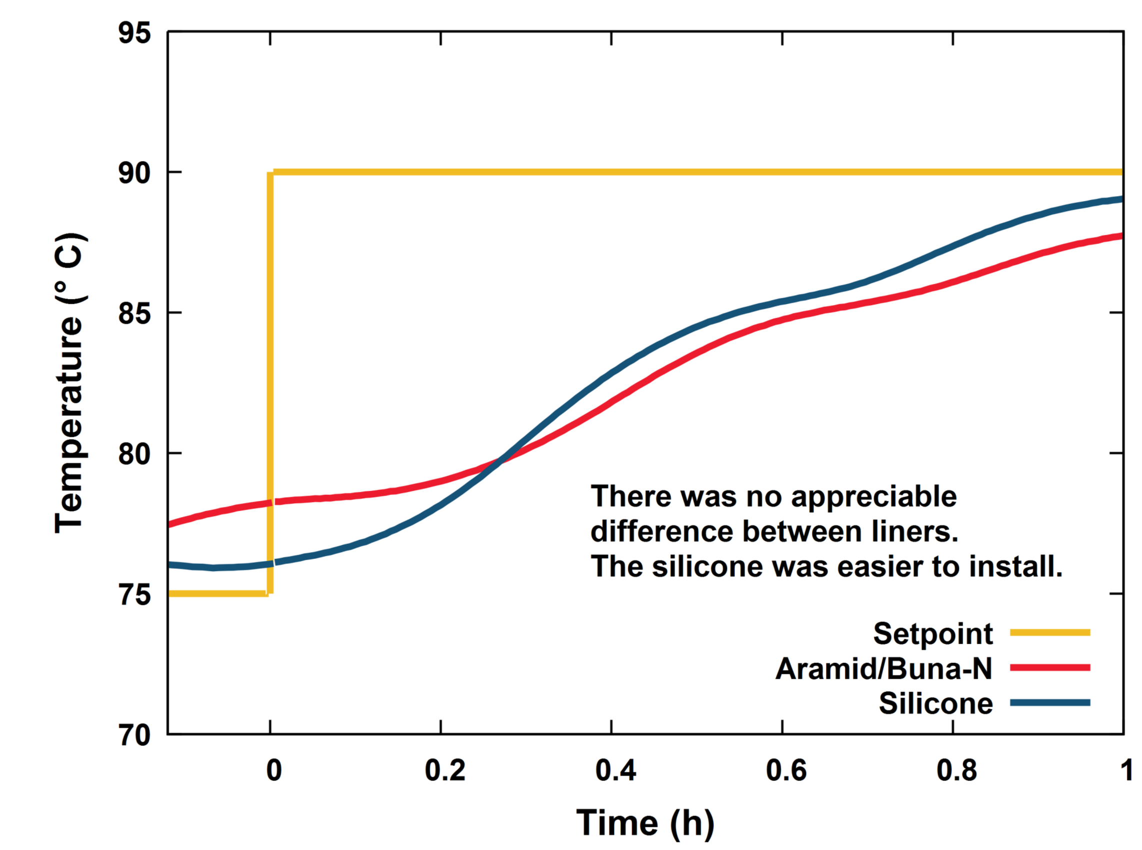
A Resistance Temperature Detector (RTD) is a device whose resistance varies with temperature according to a known function. Our RTDs can measure absolute temperatures within ± 0.15 °C.



TUBE AND LINER MATERIALS

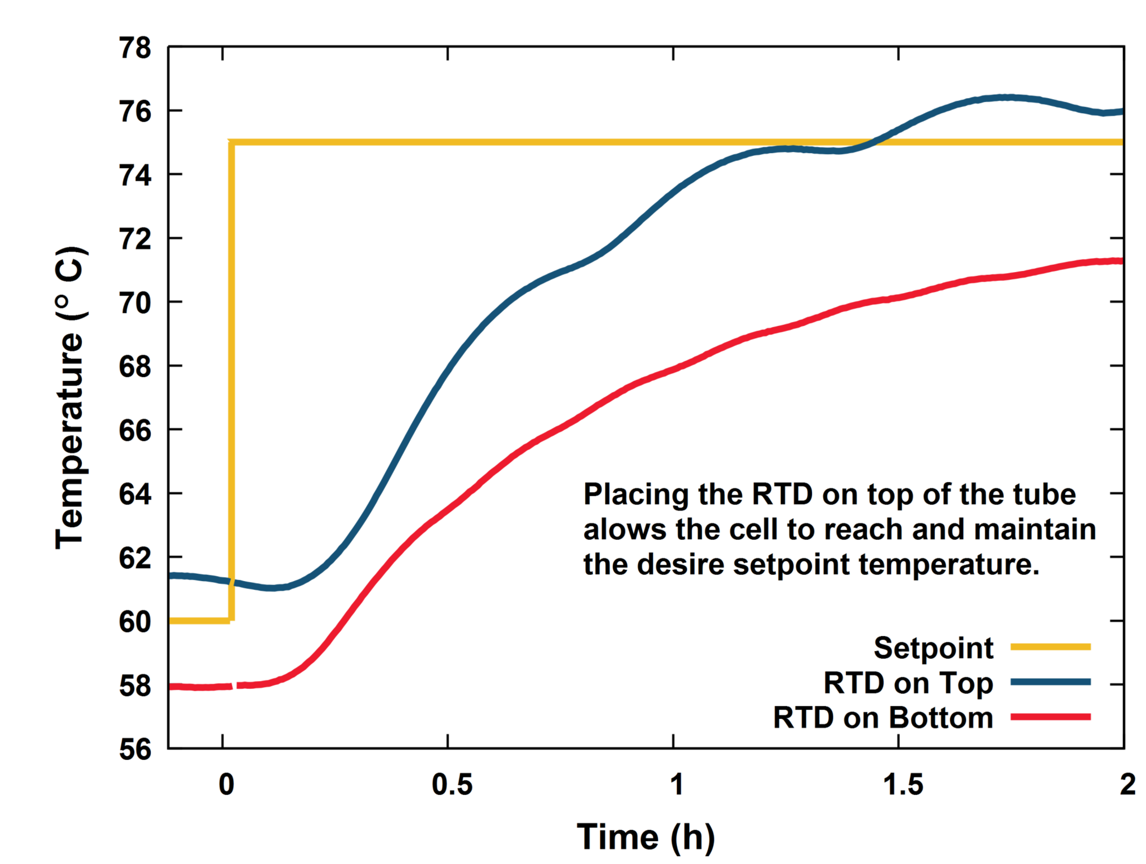
Metal tubes enable quick temperature increases and better temperature uniformity. However, cells placed directly on the metal will short-circuit. Liners conduct heat and provide electrical insulation.





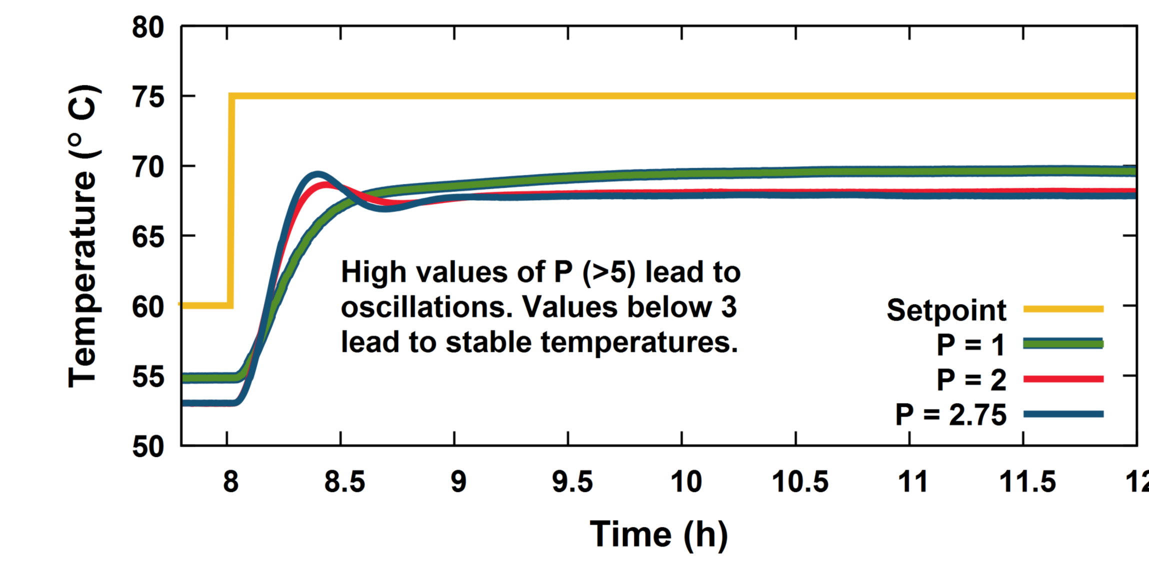
RTD POSITION MATTERS

We measured tube temperature in multiple positions. The bottom of the tube (right beside the heater) is a few degrees warmer than the top of the tube at moderate temperatures. Thicker metal tubes may help.

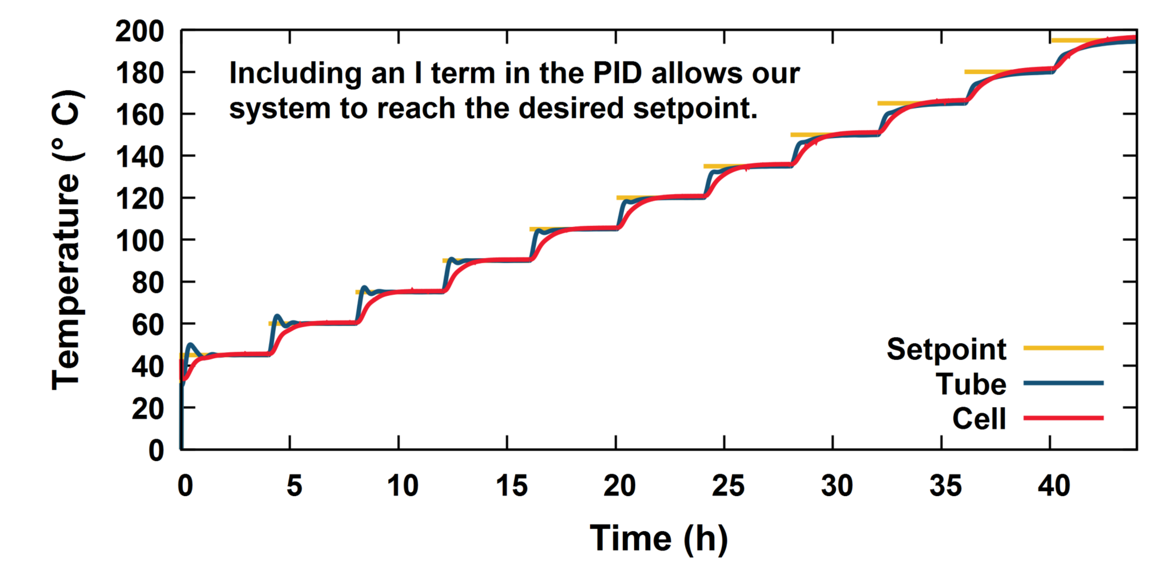


TEMPERATURE CONTROL USING PID

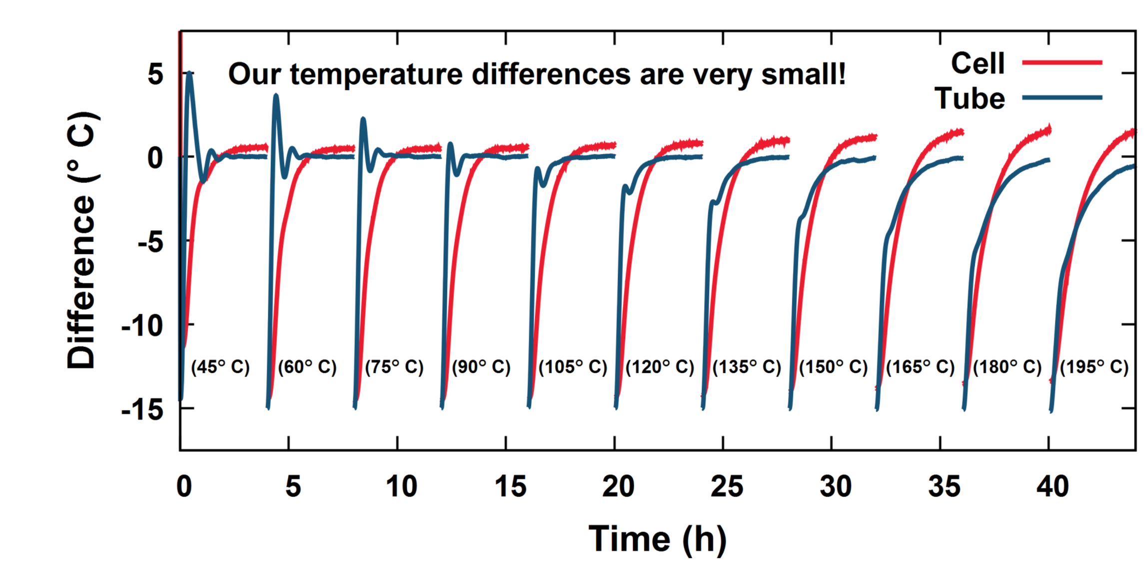
Proportional-Integral-Derivative (PID) is control loop feedback mechanism. Our control computer uses a PID routine to calculate what power to supply to the heater to best control cell temperature. We varied two parameters (P, then I) while keeping the others constant.



P = 2.75 stabilizes the cell temperature quickly, but below the set point.



We varied the I term linearly from 0.0012 at 30 °C to 0.0002 at 200 °C. These values are close to optimal but may be slightly too high. The cell temperature is slightly higher than the tube temperature.



We are now increasing P at 200 °C for a faster response at higher temperatures. Temperature differences are only a few degrees Celsius.

CONCLUSION

The tube furnace design works! We met our initial goal of reducing the uncertainty of the test cell temperature. As an added bonus, we can reach higher temperatures with same amount of heating power.

NEXT STEPS

- Investigate installation of glass wool insulation directly on the tube
- Fine tune PID control parameters and RTD position
- Test across multiple cells/RTDs to measure practical uncertainty
- Build 13 more boxes and let the electrochemistry begin!

ACKNOWLEDGEMENTS

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