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Polarization of Tempo Doped Araldite and Temperature Regulation of a Liquid Helium Evaporation Refrigerator

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UNH NPG

Background

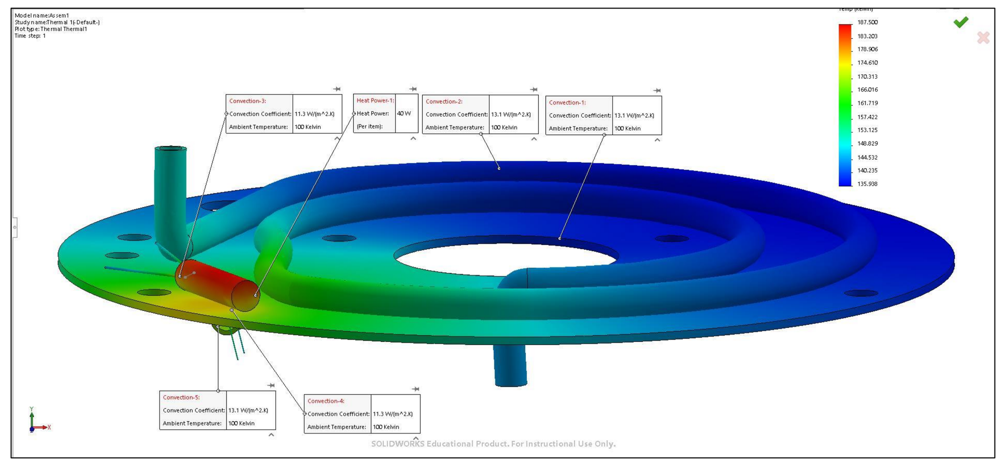
My research at Professor Karl Slifer's Polarized Target Lab was to test polarizable proton rich target material for use in our DNP polarizer (right side). Secondly, to implement a PID feedback system to regulate the temperature of the liquid helium evaporation refrigerator. This was critical to avoid overcooling which can compromise O-ring seals and lead to catastrophic failure of the protective vacuum (left side). A deconstruction of the DNP polarizer is seen below.

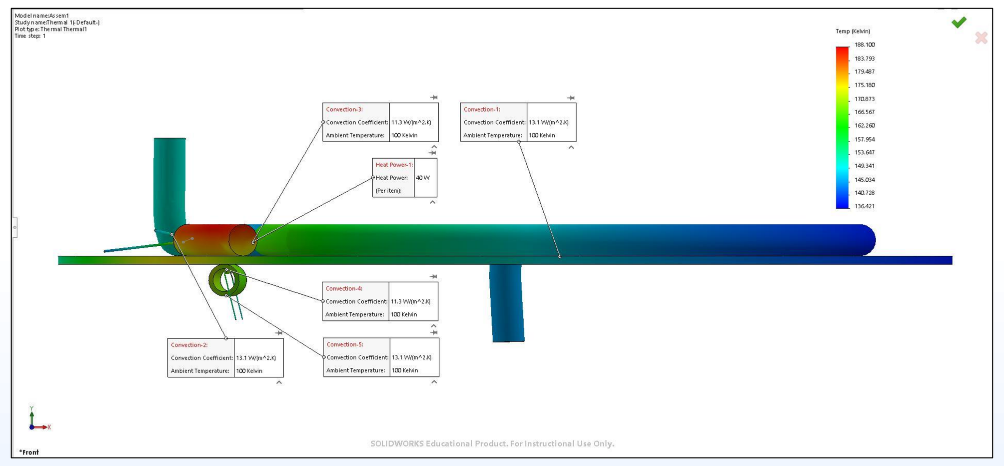
Motivation

Araldite Epoxy doped with TEMPO has been found to be a suitable target material for Dynamic Nuclear Polarization. A maximum proton polarization value of 21.05% percent has been achieved with a magnetic field of 4.998T and a temperature of about 1.2 K. Secondly, I installed and modeled a heating cartridge into the fridge assembly to control the temperature of the fridge and prevent overcooling.

Thermal Analysis of the Heating Cartridge

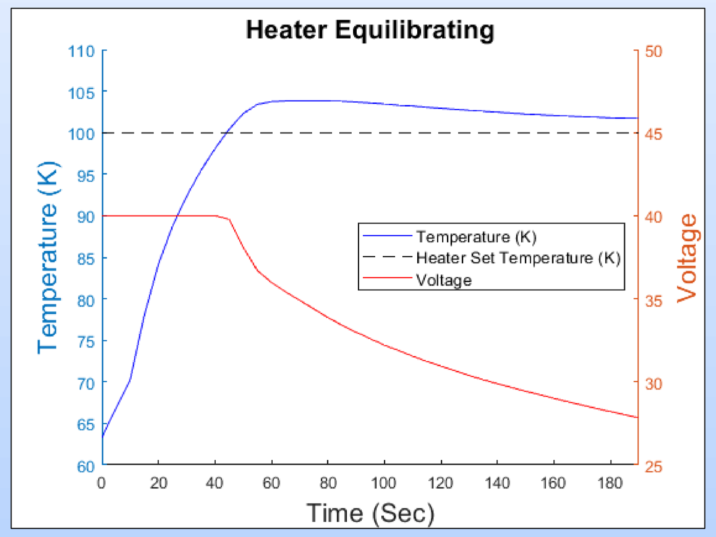
Post cooldown, a thermal analysis of the heating cartridge was done to observe its effect on the baffle and copper coil tubing. In this analysis, the ambient temperature was chosen to be 100K, and the heater power is set to 40W. These characteristics and the thermal coefficients for each part ensured an accurate representation.



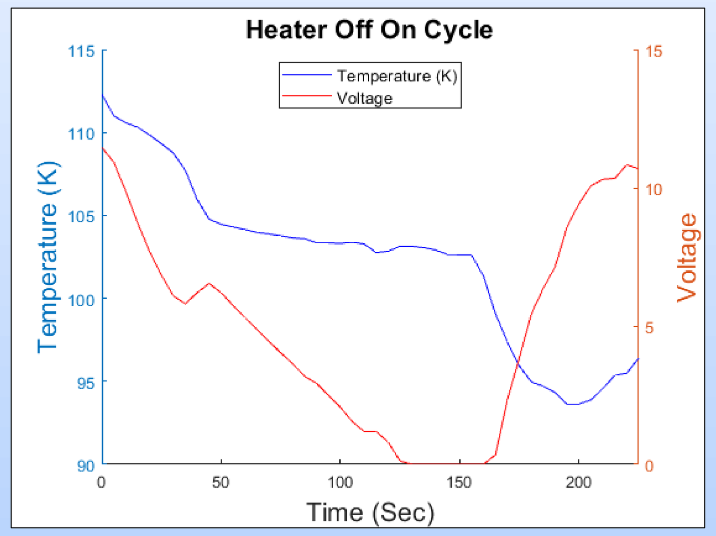


Heater Cartridge Performance

The following graphs consist of experimental data of the temperature response of the LHe radiation baffle to the heater cartridge.

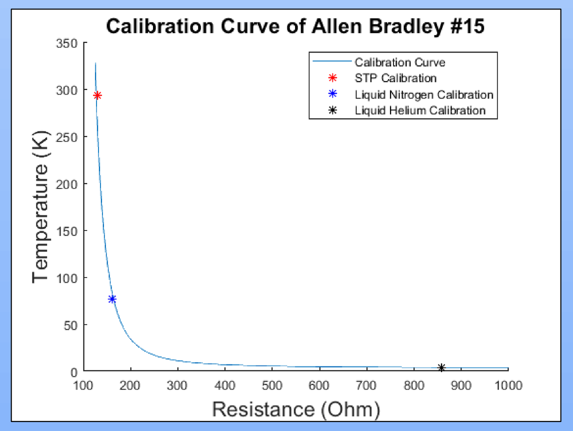


Heater equilibrating to a set point temperature of 100 K.



Heater cycle from an off state to an on.

Low Temperature Thermometry



$$T[K] = a + be^{\left(\frac{1000}{R[\Omega]}c\right)}$$

a = 2.37
b = 0.66
c = 0.78

An Allen Bradley Resistor was used to calculate the temperature inside the fridge. Allen Bradley Resistors are Negative Temperature Coefficient resistors, meaning they exhibit an exponential increase in resistance in low temperatures.

Magnet and Fridge Assembly

Fridge Assembly

Heating Cartridge and Thermometry

SOLIDWORKS rendering of the heating cartridge and Allen Bradly thermometry assembly. Located On the second baffle above the separator.

Tempo Doped Araldite Target

Target stick containing the A and Alpha target in 3rd and 4th cups. Located on the end of the target ladder on the bottom of the fridge.

Heating Element

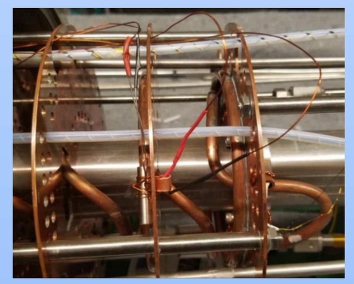
Mercury iTC

A Mercury iTC is a cryogenic programmable intelligent temperature controller. This was used to monitor temperature and resistance, while controlling the heating cartridge though a set temperature or heat flow (%).

19 Pin Connection

A D9 connector ran from the back of the Mercury iTC to the 19 pin connector. A 19 pin connector was used for electrical connections between the lab space and the vacuum environment.

Heating Element



The heating cartridge and Allen Bradley resistor separated by a copper baffle. Wiring consisted of magnet wire and spade clips connections.

Background on Polarization

$$P = \tanh\left(\frac{\mu B}{kT}\right)$$

Equation (i)

μ = Magnetic Dipole
B = Magnetic Field Strength
k = Boltzmann Constant
T = Temperature (Kelvin)

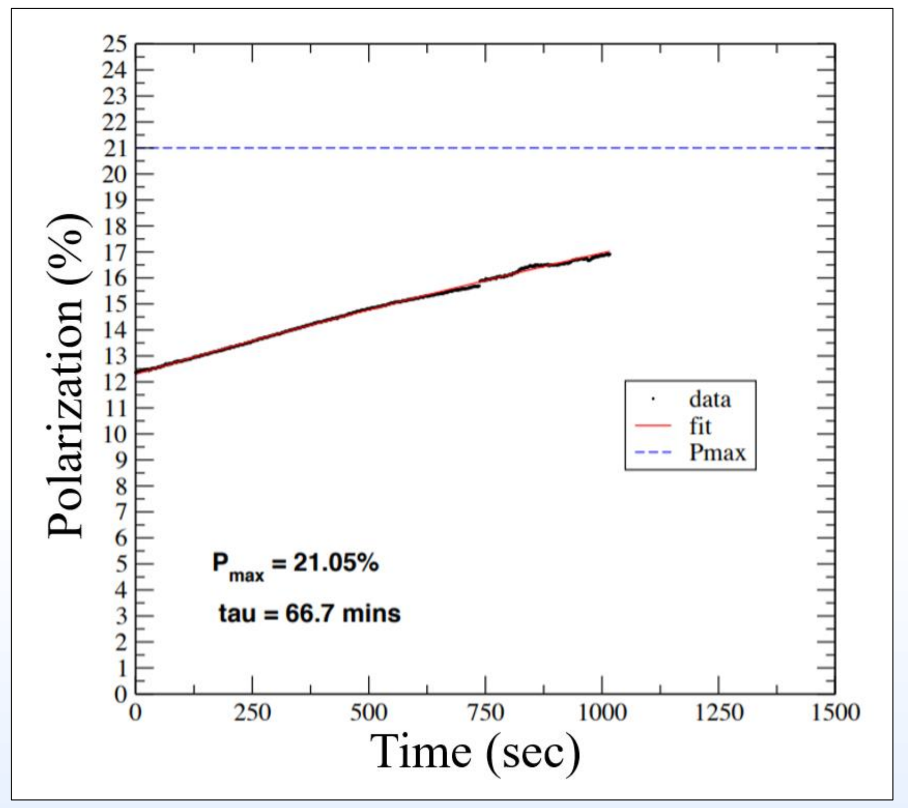
$$P_{Enhanced} = K * A_{Enhanced}$$

Equation(ii)

K = Thermal Equilibrium Calibration Constant
A = Area under the Boltzmann distribution

Equation (i) is a Boltzmann distribution used for calculating the theoretical Thermal Polarization at Thermal Equilibrium. An experimental Thermal Polarization is recorded with a Nuclear Magnetic Resonance system, which we can then generate out "K" value from, equation (ii). Our K value is our TE Polarization over the TE Area. This calibration constant will be used to relate a microwave enhanced distribution area to an unenhanced area.

Tempo Doped Araldite Spin Up



P_{max} = Maximum Polarization
tau = Experimental Time Constant

Post cooldown an analysis of our target polarization was done to determine our maximum polarization. Through analysis of our cryostat environment, magnetic field strength and other factors we determined that our polarization would have reached a maximum of 21.05% if our study had continued. Although 21.05% polarization is an great baseline achievement, we have yet to reach the 80% polarization stated in the literature. Additionally, a comparison between theoretical and experimental tau shows that we are taking too long to reach our P_{max}, we should expect to see a value between 25-30min.

Tempo Doped Araldite Targets

I mixed with 1:200 part Araldite Epoxy. This allowed us to create free form polarization targets with a magnet wire coil centered in the material. The small Tempo admixture provides the paramagnetic radicals necessary for dynamic nuclear polarization technique.

Reference

Noda, Yohei. "Thermosetting polymer for dynamic nuclear polarization:Solidification of an epoxy resin mixture including TEMPO." Elsevier. 09 Dec. 2014. <https://reader.elsevier.comAE/reader/sd/pii/...>.

Future Works

- Integrate the heating cartridge into the preexisting LabVIEW data stream.
- Optimize the placement of the heating cartridge to maximize effectiveness.
- Investigate and improve DNP System to achieve 80% Polarization

Acknowledgements

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