An Overpressure Furnace: Understanding Performance and Analysis-led Design Improvements

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INTRODUCTION: Among a new class of superconductors, $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) is a high temperature superconductor (HTS) with promising application in high field magnet development. The round wire is a multifilament, powder-in-tube (Bi-2212 in a silver matrix, illustrated in Fig.2). After winding the wire into a solenoid, a heat treatment (~890 degC) is required to melt the powder into filaments to achieve high current transport. Therefore, understanding the facility, Fig. 1, used for heat treatments is invaluable for improvements and scaling the technology upwards.

Figure 1. Overpressure furnace

Figure 2. Reacted Bi-2212 wire, after etching away silver sheath

Etched wire by P.Chen. Difference in reactions from D.Larbalestier, et al. Nature Materials 2014.

COMPUTATIONAL METHODS: The primary study focused on the non-isothermal fluid flow development within the furnace. As such, the heavily utilized interfaces included Laminar Flow *(spf)*

$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot[-p\mathbf{I} + \mathbf{K}] + \mathbf{F}$$

$$\mathbf{K} = \mu\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) - \frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}$$

$$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\mathbf{u}) = 0$$

and Heat Transfer in Fluids *(ht)*,

$$\rho C_p\frac{\partial T}{\partial t} + \rho C_p\mathbf{u}\cdot\nabla T + \nabla\cdot\mathbf{q} = Q + Q_p + Q_{vd}$$

$$\mathbf{q} = -k\nabla T$$

with the coupling Nonisthermal Flow *(nitf).*

MODEL DETAILS, Fig. 3:

2D Aximsymmetric

Initial Conditions:

- Heating elements off
- Temp everywhere 20 degC

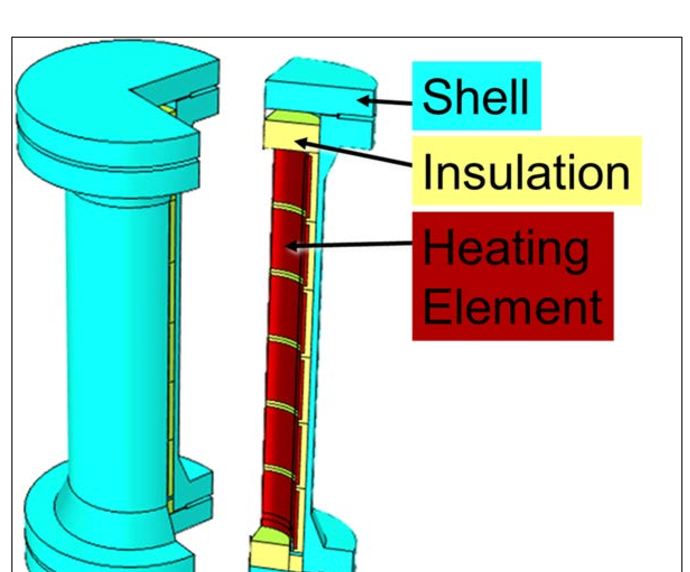

Figure 3. Furnace components

Boundary Conditions:

- Inlet mass flow rate of 5 L/min (bottom middle)
- Exhaust fixed to 50 atm (top middle)
- Internal natural convection established via density gradients (managed by introduction of novel vertical baffle)
- Heaters ramped up to power in a 10 s timespan 3 kW for upper zones and 3.8 kW for bottom zone
- Shell cooled by ambient natural convection

RESULTS: Fig. 4 illustrates the temperature profile within the furnace 15 minutes after turning the heaters on. Improved homogeneity is a direct result of better internal convection management. Fig. 5 provides a detailed visualization of the flow field coupled with the temperature profile.

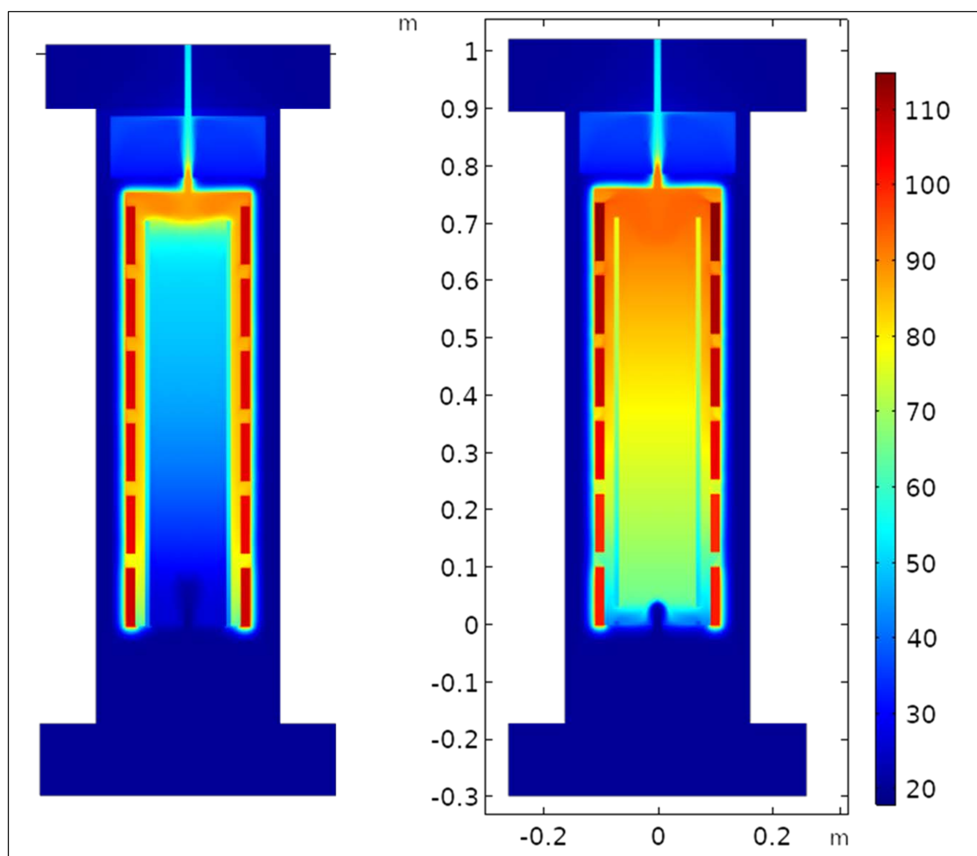

Figure 4. Managing the natural convection

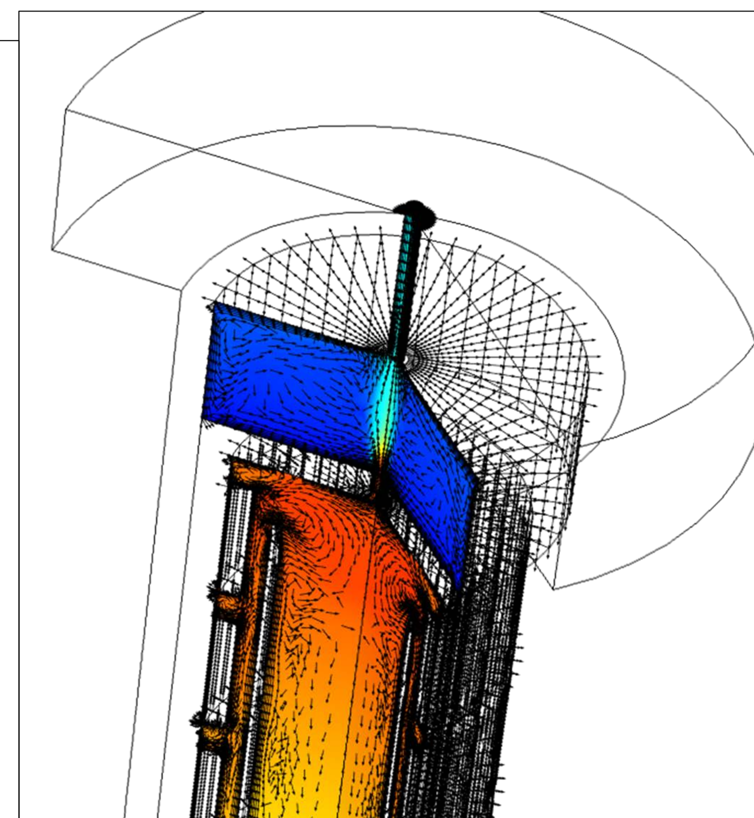

Figure 5. Arrow plot of gas flow on top of temperature profile

Fig. 6 reflects the heat schedule required for processing the Bi-2212, critical furnace requirements highlighted in red.

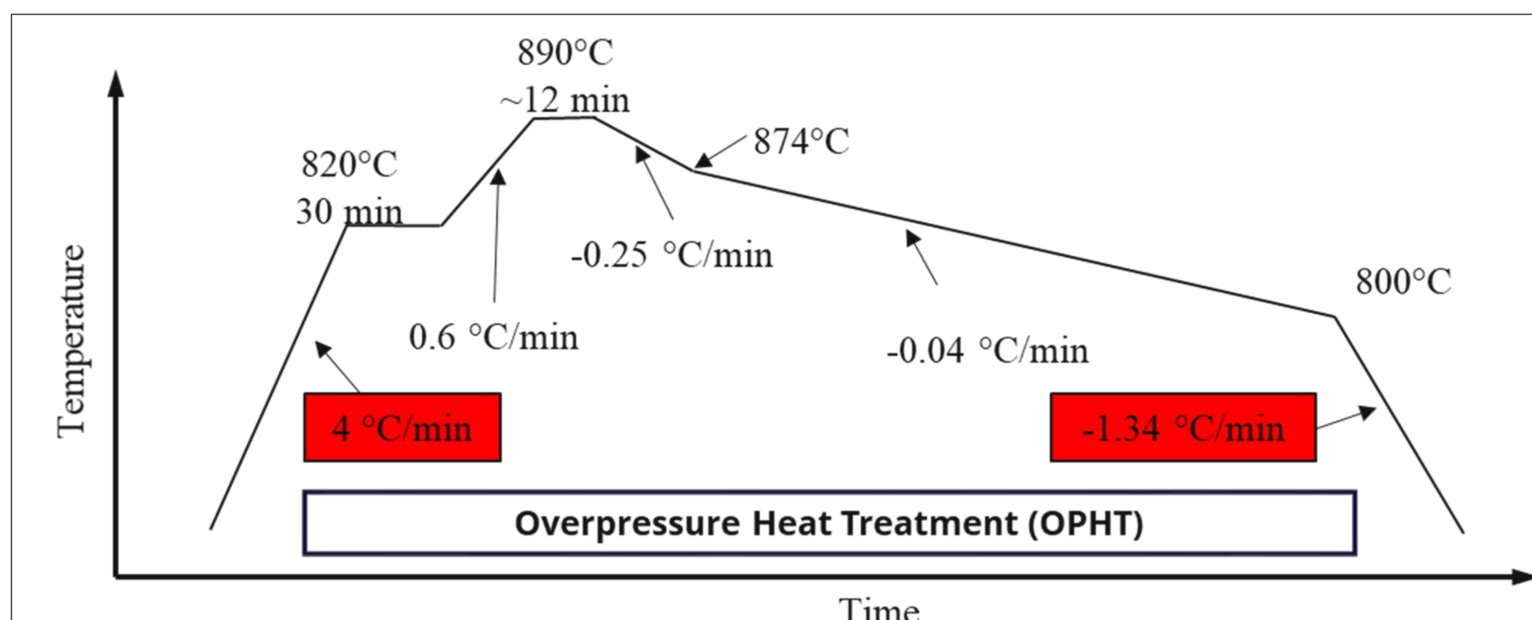

Figure 6. Bi-2212 heat treatment schedule, i.e. furnace requirements

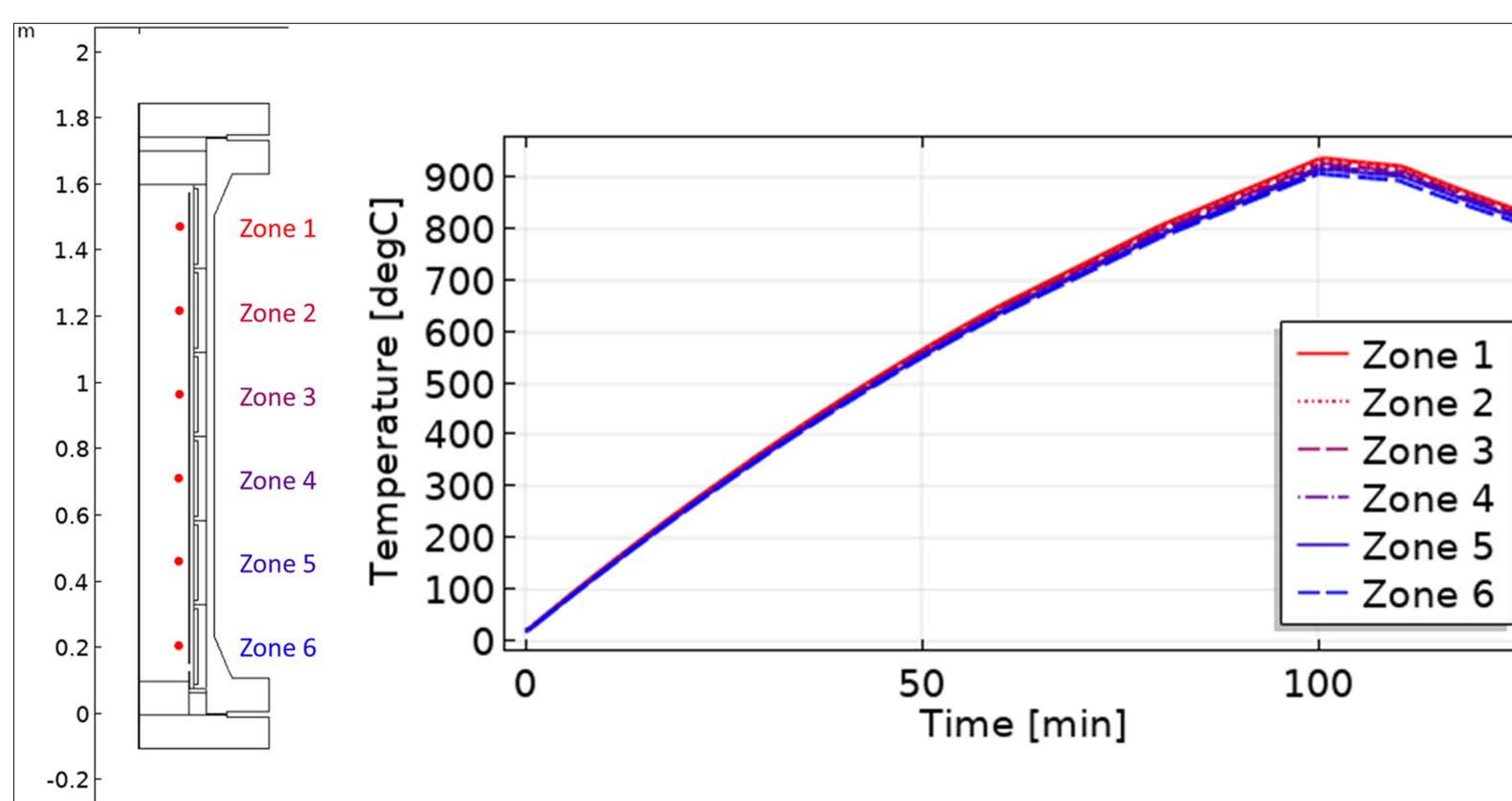

Figure 7. Computed temperature evolution of specific furnace zones

CONCLUSIONS: This analysis-led design ought to be quite robust. From Fig. 7, the available heating rate (6 C/min) and cooling rate (6.5 C/min) meet the requirements, and the temperature homogeneity is expected to be naturally good.

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