Modeling heat transfer and reaction energy of tungsten carburization in a pusher furnace

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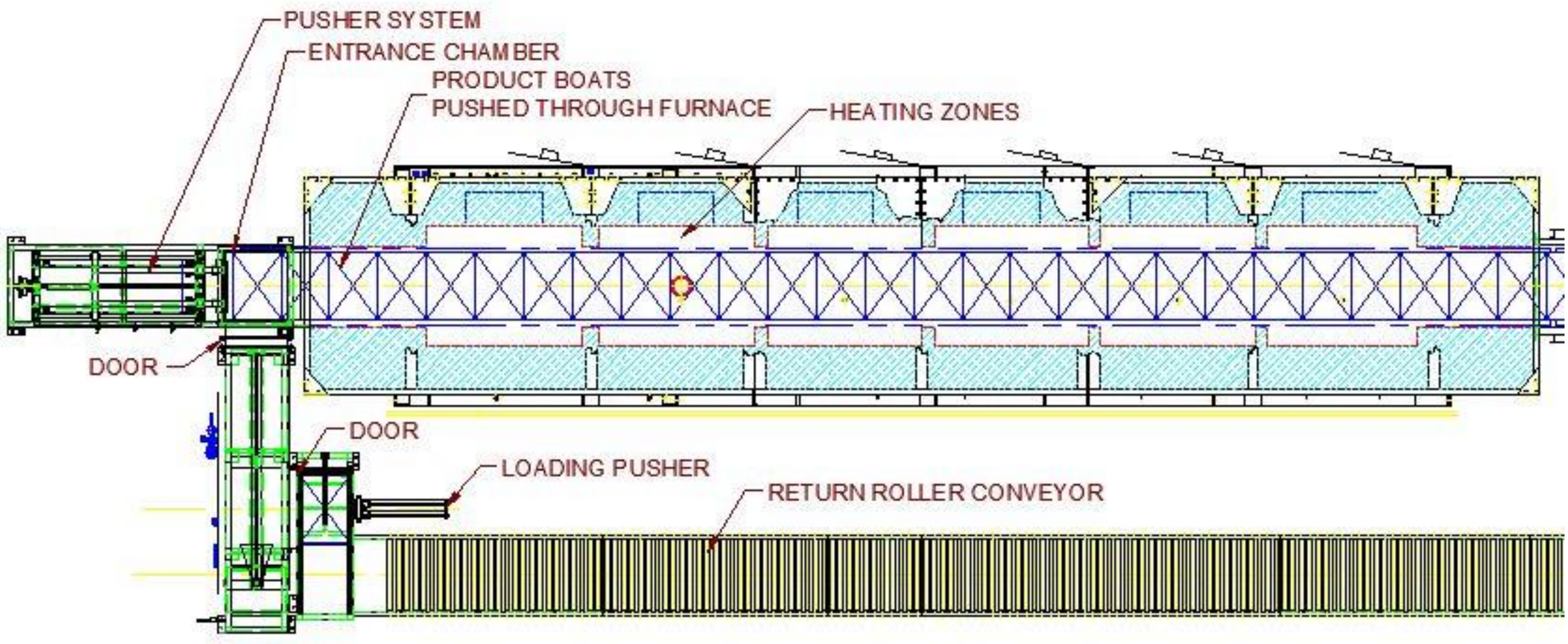
Introduction

Goals of heating of powders in a pusher furnace

- Estimation of range of powder bed properties
  - Predicted with minimal known properties
- Predict range of time to temperature for
  - Differing bed geometries
  - Range of powder density and particle sizes
  - Affects of atmospheres (hydrogen, Nitrogen, forming gas)
  - Affects of reaction energies

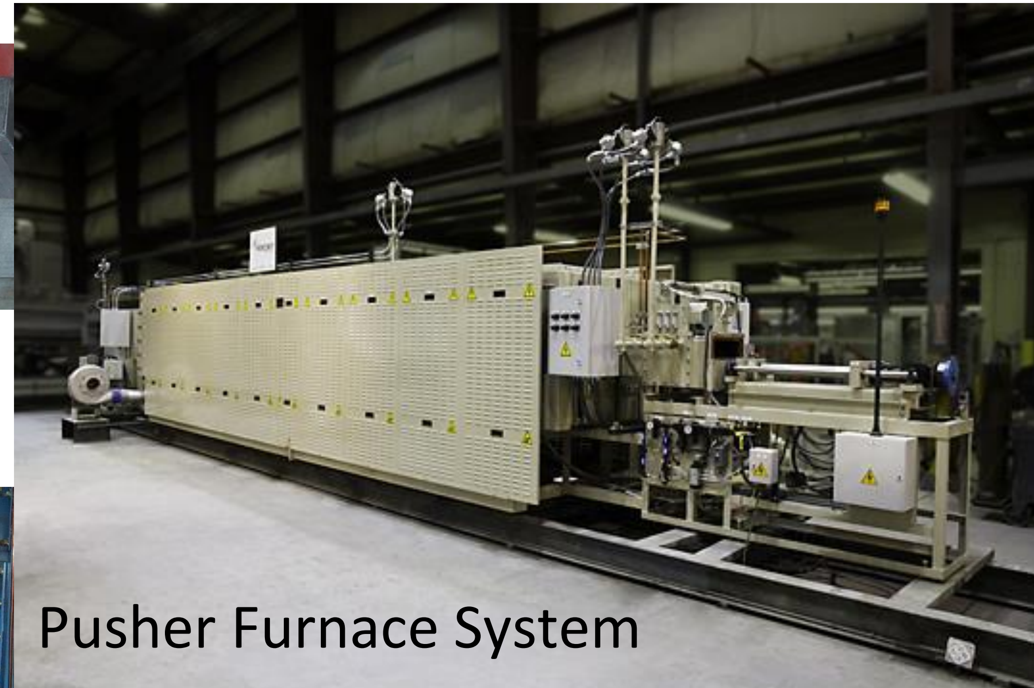
What is a "Pusher" Furnace

A "pusher" furnace is a continuous furnace which product containers (boats) are transported through the furnace by pushing the boats .

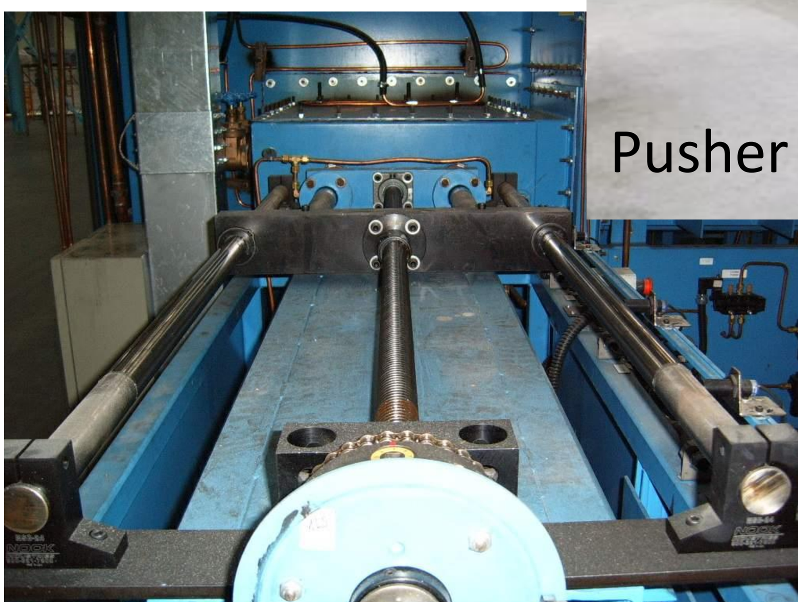


What is a "Pusher" Furnace

Product Boats



Pusher Furnace System



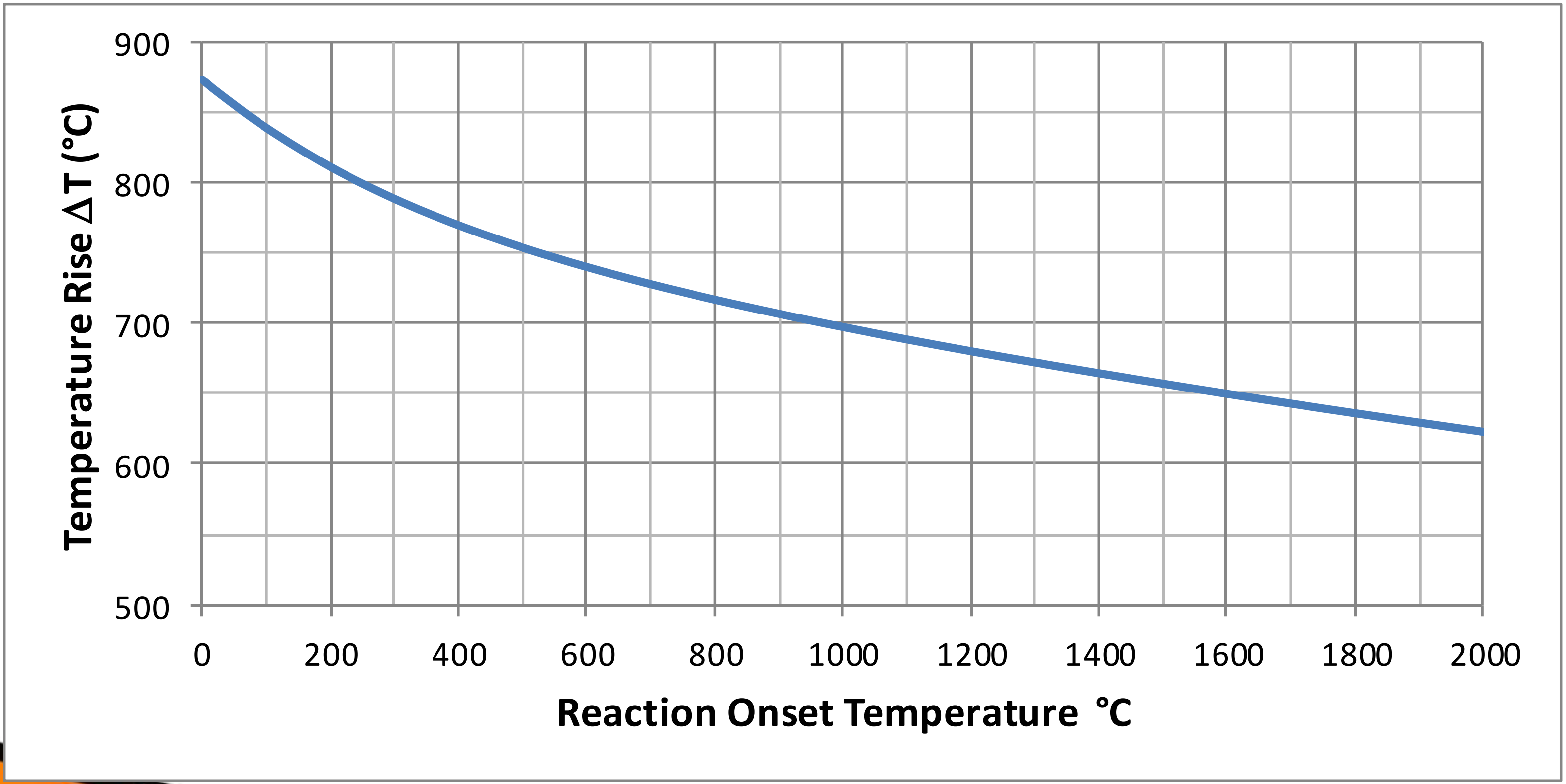
Main Pusher

W+C Exothermic Reaction

$W + C = WC \qquad \Delta H = -195$ kJ/kg WC

Change in enthalpy raises bed temperature ~750°C

Important factor in estimating bed temperature

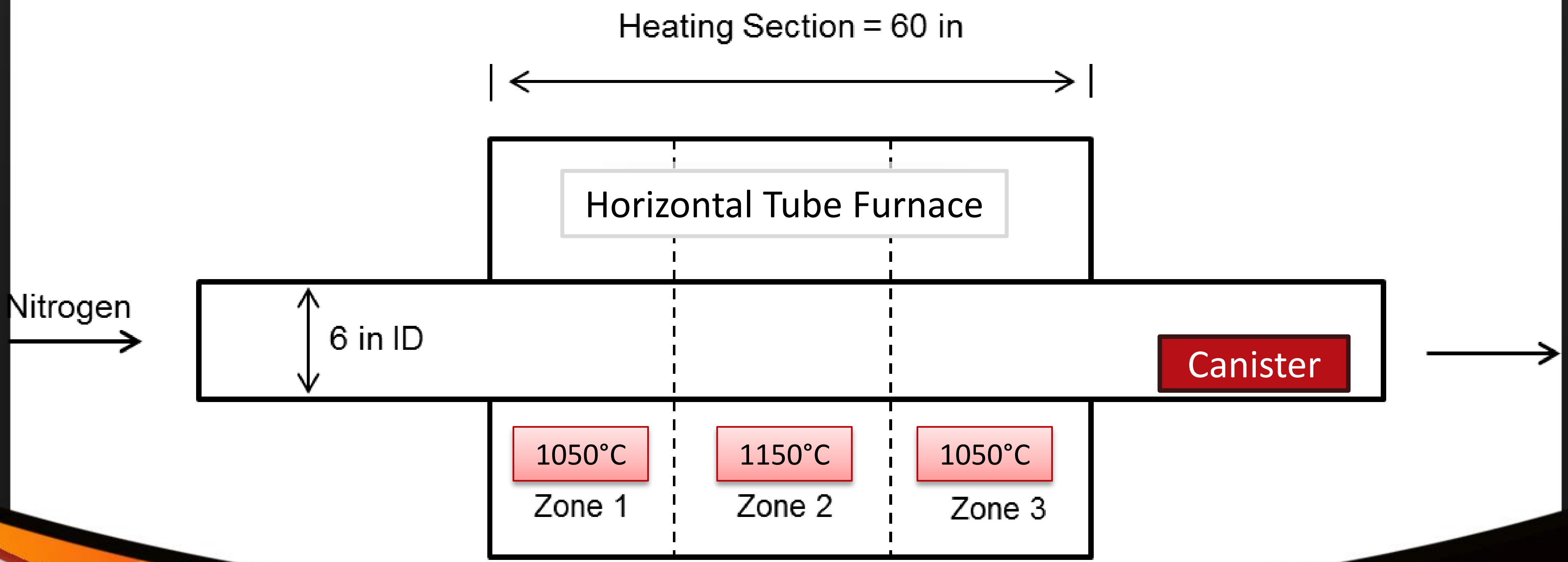


Experimental Setup

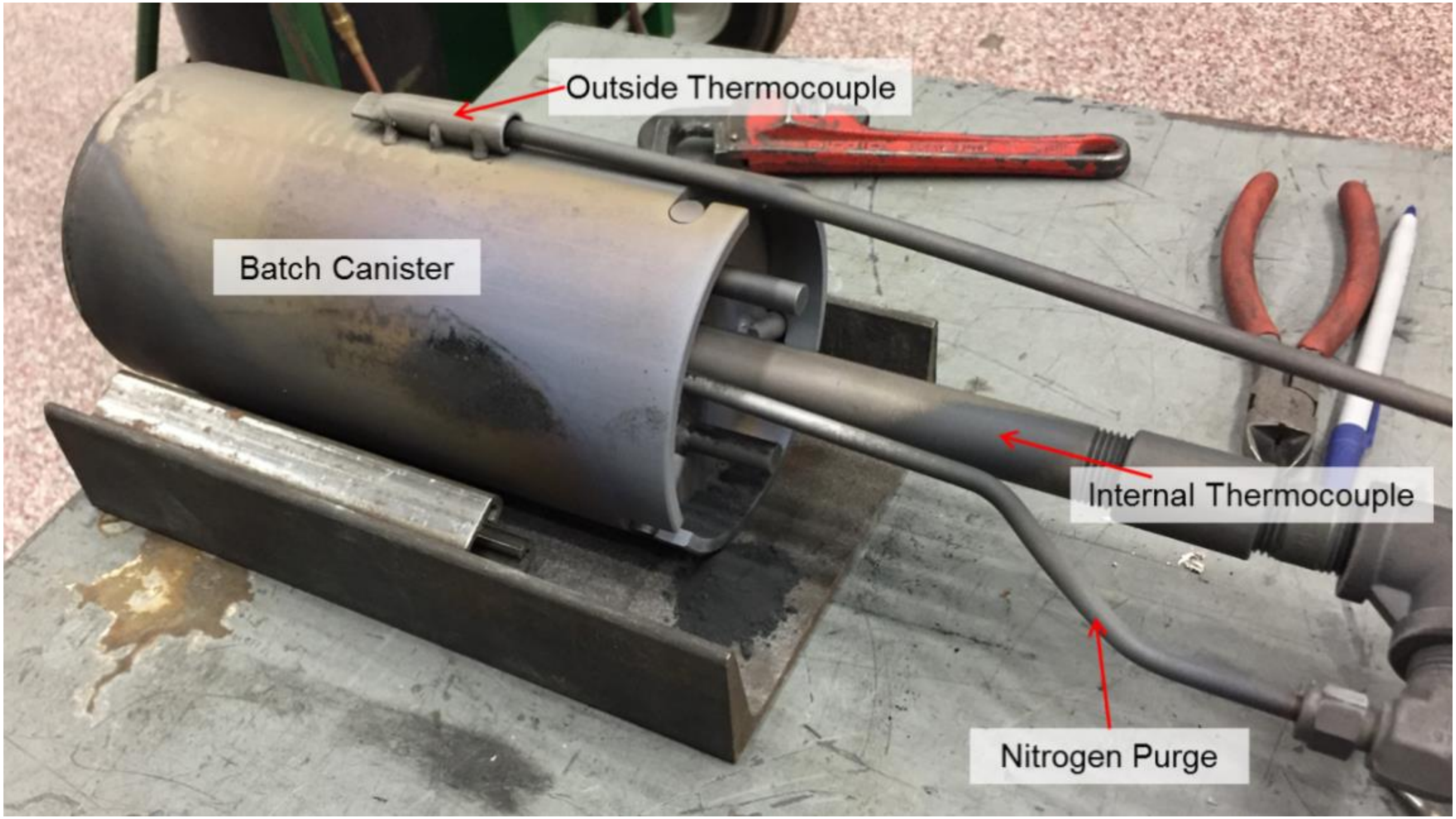
Sample Canister was inserted into Zone 2

Zone 2 temperature set to 1150°C.

Nitrogen flow through tube



Canister Instrumentation



Canister Instrumentation

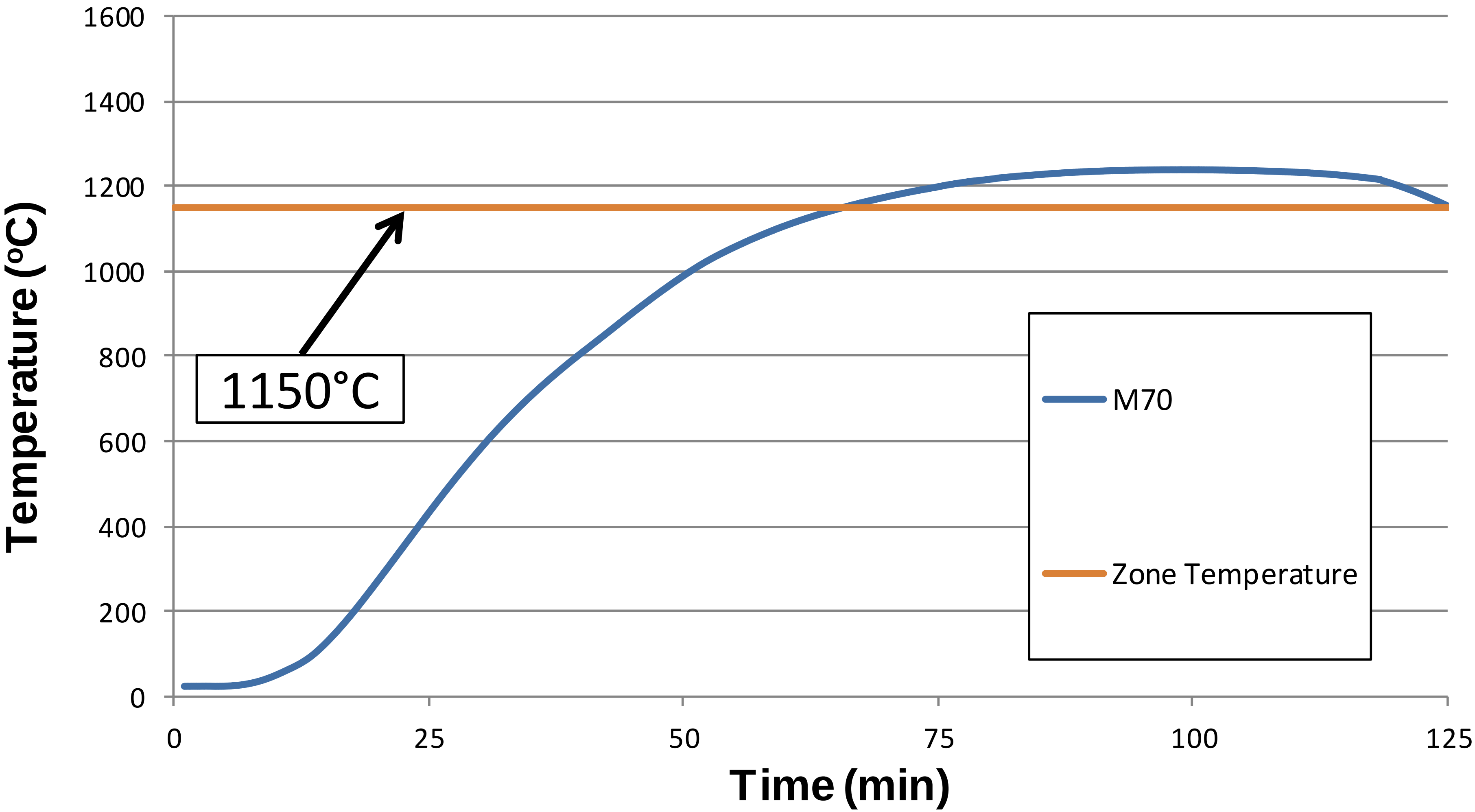
Canister Lid w/ Alumina Protection Tube

Canister Instrumentation

Experimental Setup

Trial	Material	Packing	Density	Temperature	Oxygen Content	Grain Size
#	—	—	g/mL	°C	—	µm
1	M70	Semi-loose	5.2	1150	Uncontrolled	➢ 17.5
2	M37	Semi-loose	4.2	1150	Uncontrolled	2.7 – 3.3
3	M55	Semi-loose	5.0	1150	Uncontrolled	4.7 – 5.5
4	M25	Semi-loose	4.6	1150	500 ppm	1.4 – 1.8
5	M25	Semi-loose	4.8	1150	1900 ppm	1.4 – 1.8

Experimental Results – M70



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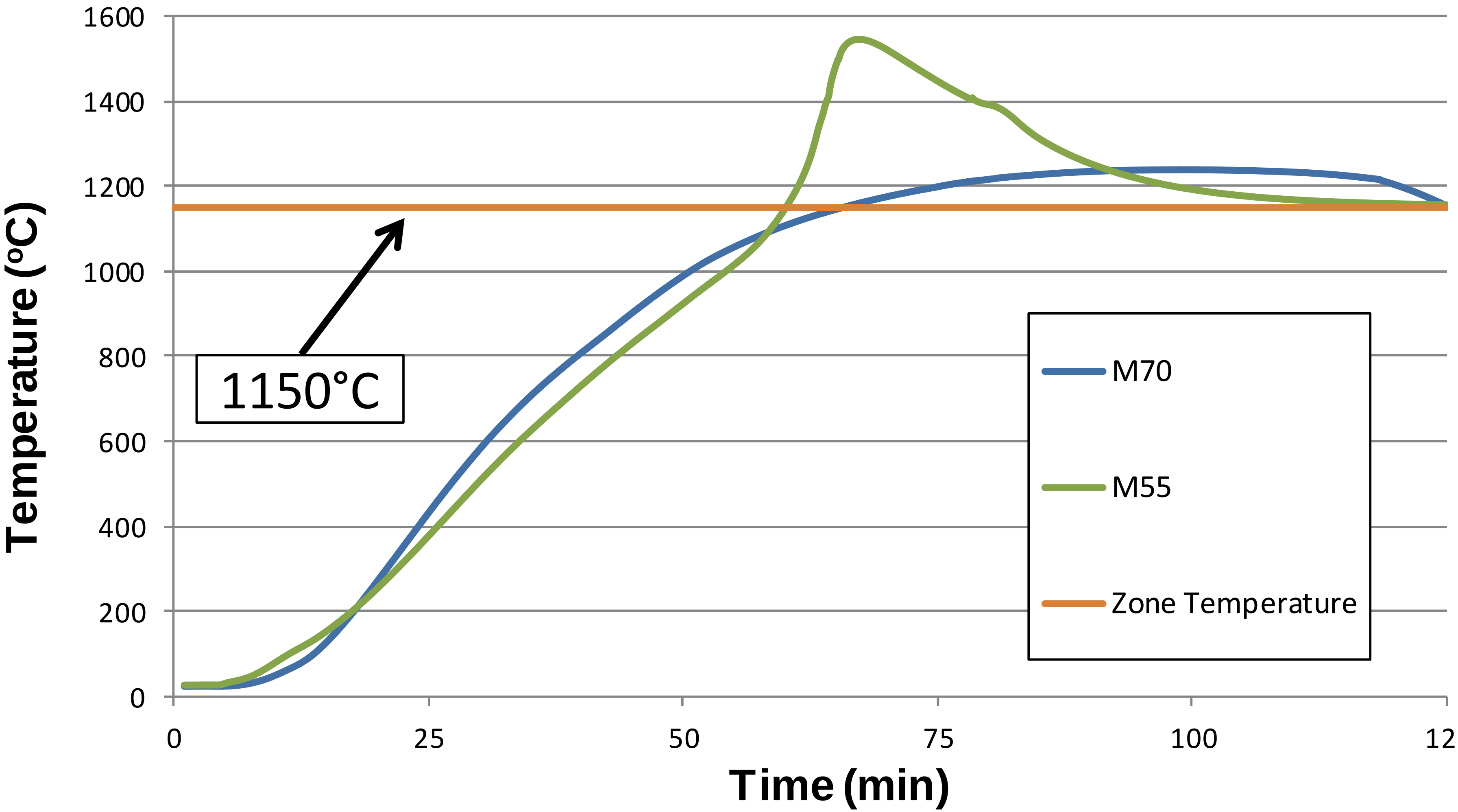
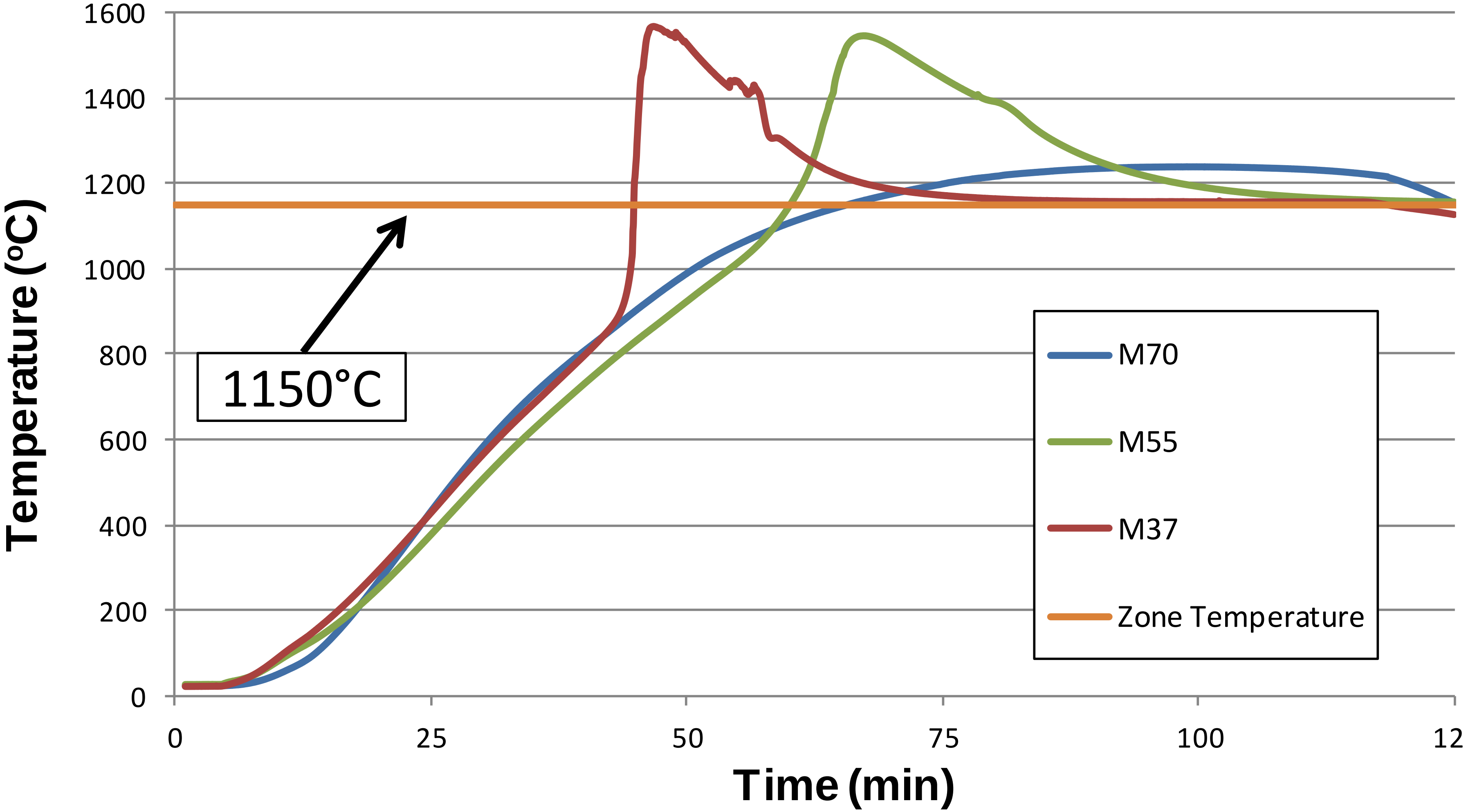
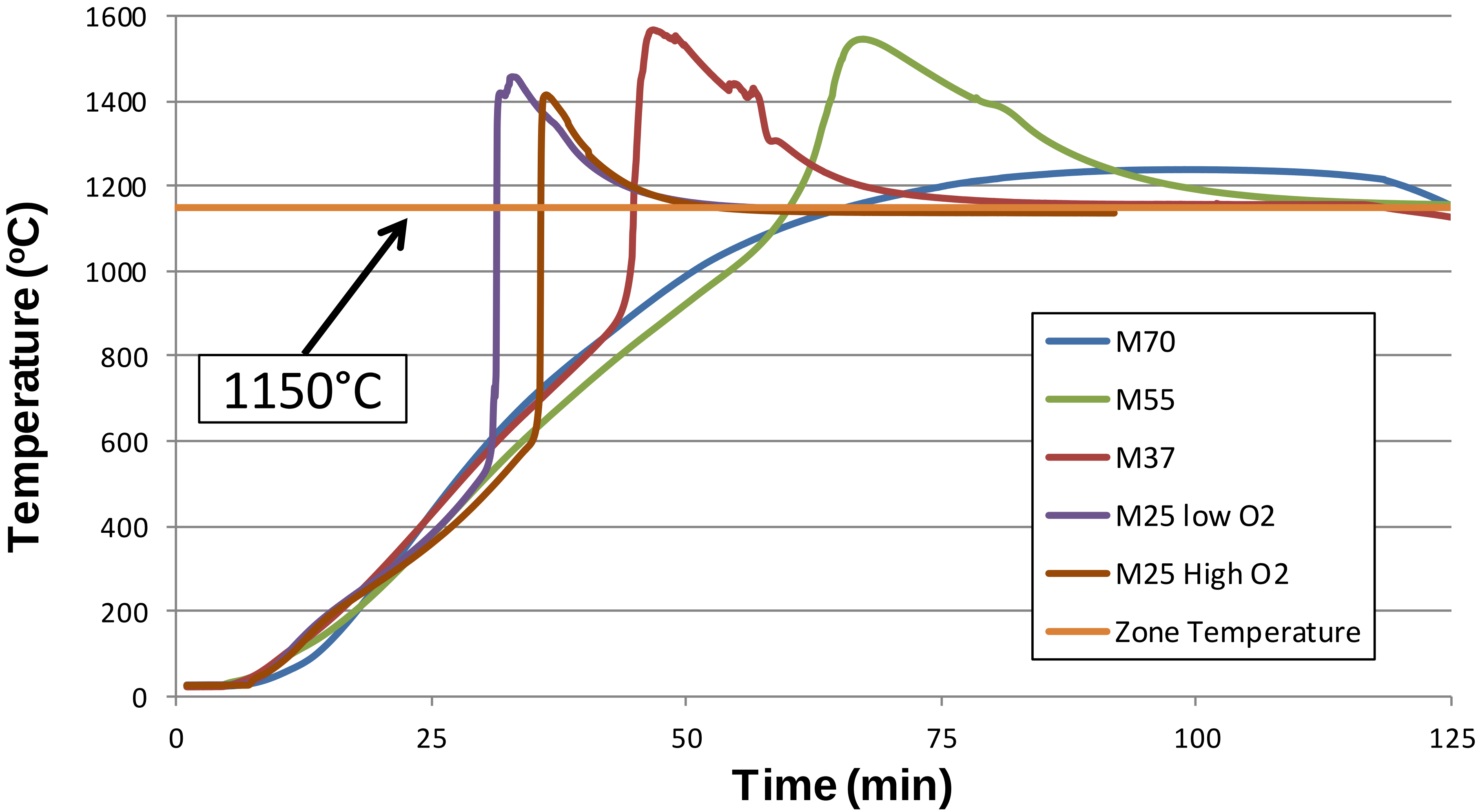
Experimental Results M70 M55



Experimental Results M70 M55 M37



Experimental Results – All Results



FEA model with Exothermic Reaction Lab Experiment Comparison

- Autodesk Simulation Mechanical FEA Package Utilized
  - FEA software cannot simulate chemical reactions
- Axisymmetric thermal model of Lab Experiment
- Material properties (specific heat, thermal conductivity) was take from previous work
- Reaction Modeling
  - Reaction onset was from the test data
  - Body heat was applied at a constant rate for a specified time period
- Transient analysis

Model of Thermal Conductivity of Powder

- The equations presented in Sih-Barlow where used for the thermal conductivity prediction.
- Model considered spherical particles.
- Significant affect of gas properties and particles sizes on conductivity

$$\frac{k}{k_g} = \left(1 - \sqrt{1-\varepsilon}\right)\left(1 + \frac{\varepsilon k_R}{k_g}\right) +$$

Free Fluid

$$\sqrt{1-\varepsilon}\left[\frac{2}{1-\frac{k_g}{k_s}}\left(\frac{1}{\left(1-\frac{k_g}{k_s}\right)}\ln\frac{k_g}{k_s} - 1\right) + \frac{k_R}{k_g}\right]$$

Core Heat Transfer

Reduced Model for spherical particles

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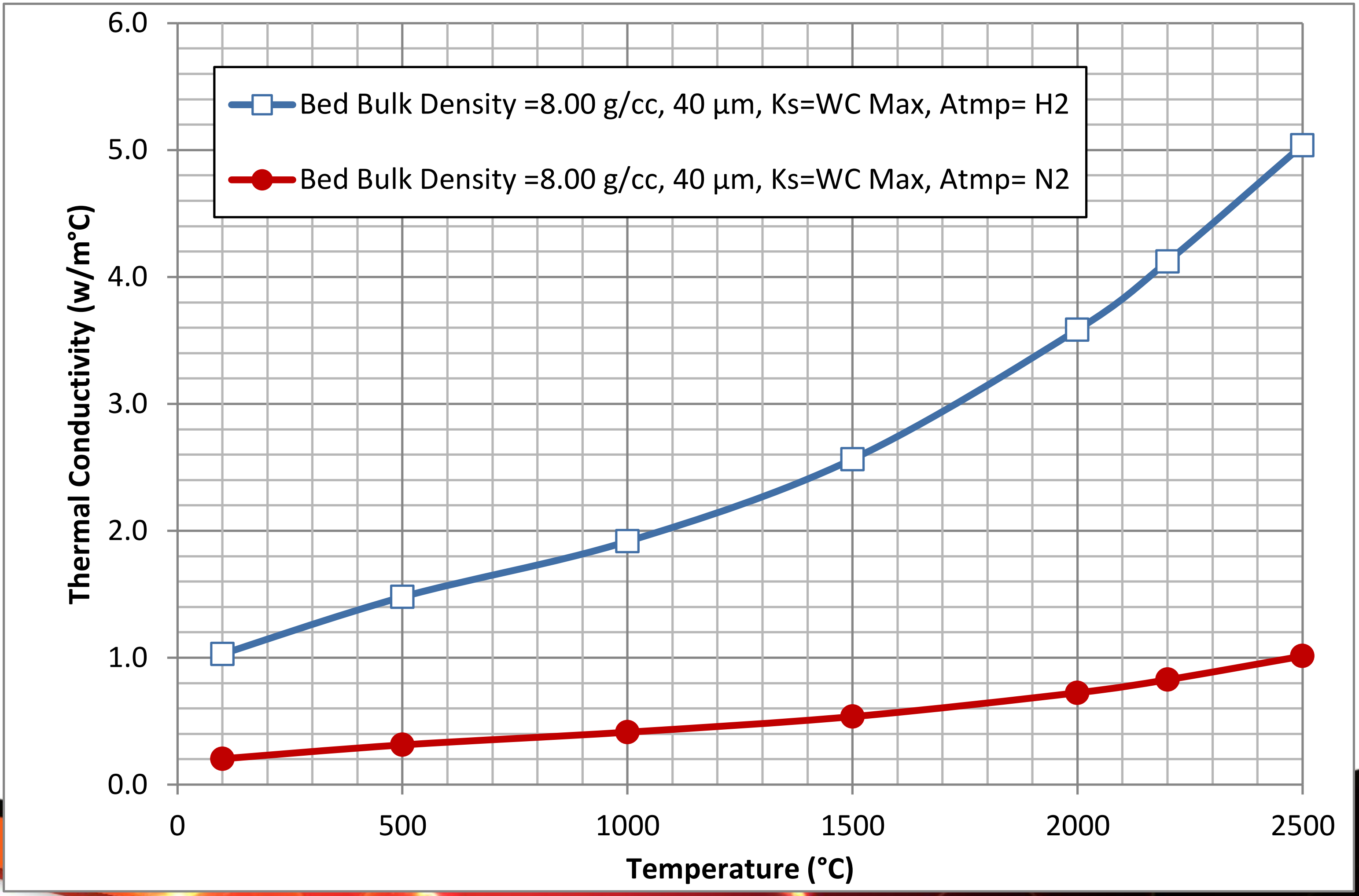
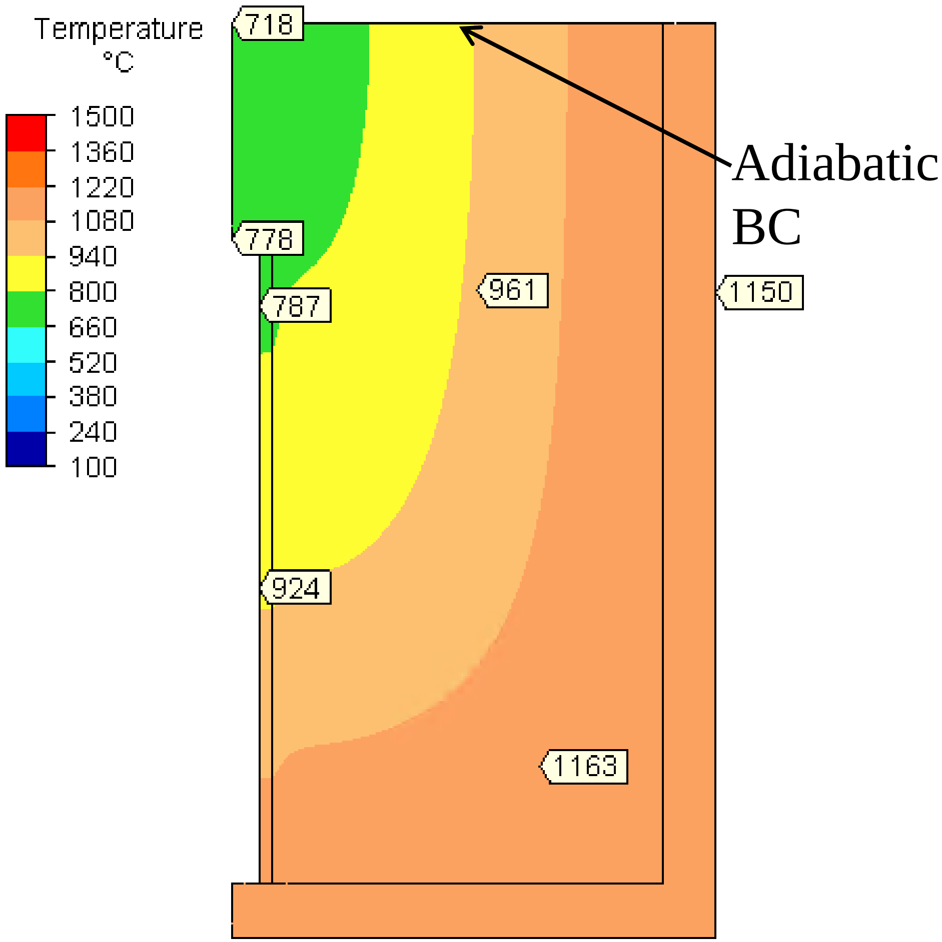
Powder Thermal Conductivity Predictions

- Model predicts increasing thermal conductivity with temperature
- H2 gas of ~7 to 10x greater than N2 → Affects bed conductivity



Results of FEA model with Exothermic Reaction

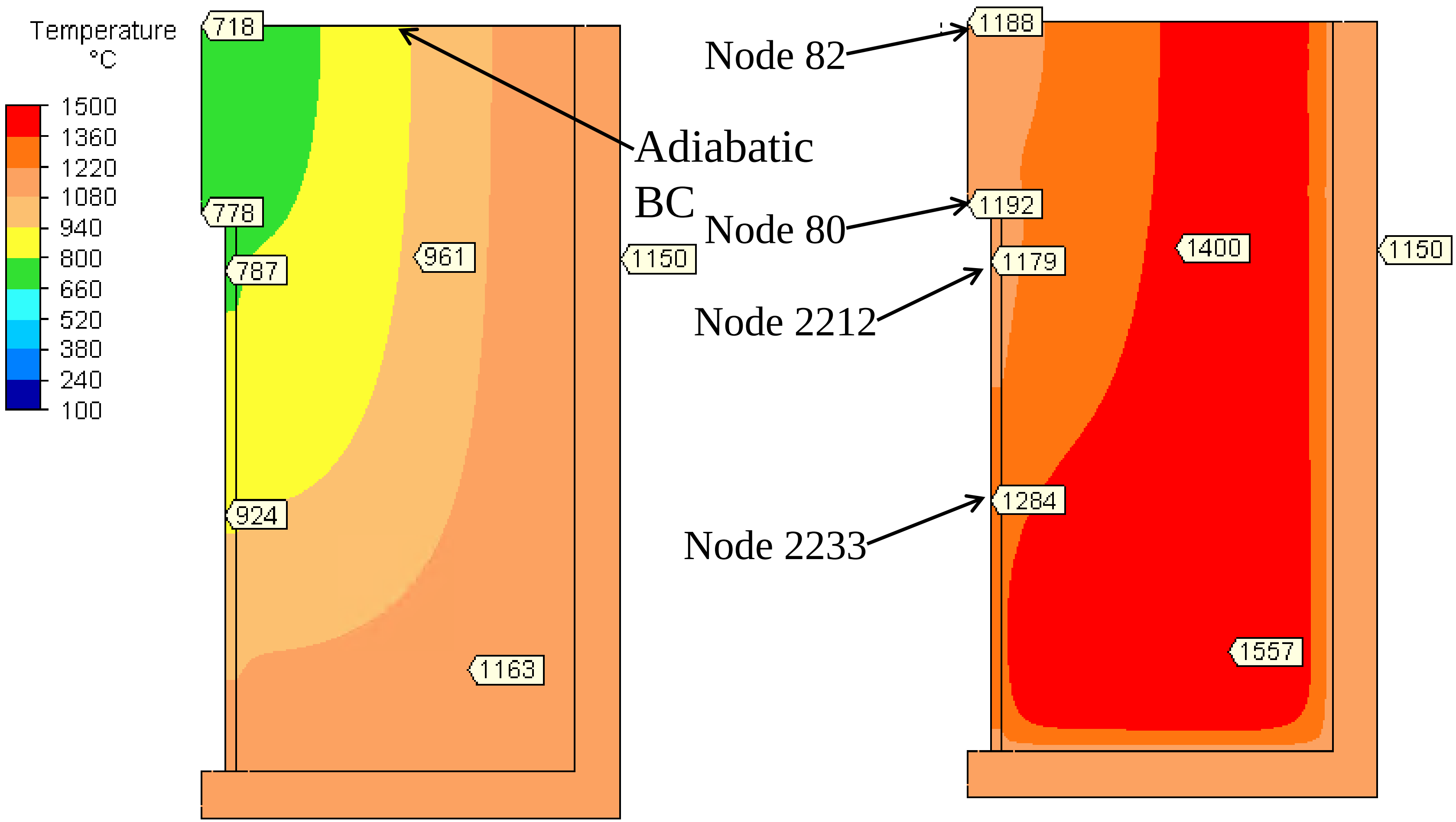


At 40 Minutes.

Just Prior to Exothermic Reaction

At 40 minutes the body heat generation applied to WC powder

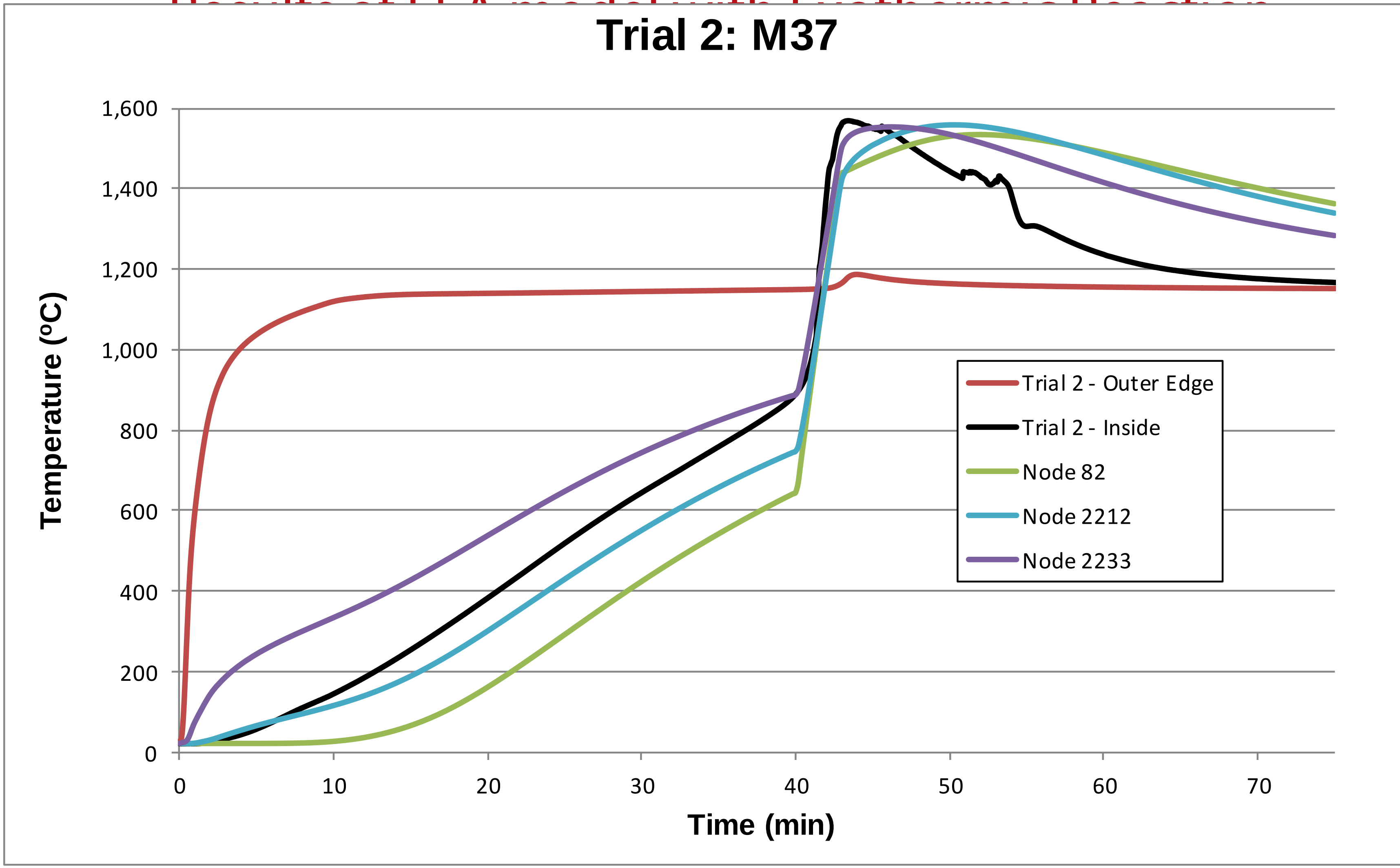
Results of FEA model with Exothermic Reaction



At 40 Minutes.
Just Prior to Exothermic Reaction

Temperature Profile at 42 Minutes.
During Exothermic Reaction

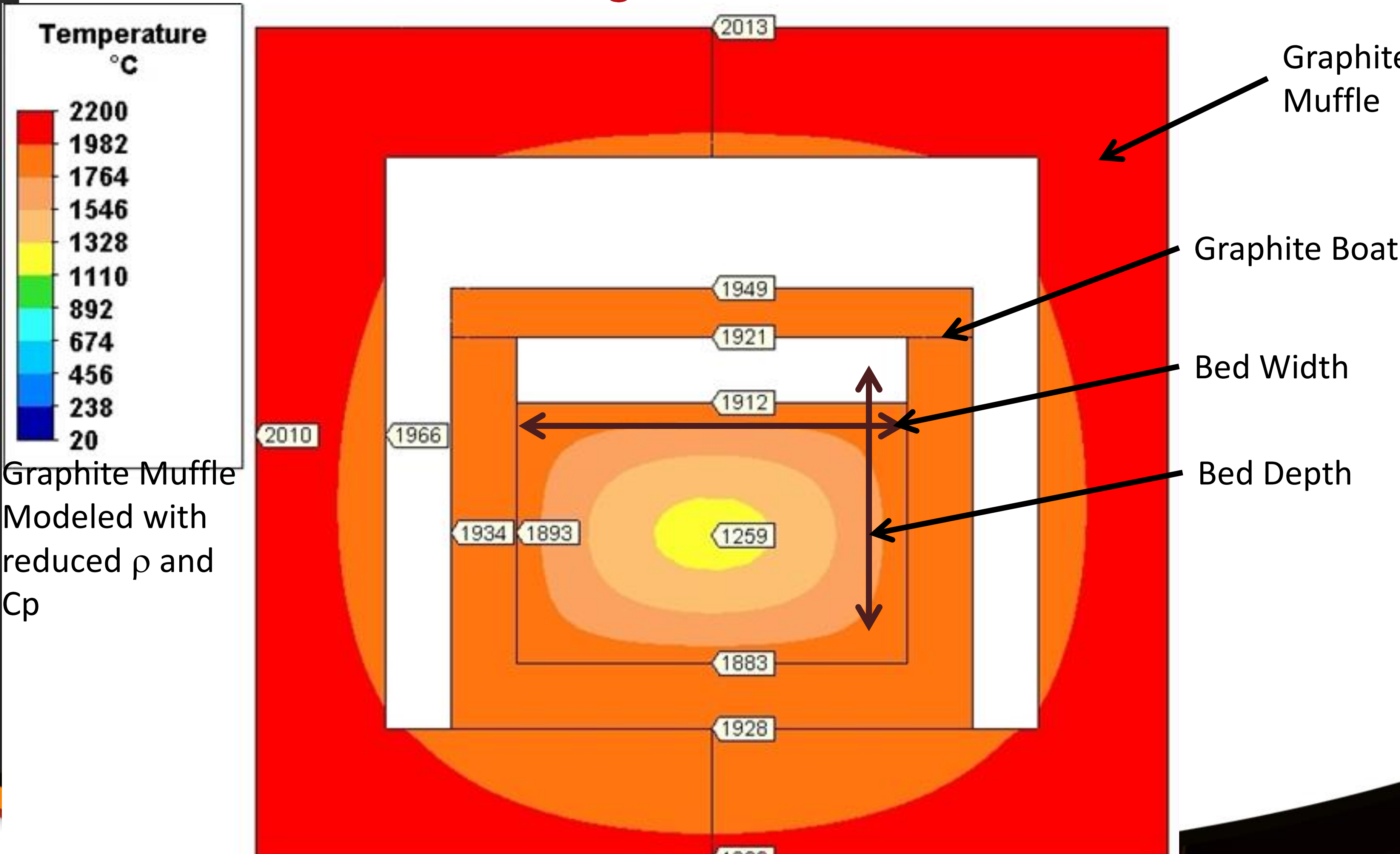
Results of FEA model with Exothermic Reaction



Transient Modeling of a Pusher Boat

- 2D model of the boat. Width and height.
- The boat and bed material move within the graphite muffle
  But 2D analysis without motion – how to accomplish?
- Graphite muffle does not move – no sensible heat.
  To simulate in 2D transient analysis reduced density and specific heat to very low values. → results in a quasi steady state model of the muffle during the transient analysis.
- Graphite boat and bed material with full density and specific heat behave as a transient

Modeling of a Pusher Boat

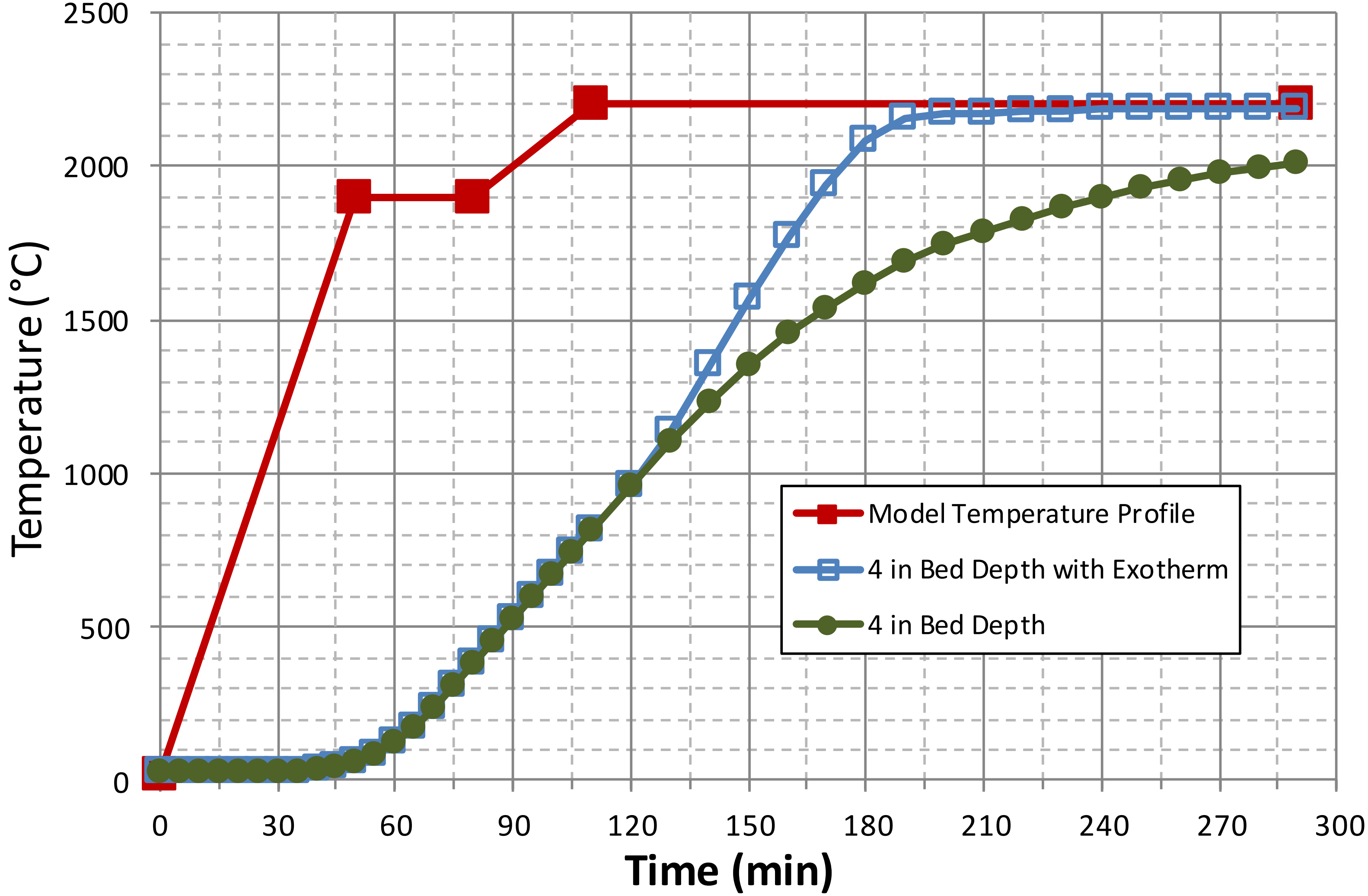


Graphite Muffle Modeled with reduced ρ and Cp

Additional of Exothermic Reaction

- N_2 Atmosphere
- A case of a 4" bed depth with a slow exothermic reaction was modeled
- Reaction start time of 120 minutes (~1000°C)
- Reaction duration of 60 minutes

Modeling of a Pusher Boat



Results for rectangular configuration

- Bed depth is controlling parameter for time to temperature
- The higher density, higher conductivity beds require more time to temperature
- Increasing width while managing the bed height can optimize the throughput
- 750°C increase in bed temperature results in faster time to temperature
- Reaction rate and onset need to be adjusted for each powder
- Experimental results suggest that reacted material has higher thermal conductivity than W+C material

Conclusions

- Minimal material properties can be used
  - To predict bed properties
  - To estimate process design parameters
- Reaction Energy
- Significant impact on time to temperature
- For modeling estimate of reaction energy and onset temperature are important
- Model predictions
  - Useful for boat geometry evaluation
  - Time to temperature prediction as well as temperature uniformity

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