Iron Fuel Cycle for Carbon-Free Coal Replacement

Noah Dollard[1], Thanai Papageorgiou[2], Echo St. Germain[3], Randall Erb[3]
Young Scholars Program Student, Winchester High School[1]
Young Scholars Program Student, Weston High School[2]
Department of Mechanical and Industrial Engineering, Northeastern University, Boston, MA, USA[3]

Abstract

The iron fuel cycle is being explored as an energy option for a sustainable future based on carbon free energy generation and storage. For iron to be a successful alternative more research into the variables which effect iron ignition need be explored.

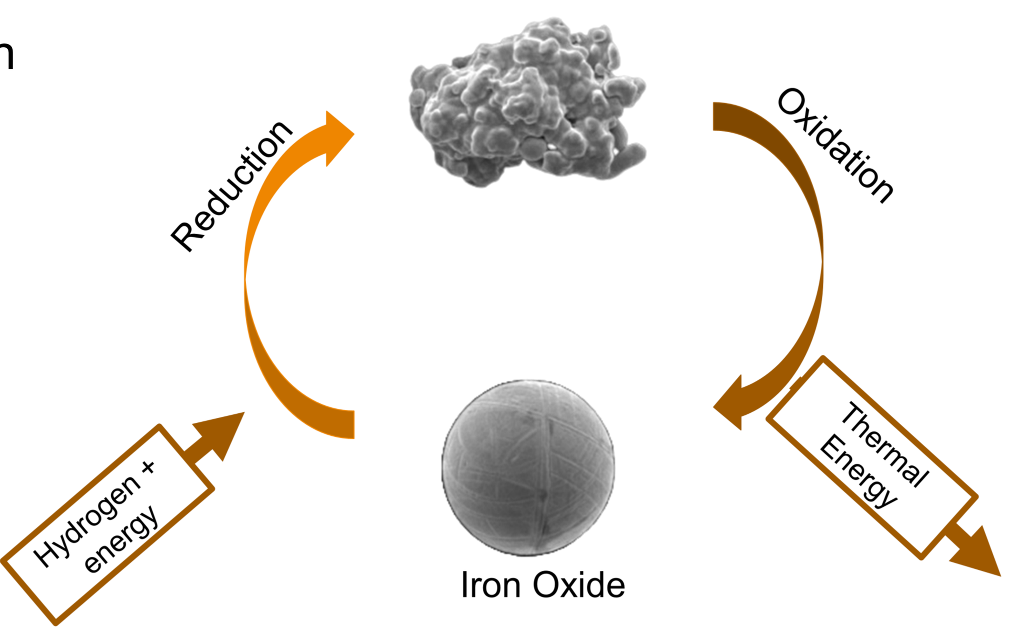
To improve the understanding of how oxidation can change the ignition properties of iron:
- ✓ Cross sections of samples were prepared for imaging by sanding and polishing pre-oxidized iron powder
- ✓ The minimum amount of time needed for each step while still achieving usable samples was investigated
- ✓ Powders collected from various furnace environments were analyzed using ImageJ to display changes in morphology
- ✓ Python code was written to correct thermocouple temperature readings, considering radiation for more accurate results
- ✓ Operating procedures for data analysis and sample preparation were created to the increase efficiency of future student training

This analysis of over 50 different samples aids in expanding researchers understanding of the sensitivity of iron as a fuel due to the formation of a solid oxide layer.

Background

Popular fuels, such as coal and oil, produce carbon emissions which contribute to climate change. While many low-carbon alternatives are currently being explored, issues with availability, transport, and cost limit their immediate viability.

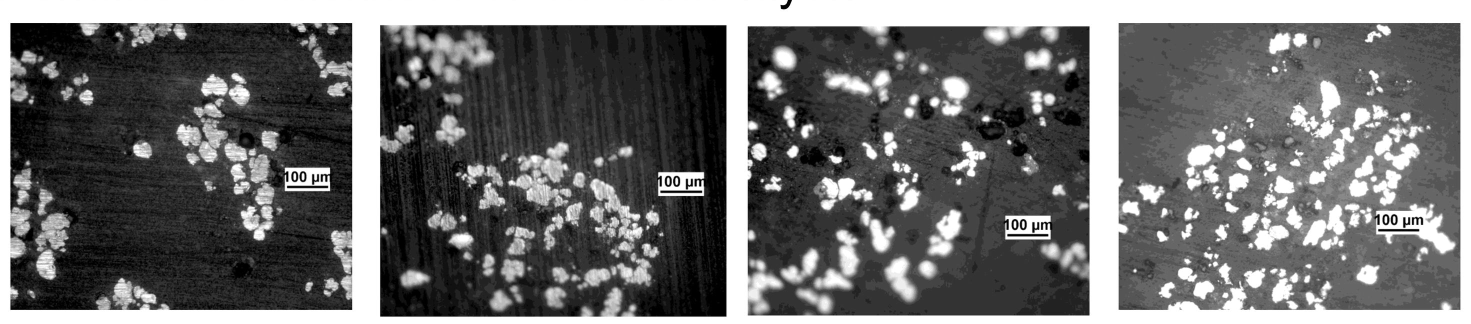
As a result, researchers are investigating metal fuels such as such as silicon, aluminum, and iron. Iron specifically is abundant, safe to transport, and can be recycled from iron oxides back to iron resulting in a relatively sustainable fuel cycle.



Visualization of iron fuel cycle

Sample Preparation

Preparation of cross sections expose the inside of iron particles and creates a flat surface for Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectrometer (EDS) which enables elemental analysis. This process identifies the materials in the sample and can be used to determine the thickness of the oxide layer.

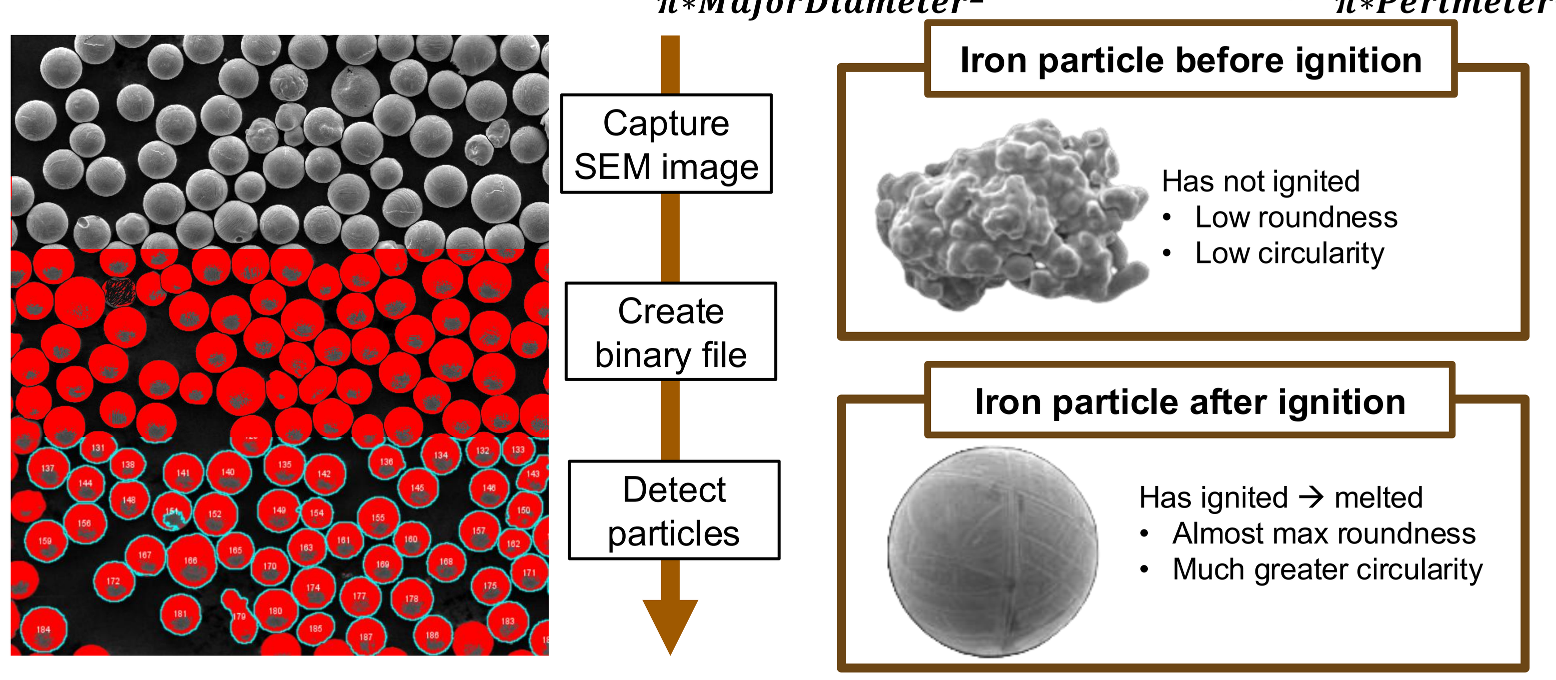


The samples were sanded with increasing grit sizes to decrease the scratch sizes. After the polishing step scratches should not be visible using a light microscope but may still be visible with SEM.

Analyzing Morphology

Analysis using ImageJ outputs important morphological values.

Key values include roundness: $\frac{4*Area}{\pi*MajorDiameter^2}$ and circularity: $\frac{4*\pi}{\pi*Perimeter^2}$



Thermocouple code

When temperature data is collected from the furnace thermocouple readings aren't accurate due to radiation from the walls of the furnace. Code that uses the below formula based on previous research to the correct values was written [1].

$$\rho C_p V\left(\frac{dT_b}{dt}\right) = Q_{convection} + Q_{radiation} + Q_{catalysis} + Q_{conduction}$$

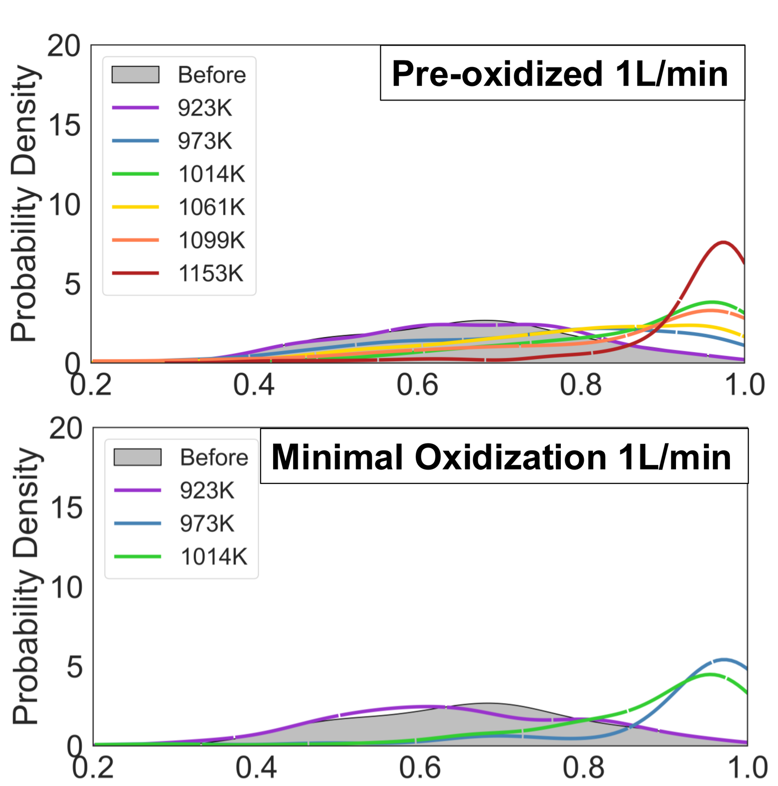
$\frac{dT_b}{dt}$ stands for the change of temperature in the thermocouple over time, which remains constant, so 0 can be substituted for the left side. The heat transfer coefficient is dependent on gas temperature, which is unknown.

$$Q_{convection} = h * A_b * T_{gas} - T_b$$
$$Q_{radiation} = \sigma * \varepsilon_b * A_b * T_w^4 - T_b^4$$

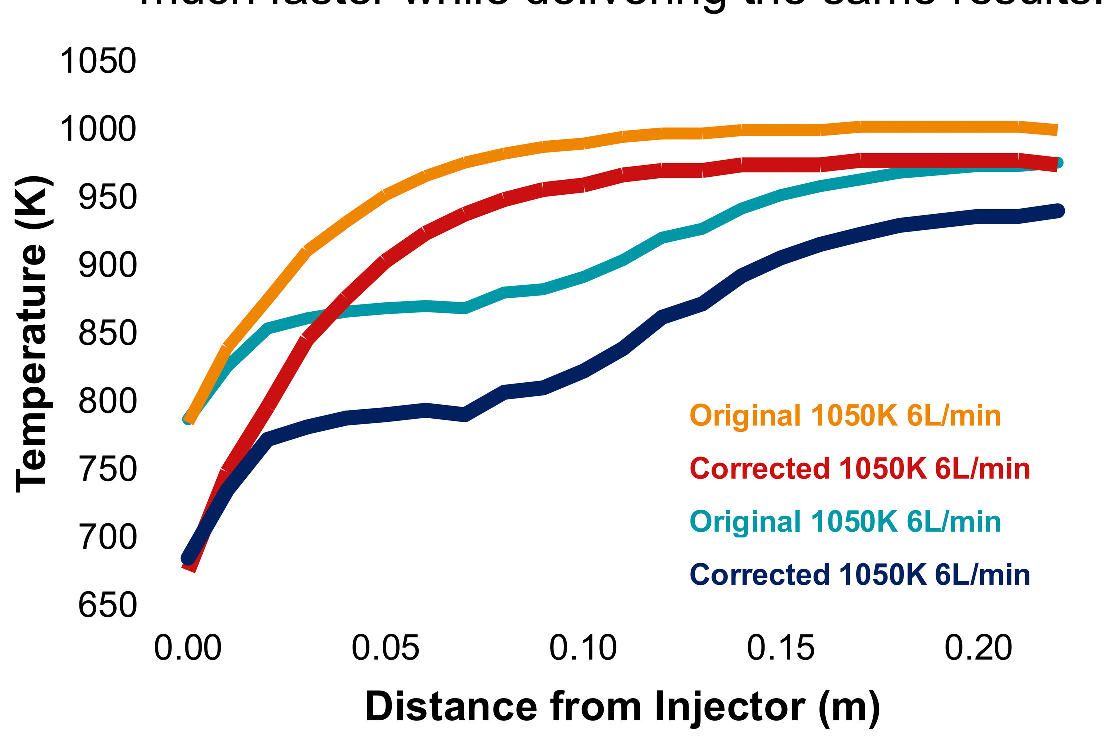
- h: heat transfer coefficient($\frac{W}{m^2K}$)
- A_b : area of thermocouple bead(m^2)
- T_{gas}: estimation of gas temperature(K)
- T_b: thermocouple bead temperature(K)
- σ = Stefan-Boltzmann constant ($\frac{W}{m^2K^4}$)
- ε_b: emissivity
- T_w: wall temperature(K)

Results

Images were analyzed for 50+ experiments with variations in factors such as furnace temperature, airflow, roundness, and pre-oxidation.

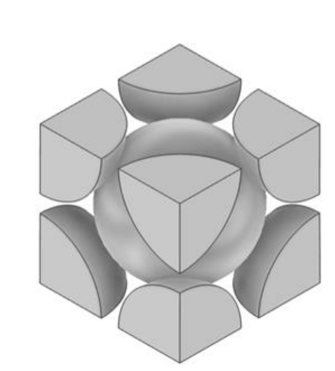


So far Python code for was used to correct temperature values for 20+ furnace profiles. The program was compared to previous Excel methods of correcting temperature and is much faster while delivering the same results.

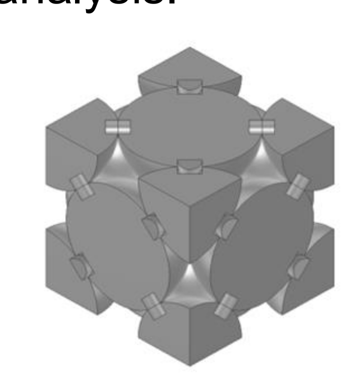


Next Steps

The thermocouple code will be used to increase efficiency for correcting furnace temperatures, and the SOP's created for sample preparation and data analysis with ImageJ will guide future researchers assisting with research and data analysis.



Body Center Cubic



Face Center Cubic

Magnetic 3D printed crystal lattices were designed and will be used in undergraduate material science classes to help explain crystal structures, which ties into the material science nature of this research project.

Citation

[1] P. A. Bejarano and Y. A. Levendis, "Single-coal-particle combustion in O2/N2 and O2/CO2 environments," Combustion and Flame, vol. 153, no. 1–2, pp. 270–287, Apr. 2008, doi: https://doi.org/10.1016/j.combustflame.2007.10.022.

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