Erosion Experimentation in Solar Power Systems

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Renewable Energy

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Introduction

- Concentrating solar-thermal power systems use mirrors to reflect sunlight onto a receiver in a tower
  - Heat exchanger in tower to convert solar energy to heat and store in gas, liquid, or particle medium
  - Allows for solar power on-demand
- US Department of Energy wants to:
  - Improve efficiency
  - Decrease overall cost
- Can use particles to thermally store the heat created by solar energy[1]
- Increasing the thermal storage temperature to greater than 700℃ can increase the efficiency of electricity production but can also create other problems[2]

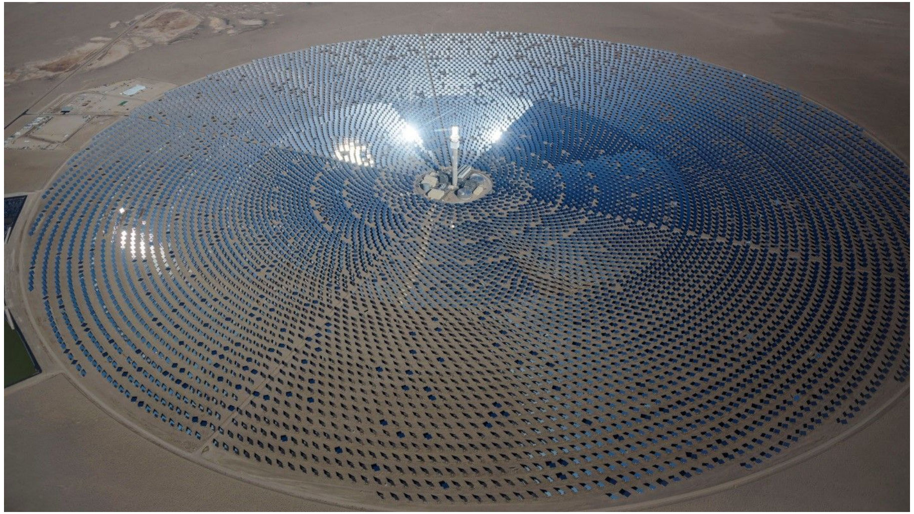

Figure 1: Concentrating solar power system.

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Objective

- Develop an effective testing method to measure (in relevant conditions) [3]
  - Degradation of particle-to-particle interactions
  - Degradation of particle-to-specimen interactions
- Testing occurs for comparison
  - At room temperature
  - At 800℃
- Evaluate changes in optical properties of particles and specimen by the use of 800℃ temperature only.
- Develop computational durability model to predict rates of particle and specimen erosion based on physical and mechanical properties.

Methods: Attrition

- Particle breakdown occurring by particle-to-particle contact in the system
- Motorized shaft rotates a steel disk
  - Rotation of disk turns the particles at a speed of ~1.8 cm/s
  - Particles rub against each other and on the steel disk
- Particles run for total ~350 hours
  - 24 hours of testing in lab is equivalent to ~3,900 hours of real time operation in a 1 MW concentrating solar power plant
- Particle size distribution measured throughout experiment
- In 800℃ experiment, additional particles thermally cycled to compare between particles
  - Can measure the effect of temperature and attrition on particle optical properties

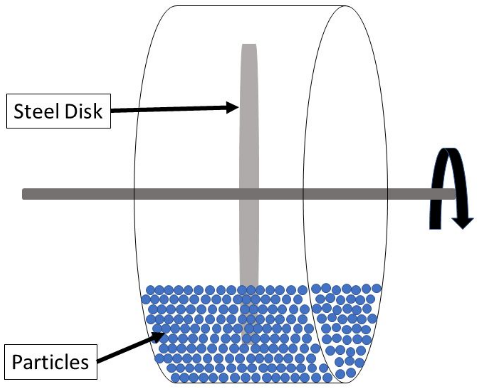

Figure 2: Sketch of attrition set up.

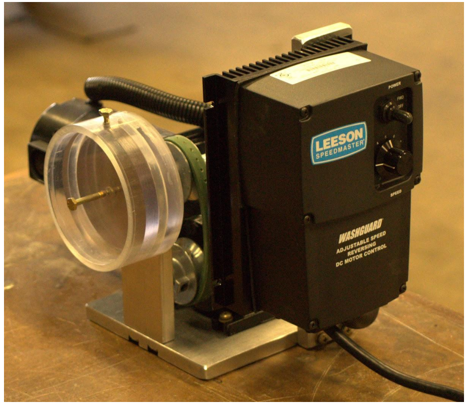

Figure 3: Room temperature attrition experiment.

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Methods: Abrasion

- Abrasion wear of specimen materials due to particle contact
- Analogy: Similar to material removal by sandpaper, where the particles are the sandpaper, and over time the sandpaper can remove material from the specimen surface
- Shaft rotates the specimens at 1.8 cm/s
  - Specimen turning the specimen in and out of a bed of particles
- Specimen weighed to see change in mass to determine the abrasion wear
- In 800°C experiment, a set of specimen are set inside the kiln to measure the effect of temperature and abrasion on specimen optical properties due to only oxidation

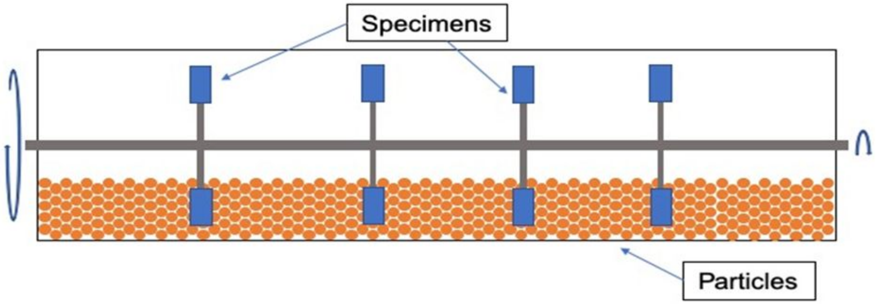

Figure 4: Sketch of abrasion set up.

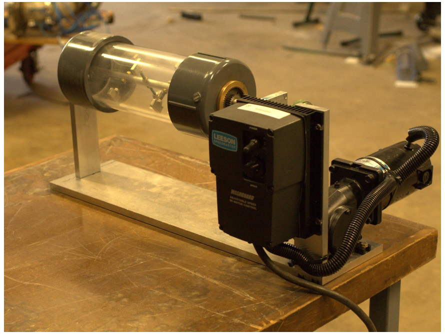
Figure 5: Room temperature abrasion experiment.

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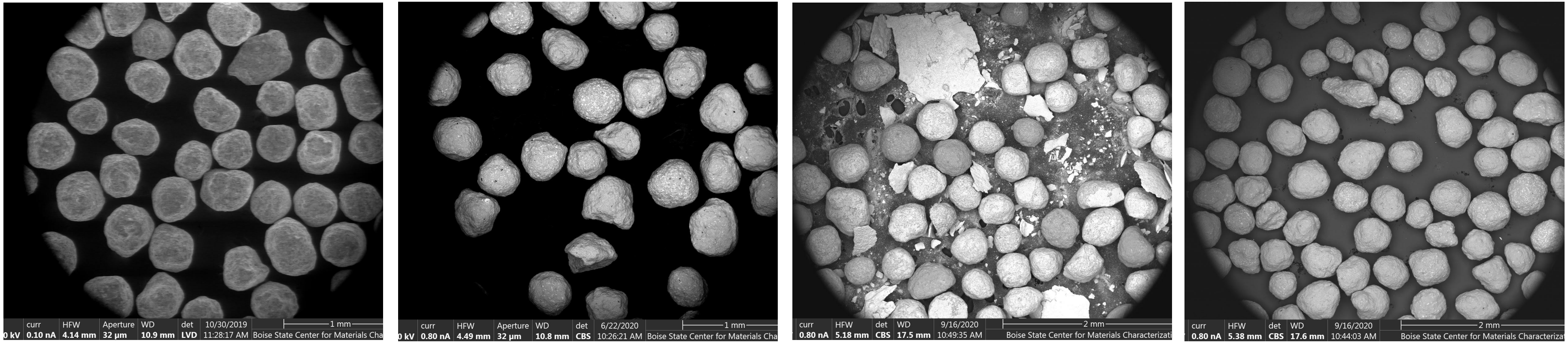
Results: Attrition with CARBOHSP Particles

- Scanning electron microscope (SEM) images were taken to show the particle break down



(a) (b) (c) (d)

Figure 6: SEM images of high grade CARBOHSP particles at (a) before testing, (b) after 354 hours of testing at room temperature, (c) after 123 hours of testing at 800℃, (d) thermally cycled only after 123 hours of testing at 800℃.

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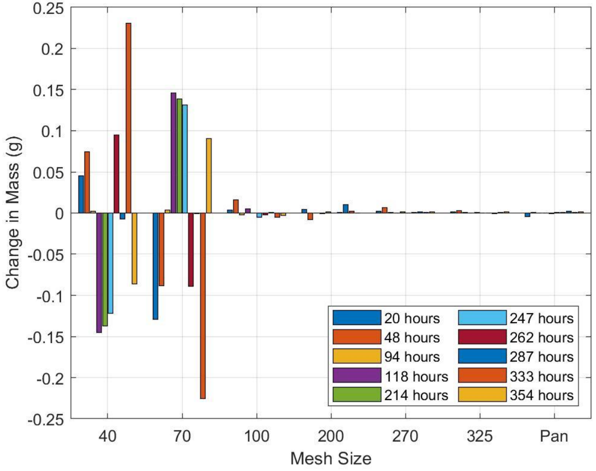
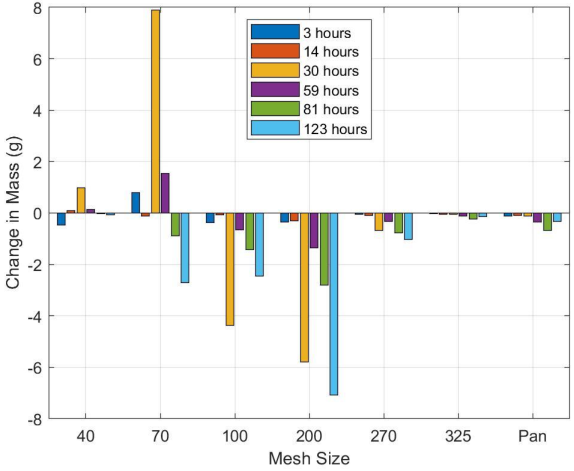
Results: Attrition with CARBOHSP Particles

- Sieving the particles determined a particle size distribution for each test
- Amount of ‘pan’ sieve for 800°C test (Fig 5b) increased over time, potentially due to oxide mixed in with particles



(a)



(b)

Figure 7: Graph of the change in mass based on sieve size for (a) room temperature and (b) 800°C temperature.

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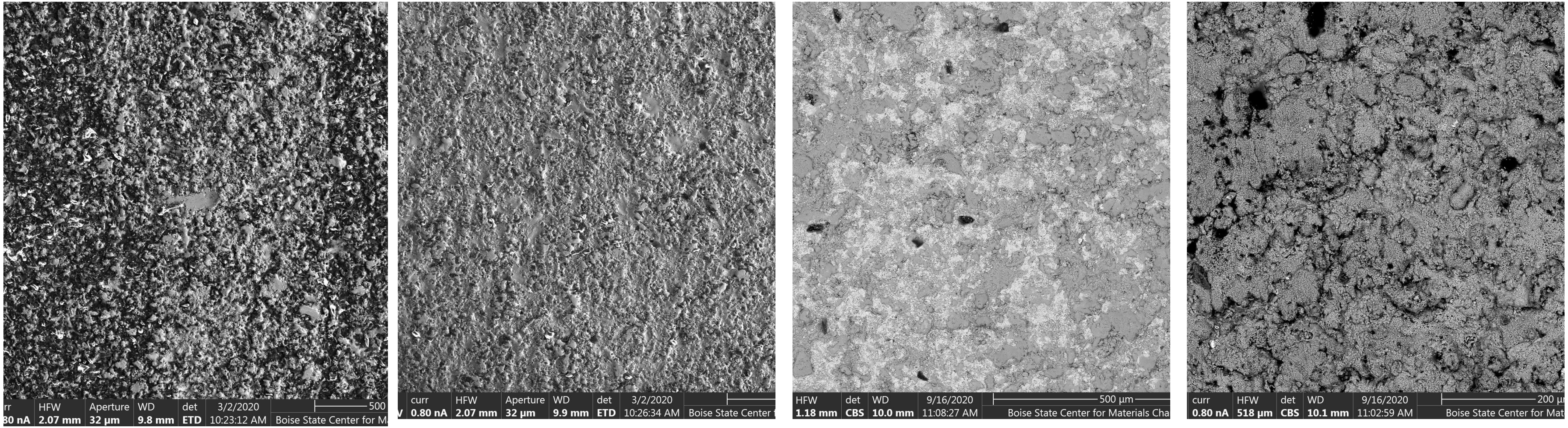
Results: Abrasion with Haynes Alloy & Silica Quartz Particles

- SEM images were taken on the haynes alloy to see wear that abrasion caused



(a) (b) (c) (d)

Figure 8: SEM images of haynes alloy (a) before testing, (b) after 350 hours of testing at room temperature, (c) after 123 hours of testing at 800℃, (d) oxidation only haynes after 123 hours of testing at 800℃.

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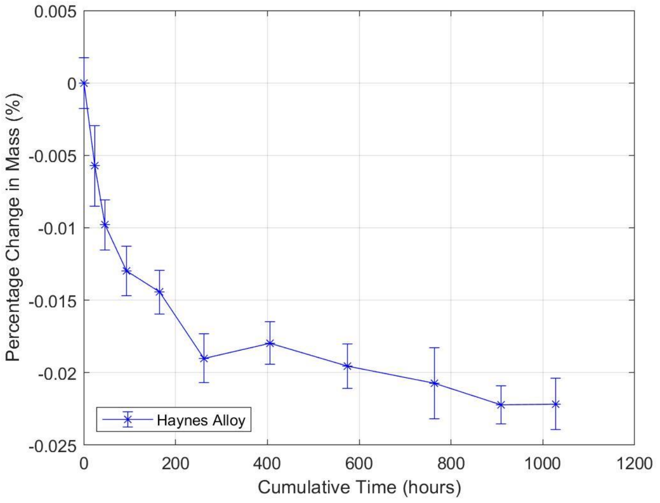
Results: Abrasion with Haynes Alloy & Silica Quartz Particles

- For 800°C (Fig 7b) the haynes alloy oxidation only increased in mass, which could be because a build up of oxidation on the surface.



(a) (b)

Figure 9: Graph of percentage change in mass of haynes alloy for (a) room temperature and (b) 800°C temperature.

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Conclusions

- Attrition
  - Particle breakdown increases as the amount of time increases.
    - Most visible in the 800℃ test.
  - Particles extracted from the 800℃ tests had oxide (size<40um) mixed in the particles.
  - Particle breakdown is believed to be due to changes in mechanical properties from thermal cycling.
- Abrasion wear increases with an increase of temperature.
  - Effects of temperature varied, depending on the material.
  - Mass increase of oxidation only specimen that could be because a build up of oxidation on the surface.
  - The increase in abrasion wear is believed to be from the exfoliation oxide layer, and the sharp drop refers to the majority of the oxide layer leaving.

Future work

- Continue testing and evaluating more particles and specimen for both attrition and abrasion experiments at both room temperature and 800℃.
- Create a durability model
  - Predicts attrition & abrasion based on mechanical properties

Preliminary work indicates this method of utilizing particles would **impact** concentrated solar power systems by **improving efficiency** and **decreasing overall costs**.

References

[1] ”Concentrating Solar-Thermal Power,” The Office of Energy Efficiency and Renewable Energy. 2020. https://www.energy.gov/eere/solar/concentrating-solar-power.

[2] Ho, C. K., Christian, J. M., E. Yellowhair, J., Armijo, K., Kolb, W. J., Jeter, S., Golob, M., and Nguyen, C., 2019, “On-Sun Performance Evaluation of Alternative High-Temperature Falling Particle Receiver Designs,” J. Sol. Energy Eng., **141**(1).

[3] Baumann, T., and Zunft, S., 2015, “Properties of Granular Materials as Heat Transfer and Storage Medium in CSP Application,” Sol. Energy Mater. Sol. Cells, **143**, pp. 38–47.

Acknowledgments

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1 Boise State University, Thermal Transport and Solar Energy Laboratory
2 The University of Tulsa, Erosion Corrosion Research Center