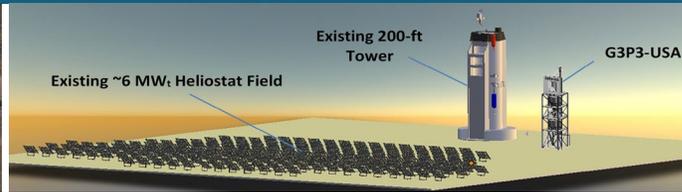




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EFFECT OF QUARTZ APERTURE COVERS ON THE FLUID DYNAMICS AND THERMAL EFFICIENCY OF FALLING PARTICLE RECEIVERS

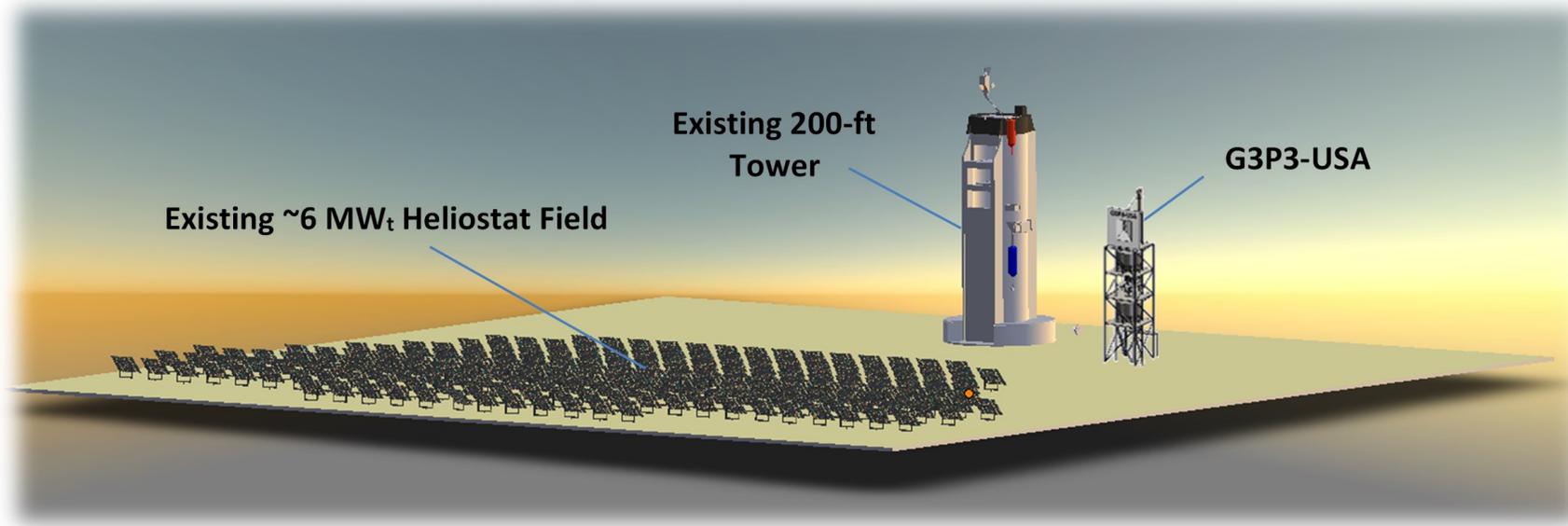


Gen 3 Particle Pilot Plant (G3P3)

Lindsey Yue, Brantley Mills, Clifford K. Ho



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The Gen 3 Particle Pilot Plant (G3P3) is currently being designed for realization at the National Solar Thermal Test Facility. The plant uses small, sand-like ceramic particles as the heat transfer medium.

Project in-line components include:

- 1 MW_{th} cavity receiver
- Hot and cold storage bins
- Particle-to-supercritical CO₂ heat exchanger
- Particle handing system



G3P3 Project



Falling particle receiver: a curtain of particles falls through the cavity

Potential to operate at higher temperatures:

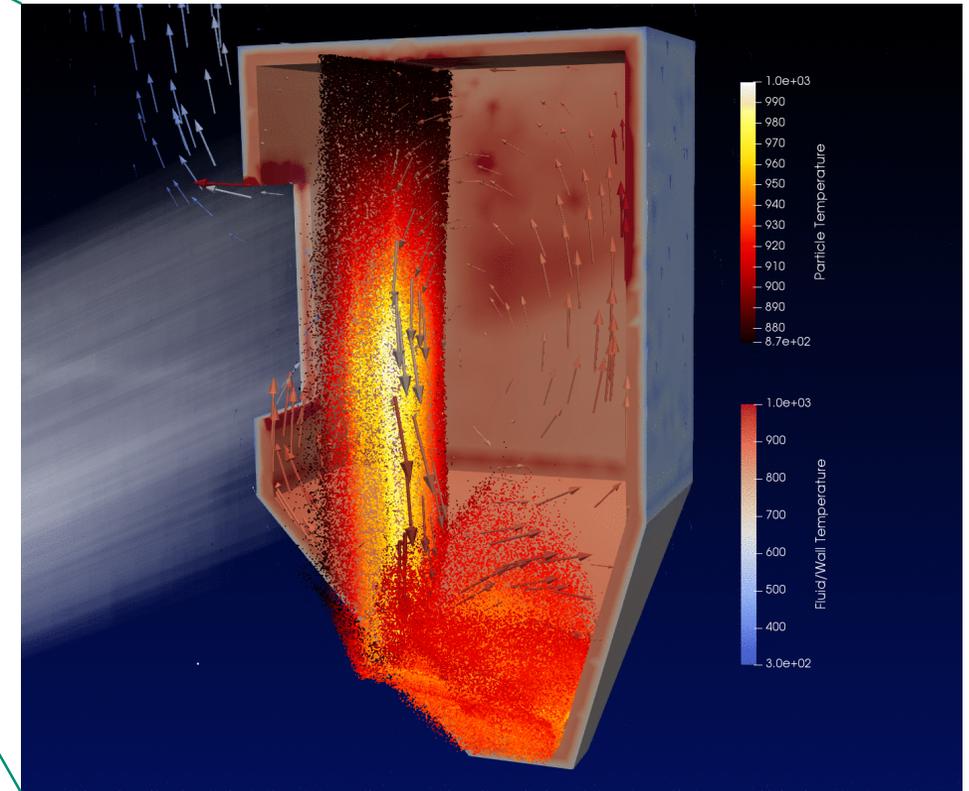
- Increasing the maximum potential power cycle efficiency
- Increases heat losses through the aperture

The dominant heat loss mechanism is hot air escaping out of the receiver aperture.

Question: Can quartz half-shell aperture covers decrease advective losses and increase receiver efficiency?



Example of a falling particle receiver geometry



Quartz half-shell aperture covers

Fused quartz is

- Transparent to solar radiation
- Opaque to expected thermal emissions from receiver interior and particle curtain

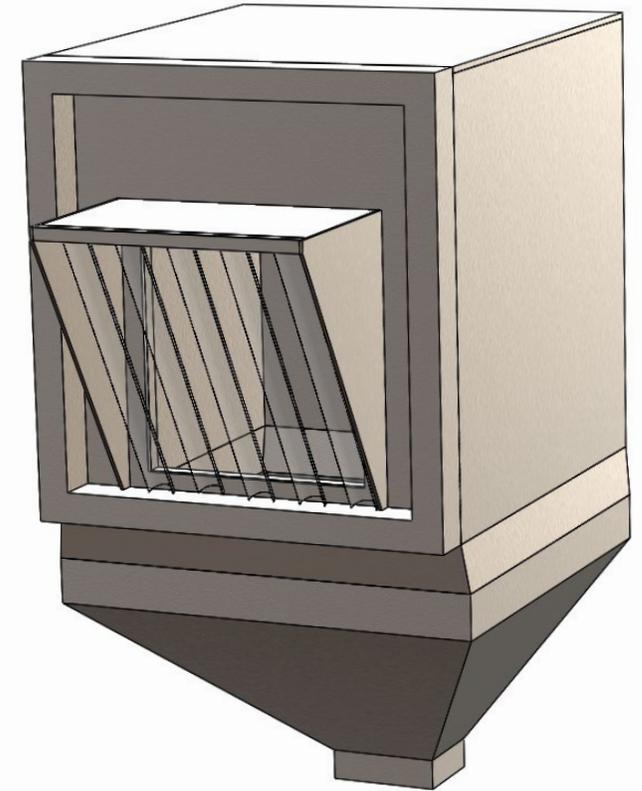
Hypothesis: Quartz aperture covers may reduce radiative and advective losses while minimally reducing concentrated solar radiation entering the receiver.

Half-shells (2.5 mm thick with diameter 110 mm) are considered for their increased strength and potential for concentrating/light trapping over flat quartz panes.

Three cases are compared in this study (receiver geometry based on existing falling particle receiver at the National Solar Thermal Test Facility):

- Open aperture (no coverage)
- Partially covered aperture where adjacent half-shells have 110 mm spacing (half coverage)
- Fully covered aperture (full coverage)

‘Half coverage’ case



Falling particle receiver subdomain



Subdomain of receiver and surrounding air

- Turbulent fluid dynamics
- Motion of particle curtain
- Two-way turbulence interaction between particles and air
- Heat transfer due to radiation, convection, and conduction

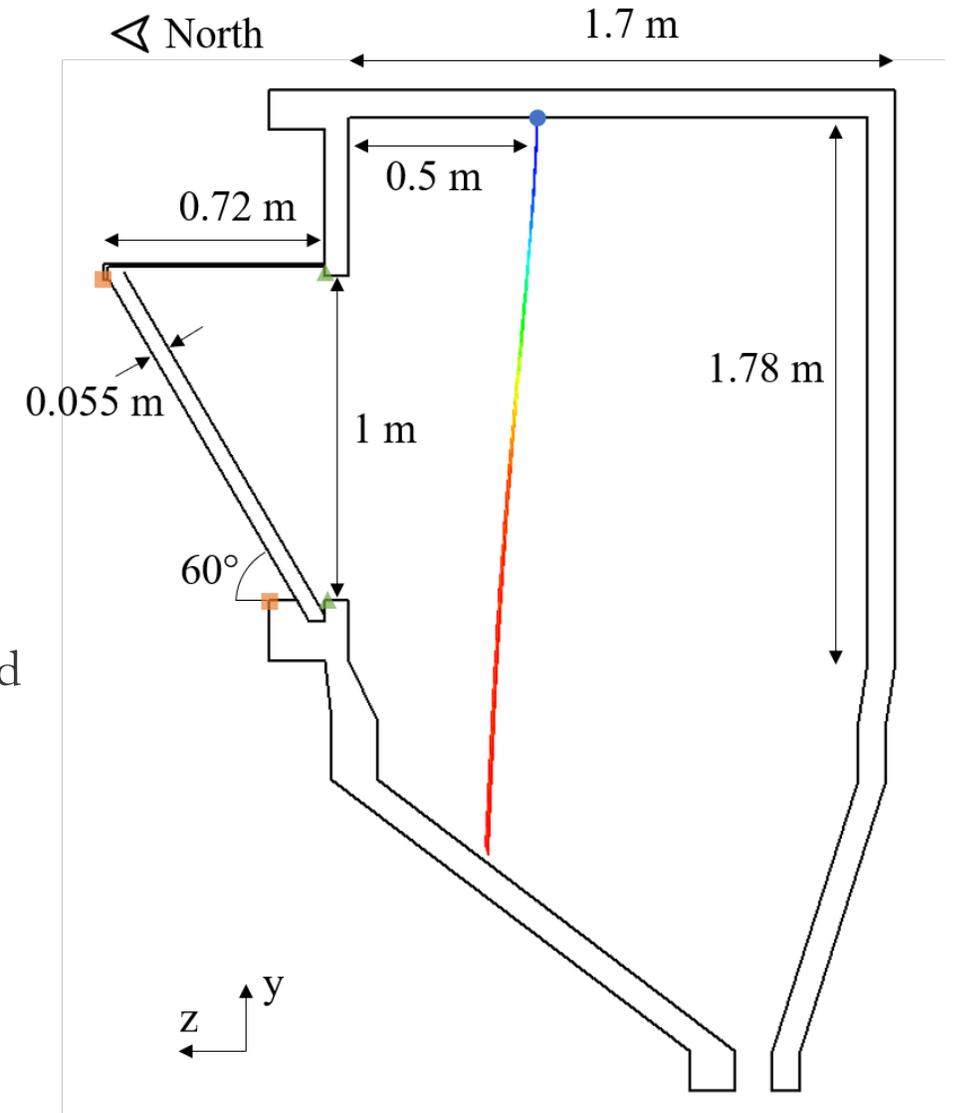
Compare cases based on:

- Advective, wall, and radiative losses
- Thermal efficiency

Two receiver ‘control volumes’ are used for evaluating losses and efficiency:

- Receiver aperture (marked with green triangles)
- Hood aperture (marked with orange squares)

Subdomain is idealized and does not predict full 3D receiver performance. Results should be viewed comparatively, not quantitatively.



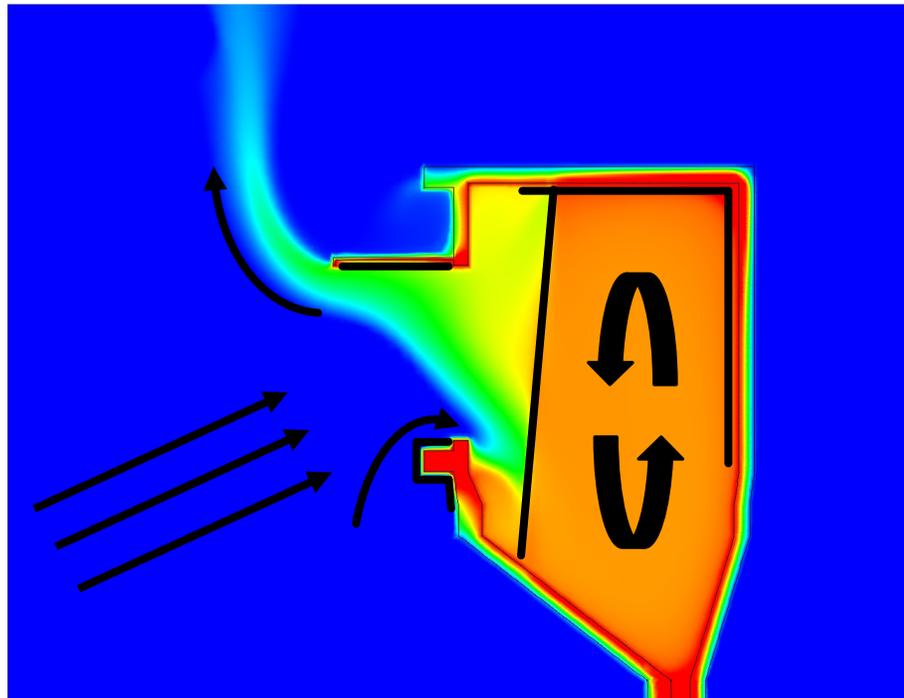
Model Results: Temperature Contours



Observable phenomena: Particle and receiver wall heating (radiative exchange and losses; wall losses), air entrainment in particle curtain, insulated region of air behind the particle curtain, hot air plume rising from north edge of receiver (advective losses)

center-temperature
Static Temperature

‘No coverage’ case



‘Full coverage’ case



Model Results: Thermal Losses



Wall losses (shown in blue, stacked on the top)

- Do not appreciably change with coverage

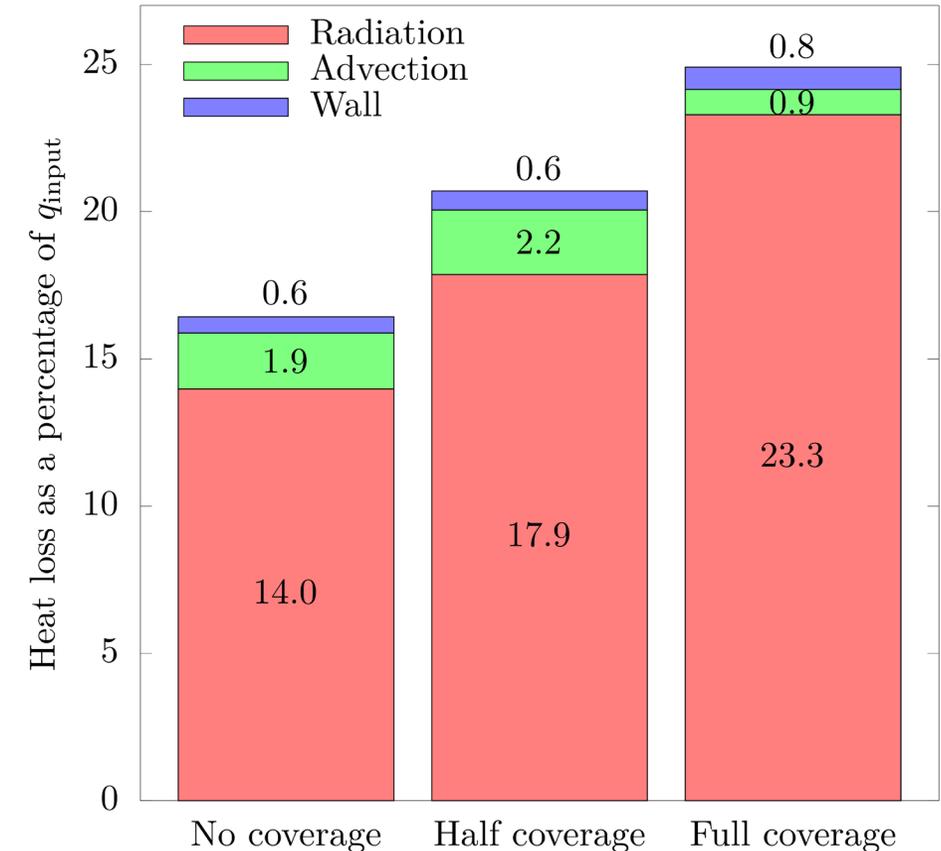
Advective losses (shown in green, stacked in the middle)

- Decrease for full coverage case, as expected, but not completely eliminated. Elevated quartz temperatures results in convective losses from the outward quartz faces.
- Increase for half coverage case, hot quartz appears to act as fins, transferring additional energy to the hot air leaving the receiver

Radiative losses (shown in red, stacked on the bottom)

- Increase with increase coverage

Question: Why are the radiative losses increasing? Are thermal emissions from the interior increasing due to the elevated temperature or is more concentrated solar radiation being reflected?



Model Results: Radiative Losses by Band



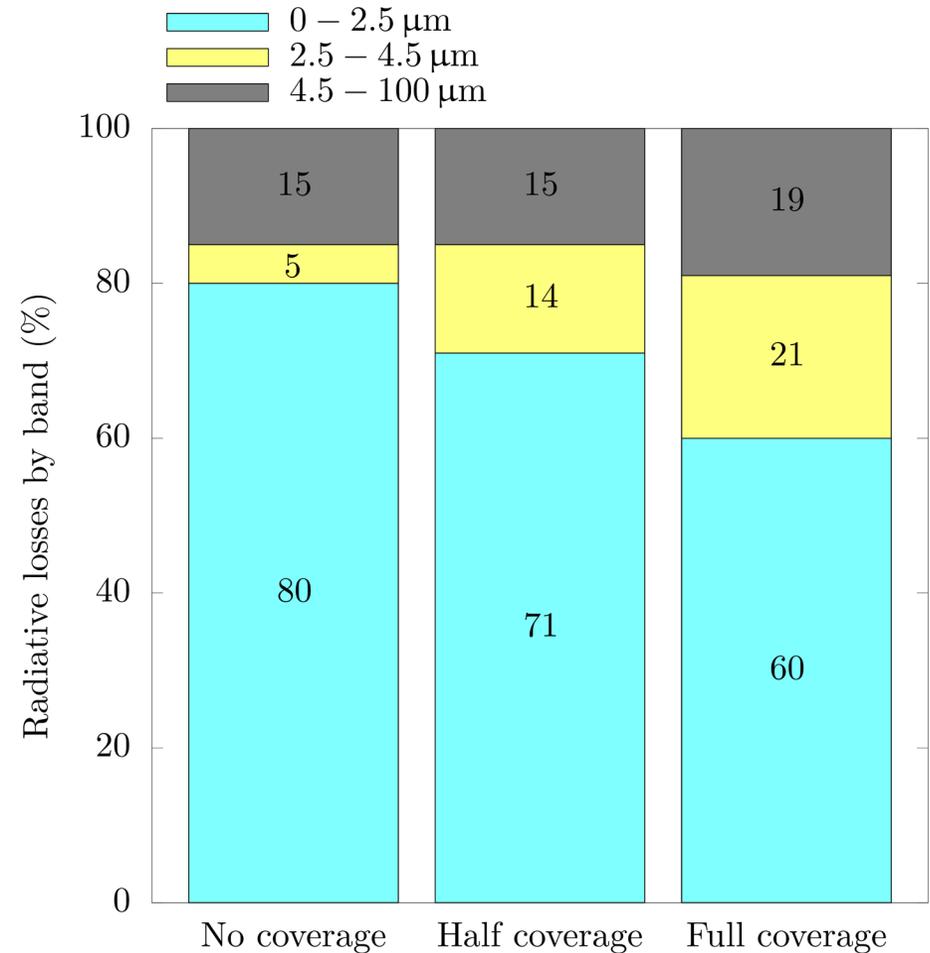
Radiative losses divided by band answer the question.

Radiative losses are dominated by reflection losses in short wavelength band (0–2.5 μm), shown in teal, stacked on the bottom.

However, longer wavelength band radiative losses increase with increasing coverage, thus increased radiative losses are due to:

- Increased thermal emissions (2.5–4.5 and 4.5–100 μm bands)
- Not due to increased reflections which would present in the 0–2.5 μm band.

This trend in radiative losses is not observed as strongly in losses leaving the receiver aperture (behind the quartz) but is observed in radiative losses leaving the hood aperture (in front of the quartz), thus can be mostly contributed to increased quartz emissions.



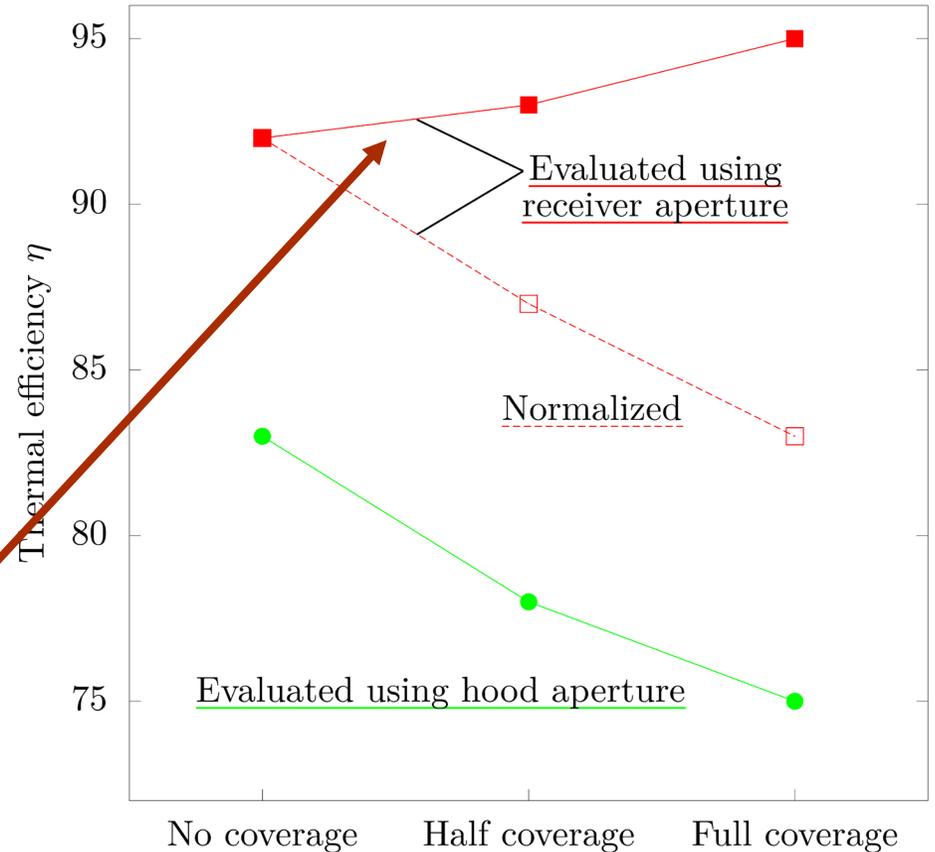
Model Results: Thermal Efficiency



Receiver thermal efficiency compares radiation entering the receiver to power absorbed by the particles

$$\eta = \frac{q_{\text{particles}}}{q_{\text{rad}}} \times 100\% \quad q_{\text{particles}} = \int_{T_{\text{in}}}^{T_{\text{out}}} \dot{m} c_p dT$$

Case	No coverage	Half coverage	Full coverage
q_{rad} hood aperture	111 kW	111 kW	111 kW
q_{rad} receiver aperture	100 kW	93 kW	87 kW
$q_{\text{particles}}$	92 kW	87 kW	83 kW



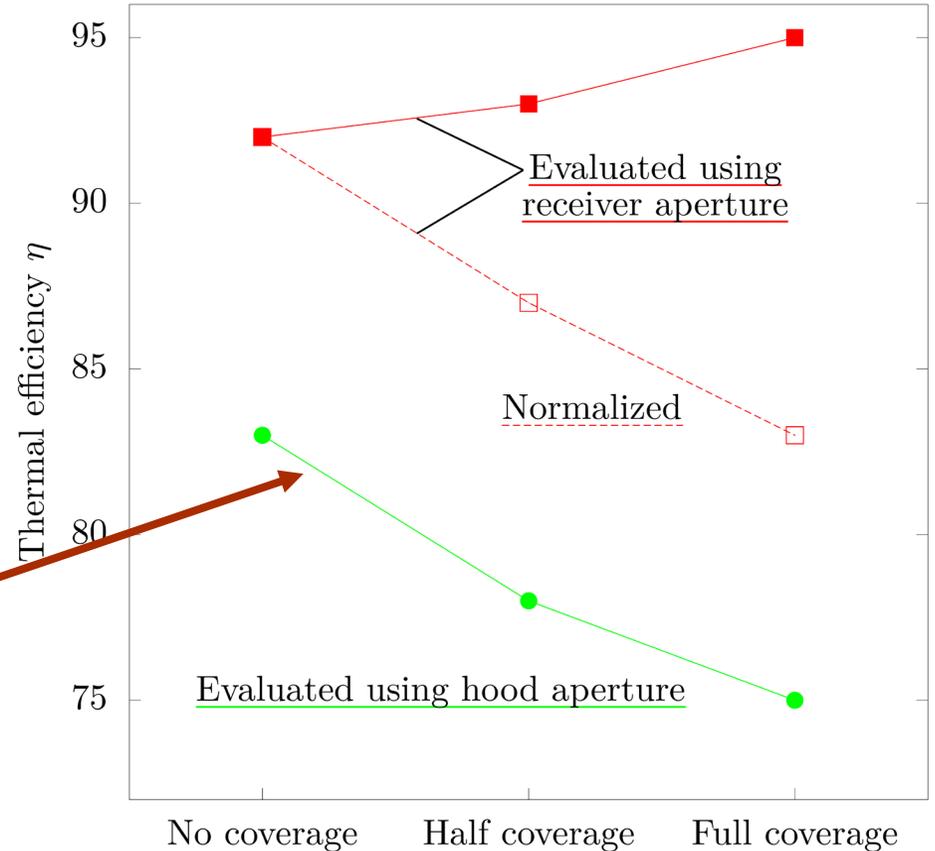
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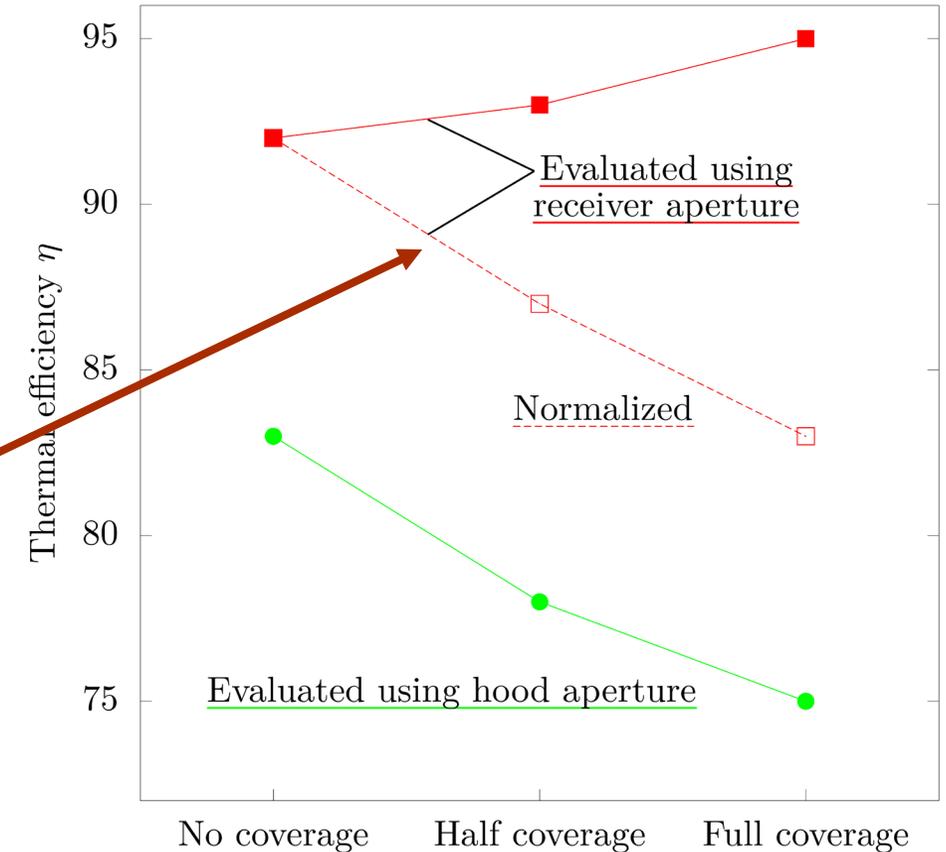
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Model Results: Sensitivity to Quartz Absorptivity



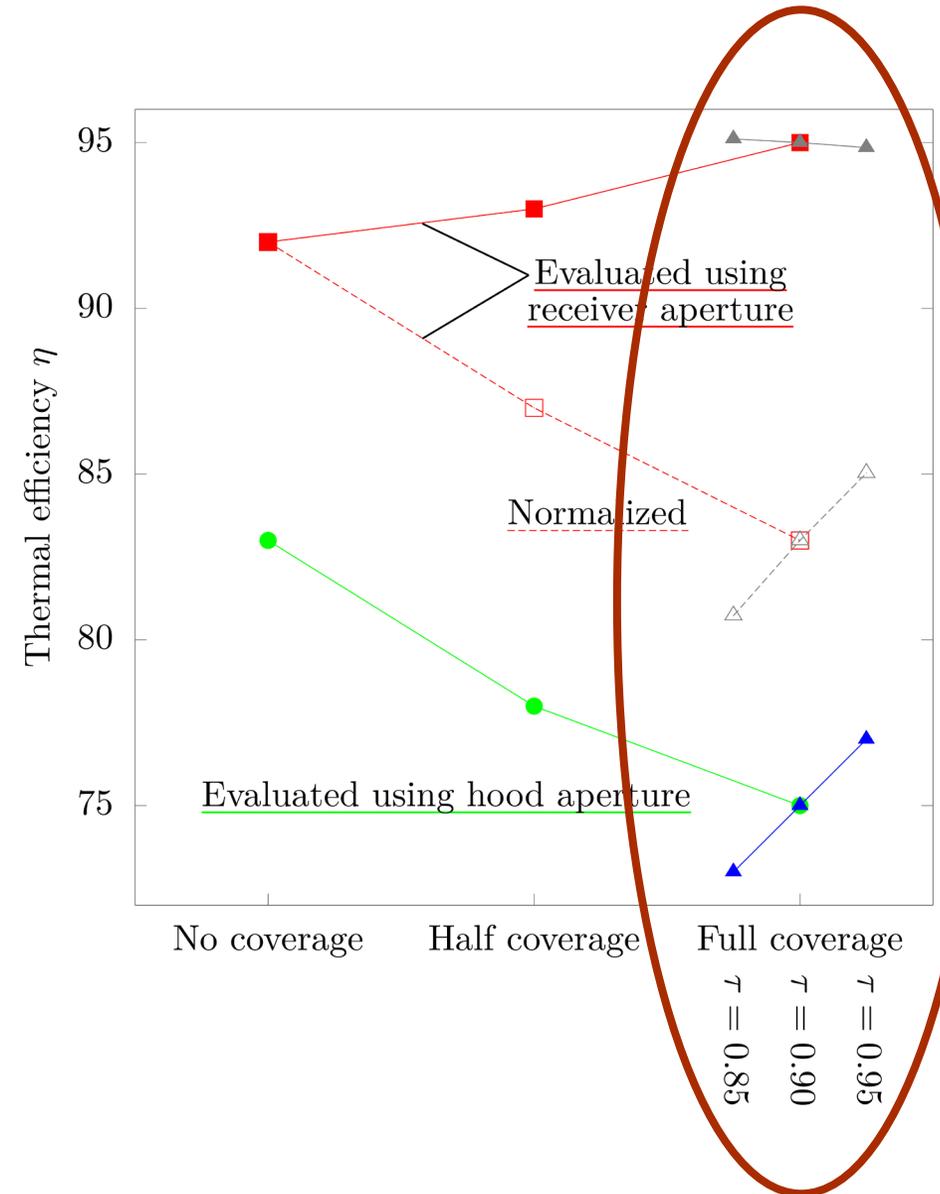
Quartz temperatures drive increased radiative losses and, in the half coverage case, increased advective losses.

Question: How sensitive are the results to quartz volumetric transmissivity?

Increased and decreased quartz volumetric transmissivity from the baseline of 90% in the solar band to 95% and 85%, respectively.

5% increase or decrease in volumetric transmissivity results in 2% increase or decrease in thermal efficiency.

Quartz volumetric transmissivity can vary by manufacturer, manufacturing technique, and also may vary due to 'prefiltering' of concentrated solar radiation through heliostat glass.



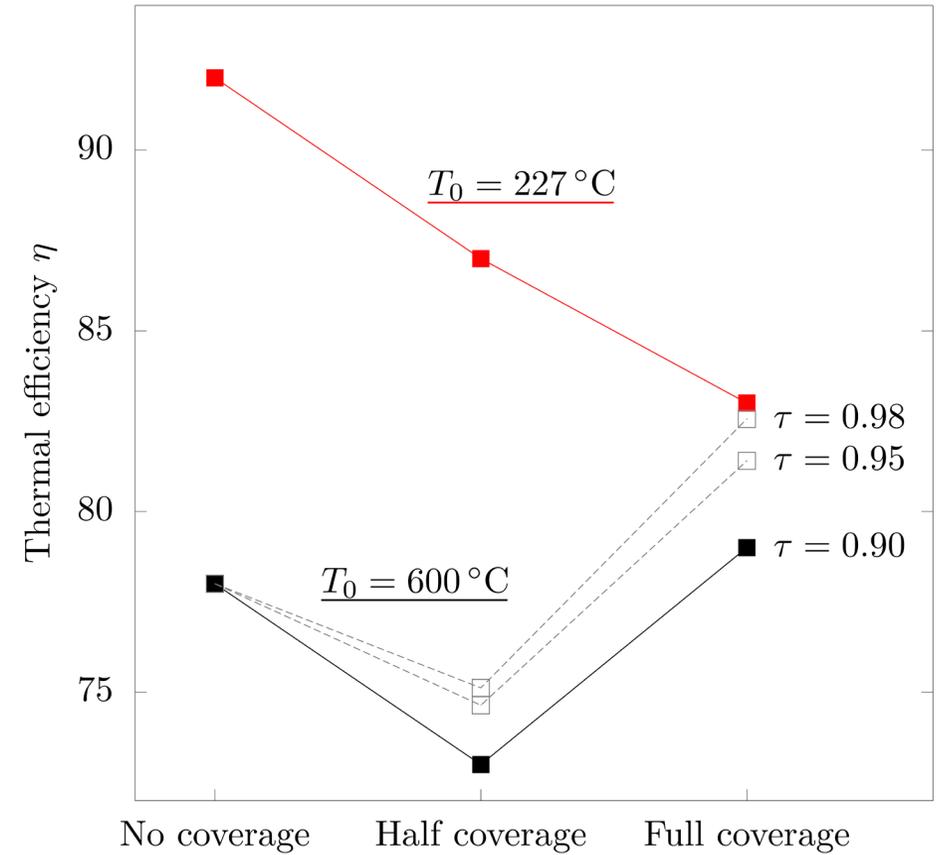
Model Results: Particle Inlet Temperature

Increasing particle inlet temperature from 227 to 600°C results in increased advective losses.

Full coverage case performance is comparable to the baseline no coverage case for $T_0 = 600^\circ\text{C}$.

When advective losses increase, beneficial affect of a full coverage aperture cover outweighs the detrimental ones.

The beneficial effect of a full coverage aperture cover is expected to be magnified in the presence of wind which can further increase advective losses.



Evaluated using the hood aperture

Model Results: Particle Inlet Temperature

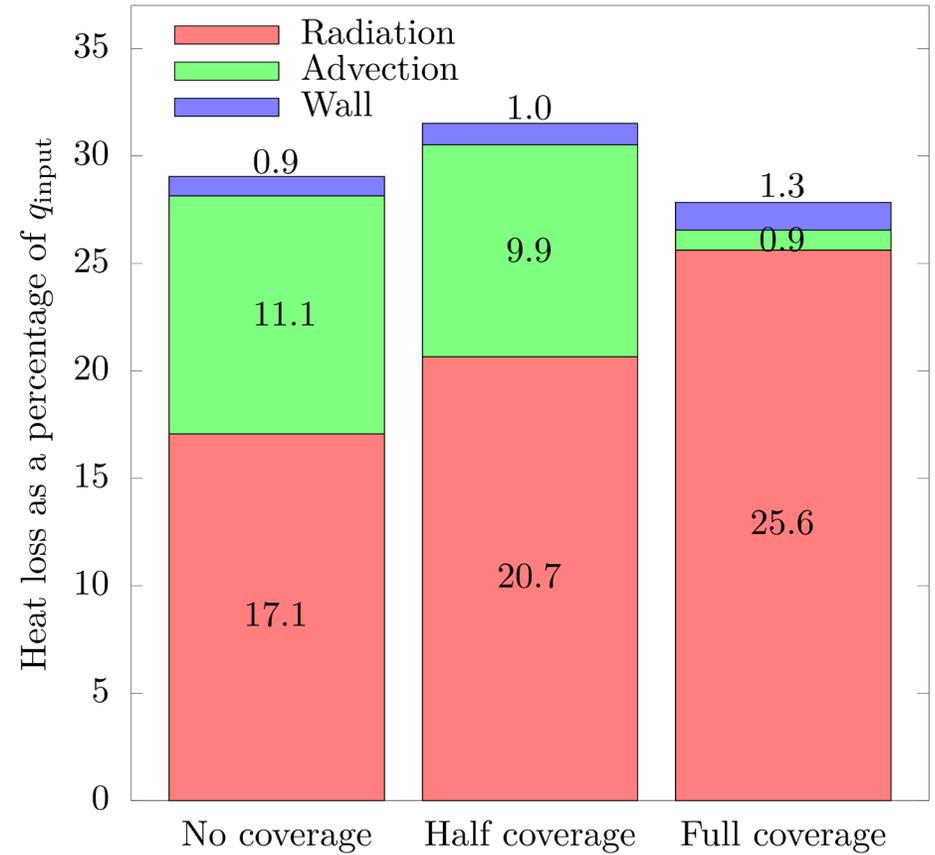


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Evaluated using the hood aperture



Three affects observed with quartz half-shell aperture covers:

- Advective losses can increase or decrease with coverage
- Radiative losses increase with coverage → quartz half-shells act as a ‘short circuit’ for radiative losses
- Radiation entering the receiver decreases with coverage

Question: Can the one potential beneficial outcome (decreased advective losses) outweigh the two detrimental ones (increased radiative losses and decreased radiation entering the receiver)? Under what conditions could aperture covers have a net benefit?

Answer: Possibly when operating at higher temperatures and when subjected to wind which further increases advective losses.

Ongoing work:

- Modeling full 3D receiver geometry with quartz half-shell aperture covers to investigate wind effects
- Experimental investigation of quartz absorptivity of concentrated solar radiation
- Scale up challenges: what is the longest, feasible length scale?



Thank you

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