Faculty of Engineering
School of Photovoltaic and Renewable Energy Engineering

A Novel Receiver Concept for Solid Storage Mediums in High Temperature (CST) Plants

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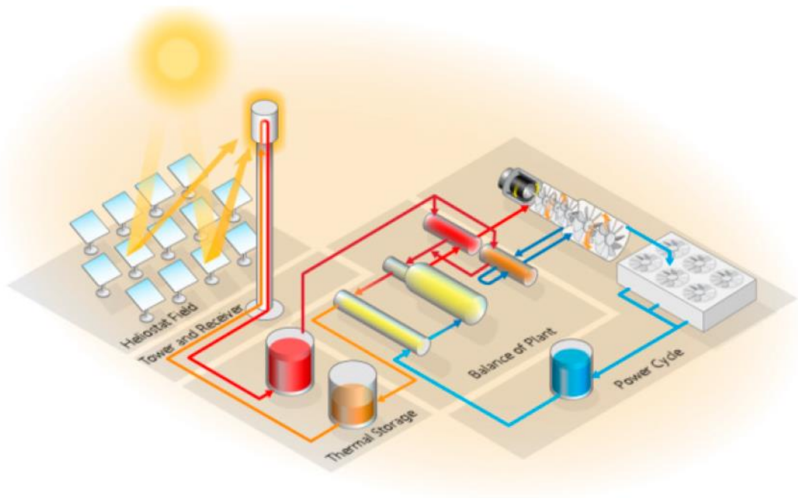
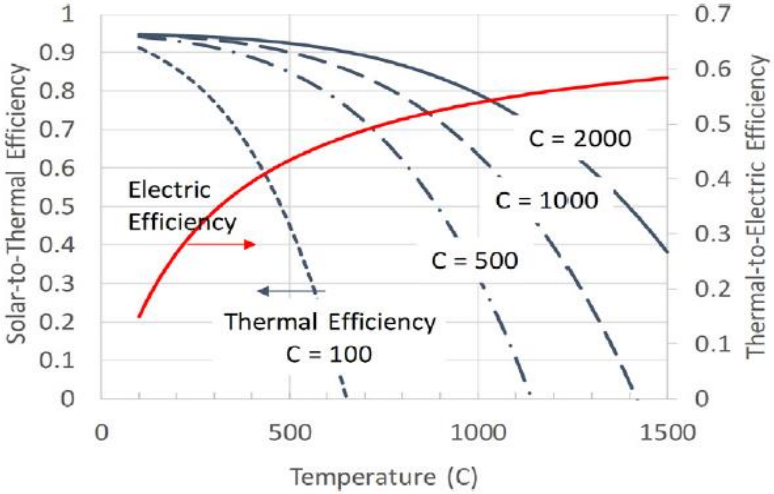
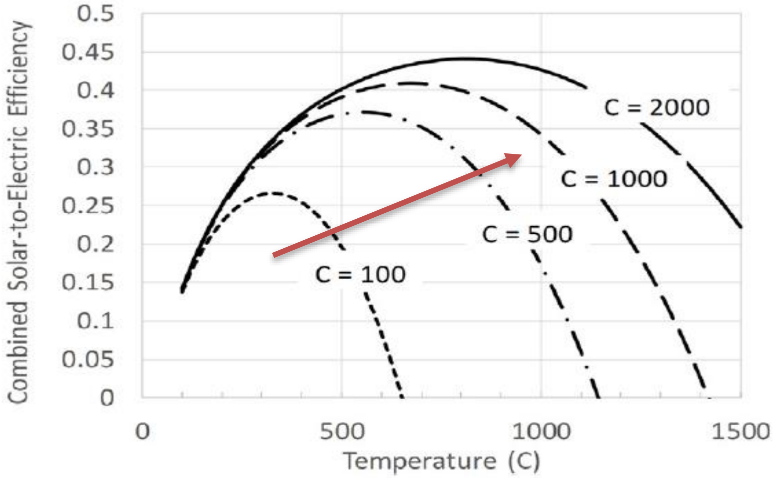
David Saldivia Salazar, Dr. Robert A. Taylor
d.saldiviasalazar@unsw.edu.au

CSP: Toward higher efficiency

$$\eta_{overall} = \eta_{Solar} \times \eta_{Power}$$







Source (left): X. Zhuang et al. (2019), *Energies*, vol. 12, no. 7, p. 1394.

Source (right): C. K. Ho (2016), *Appl. Therm. Eng.*, vol. 109, pp. 958–969.

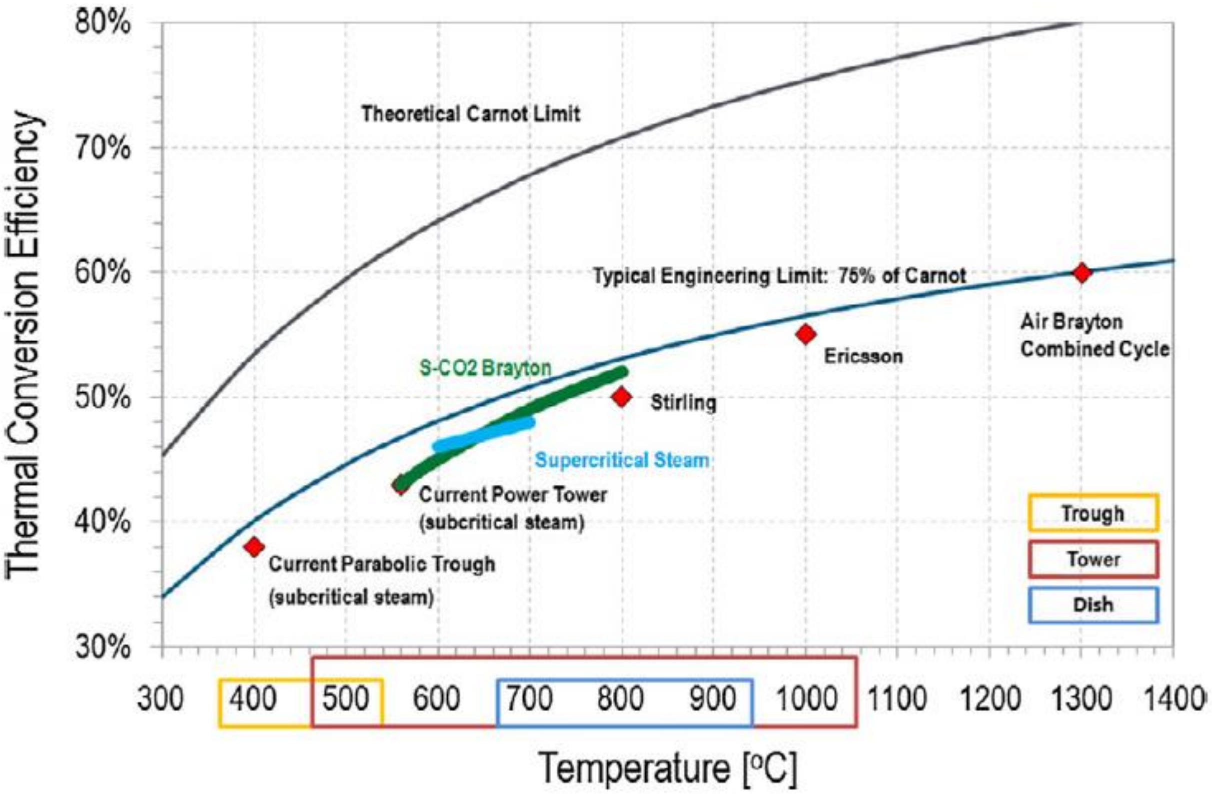
Challenges at High-temperature Operation

	Heat Transfer Fluid	Thermal Storage	Power Cycle
Conventional (Limited to <650°C)	• Liquid HTF: Synthetic Oil, Molten Salts	• Liquid Sensible (same HTF)	• Steam Cycle (Rankine)
Alternatives	• Solid Mediums. • Liquid Metals. • Gases (CO2, Air). • Novel molten salts.	• Solid Storage. • Phase Change Materials. • Thermochemical. • Hydrogen. • CAES.	• Supercritical Rankine. • sCO_2 Brayton. • He Brayton. • Hybrid cycles.

- **Selected Solution:** Solid Heat transfer Medium, Solid Storage, sCO_2 Brayton.

sCO_2 Brayton as Power Cycle

- Increasing interest in recent years.
- High theoretical efficiency ($\sim 50\%$).
- Smaller turbomachinery (up to 10% of Rankine cycle).
- Non-expensive working fluid (CO_2).



Sources: Stein & Buck (2017), *Sol. Energy*, vol. 152, pp. 91–105.
Iverson et al. (2013) *Appl. Energy*, vol. 111, pp. 957–970.

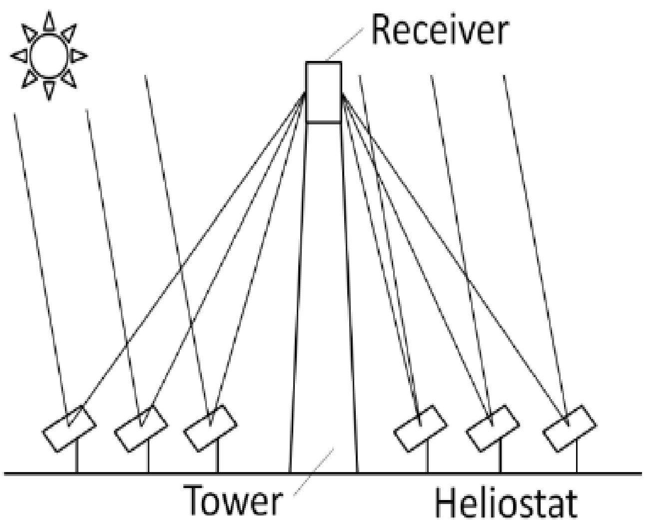
Solid Materials…

	Advantages	Challenges
… as Heat Transfer Medium	• Low density changes. • No pressure problems. • No evaporation, freezing or crystallisation. • No chemical reactions. • No leaks.	• How to move the material to the top of the tower?
… as Storage Medium	• High energy density. • High temperature range operation. • High storage efficiency. • Long-term stability (lifespan).	• **Charge:** How to charge homogeneously. • **Discharge:** How to provide a constant output (Power & T°.)

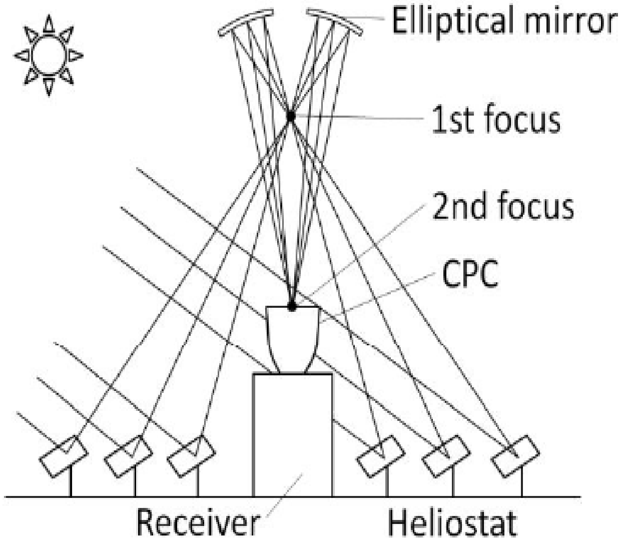
Sources: Gil et al. (2010) *Renew. Sustain. Energy Rev.*, vol. 14, no. 1, pp. 31–55
Medrano et al. (2010) *Renew. Sustain. Energy Rev.*, vol. 14, no. 1, pp. 56–72

Beam-Down Receiver

Conventional Solar Tower



Beam Down concept

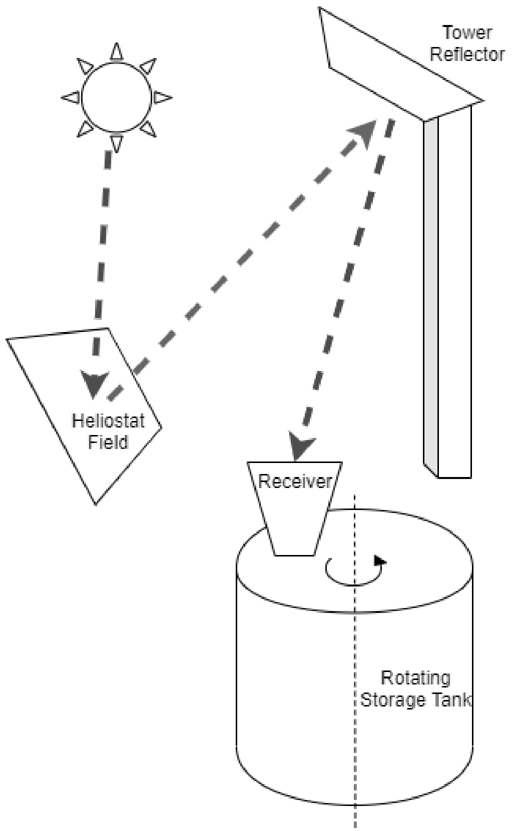


- Avoid to move solid material toward top of the tower.
- Allow to heat up directly the storage material.

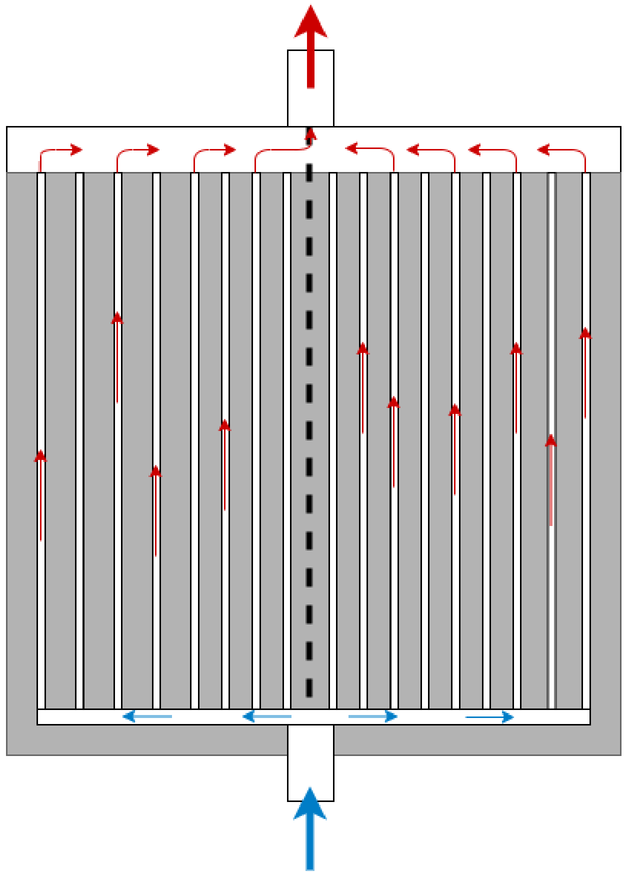
} **Dual Receiver-Storage concept**

Proposed Solution: Rotating Solid Block Storage

Charging Stage



Discharging Stage



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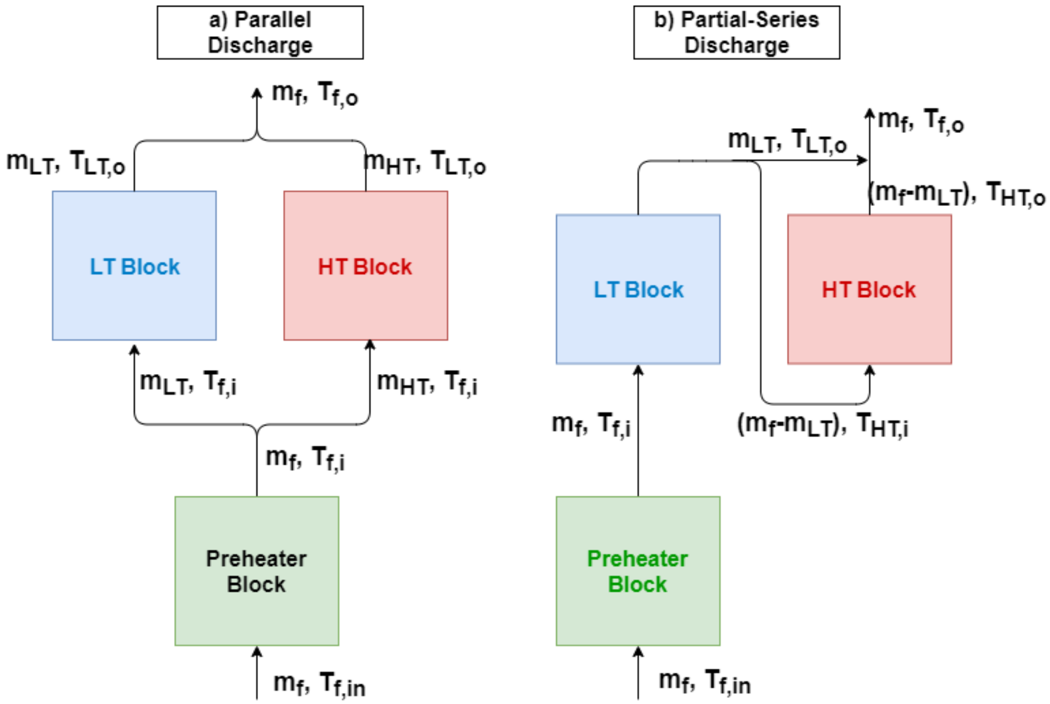
Proposed Solutions: Discharging Strategy

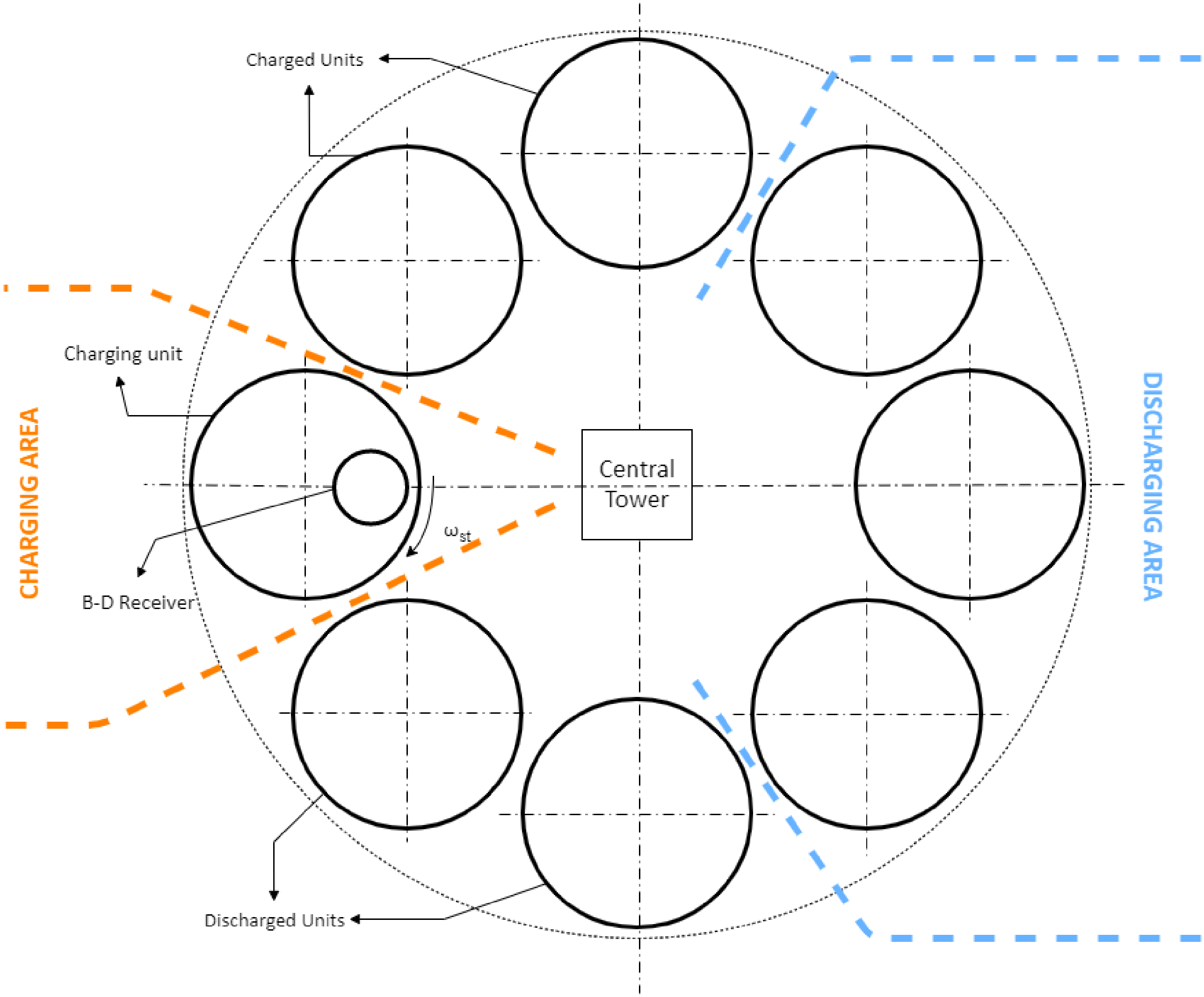
Problem: How to provide a constant output (mass flow rate and temperature) with a unit that is cooling down?

Solution:

- Charge several modules.
- Discharge more than one unit to drive the power cycle.
- Split the flow in order to get the desire output.
- HT block becomes LT block, LT block becomes Preheater



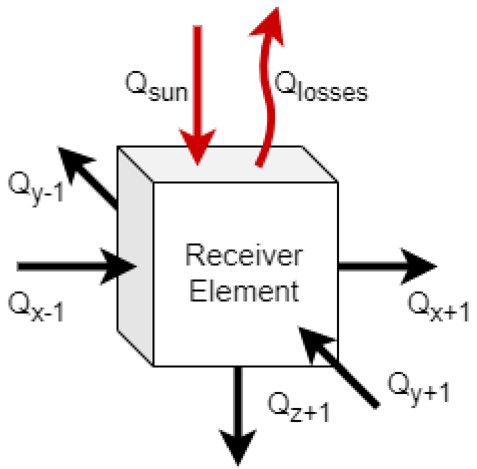
Proposed Solution: Layout



Numerical Model

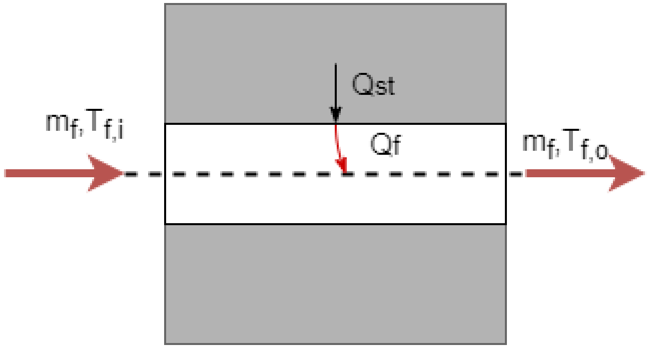
Charging

- 3D Model programmed in Python.
  - Energy & Heat transfer equations
  - Finite Volume Method and implicit time.
  - Correlations for HTC.
  - Constant solar flux and thermophysical properties.
- Allows to change operation and geometric parameters.
- Outputs: Temperature field and Performance parameters.



Discharging

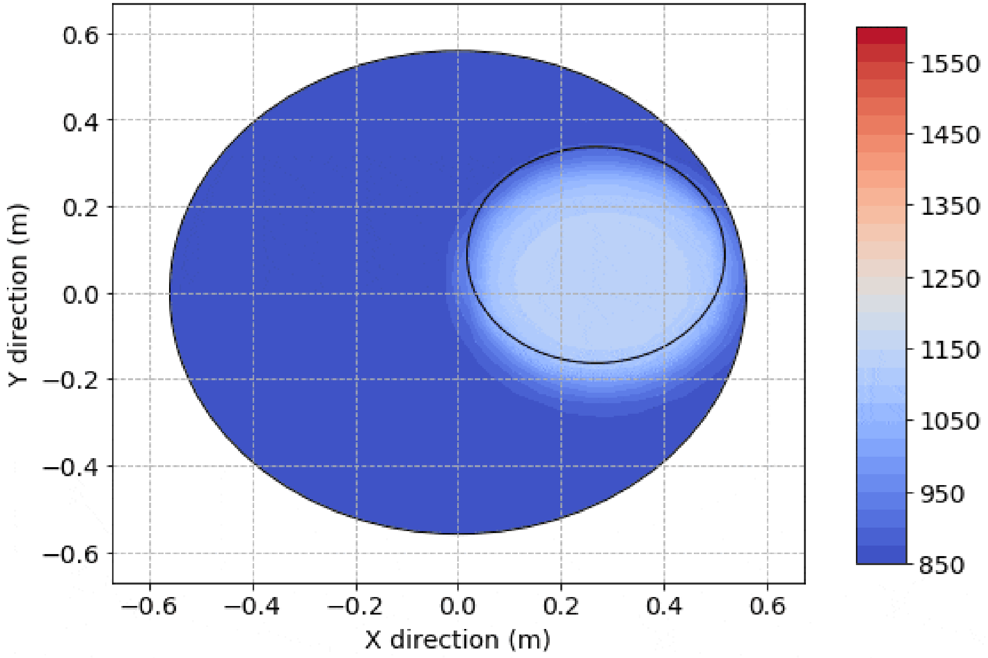
- 1D Model for pipe-solid material heat transfer.
- Extended lumped approach.

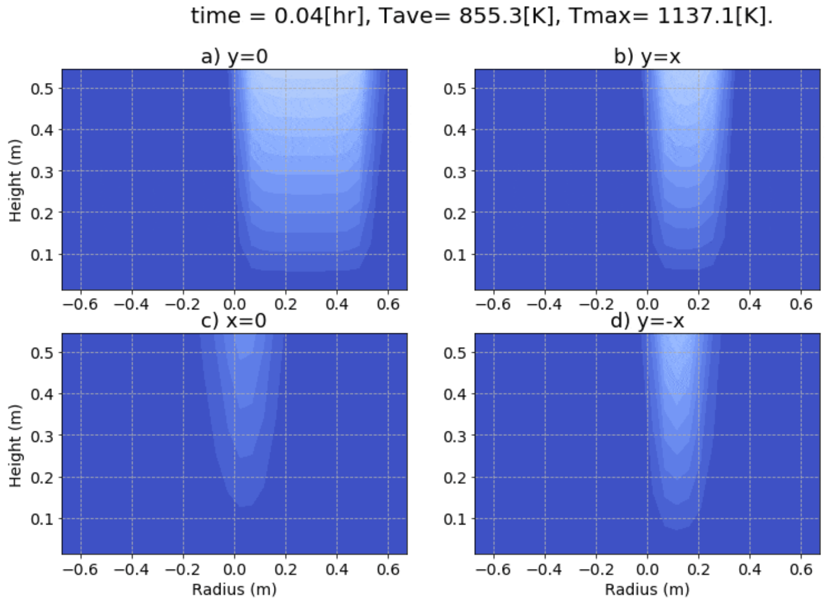


Results

- **Charging process: Temperature Field.**

Upper view with r_r=0.2[m], D=1.1[m], H=0.6[m], mat=Cast steel

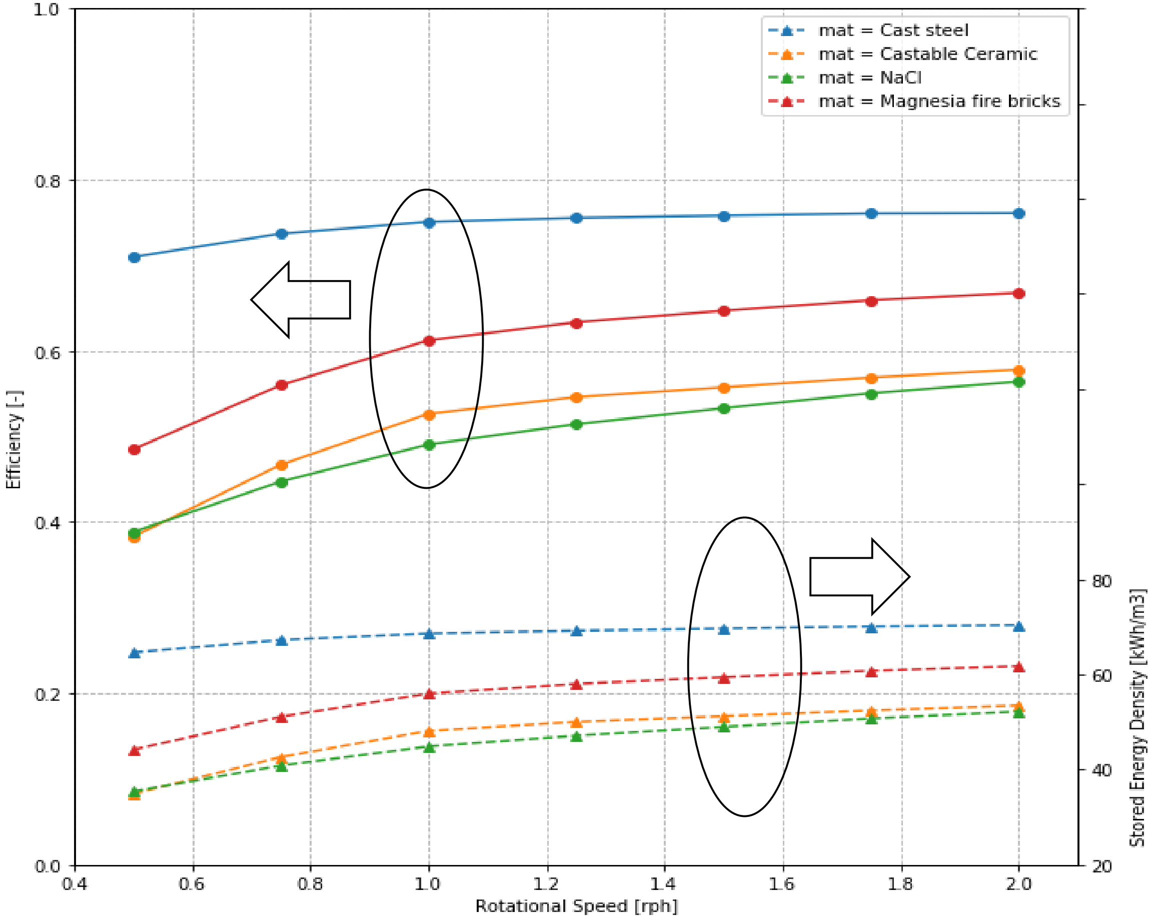




Results

Charging process: Performance Analysis.

- Four material tested: Cast steel, Castable Ceramic, NaCl, Magnesia bricks
- Best performance: Cast steel ($\eta_r \approx 75\%$)



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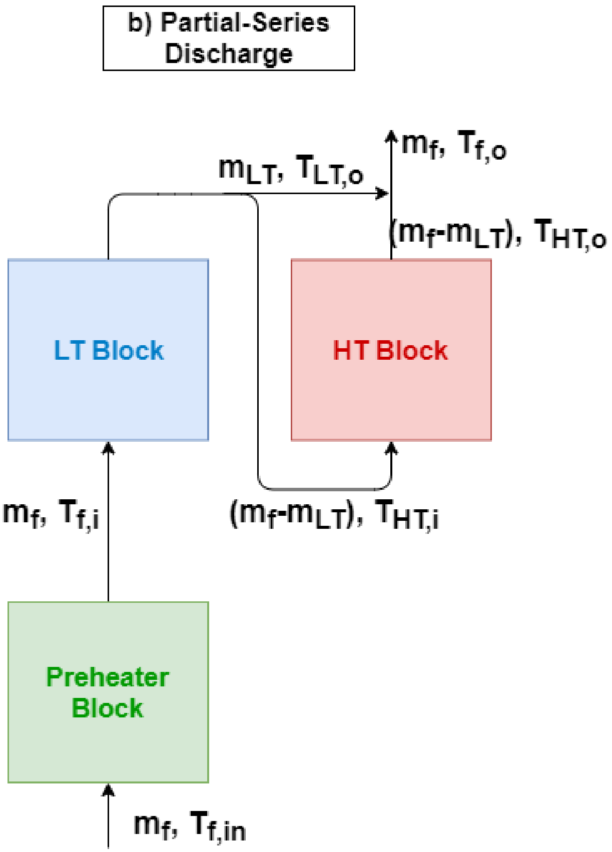
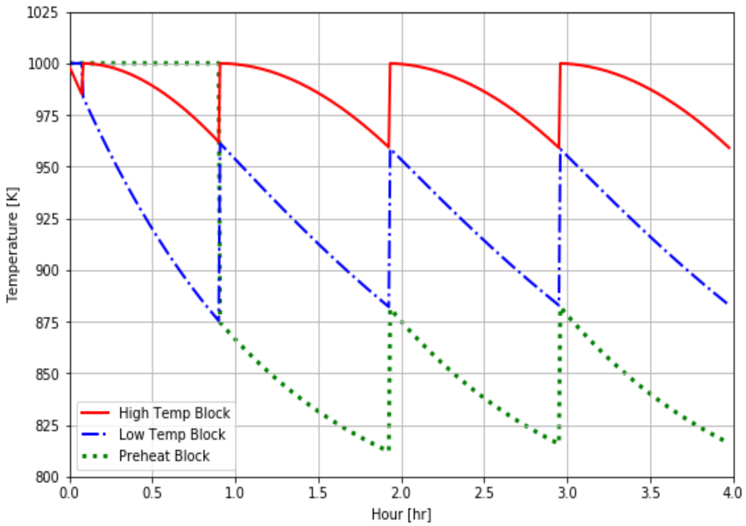
Preliminary Results: Discharging Process

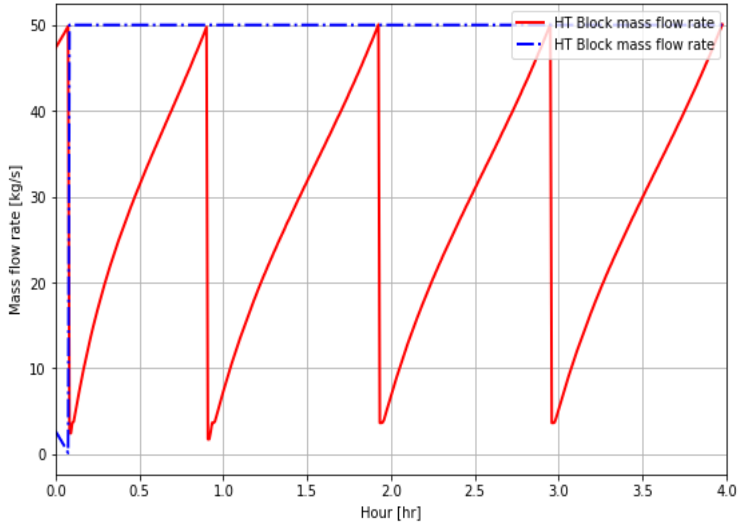
- **Best performance:**
  - Partial-Series Strategy



Outlet temperature



Mass flow rate



Conclusions & Future Work

- **Conclusion:**
  - A novel concept is presented: Dual receiver-storage using **beam down** concept and **rotating storage**.
  - A numerical model was developed to evaluate this concept.
  - **Cast steel** is the best material and $\eta_r > 70\%$ is expected.
  - A strategy to **discharge** the units to obtain a constant output is presented.

- **Future Works:**
  - Validate the model with experimental data (heat transfer coefficients).
  - Assess the solution in a complete CSP-sCO_2 power plant.
  - Optimisation based on economic output (annual production and LCOE) and environmental impact (LCA).

Thanks! | ¡Gracias!
Questions? | ¿Preguntas?

David Saldivia Salazar

d.saldiviasalazar@unsw.edu.au

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