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Test plans for the ASTRI sodium receiver

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Introduction

The Australian Solar Thermal Research Institute (ASTRI) has been developing technologies designed to collect and store solar energy at high-temperature to drive a new high-efficiency power block based on the supercritical CO_2 Brayton cycle. At design point, the temperature range of of this power cycle is 520°C-700°C, which is above the stability limit of the conventional heat transfer and storage media used in state-of-the-art concentrating solar power (CSP) plants. Instead, ASTRI is pursuing two alternative pathways: one is based on the use of liquid sodium as a heat transfer fluid, with storage provided by low-cost sensible and latent storage materials; and the other is based on the use of solid particles for both energy collection and storage [1]. The development of these two parallel streams is closely aligned to international research efforts, in particular the U.S. Gen3 CSP program [2]. The current work describes ASTRI's plans to test sodium-based solar receivers at a scale of 700 kW_{th} in an on-sun environment at CSIRO Energy's Newcastle heliostat/tower facility during the coming year.

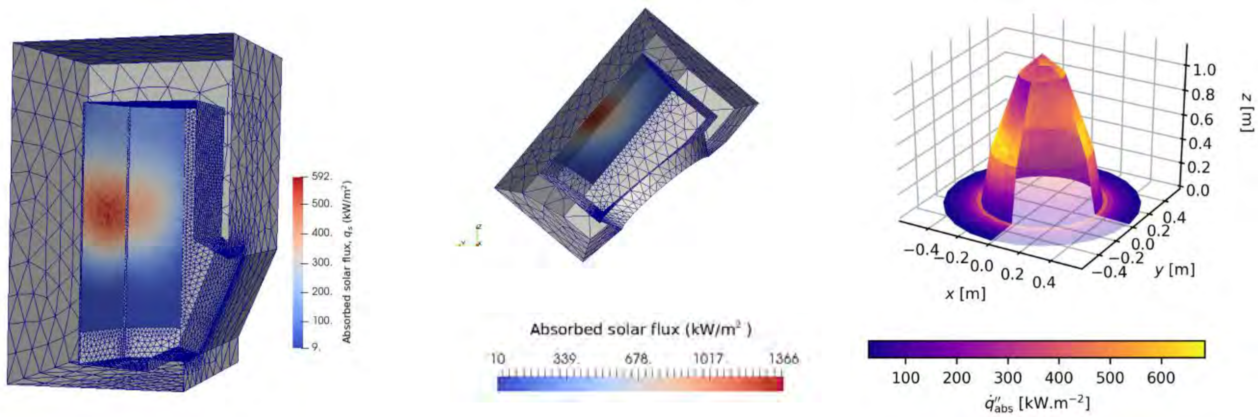
The testing in 2020 will be divided into two phases. In the first phase, ASTRI will test an existing cavity solar receiver developed by Abengoa and tested previously at CSIRO at that time with CO_2 as the heat transfer fluid [3] (Figure 1a). Minor modifications will be made to the flow path and aperture, to upgrade the receiver for use with sodium. The design outlet temperature of the receiver is 740°C, and as this will be the first time a sodium receiver has been tested on-sun at such a high temperature, the aim is to demonstrate safe operation with a relatively conservative design, and to gain operational experience. The receiver is a little oversized for the 700kW_{th} design output, which allows solar flux levels to be kept relatively low - below 600kW/m^2 at all times of the year. The overall receiver efficiency, defined as the net heat gained by the sodium fluid divided by the energy reflected from the mirrors, is expected to be around 84-87%.

In the second phase of testing, ASTRI will demonstrate a new design, with the geometry tailored to make the most of the capacity of sodium receivers to operate at higher fluxes. Two options being considered in this round are a modified version of the Abengoa receiver, under development at CSIRO (Figure 1b), and a bell-shaped cavity design with front spillage-skirt, under develompent at ANU (Figure 1c). A down-selection process to finalise the concept is still in progress, but it is expected that a significant increase in receiver efficiency will be demonstrated, up to around 90-93%.

Why cavity receivers?

Cylindrical receivers are employed at the majority of commercial scale power tower plants, hence the starting point within ASTRI for high-temperature sodium receiver design was this simple geometry. However, modelling at ANU indicated that after optimisation of cylinder dimensions (with heliostat optical error of 2 mrad and optimised aiming) receiver efficiency was only 82.0%, perhaps too low to meet aggressive LCOE targets, such as the 0.05 USD/kWh Sunshot 2030 goal. Constraints on receiver geometry were relaxed, and machine-learning driven multi-objective optimisation was used to generate new families of receiver shapes with three principal design objectives: maximising receiver efficiency, minimising peak flux, and minimising cost. Some findings relating to this work were:

- Cavity geometries are of benefit in this temperature range
- Heliostat field optical quality is particularly important for high temperature receivers



(a) (b) (c)

Fig 1. Sodium receiver design options showing absorbed flux for three different concepts: (a) Abengoa/CSIRO CO_2 receiver selected for initial testing; and two higher-performance concepts from (b) CSIRO and (c) ANU under consideration for the second phase of testing.

- Single aim point strategies are feasible without breaching peak flux constraints. This benefits performance (reduction in spillage loss), is simpler in terms of heliostat field operation, and is more intrinsically safe, reducing the likelihood of localised hot spots.
- The tradeoff between thermal loss and spillage loss leads to separate treatment of a high flux zone and a low flux zone, where the cavity is beneficial in the high flux zone but a "spillage skirt" is preferred in the low flux zone.

A decision was made within ASTRI to focus on a polar field arrangement for the sodium receiver prototype because of the heliostat fields available in Australia. However, the findings from this work are also applicable to a surround heliostat field, and exploring receiver designs suitable for such fields is the subject of further work in ASTRI.

Conclusion

Two sodium receivers with cavity geometries will be tested on-sun at CSIRO Energy in Newcastle in 2020. Performance simulations indicate that cavity receiver concepts might be key to reach cost competitiveness for the next generation of CSP systems.

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