Design and Construction of a 700kW High-Temperature Sodium Receiver

Joe Coventry¹, Felix Venn¹, Daniel Potter², Charles-Alexis Asselineau¹, Wilson Gardner², Jin-Soo Kim², William R. Logie¹, Robbie McNaughton², John Pye¹ and Wesley Stein²

¹ School of Engineering, Australian National University, Canberra, Australia.
² CSIRO Energy, Newcastle, New South Wales, Australia
* Corresponding author: joe.coventry@anu.edu.au

1. 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 CO₂ Brayton cycle. ASTRI is pursuing two alternative pathways: one based on the use of liquid sodium as a heat transfer fluid, and the other based on the use of solid particles. The current work describes ASTRI’s progress towards design and construction of a 700kW prototype sodium receiver suited to this type of system, which will be tested at CSIRO’s solar field at the National Energy Centre in Newcastle, Australia.

2. Receiver design

After down-selection between two different cavity receiver concepts [1], a design was selected with similar overall cavity geometry to a CO₂ receiver developed by Abengoa and tested previously at CSIRO [2]. However, substantial changes were made to tailor this design to the sodium heat transfer fluid at the design operating temperature range of 520-740°C. Potter et al. [3] describe the concept performance modelling process, in which ray tracing and the receiver heat transfer modelling were implemented using CSIRO’s HelioSim software. The initial design was a tilted cavity, with banks of tubes facing down towards the heliostat field. However, in a further iteration, the tube banks were re-oriented vertically to simplify their mounting (on spring hangers), and to reduce the likelihood of sodium egress from the aperture in the event of a sodium leak. Fig. 1(a) shows the final design, which includes a door that can be closed when the receiver is in warm standby, or in the event of tube failure to minimise smoke egress. Fig. 1(b) shows a section view with the door removed to show the aperture position relative to the tube bank. Predicted solar flux on the tube bank at design point is shown in Fig. 1(c). The 10 tube banks (each consisting of 7 tubes, 25.4 mm × 1.65 mm, from NO6625 material) are split into left and right sections, as shown in Fig. 1(d). Two separate fluid supply lines (with separate pumps) introduce sodium to the two banks at the centre of the receiver, and then fluid flows in a serpentine manner through the tube banks to the outside. In this way the highest flux region corresponds the coldest fluid region.

![3D models of the sodium receiver showing (a) the full receiver, including the door in the closed position, (b) a section view through the centre of the receiver, with the door removed to show the aperture, (c) the flux profile predicted on the receiver tubes at the design point, and (d) the tube bank arrangement including the drain and fill lines.](image)

At the design point (equinox noon, DNI=900 W/m²) the receiver is predicted to have 782 kW of solar power...
passing through the aperture, from 235 heliostats. Receiver thermal output (i.e. power captured by the flowing sodium) is predicted to be 711 kW, for a receiver efficiency of 90.9%. Despite the small scale, the receiver was designed to have high optical and thermal performance including with regard to spillage losses. Spillage is predicted to be around 38.5kW, for an overall combined interception and receiver efficiency of 86.6%. Maximum predicted outer wall temperature of 789°C occurs on the second-to-last tube bank from the edge. The design was a joint effort between ANU and CSIRO, with the concept design phase mainly led by CSIRO and the detailed design phase mainly led by ANU, including the panel mounting, enclosure and door. FE Consultants assisted with the structural integrity analysis and engineering drawings, helping ensure that the receiver was designed in accordance with Australian Standard AS1210-2010 Class 1 for a minimum design life corresponding to the duration of the planned testing (1,000 hr and 500 design thermal cycles) although significantly longer lifetime is expected in practice. Further information, such as the temperature and flux distributions, structural integrity analysis, and details regarding the design, operation, insulation, instrumentation, safety features, etc, will be provided in the full paper.

3. Construction

The receiver tubes were bent and welded to the headers to form the tube banks by MCM Manufacturing in Newcastle. They were then painted with the Pyromark 2500 absorber coating, and transferred to Performance Engineering Group, also in Newcastle. There the receiver enclosure and door were fabricated, and the tube banks mounted within. Images of various stages of construction are shown in Fig. 2.

![Figure 2. The sodium receiver in various stages of construction showing (a,b) the completed tube banks, (c) the tube banks welded to the interconnecting piping, and (d) the receiver enclosure and door.](image)

4. Testing

The receiver will be tested on-sun in a new sodium loop in Field 2 at CSIRO Newcastle. This loop has a skid-mounted design and will be commissioned on the ground, before it is lifted on the tower for the on-sun testing. Design and procurement of major equipment items for the loop has been completed by CSIRO and Vast Solar, with the sodium loop assembly soon to commence. On-sun testing is expected to commence in late 2022 and continue through to mid-2023.

References

