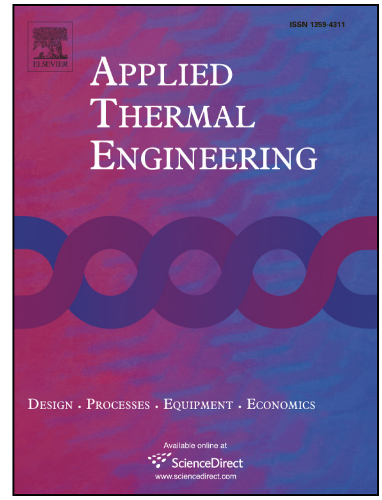
Accepted Manuscript



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PII: S1359-4311(17)37302-7
DOI: https://doi.org/10.1016/j.applthermaleng.2018.05.080
Reference: ATE 12219

To appear in: *Applied Thermal Engineering*

Received Date: 15 November 2017
Accepted Date: 19 May 2018

Performance of molten sodium vs. molten salts in a packed bed thermal energy storage

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Abstract

Concentrating solar power plants are currently working with Solar Salt and conventional Rankine steam power cycles with upper temperatures of 565 °C. To achieve higher efficiencies, advanced power cycles are currently investigated (500 °C to 700 °C). As heat transfer fluids, both molten sodium and three types of molten salt are considered in this study. For power tower plants, the heat transfer fluid is typically also the storage medium. This is the case for state-of-the-art commercial plants using molten salt, and past and present pilot plants using sodium. However, this work shows for both cases that a packed bed arrangement, where the heat transfer fluid is replaced by a filler material, may be a technically feasible and economically viable alternative. Furthermore, for sodium there are additional safety concerns related to having a large sodium inventory, which the packed bed arrangement can help alleviate. In this study, a 40 MWh_{th} storage system with quartzite as filler material is numerically investigated with a one-dimensional model. The results are evaluated in terms of discharge efficiency, pumping power, storage cost and thermocline degradation during standby to assess the potential of this storage solution for future scientific investigations. The packed bed system with sodium shows slightly higher discharge efficiencies (96.8 %) than with molten salt (95.2 - 95.7 %) and also lower required pumping power. However, the thermocline region expands faster during standby due to the high thermal conductivity of sodium. The influence of porosity, tank diameter-to-height ratio and filler particle diameter is analysed in a parametric study. Highest discharge efficiencies are achieved for both sodium and molten salts with small tank diameter-to-height ratios and small filler particles. For sodium, low porosities are preferable, while for molten salts, high porosities lead to better discharge efficiencies.

Keywords: liquid metal, sodium, thermal energy storage, thermocline, packed bed

1. Introduction

Operational concentrating solar thermal power plants like Gemasolar or Crescent Dunes use a $NaNO_3$-KNO_3 mixture (composition by weight 0.60-0.40) called 'Solar Salt' as the heat transfer fluid (HTF) and as the storage medium. To increase the efficiency of central receiver systems, advanced power cycles with higher upper temperature limits are currently considered [1], [2]. However, the operating temperature range of Solar Salt is limited by its decomposition temperature ($\approx$ 600 °C). For higher temperatures, alternative HTF candidates are proposed.
A review by Pacio et al. [3] shows that liquid metals (e.g. sodium, lead-bismuth-eutectic, sodium-potassium and tin) might qualify as attractive HTFs, because of their excellent heat transfer properties. Among these, sodium stands out due to its low melting point and high boiling temperature. Sodium has already been tested as HTF at the IEA-SSPS central receiver facility in Almeria, Spain, during the 1980s [4] and currently in a pilot-scale (1 MW_e) plant at Jemalong, Australia [5]. However, its comparably low volumetric thermal capacity ($\rho_f c_{pf}$) and high cost do not advertise it as storage fluid in a direct two-tank configuration, as is currently applied in operational solar tower plants with molten salts. Furthermore, sodium reacts exothermally in contact with air and water. However, with the high standards of safety inherited from the long term nuclear industrial experience, these risks can be minimized [6]. Therefore, a thermocline packed-bed thermal energy storage system is suggested, leading to less sodium inventory, higher storage densities and lower storage material cost, as shown by Niedermeier et al. [7].

On the other hand, alternative salt compositions are also considered as HTFs for advanced power cycles. These are not only interesting due to higher decomposition temperatures compared to the commonly used Solar Salt, but also due to their applicability as storage media. The main disadvantage is their relatively high melting temperature, which makes extensive heat tracing inevitable. The Con-

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