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A tubed, volumetric cavity receiver concept for high efficiency, low-cost modular molten salt solar towers

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Abstract

Small molten salt modular towers linked together to feed into a large power block, including storage, offer the potential to significantly reduce the cost of solar thermal energy. This is primarily through the significant increase in solar field and receiver efficiency that are achieved while still retaining the benefit of scale in the power block. Such towers would use cavity type receivers that are inherently more efficient than an external receiver. This paper examines the potential for a new concept for a cavity receiver, suitable for molten salt, which can increase efficiency and reduce metal hot-spot temperatures. By distributing the tubes within the volume of the cavity and arranging for the cooler inlet tubes to take the highest flux, the metal temperatures can be reduced close to the outlet salt temperature. The proposed design concept has the potential to solve a number of design issues that increase the cost of receiver systems. The paper provides a first-stage, simplified, theoretical analysis to show how receiver efficiency (from a radiative perspective) and hot-spot temperature are affected by the number of heat transfer layers and the degree to which each layer blocks the radiation. The work shows promising results that needs to be taken forward in a number of areas.

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Nomenclature

A_{ij}	number of absorbed rays emitted from surface i and absorbed by surface j
B_i	Blockage factor for the i_{th} surface layer
c_p	specific heat capacity of molten salt
D_H	hydraulic diameter of heat-transfer tube
G	irradiation, the incident radiation energy on a surface
h	heat transfer coefficient
k	thermal conductivity of molten salt
N_{ray}	total number of rays emitted from each surface in the ray tracing calculationns
Nu	Nusselt number
P	probability
Pr	Prandtl number, $c_p\mu/k$
Q_i	emitted (radiated) power from a surface i or of a ray
Re	Reynolds number, $\rho v D_H/\mu$
T	temperature
v	fluid velocity
α	absorptivity
ε	emissivity
μ	dynamic viscosity
μ_w	dynamic viscosity at the tube wall temperature
ρ	density of molten salt
σ	Stefan-Boltzmann constant, $5.67\text{x}10^{-8}$

1. Introduction

Cavity receivers, such as those used in PS10 and PS20 [1], have tube-bank, heat absorbing surfaces that make up some part of the inside of the cavity and an aperture through which the radiation is beamed. These tube-bank panels are also used in molten salt external receivers such as Solar Two [2] and is shown in Figure 1a.. Tubes containing a heat transfer fluid are mounted adjacent to one another to provide a continuous heat-transfer surface. A volumetric receiver, on the other hand, can be described as one where heat is transferred within a volume of a material or a material structure. The most obvious benefit is to increase the heat transfer surface area, reduce hot-spot temperatures and to arrange for the hottest parts of the receiver to be furthest from the external surface so that radiation losses are minimized. An obvious example of such a system would be one in which cool air is drawn into and through a porous, irradiated surface; the air gets hotter as it flows further into the receiver leaving the cooler parts of the receiver close to the surface to limit the amount of radiation lost to help increase receiver efficiency. A review of volumetric receivers is given in [3]

This paper introduces a combination of both approaches that offers the potential to avoid a number of technical challenges that can add to the cost of external receivers and, at the same time, improve the efficiency of a cavity receiver. It distributes a tubed heat transfer surface within the cavity with the result that the receiver is suitable for liquid heat transfer fluids, such as molten salt, and creates a design that may be cheaper to manufacture and have a higher efficiency. It is therefore described as a "tubed volumetric cavity receiver". Such receivers are envisaged for CSP plants that use multiple, small, molten salt solar towers, feeding a large central power block and thermal store.

Previous work [4], comparing the economics of this and other CSP concepts, has shown that a multiple, modular molten salt tower approach has, potentially, the lowest levelised cost of energy of any of the currently commercial CSP technologies. It combines the significant benefit of higher solar field and receiver efficiencies, but still retains the economic and thermodynamic efficiency benefit of a large-scale, central power block, with thermal storage enabling greater utilisation of the power block as well as providing more reliable power. Work on this concept started to develop a design of a small solar test tower of less than 10MWth. Although this was not progressed, budget quotations for conventional tubed panel receivers were sought and found higher than expected. Part of this