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Thermal performance analysis for a heat receiver using multiple phase change materials

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Abstract

To solve the problems associated with employing the single melt point phase change material in a heat receiver for the NASA 2 kW solar dynamic power system, this paper presents a practically easy to carry-out PCM receiver model composed of three different phase change temperature materials together with the corresponding physical model. A numerical solution is also given by which the maximal temperature for heat transfer, working fluid exit temperature, and liquid PCM fraction of the total heat transfer tube in whole are calculated. Furthermore, the results are compared with those obtained from the single PCM heat receiver. The results show that it is possible to improve the receiver performance and to reduce both the fluctuation of working fluid temperature and the weight of the heat receiver. All results of the calculation can be used to guide the heat receiver design.

Keywords: Solar dynamic power; Multiple PCM; Thermal analysis

1. Introduction

The Solar Dynamic Power Module, based on a closed Brayton cycle (CBC) system, consists of three basic equipment components: the heat source, the heat engine, and the heat sink. The heat source includes the concentrator and the receiver. Sunlight is captured by the concentrator and

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Nomenclature

c	specific heat
F	geometric view factor
h	specific enthalpy
J	effective surface radiation
q	pure radiating flux
t	time
T	temperature
T_m	PCM phase change temperature
σ	Stefan–Boltzmann constant
ε	surface emissivity
ρ	density
ΔH_m	heat of fusion

Subscripts

j	number
k	number
l	liquid PCMs
s	solid PCM
w	canister wall material

focused into the solar receiver. The receiver have two functions: (1) it works as heat exchanger that transfers the coming solar heat to the cycle gas, and (2) it stores solar energy as a thermal energy storage (TES) device during the daylight portion of the orbit for later use during the eclipse period [1,2].

The NASA 2 kW receiver comprises of a cylindrical receiver cavity, the walls of which are lined with a series of Haynes 188 tubes running the length of the cavity. The receiver incorporates integral thermal storage using a eutectic mixture of lithium fluoride and calcium difluoride as the thermal storage solid-to-liquid phase change material (PCM) [2] (shown in Fig. 1).

Because of the asymmetry canisters, circumferential surface flux, and the different temperature at the side wall, research has found that PCM in inlet canisters could not be melted, and the fraction of liquid PCM in the receiver tube was low. Thus the efficiency of PCM decreased, which consequently caused the increase of ineffective system mass, therefore a lower gas exit temperature and a larger gas exit temperature fluctuation could be caused, and the system could not work normally.

Thermal storage systems using multiple PCMs have attracted increasing attention in recent years because of their potential for superior thermal performance. Farid and Kanzawa [3] proposed a thermal energy storage system using multiple families of PCMs which were contained in a number of cylindrical capsules with air flowing across them. Gong and Mujumdar [4–6] carried out a thermodynamic analysis for energy storage using multiple PCMs. They extended their analysis from only a change process to a combined charge–discharge process and found the increase of the overall exergy efficiency can be doubled and even tripled by use of multiple PCMs. In