International Journal of Thermal Sciences 108 (2016) 17–27

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

On the use of thermal conductive focusing for solar concentration enhancement

Francisco J. Arias [a], [b], *

[a] Department of Fluid Mechanics, Universitat Politècnica de Catalunya, BarcelonaTech, ESEIAAT C/Colom 11, 08222, Barcelona, Spain
[b] Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, CB2 1PZ, United Kingdom

ARTICLE INFO

Article history:
Received 4 May 2015
Received in revised form
22 April 2016
Accepted 25 April 2016
Available online 4 May 2016

Keywords:
Thermal concentration
Conductive heat transfer
Radiative heat transfer
Solar energy

ABSTRACT

We discuss the possibility for solar concentration enhancement via conductive heat transport. Here, we are concerned, as in orthodox approaches, about maximizing the solar concentration to obtain the highest receiver temperature possible, but with one important difference: In the proposed approach, the solar concentration enhancement is attained not by the use of lenses, mirrors, or funnels (i.e., by optical concentration based on radiative transport), but via thermal conduction, what we call thermal conductive focusing. Among the additional advantages of thermal conductive focusing is the capability to concentrate indistinct direct incidence as well as diffusive radiation. Thus, the concept is especially insensitive to cloudy days and particularly attractive in application to environments with important diffusive components of light. Utilizing a simplified geometrical model, an analytical expression for the temperature and concentration gain at the receiver was derived. The particular application for a parabolic solar trough was analysed. Additional research and development is required to explore the possibilities of solar flux enhancement by thermal conductive focusing as well as the optimization of several variables.

1. Introduction

The object of this work is to analyse an approach for solar concentration enhancement to maximise the temperature at the receivers in concentrating solar power systems. Here, contrary to the current approaches based on optical concentration, i.e., based on the use of mirrors, lenses, or funnels, we are interested in attaining a solar concentration enhancement via thermal conductive heat transport, what we call *conductive focusing*.

1.1. State-of-the-art solar concentration systems

Today, systems for concentration of solar radiation become necessary when high temperatures are desired at the receiver. Such systems, known as concentrating solar power systems, encompass a broad spectrum of familiar technologies such as parabolic troughs, parabolic dishes, power towers, and compound parabolic concentrators. For more thorough discussions of the concentration solar technologies, the reader is referred to the classical books by Lovegrove [1], Francis [2], and Garg & Prakash [3]. Nevertheless, despite the aforementioned myriad of solar concentrator technologies, all of them, in one way or another, are based on the use of lenses, mirrors, or funnels, where the solar concentration is attained by radiative transfer, i.e., by focusing the direct incidence of sunlight beams by reflection and/or refraction of the light.

In this manuscript, we will assess the possibility to boost solar concentration by thermal conduction. As far as the author knows, this idea has not been contemplated before.

2. Thermal conductive focusing concept

2.1. Statement of concept

Thermal conductive focusing may be implemented in solar concentration technology in several ways and many different geometries to do so may be envisaged. However, as a first approximation, and to generalise the theoretical treatment of the concept, the simplest geometry is a slab, which will allow us to identify the variables involved in the performance of thermal conductive focusing as well as the maximum ideal, theoretical values attained.

---

* Department of Fluid Mechanics, Universitat Politècnica de Catalunya, BarcelonaTech, ESEIAAT C/Colom 11, 08222, Barcelona, Spain.
E-mail address: fjarias@mf.upc.edu.

http://dx.doi.org/10.1016/j.ijthermalsci.2016.04.019
1290-0729/

Because such a slab will act between classical solar collectors and receivers, hereafter, we will refer to this slab as a *transceiver.*

The essentials of a transceiver are depicted in Fig. 1. The performance of a transceiver is a compromise between the radiative and convective losses being re-emitted into the environment and the effective conductive heat flow being transported to the collector. Both of these factors, thermal leakage, and thermal conduction are determined by the temperature of the transceiver. It might be thought, at first sight, that increasing the transceiver length indefinitely would cause the heat flux at the collector to be increased indefinitely. However, after some careful thought, it is easy to see that increasing the length of the transceiver will result in an increase of its internal temperature and of its thermal losses. It would soon reach a point where it would no longer produce useful heat flux at the collector, i.e., the radiative heat losses at the wall will be larger than the internal conduction heat flow toward the collector.

In addition, the reader should keep in mind that according to the second law of thermodynamics, the source of energy for the transceiver, i.e., the sun, must always be at a higher temperature than the receiver (the whole system). However, there is nothing preventing, at least not from the second law, a collector with a lower temperature than the receiver and yet having heat flow in the direction collector → receiver. Entropy is an extensive magnitude and must be calculated considering the entire system. As Max Planck pointed out early on: *'carefully we must proceed when estimating the entropy of any system from the entropies of its constituents. It is strictly necessary, when dealing with any part of the system, first to ask whether it is possible that any other place in the system there is a coherent part of the system. Otherwise phenomena apparently contradicting the entropy principle might occur in the case of the unexpected mutual action of two sub-systems.'*, [4].

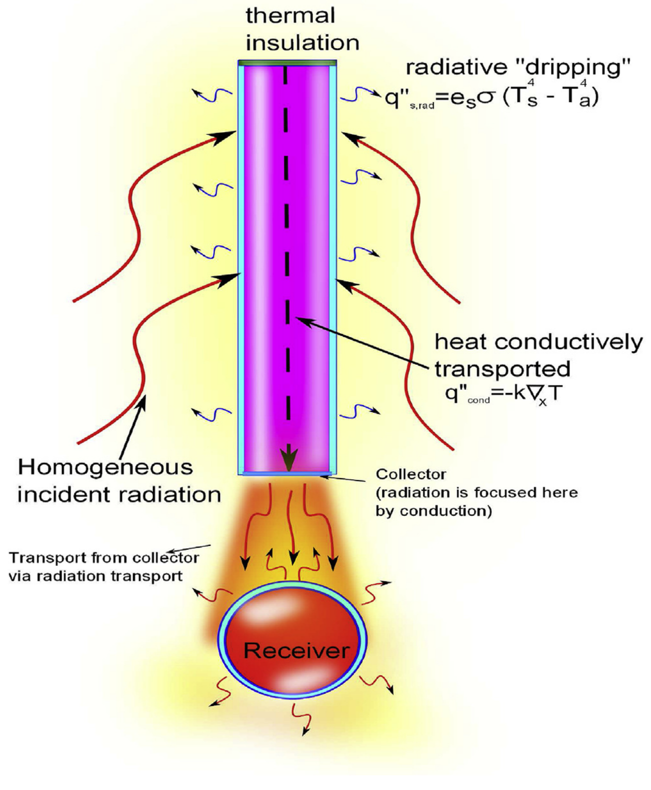

Fig. 1. The thermal transceiver concept.

Before developing the theoretical treatment of a transceiver, the reader may perhaps gain some good insights by considering the following analogy. The transceiver could be viewed as the thermal equivalent of a classical hosepipe, where the temperature and heat flux are the equivalents of the pressure and the fluid flow in the hosepipe, respectively. Thus, for a hosepipe, if the pressure (the temperature in the transceiver) increases then the fluid flow at the hosepipe-nozzle (the heat flux at the collector in the transceiver) increases. However, if the pressure in the hosepipe (the temperature in the transceiver) increases beyond a certain threshold, then leakage will appear (radiative losses plus convective losses in the transceiver) and the fluid flow at the hosepipe-nozzle (the heat flux at the collector) attains a maximum value.

Let us consider, for the sake of illustration, the simple transceiver depicted in Fig. 1, but now including its dimensions and several parameters necessary for the theoretical treatment in Fig. 2. Consider a transceiver with a length $\mathbf{x} = \mathbf{b}$, width $\mathbf{y} = \mathbf{l}$, and thickness $\mathbf{z} = \mathbf{t}$. The incident radiative heat, $\mathbf{q}''$ (e.g., the solar irradiation) is being collected in the surface $P \cdot b$ where P is the perimeter of the slab, (in this case, $P = 2l + 2t \approx 2l$). In addition, the top wall boundary of the slab located at $\mathbf{x} = \mathbf{0}$ is thermally isolated and can be considered adiabatic with temperature T_o. On the other hand, the opposite wall, located at $\mathbf{x} = \mathbf{b}$, is called the 'collector' and has surface $\mathbf{A}_c$ and temperature T_c. The receiver that is facing the collector has a radius $\mathbf{a}$, a surface $\mathbf{A}_r$, and is a distance r from the collector wall. Inside, the slab is composed of a material with high thermal conductivity κ and with a surface area $P \bullet b$ covered with a selective coating featuring a low emissivity and high absorption, $\bar{\varepsilon}_s$. In contrast, the collector features high emissivity, $\bar{\varepsilon}_c$. Finally, the receiver is covered with a very low emissivity and high absorption layer, $\bar{\varepsilon}_r$.

First, consider a rough calculation of the typical expected Biot number for a transceiver as a preliminary step, before starting our theoretical treatment. This calculation will allow us to apply some simplifying assumptions that will eventually enable us to derive an analytical expression for a coupled radiative-conductive system.

First, we need to identify the thermal losses in the transceiver,

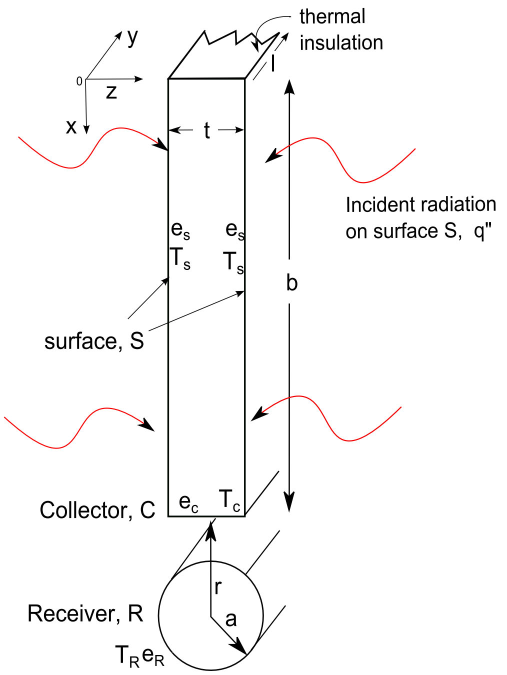

Fig. 2. Physical model for the calculation of heat transmission in the slab.