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Model to predict design parameters and performance curves of vacuum glass heat pipe solar collectors

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ABSTRACT

Glass heat pipe solar collectors are becoming very popular for heating/sanitary water production. The use of a double glass system, with vacuum in between (Dewar scheme), allows to minimize heat dispersion to the environment, and to reach potentially temperature levels in competition with much more expensive parabolic trough concentrating solar collectors (stagnation temperatures in excess of 200 °C are reported). It opens their use to solar energy conversion (i.e. low-temperature ORC technology). However, in the technical literature there is not much information on the design criteria of these collectors, and of models for evaluating absorbed solar radiation and thermo-fluid-dynamics performance.

Starting from the collector's location weather data and tilt angle, a model to evaluate the absorbed solar radiation is developed. It is based on (I) calculation of the actual angle between solar radiation and the absorbing cylindrical pipe surface; and (II) calculation of the actual absorbed radiation by the heat pipe surface, also including the mutual shading between the different heat pipes, allowing the estimate of the performance in design conditions. Sensitivity to the main design variables is examined. The model includes heat transfer (radiation, forced/natural convection, phase transition) in the different sections of the heat pipe.

1. Introduction

The glass heat pipe design has become a best-seller in advanced applications of solar energy thermal utilization, with special reference to systems designed for providing heat in regions with low radiation, or during winter; the most performing collectors use a double-pipe design for the absorbing section, with deep vacuum in between, forming a kind of "Dewar" bottle which is very effective in reducing convective heat transfer, and allows thus to reach high absorber temperatures: a typical example of this solution (DGVHP for Double Glass Vacuum Heat Pipe) is shown in Fig. 1, while Fig. 2 represents two detached heat pipes. Currently, most of these devices are produced in China [1] and are often re-branded for worldwide commercialization; their application is limited to hot water production.

The idea pursued in this paper is to develop a mathematical model of the DGVHP, in order to be able to modify its design so that it can be adapted to producing a fluid flow at a temperature level interesting for applying thermodynamic energy conversion to small CHP applications, providing heat and electricity to small, distributed users (residential, commercial, SME industrial production processes). The DGVHP, within such systems [2,3], represents totally or partially the component dedicated to the conversion of radiation into thermal power, which is then transferred to a suitable working fluid (water/steam, organic or engineered fluid). It has been demonstrated in previous works [4,5] that irreversibilities during this specific step of energy conversion are the main source of inefficiency in SEGS systems.

2. Traditional and DGVHP

The introductions to the working principles of heat pipes are beyond the purpose of this paper; the reader is referred to the literature [6].

The DGVHP (see Fig. 3 for the schematic section) represents an atypical case of heat pipe: no wick structure is used, and the inner surface where the primary loop working fluid is contained is a non-porous glass enclosure. The circulation of the working fluid (usually, ethanol) is only controlled by gravity and by the surface tension effects taking place on the flat glass/liquid interface.

The evaporator section covers most of the device length (1–2 m typically); it is built as a double glass burette, with vacuum inside ($p_V = 0.005$ Pa) in order to form a typical Dewar bottle design, effectively suppressing convection and conduction heat transfer.

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Fig. 1. Example of solar collector using an array of glass heat pipes.

The outer surface of the inner pipe is covered with a selective coating ($\alpha = 0.92$, $\varepsilon = 0.08$). At the top of the heat pipe, a single-sheet glass bulb performs as the condenser, which is connected to a manifold or reservoir (using a gasket, or a conductive metal sealed sheath), where heat is transferred to the (colder) secondary fluid.

Fig. 2. Detail of three detached heat pipes.

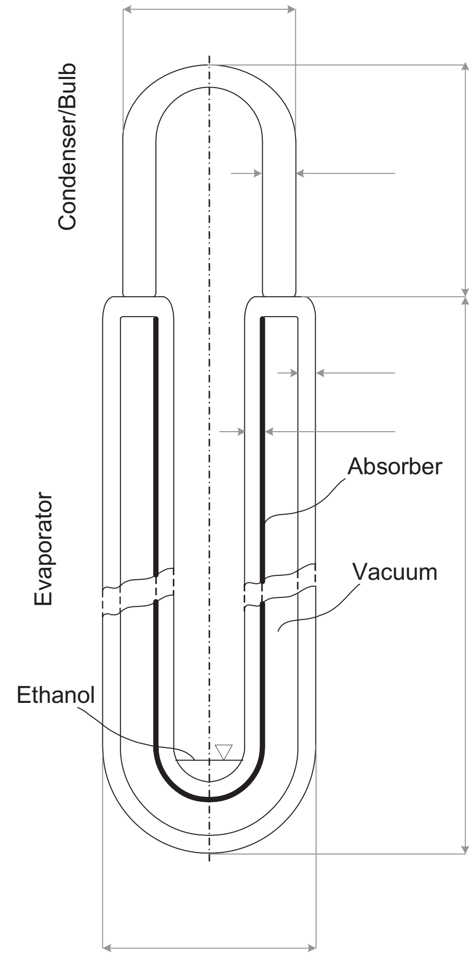

Fig. 3. Schematic of DGVHP.

This type of design represents the current state of the art, with some notable advantages with respect to the previous versions using copper heat pipes [7,8], which suffered to a certain extent of the contact resistance between glass Dewar envelope and copper absorber; and of the limited size of the copper condenser/bulb section (which is however an advantage from the point of view of sealing). Most applications of this design are for water heating in cold locations, and the potential for producing a higher temperature fluid has not yet attracted attention, even if stagnation temperatures[1] as high as 230 °C are reported in the technical literature. No back reflector was considered, as this component is often incompatible with installation guidelines for many building applications.

3. Overall model of DGVHP

Although patents have been issued since 1984 [9], and many manufacturers exist [1], very little can be found in the literature about sizing criteria and thermo-physical models for DGVHPs. The purpose is here to develop a model for the prediction of the efficiency curve, as can be validated by means of an accepted testing procedure [12]; moreover, the model should allow the simulation of full-day or long-term performance, and provide design

[1] The stagnation conditions for a solar collector [15] are reached when no useful heat is extracted from the collector; under these conditions (no outlet flow), the thermal efficiency falls to zero as all the heat collected by the absorber is lost to the environment.