Desalination 399 (2016) 165–170

Contents lists available at ScienceDirect

Desalination

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

Initial evaluation of a phase change solar collector for desalination applications

G. Martinopoulos [a,*], A. Ikonomopoulos [b], G. Tsilingiridis [b]

[a] International Hellenic University, School of Science and Technology, 14th km Thessaloniki-Moudania, EL 57001, Thermi, Greece
[b] Aristotle University of Thessaloniki, Department of Mechanical Engineering, Process Equipment Design Laboratory, POB 487, EL 54124, Thessaloniki, Greece

HIGHLIGHTS

- An experimental evaluation of a phase change solar collector is presented.
- The influence of different parameters to system efficiency is reported.
- This collector presents an attractive option for solar desalination systems.
- It combines good energy behavior with simplicity in manufacture and low cost.

ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 12 August 2016
Accepted 8 September 2016
Available online xxxx

Keywords:
Solar energy
Solar collector
Phase change materials
Desalination

ABSTRACT

Although desalination techniques for the preparation of fresh water from seawater and brackish water have been used for decades, they present the problem of high cost, as they are inherently energy intensive processes based on electricity or fossil fuel consumption. Solar thermal collectors could be used in thermal desalination plants in order to overcome some of the issues that they currently present, as long as they become more cost effective and efficient. One of the techniques that are under research in order to achieve this is the use of liquids with low boiling point as heat transfer mediums which minimize thermal losses to the environment by operating in lower temperatures, and utilize the enthalpy of evaporation. In this paper the experimental evaluation of a 2 m^2 novel phase change flat plate solar collector is presented. The influence of the ratio of heat carrier volume to available collector volume and of the inclination of the collector, as well as of mass flow rate to the efficiency of the system is assessed in order to find a combination of the above parameters that optimize collector's efficiency and make solar thermal systems more attractive for possible use in desalination applications. A 50% volume filament at a 40° inclination, presented an overall better system efficiency which increased proportionally with increased mass flow rates, leading to an increase of 2 °C per meter of heat exchanger (for a mass flow rate of 5 kg/min) to the heat removal fluid.

1. Introduction

Worldwide interest for water sources keeps on expanding whilst freshwater sources are becoming rarer due to a constant increase in consumption and the more pronounced effects of climate change, especially in semi-arid and coastal/islandic areas [10].

According to the literature, worldwide water consumption surpasses 4.000 billion m^3 annually, and around a quarter of the population worldwide is experiencing water shortage. In an effort to meet the demand for freshwater, a lot of effort has been put towards desalination of sea and brackish water. This move is more evident in countries of the Middle East and North Africa (MENA countries) which have been long plagued by water scarcity issues [10].

There are currently more than 15.000 desalination plants worldwide that produce more than 70 million m^3 of fresh water daily with the vast majority using seawater as its source [3].

Water scarcity is not an issue that affects only MENA countries, drought events are occurring in most areas around the world and cause serious impacts on the local societies as well as to the local environment and economy. For instance, Greece experienced a drought during the 2006–07 period, which lead to a reduction of primary agricultural production and heavily impacted the constant supply of freshwater [26].

In the case of Greece, the existence of a great number of remote islands which attract a large number of tourists seasonal, heavily burdens the local fresh water resources, as it places a strong seasonal variation in water demand during summer, when the water resource is at a

* Corresponding author.
E-mail address: g.martinopoulos@ihu.edu.gr (G. Martinopoulos).

http://dx.doi.org/10.1016/j.desal.2016.09.009
0011-9164/

premium. This has led to a number of desalination plants in various islands throughout the Aegean in order to cover these needs. The situation presented above is not unique in Greece, as Greece's hydrologic regime is similar to that of most Mediterranean countries [10].

Although desalination techniques for the preparation of seawater and brackish water have been used for a number of years and can help with the current water shortage problem, they present the problem of high cost, as they are inherently energy intensive processes that are based on fossil fuel consumption. This impacts the sustainability of these plants heavily, as apart from the high cost, the insular nature of the areas that require their use provide serious logistical problems.

The two main categories that desalination technologies can be divided are, thermal which use heat to vaporize fresh water and reverse osmosis that uses high pressure in order to separate fresh water through a membrane from sea water or brackish water [23]. The use of renewable energy as an energy source for desalination plants has been studied by a number of researchers during the last decades [20], but real life deployment has been minimal, with less than 1% of today's desalination capacity being attributed to renewable energy. Solar energy is the dominant renewable energy form used either by employing photovoltaics or solar thermal systems providing electricity for the equipment or heat for the desalination process [10].

Solar powered/driven desalination has attracted a lot of attention, and a lot of research has been carried out worldwide. Researchers have investigated solar coupled thermally driven conventional desalination plants, employing either Multi-Stage Flash (MSF) or Multi-Effect Distillation (MED) technologies that nowadays cover almost 22% of plants in operation. The low specific energy requirements that membrane technology presents, gave a significant advantage to Reverse Osmosis (RO) desalination plants which consist 16% of the total. In the majority of the solar coupled thermally driven systems the mean operating temperature ranges between 45 and 90 °C [2,9].

Thermal desalination plants, which are based on the principles of evaporation and condensation, could employ solar thermal collectors in order to solve some of the problems that they currently present, as currently the cost of solar desalination ranges between 3 and 9 €/m^3, which correspond to between 4 and 12 \$/m^3, [23] depending on the technology used and the scale of the plant [6,15].

In Greece desalination plants were introduced in the late 1980′s in many islands of the Aegean Sea which were only partly supplied by local groundwater sources as well as in smaller islands like Milos, Kimolos, Symi and Kastelorizo among others that possess insufficient water resources and have to be supplied via tanker ships at a high cost [8].

Seawater desalination using solar energy is an emerging option for these islands, especially as the high seasonality of water demand (due to irrigation and tourism) during the summer coincides with the high solar potential availability and today there are more than thirty plants in operation [13] with an operating cost that ranges from 0,13 €/m^3 to 2,70 €/m^3 [27]. Most of them use reverse osmosis techniques.

It is obvious that in order for solar thermal desalination systems to become more cost effective, low cost and more efficient solar collectors are necessary that can operate at higher temperatures and mass flow rates [15,16]. During the last few years a lot of effort is put towards the optimization of flat plate collector efficiency [4,24]. One of the techniques employed is the use of liquids with low boiling point as the heat transfer fluid in solar collectors. The collectors that employ this technique are called phase change collectors.

In this paper an experimental evaluation of a phase change heat-plate solar collector is presented as a continuation of previous work [17,18] as a cost effective solution for solar thermal desalination plants. Furthermore, the influence of the ratio of heat carrier volume to available volume inside the pipe, of mass flow rate, as well as from the inclination to system efficiency is reported. The novelty of the current collector is that the copper pipes are welded in the upper part with a double shell copper heat exchanger that acts as a condenser that is more compact and with a considerable smaller volume than that of previous studies [19,21] making production easier and with lower cost.

2. Heat plate collector description

In its simplest form, a heat-pipe is a sealed tube inside of which a small amount of liquid (such as water or ethanol) that presents high vapour pressure is placed, in low vacuum conditions. When such a pipe is inclined and heated, liquid will quickly evaporate and the vapours formed will rise to the upper part where they can condense by giving

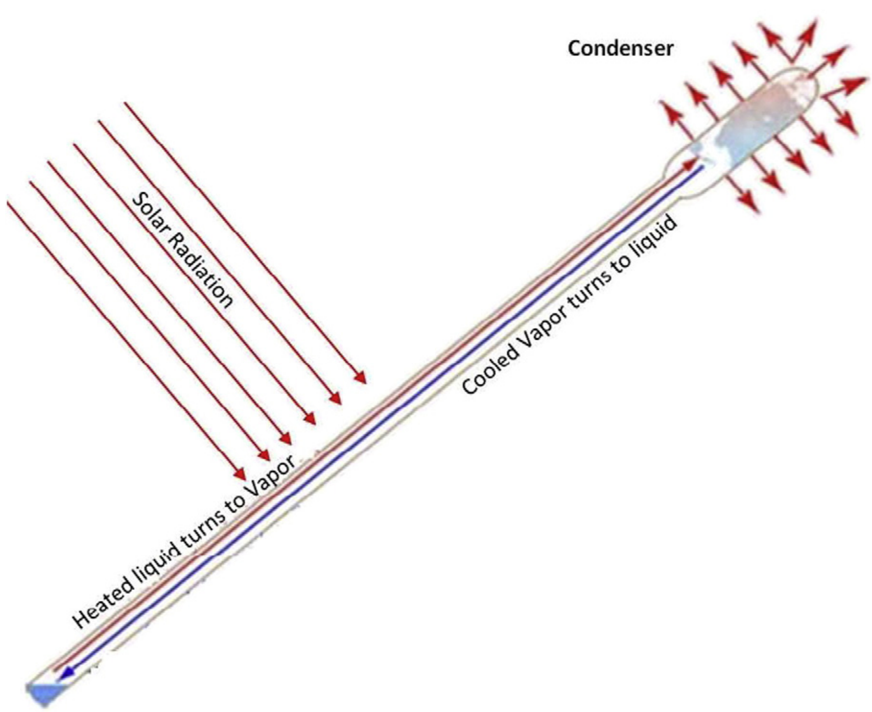

Fig. 1. Operation principle of a heat plate.