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Numerical simulation of PV cooling by using single turn pulsating heat pipe

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ABSTRACT

Electrical efficiency of photovoltaic (PV) modules depends on their working temperature. Effective cooling is required in order to achieve higher performance. Pulsating heat pipes (PHPs) are compact heat transfer devices with high effective thermal performance due to the two-phase heat transfer mechanism. Since the lower temperature of PV modules leads to higher electricity generation and better efficiency, PHPs can be applied for PV cooling. In this work, the PV cooling by applying a single turn PHP is numerically investigated. In addition, a copper fin with the same dimensions as the PHP for cooling the PV panel is simulated to compare the performance of the PHP with a solid metal like copper. Results indicated that PHPs are an appropriate option for PV cooling and has the capability to increase PV modules efficiency. It was found that a PV panel using the PHP may have approximately 18% enhancement in electrical power generated compared with that without any cooling system.

1. Introduction

Due to environmental problems of using fossil fuels and completion of these fuels [1], renewable energies are developing significantly in recent years [2–4]. Solar energy is one of the popular type of renewable energies which are applied for various purposes such as heating, desalination, and electricity generation [5,6]. Solar energy can be applied directly using solar PV modules or indirectly via thermal power plants, for electricity generation [7,8]. Both of these approaches are widely used and several previous studies have focused on their performance enhancement [9,10].

Enhancement in the efficiency of electricity generation systems would lead to obtaining electricity at more affordable price and lower environmental unfavorable effect. PV solar cell performance depends on the operating temperature. Generally, increase in solar cell temperature causes a decrease in efficiency [11]. To improve the efficiency of PV solar cells, the cooling of PV is one of the methods [12]. There are various PV cooling methods [13]. For example, Akbarzadeh and Wadowski [14] used thermosyphon for PV cooling. Results indicated that it is possible to achieve higher efficiency using this approach. Aldossary et al. [15] examined the PV cooling by using water channels. Most of the methods applied to PV cooling are active cooling since the passive cooling had some disadvantages such as inadequate heat dissipation at high temperatures [15]. Heat pipes are passive cooling devices with high effective thermal performance which can be applied for PV panel cooling.

There are several types of heat pipes. Pulsating heat pipes (PHPs) are more applicable in devices which have compact sizes and high heat fluxes such as electronic systems [16,17]. Pulsating heat pipes (PHPs) are widely used for heat transfer purposes due to appropriate performance in heat dissipation [18–20]. The PHPs consist of a capillary tube with several turns [21,22]. The internal diameter of the PHPs must be small enough for slug-plug regime formation [23]. There are two major types of PHPs: closed loop and open loop [24]. In closed loop PHPs, two ends of capillary tubes are connected to each other while are separated in open loop ones [16]. Several parameters are influential in their thermal performance including filling ratio, working fluid, inclination angle and etc. Previous studies have been conducted to improve their

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Nomenclature

h_h	convective heat transfer coefficient (W/m^2 K)
l	length (m)
l_{eff}	PHP effective length
Nu	Nusselt number
q_{PHP}	heat transfer through PHP (W/m^2)
q_s	sun radiation heat input (W/m^2)
q_{el}	electrical power (W/m^2)
q_h	convective heat transfer (W/m^2)
q_h	radiative heat transfer (W/m^2)
q	heat flux (W/m^2)
Pr	Prandtl number
Ra	Rayleigh number
R	thermal resistance (K/W)
T	temperature (K)
ρ	density (kg/m^3)
ε_0	q_s
β	PV panel efficiency

Subscripts

ad	adiabatic
a	ambient
c	condenser
e	evaporator
s	PV panel surface

thermal performance by applying different approaches such as using nanofluids [25] and changes in structure [26].

The main mechanism of heat transfer in the PHPs is two-phase heat transfer, evaporation in evaporator and condensation in the condenser [27]. The driving force for fluid motion is pressure difference between condenser and evaporator which is attributed to boiling phenomena [24]. In addition to electronic systems, the PHPs are also employed in solar water heaters, phase change materials and solar desalination systems [28,29]. In the present study, the thermal performance of a PHP for PV cooling is investigated numerically with using the results of Saha et al. [30]. Details about the PHP geometry and thermal performance are presented in next section.

2. Analysis

In this work, a pulsating heat pipe (PHP) is employed according to the data of Saha et al. [30]. The inner diameter of the PHP is 4 mm and it was made of quartz. The dimensions of the PHP were shown schematically in Fig. 1. The total length of the PHP was 150 mm and divided into three parts including condenser, adiabatic and evaporator with 30, 60 and 50 mm in length, respectively.

PV panels must be installed in an orientation in which the solar irradiation is normal to it. Kacira et al. [31] investigated the performance of a PV panel in various inclined angles. They found that the best performance was obtained in the range of 20–40 inclination angle and the highest radiation was noted in 30° inclination angle. Besides, they indicated that the PHP had its best thermal performance in 40% filling ratio. Therefore, in this work, the thermal resistances in 40% filling ratio at the tilt angle of 30° for PV panel is considered for simulation.

To model the transport of the PHP, effective thermal conductivity of PHP should be calculated. Eq. (1) stands for effective thermal conductivity of PHP based on its geometry.

$$Q = A_c * q_{PHP} = \frac{\Delta T}{R} = \frac{\Delta T}{\frac{l_{eff}}{k_{eff} A_c}} \tag{1}$$

where the effective length of the PHP is:

$$l_{eff} = \frac{\int_{L_e}(\int_0^x q'_e dx)dx + L_{ad} q_{c,max} + \int_{Lc}(\int_{L_e+L_{ad}}^x q'_e dx)dx}{q_{c,max}} \tag{2}$$

Since thermal resistance of PHPs is a function of temperature difference between evaporator and condenser, a correlation is obtained to indicate the relationship between temperature difference and thermal resistance and used for evaluating the effective thermal conductivity in the numerical simulation. The thermal resistance as a function of temperature difference is represented in Eq. (3).

$$R = -0.00000539905(\Delta T)^3 + 0.001124605(\Delta T)^2 - 0.07636998(\Delta T) + 2.102284 \tag{3}$$

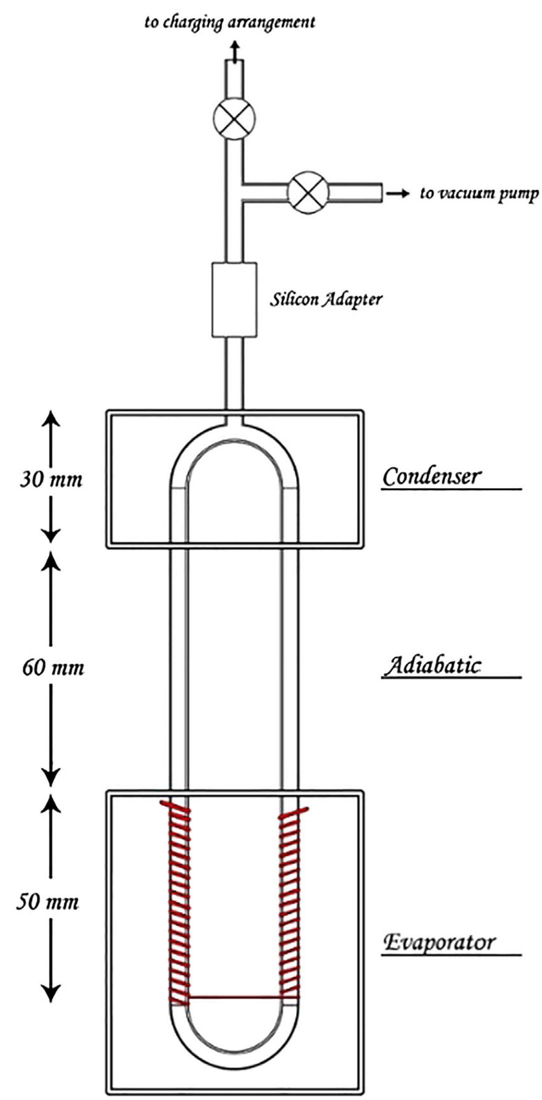

Fig. 1. Schematic diagram of the PHP experimental set-up [30].