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Heat transfer enhancement in a hybrid microchannel-photovoltaic cell using Boehmite nanofluid☆

Nooshin Karami, Masoud Rahimi *

CFD Research Center, Chemical Engineering Department, Razi University, Kermanshah, Iran

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ABSTRACT

Experiments were conducted to investigate the cooling performance of water-based Boehmite ($AlOOH \cdot xH_2O$) nanofluid in a hybrid photovoltaic (PV) cell. A Perspex plate consists of 40 parallel rectangular microchannels with a hydraulic diameter of 783 μm, a length of 24 cm, a width of 1.8 mm and a depth of 500 μm attached to the back of the cell. Cooling performances of water, as the base fluid, and three different concentrations of nanofluid (0.01, 0.1 and 0.3 wt.%) were compared. The nanofluid thermal performance has been assessed from the obtained results for outlet flow temperature and the average PV surface temperature. The average PV surface temperature decreased from 62.29 °C to 32.5 °C at zero and 300 ml/min of flow rate for 0.01 wt.% nanofluid, respectively. Moreover, the highest improving in the electrical efficiency was achieved about 27% for 0.01 wt.% concentration of the nanofluid at this flow rate.

1. Introduction

One of the most significant current discussions in photovoltaic industry is the increasing efficiency of solar cell. An effective method of improving efficiency of a photovoltaic (PV) module is by decreasing the operating temperature of its surface. This can be achieved by cooling the PV module during operation which leads to higher heat dissipation rates from PV cells [1–4]. As a result, most of the research to date has tended to apply different methods to cool PV cells [5–11]. It could be seen that the most favorable methods are impinging jets and micro-channels since their low enough thermal resistances for acceptable cooling performance [12]. The microchannel heat sink demonstrates the ability to remove a large amount of heat from a small area which is a desirable feature for heat transfer enhancement. Therefore, researchers have shown an increased interest in the development of micro cooling technology for various applications [13–16]. Here, it must be mentioned that on the basis of the various definitions for microchannel any flow channel diameter or hydraulic diameter of 1 mm or below is broadly considered as 'microchannel' [17,18]. Energy and exergy analysis of a hybrid microchannel PV module under constant mass flow rate of air was carried out by Agrawal et al. [19]. Moreover, several theoretical studies of hybrid microchannel photovoltaic thermal systems are available in the literature. An optimization methodology for a microchannel, plate-fin heat sink in two different microchannel configurations was applied by Karathanassis et al. [20]. An investigation of the heat transfer performance of liquid-cooled heat sinks with conventional and novel micro-channel flow field configurations for application in concentrated solar cells was carried out by Ramos-Alvarado et al. [21].

Achieving as high thermal performance as possible using nanofluid with low concentration in microchannel heat sinks has been proposed by many authors for various applications [22–28]. Furthermore, extensive research has been carried out to investigate effects of different nanofluids on the cooling performance of solar collectors. Otanicar et al. [29] investigated both experimentally and numerically the effects of different nanofluids on the performance of a micro scale direct absorption solar collector. Saidur et al. [30] studied the potential of aluminum/water nanofluid for use in direct absorption of heat from solar collectors. Tyagi et al. [31] investigated the effects of nanoparticles size on the collector efficiency. No significant increase in the efficiency was found with an increase in the size of nanoparticles. Taylor et al. [32] compared a nanofluid-based concentrating solar thermal system with a conventional one and indicated that the use of a nanofluid in the receiver can improve the panel efficiency. Li et al. [33] investigated the effects of using three different nanofluids on the performance of a tubular solar collector.

The reported satisfactory results indicate that sing nanofluids for cooling the PV systems could be practical. However, limited discussion exists which adequately covers the potential of using nanofluid as working fluid in microchannel heat sinks to cool solar. The aim of the present work is to introduce a hybrid microchannel PV/T using nanofluid as working fluid. This was done to reduce the module

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* Corresponding author at: Chemical Eng. Dept. Razi University, Taghe Bostan, Kermanshah, Iran.
E-mail addresses: masoudrahimi@yahoo.com, m.rahimi@razi.ac.ir (M. Rahimi).

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temperature and increase the conversion efficiency of the PV cell. In addition, this work aims to determine whether nanofluid can enhance the PV cell performance better than base fluid. Finally, the performance evaluation of PV system under cooling condition for various concentrations of nanofluid will be discussed in detail.

2. Experiments

2.1. Channel fabrication and cell modules

The proposed system consists of a mono-crystalline silicon photovoltaic module which includes 36 cells connected in parallel and series with an active area of 18 mm by 50 mm. The PV cell effective area was cooled by a 24 × 16 cm microchannel fabricated on a Plexiglas plate with a thickness of 10 mm. The microchannel with a hydraulic diameter of 783 μm is attached at the back of the PV cell. The cooling part consists of 40 parallel rectangular channels with a length of 24 cm, a width of 1.8 mm and a depth of 0.5 mm. As it is shown in Fig. 1, to reach an equal flow distribution and pressure drop one inlet was considered approximately for every ten microchannels and fluid leaves the system from three outlets.

2.2. Nanofluid preparation

In the present work, the nanometer-sized Boehmite particles ($AlOOH \cdot xH_2O$) (purchased from Jian Haohua Company) with an averaged particle size of about 5–10 nm and 99.9% purity were dispersed in deionized water as the base fluid to form the Boehmite-water nanofluid. The structure of Boehmite is shown in Fig. 2. Nanofluid of the desired volume fraction of Boehmite was formulated by mixing appropriate quantities of nanoparticles with the base fluid in a flask. The nanoparticles were dispersed in an ultrasonic vibration bath for at least 90 min in order to obtain a uniformly dispersed solution.

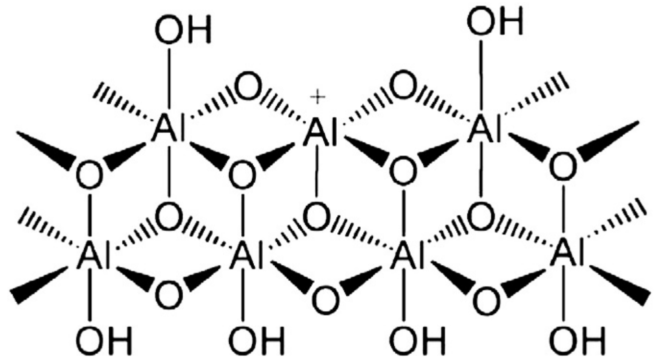

Fig. 2. Structure of Boehmite.

2.3. System descriptions

The main components of the experimental rig are pumping section, test module, data acquisition system and solar simulator. The working fluid enters the loop from a reservoir through a regulating valve and is continuously circulated by a pump. A coil was used in order to control the inlet temperature of the working fluid in the tank. Furthermore, another pump was used to deliver cold water through the coil and its flow rate was controlled by a valve.

The test module consists mainly of a microchannel heat sink, which is attached underneath the PV cell. In order to measure the PV cell temperature, 12K-type thermocouples were positioned across the PV surface as shown in Fig. 3. As illustrated in this figure, the thermocouples were equally located at an interval of 38 mm starting 40 mm from the inlet zone. Moreover, two other thermocouples were used to obtain variation of the outlet and inlet working fluid temperature. Eventually, in the data acquisition system, the thermocouples were connected to a thermometer (Lutron, BTM-4208SD), which was applied to record the temperatures. The recorded data were accessed through a

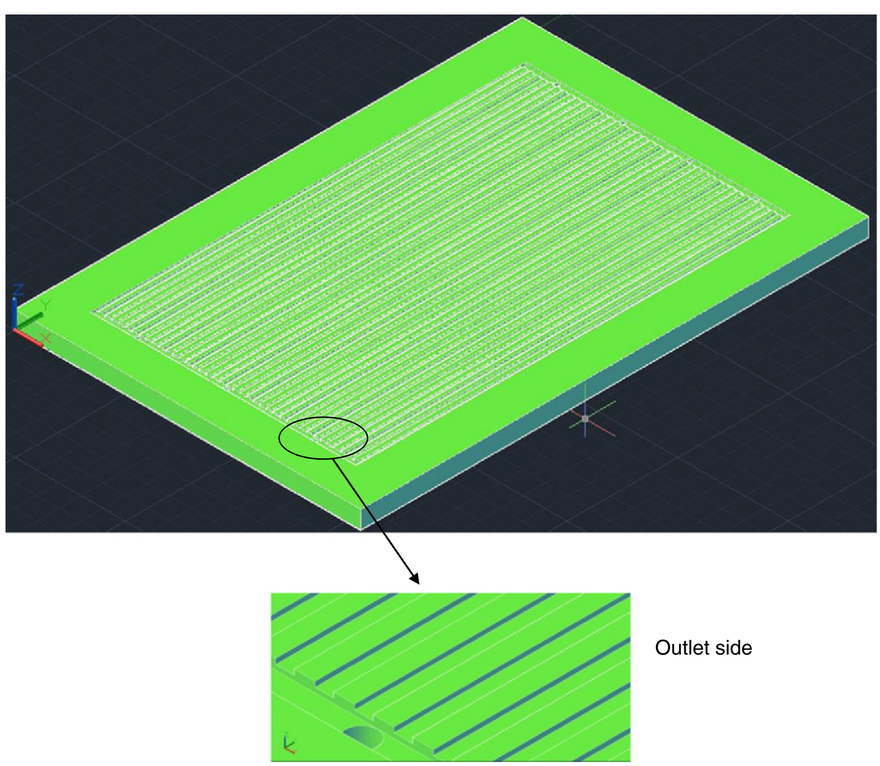

Fig. 1. The 3D schematic view of the microchannels.