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A review on the solar applications of thermosyphons

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ABSTRACT

Thermosyphons are used in various energy systems due to their efficient performance in heat transfer. These devices can be employed in several solar energy systems because of their high effective thermal conductivity. The most important solar applications can be listed as PV cooling, desalination units, water heating systems and thermoelectric. In the current study, the mentioned applications and the key findings of the related researches are reviewed and represented. Based on the reviewed publications, the thermal specifications of the thermosyphons affect the overall performance of the systems assisted with thermosyphons. For instance, by using nanofluids, the thermal performance of these devices improves which results in higher efficiency of the systems. Using novel ideas such as using wick in the evaporator section is another approach to achieve more proper performance of the thermosyphons in solar energy systems.

1. INTRODUCTION

Thermosyphons are efficient thermal mediums which are broadly employed in various energy systems such as ventilation, heat exchangers and etc. [1–4]. The performance and heat transfer ability of these devices depend on various factors. Operating fluid, inclination angle, filling ratio and heat input are among the most important effective parameters [5–7]. The main reason of heat transfer in thermosyphons is evaporation in heat source and condensation in heat sink [8]. A schematic of thermosyphon is depicted in Figure 1.

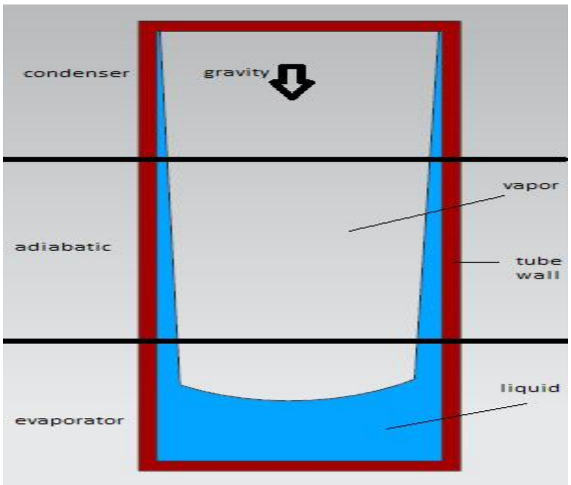

Figure 1. Schematic of thermosyphon

As it was mentioned, working fluid plays key role in the thermal behavior of thermosyphons [9-10]. Using nanofluids, due to their high thermal conductivity [11-12], is a conventional approach which is suggested by several researchers. Employing nanofluids can lead to augment in thermal performance of various kind of heat pipes [13-15]. In addition to the operating fluid, its charging ratio is another influential factor [16]. The optimum charging ratio differs for various case studies and obtained experimentally. Since the gravity causes fluid motion inside thermosyphon, most of the studies concluded that the best thermal performance is achievable near vertical orientation. In addition to the mentioned factors, heat input, due to two-phase heat transfer of thermosyphons, affects thermal resistance of the thermosyphons. Increase in heat input, enhances boiling heat transfer; however, at very high heat loads, the dry-out phenomenon occurs due to lack of liquid in evaporator.

Renewable energy sources have several environmental advantages compared with fossil fuels [17–20]. Among various renewable sources, solar energy gains importance due to its availability and high intensity. Solar energy is applicable for several purposes including heat exchangers [21], desalinating water [22], heating [23-26] and power generation [27]. Power generation can be achieved by using PV panels or extracting thermal energy of the sun to run thermodynamic cycles such as Brayton or Brayton-Rankine [28-29]. For desalination systems, the generated electricity via solar energy can be applied in reverse-osmosis systems. In addition, solar thermal energy can be used in other types of desalination units such as humidification-dehumidification types.

In order to efficiently use solar thermal energy, it is necessary to apply thermal devices with appropriate heat transfer ability. Thermosyphons are favorable candidates to be employed in the systems require efficient heat transfer. These types of heat pipes are used in various solar-based technologies in recent years. In the current studies, the applications of thermosyphons in solar energy systems are reviewed and their findings are represented.

2. APPLICATIONS OF THERMOSYPHONS IN SOLAR ENERGY SYSTEMS

There are several researches concentrated on the applications of thermal mediums in solar energy technologies. The aim of the current study is representing the use of thermosyphons in these systems. In the following subsections, the most attracting applications of thermosyphons in solar energy are reviewed.

2.1 PV cooling

P Photovoltaic (PV) panels are employed to produce electricity from solar irradiations [30,31]. Various parameters effect on their efficiency such as tilt angle, irradiation intensity and working temperature [32–35]. Studies have shown that increase in solar cell temperature causes reduction in efficiency [36]. Finding appropriate methods to cool down the PV panels results in efficiency enhancement. PV/T systems are among the most conventional approaches used for PV cooling [37]. In these configurations, a cooling fluid is applied to cool down the cell. In addition to using cooling channels at the back of PV modules, using cooling devices such as heat pipes is an efficient approach to prevent efficiency reduction due to temperature increase. Akbarzadeh et al. [38] suggested a PV/T system which was a combination of solar concentrator system and PV panel. The schematic of the system is shown in Figure 2. In order to assess the influence of cooling system on the performance, the tests were performed by the cooling apparatus with and without fluid. The results revealed that without using the fluid, the output power of the cell had 50% reduction compared with utilizing the cooling system. It was concluded applying thermosyphon is an influential approach to cool down the PV panel.

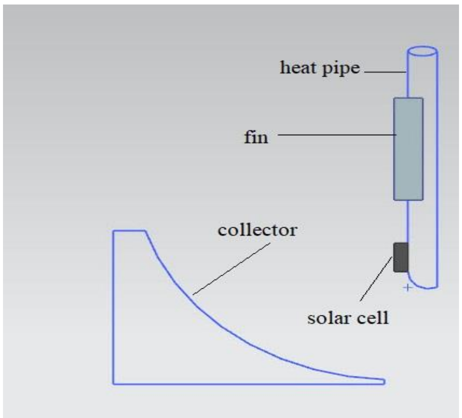

Figure 2. Schematic of PV/T system with thermosyphon [38]

Another configuration for PV/T system with an array of thermosyphons was experimentally evaluated by Moradgholi et al. [39]. 16 thermosyphons were applied for cooling the PV and the total area of the cell was equal to 0.003 m^2. The applied thermosyphons was made of aluminum and Al_2O_3 /methanol and methanol used as operating fluids. Results indicated that using thermosyphon led to lower operating temperature of PV panel. In addition, it was observed that by using methanol as working fluid, the electrical efficiency of the PV/T system was 0.7% higher compared with PV panel without cooling mediums, while using nanofluid resulted in 1% higher efficiency. Increases in the energy efficiency of the systems for the systems used methanol and the nanofluid were 15.3% and 27.3%, respectively.

2.2 Solar desalination

Typically, desalination systems require thermal energy or electricity for fresh water production [40,41]. Both of these two types of energy can be provided by applying solar radiation [42]. There are various types of desalination systems including Reverse-Osmosis (RO), humidification-dehumidification (HDH) and etc [43,44]. Behnam et al. [45] experimentally investigated a thermosyphon-assisted HDH desalination. The desalination system consisted of air humidifier, thermosyphon, dehumidifier, and evacuated tube collector. The thermosyphons were used to transfer absorbed heat by the collector to heat up the water. The evaporator section of the thermosyphon was located at the center of collectors and its condenser was in humidifier. The transferred heat by the thermosyphon caused boiling in humidifier section. Results showed that by using oil between the collector and thermosyphons, up to 65% efficiency for the system was achievable which indicated appropriate performance of the thermosyphons.

Faegh et al. [46] designed a novel solar desalination system by using Phase Change Material (PCM) and thermosyphon. In this system, solar energy used for evaporating the water during daytime. The PCM was applied as energy storage unit and charged by heat transfer with vaporized water. Heat transfer between the vaporized water and PCM resulted in vapor condensation and energy absorption by PCM. In the evening, the stored energy by the PCM transferred to the saline water, via thermosyphon, to produce fresh water. Comparing the performance of the systems with and without PCM showed 86% increase in efficiency in the case of applying PCM.

2.3 Water heating systems

The solar energy can be employed to provide hot water for facilities and buildings without consumption fossil fuels [47-49]. These types of water heating systems can be coupled with storage tanks to be applicable during night-time [50]. Thermosyphons are appropriate devices for transferring the absorbed thermal energy of sun to warm up water [51-52]; in addition, thermosyphons can be used in the heat exchangers applied in water heating systems [53]. The performance of the solar water heater depends on several factors such as temperature of cold water, quality of manufacturing and design specifications [54-55]. In the thermosyphon-assisted water heating systems, the evaporator section of the thermosyphon located in solar collector. By receiving the solar thermal energy, the working fluid inside the thermosyphon evaporates and moves to condenser section which is water storage tank [56]. Heat transfer between condenser section of thermosyphon and content of the storage tank results in condensation of vapor. The vapor returns to the evaporator part and this process continues. Since the performance of the thermosyphon depends on its working fluid, changing the operating fluid affects the overall efficiency of the system. Based on a study carried out by Esen et al. [56], three operating fluids including R410a, R407C and R-134a were used in the thermosyphon of the system shown in Error! Reference source not found. Results demonstrated that using R410a led to the maximum efficiency of the system among the tested fluids. The highest daily collecting efficiency of the system filed with R410a was 58.96%.

Since the thermal performance of thermosyphon in water heating systems influences on the efficiency of these technologies, enhancement in the heat transfer capability of thermosyphons results in performance improvement. Huang et al. [57] investigated the effect of filling ratio and evaporator structure on the performance of two-phase closed loop thermosyphon used in solar water heater. The filling ratio of the thermosyphon was methanol. Two filling ratios including 40% and 60% were considered in the study to analyze the effect of charging rate. In addition to conventional structure, in another thermosyphon a porous wick was inserted in the evaporator part. Obtained results revealed that using the wick in evaporator led to 12.7% efficiency enhancement of the system. Moreover, it was concluded that at high heat inputs, 60% filling ratio resulted in better performance in comparison with 40%. The effect of filling ratio on the performance of water heating system with thermosyphon was investigated in another study performed by Zhang et al. [58]. In their research, the operating fluid was R600a and five filling ratios including 10%, 20%, 30% and 50% were evaluated to obtain the best condition. Results revealed the highest efficiency was achievable in the filling ratio between 30% and 50%.

In another research, a novel configuration of heating system introduced by Velmurugan et al. [59] which was used for heating air and water by employing thermosyphon as thermal medium. In the proposed configuration, three circuits were used to circulate heat carrying fluid, fluid and air used for consumer utilization. The performance of the system was evaluated under two modes for water and air heating. Based on the results, the maximum efficiencies of the system for water and air heating were 73.68% and 69.18% respectively.

2.4 Solar thermoelectric systems

The thermal energy of sun is applicable in thermoelectric to obtain electricity [60-61]. A configuration integrated with thermosyphon was introduced by Miljkovic et al. [62] to passively transfer the thermal energy to another cycle in order to utilize it for various purposes. In this configuration, the evaporator section of thermosyphon was connected to the cold side of the thermosyphon. Due to temperature gradient between two sides of the thermoelectric, the electricity was generated. In addition, the thermosyphon was applied to axially transfer heat from cold side of the thermoelectric. Based on the results of modeling, the performance of the system was dependent on several factors such as temperature of bottoming cycle (thermosyphon condenser) and solar irradiation. It was concluded that increase in solar concentration led to improvement in both thermal and electrical efficiencies.

In another study [63], a thermosyphon and thermoelectric module were applied in a solar pond to generate electricity. In the proposed system, the thermosyphon was employed in order to transfer heat from hot part to the cold part of the solar pond. The thermoelectric module was connected to the top section of the thermosyphon which was located at the upper convective zone. The schematic of the introduced system is shown in Figure 3. The dimeter and length of the thermosyphon were 100 mm and 2 m, respectively. 16 thermoelectric cells with $40\times 40 \times 3.9\ mm$ dimensions were used in this configuration. Results revealed that by using the configuration, it is possible to passively produce electricity with solar ponds. The maximum generated power by this system was 3.2 W which shows its efficient performance.

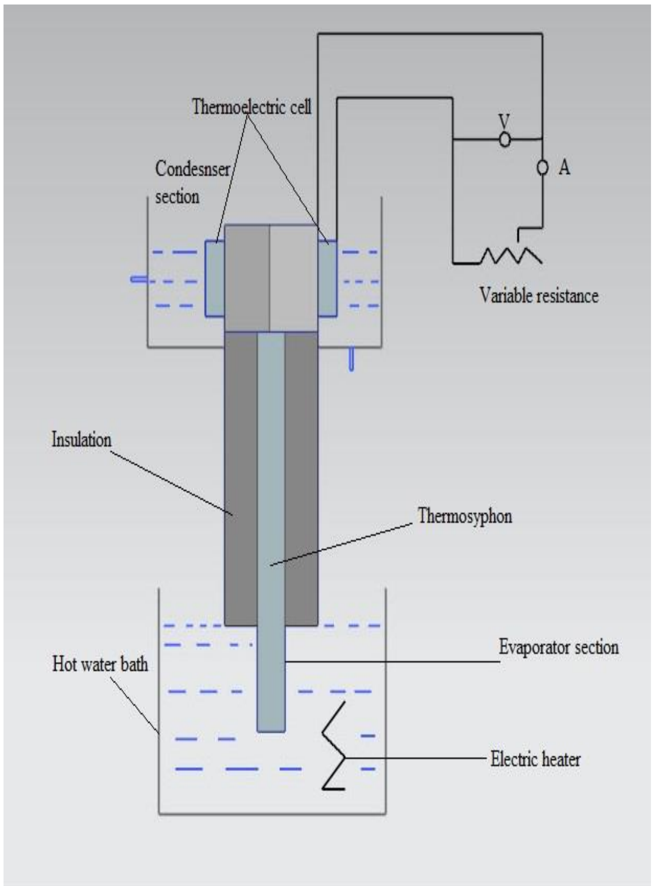

Figure 3. Schematic of the solar pond with thermosyphon and thermoelectric

2.5 Solar collectors

Thermosyphons can be employed in solar collectors in order to have efficient heat transfer. The performance of the thermosyphon-assisted solar collectors is dependent on the thermal behavior of the thermosyphon which is affected by working fluid, inclination angle and etc. According to the various studies [64-65], by using nano-sized materials, the efficiency of the systems can be enhanced. Chougule et al. [66] evaluated the performance of a two-phase thermosyphon applied in solar collector. In their study, pure water and CNT/water nanofluid in four volumetric concentrations including 0.15%, 0.45%, 0.60% and 1% were employed as operating fluid of the thermosyphon. Moreover, the five tilt angles (20, 32, 40, 50 and 60 deg) were tested to investigate the thermal performance. It was observed that utilizing the nanofluid led to enhancement of the efficiency of the system. The average efficiency of the collector in various concentrations of the nanofluid is represented in Figure 4.

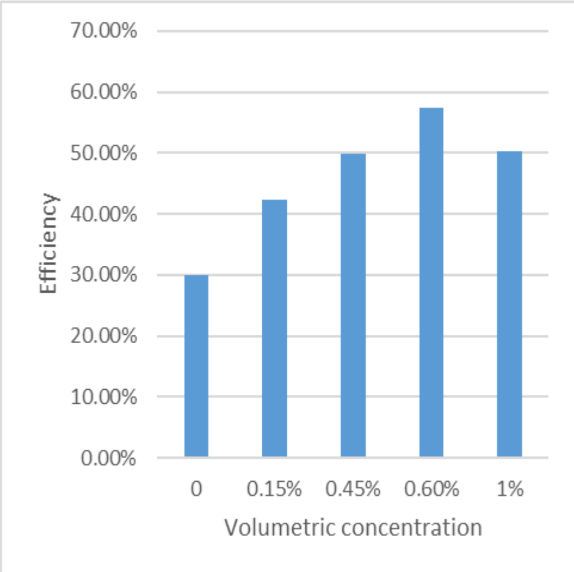

Figure 4. Effect of volumetric concentration on the efficiency of solar collector

As shown in Figure, there was an optimum value for the concentration in order to achieve the highest efficiency. In addition, it was found that for the system with water as thermosyphon operating fluid, the maximum efficiency obtained in 50 deg.

3. CONCLUSIONS

In the present review article, a comprehensive review is conducted on the solar applications of thermosyphons. It is found that thermosyphons can be employed in various solar energy systems as thermal medium in order to have efficient and reliable heat transfer. The most conventional applications of thermosyphons in solar systems are desalination, water heaters, collectors and PV cooling. Based on the results of the reviewed studies, improving the thermal performance of the thermosyphons leads to augment in overall efficiency of the systems. Using nanofluids, novel structures such as inserting wick in the evaporator section and working on optimum filling ratio and tilt angle are among the most applicable approaches to reach the highest efficiency. Future researches can be performed on other related applications of thermosyphons. Moreover, investigating other factors such as working conditions, hybrid fluids and material of the thermosyphons affecting thermal performance and their influences on the efficiency of the systems will be the aims of future studies.

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