JREE: Vol. 10, No. 4, (Autumn 2023) 146-155

Journal of Renewable
Energy and Environment

Journal Homepage: www.jree.ir

Materials and Energy Research Center
MERC

Review Article

Thermal Performance and Efficiency Enhancement in Evacuated Tube Solar Collectors Using Various Nanofluids

Mohamed Ramadan Gomaa*, Njoud Hussein Alhababhh, Mohammed Abbas Al-Nawafleh

Department of Mechanical Engineering, Faculty of Engineering, Al-Hussein Bin Talal University, Maan, Jordan.

PAPER INFO

Paper history:
Received: 20 January 2023
Revised: 28 July 2023
Accepted: 30 August 2023

Keywords:
Evacuated Tube Collector,
Energy Enhancement,
Thermal Efficiency,
Nanofluid

ABSTRACT

This research reviews various studies on the effect of using nanofluids in evacuated tube solar collectors (ETSC). The initial segment of this study elaborates on the importance of using the ETSCs and categorizes these collectors in terms of classification and application. The second segment evaluates the physical properties of nanofluids incorporated in the solar system collector and presents some applications of nanofluids. The last segment of the research reviews the works of a group of researchers who have already applied nanofluids to evacuated tube solar collectors for various purposes, including increasing the heat transfer coefficient and improving efficiency. Among the prevalent nanofluids employed in solar applications, Al_2O_3, CuO, and TiO_2 feature prominently, whereas Ag, WO_3, and CeO_2 find limited application in the solar context. Furthermore, nanofluids within the size range of 1–25 nm, 25–50 nm, and 50–100 nm constitutes 54%, 25%, and 11% of the applications, respectively. Particularly noteworthy, the single-walled carbon nanotubes/water (SWCNT/water) heat pipe showcases the most remarkable efficiency enhancement, achieving an impressive 93.43% improvement.

https://doi.org/10.30501/jree.2023.374760.1507

1. INTRODUCTION

In conjunction with the increase in the population and the increase in demand for energy, fossil fuels threaten the environment, which is the main cause of emissions that cause pollution and climate change. For this reason, it was and is necessary to seek alternative sources of energy that are less harmful, clean, and inexpensive (Al-Bawwat et al., 2023; Al-Bawwat et al., 2023; Marmoush et al., 2018; Rezk et al., 2019; Zambolin & Del Col, 2010). Renewable energy sources such as solar energy are among the most widely used. Solar energy is clean, safe for the environment, less harmful than fossil fuels, and relatively cheap because the main source of its provision is the sun, which is free (Gomaa, et al., 2020; Gomaa et al., 2020). However, there are still limitations with respect to the use of solar energy, including the relatively low energy density compared to other renewable energy sources; and the difficulty exploiting it during evening and night times or in unsuitable weather conditions. With this said, a new trend attempts to improve the efficiency of solar collectors with highly effective technologies that improve the use of collectors in inappropriate conditions (Ayompe & Duffy, 2013; Selvakumar et al., 2014). There are several types of solar collectors, such as flat-plate collectors (FPC), evacuated tube collectors (ETC), parabolic collectors, etc. and they are used based on several factors, including the required temperature and the purpose of use (Morrison et al., 1984).

The ETSC has a strong heat derivation capability due to vacuum insulation and selective surface coating of absorber components, making them suitable for foggy or severely cold circumstances. Additionally, the working fluid is a component that must receive the highest amount of heat from the collector, and changing it into nanofluid from pure fluids is one of the most common ways to accelerate heat transfer in the collectors under study (Elsheikh et al., 2018). A fluid that contains a small amount of uniformly distributed, suspended nanometer-sized particles, with an average size of under 100 nm in the base fluid, is referred to as a nanofluid (Estellé et al., 2017; Kolsi et al., 2017; Selimefendigil & Öztop, 2019). The ability to completely understand the heat fluid transfer mechanism of conduction in nanofluids and to identify possible enhancements is presently a major difficulty in the field of nanofluids. To fully understand the dynamic and static nature of these systems, future research on nanofluids is about to achieve its primary objective (Das, 2008). Recently, numerous researchers have presented multiple strategies for employing nanofluids as the working fluid in solar collectors. The current work offers a thorough overview of the most recent advances in the use of a nanofluid in evacuated tube solar collectors. This study aims to evaluate how efficiently they contribute to the overall efficiency of an evacuated tube solar collector system. Numerous researchers have also noted improvements in the thermo physical characteristics and heat transfer coefficient of nanofluids in comparison to basic fluids. This research conducted a review-based investigation into the significance of nanofluids in the performance of evacuated tube solar collector systems.

---

*Corresponding Author's Email: *Behiri@bhit.bu.edu.eg* (M. R. Gomaa)
URL: https://www.jree.ir/article_178754.html

Please cite this article as: Gomaa, M. R., Alhababhh, N. H., & Nawafleh, M. A. (2023). Thermal Performance and Efficiency Enhancement in Evacuated Tube Solar Collector using Various Nanofluids, *Journal of Renewable Energy and Environment (JREE)*, 10(4), 146-155. https://doi.org/10.30501/jree.2023.374760.1507.

1.1. Solar collector types

Sunlight is collected by solar collectors and converted into heat which is, in turn, transferred to the working fluid (usually water or air). Solar collectors are characterized by a variety of forms and one’s choice depends on the temperature that the collectors are expected to reach, their main purpose, and the working temperature specific to each type in a specific range (low, medium, and high) (Muhammad et al., 2016; Sayed et al., 2022). The FPC is generally recommended and suitable for application within the temperature range of 20–80 ºC and is applicable to domestic water heating. The outlet temperature of this collector type (FPC) is considered low, given the losses resulting from the glass cover and its lack of a sun tracking system. Therefore, the efficiency is considered to be lower than other types (Tang et al., 2010). Evacuated tube solar collectors are mostly used for medium-operating temperatures between 50-200 ºC. The ETSC is often used in domestic water heating and this type is more suitable than FPC in case of cold weather conditions (the presence of clouds) (Papadimitratos et al., 2016).

Parabolic Trough collectors represent moving or tracking collectors that track the sun throughout the day and they are mostly used in power plants. This type is considered a viable option due to its commercial and technological advantages as well as its ability to couple with fossil fuel systems to facilitate higher outlet system temperatures at night. The temperature of the Parabolic Trough collector system ranges between 400 and 500 ºC (Gomaa et al., 2020; Gomaa et al., 2020; X. Li et al., 2019). The Compound Parabolic Collectors (CPC), generally fixed, do not have a sun tracking system. The CPC is effective in collecting and focusing the sun's rays at a certain angle of incidence with a temperature range of 60–240 ºC (Arunkumar et al., 2016). Parabolic Dish Reflectors (PDR) are used at high temperatures and can achieve an excess of 1500 ºC. This collector type is similar to an electric generator upon exploiting solar energy and converting it into electricity. The parabolic dish reflector collector fully tracks the sun rays (L. Li & Dubowsky, 2011).

1.2. An overview of evacuated tube solar collectors

There are three ETSC categories namely Thermo-syphon, U-pipe, and Heat pipe and the mechanism of each one has been studied.

1.2.1. Thermo-syphon

The collector consists of about 15 to 40 tubes and it is connected to a horizontal tank directly. Heat is transmitted in the Thermo-syphon collector through the convection of water. As the sun's radiation targets the tubes at the top of the tank, the temperature of the water inside the tubes increases and is replaced by cold water due to the density difference (Budihardjo et al., 2007). Figure 1 represents the actual thermosyphon solar water heater (Tang & Yang, 2014).

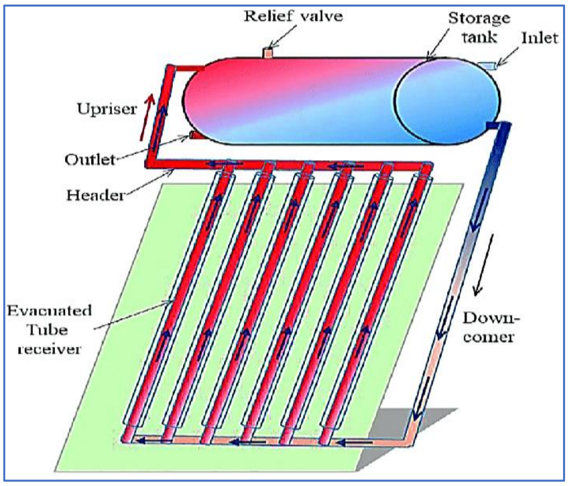

Figure 1. Thermo-syphon solar collectors.

1.2.2. U-pipe evacuated tubular solar collector

The U-pipe ETSC is considered the most common type used for several reasons including its simple geometric shape and high thermal efficiency. This type consists of tubes in the shape of a U made of copper. The liquid inside these tubes is heated as a result of solar radiation, and the heat energy is transmitted to a storage tank through a heat exchanger (Nie et al., 2017). Figure 2 represents three sections: the evaporator, the adiabatic, and the condenser. The evaporator's working fluid boils because of the external heat source, as shown in Figure 2(a). Heat is released to the cooling medium when vapor passes through the adiabatic portion, as illustrated in Figure 2(b), and into the condenser section (Figure 2(c)), which is above it. Due to the gravity, the condensed liquid flows back to the evaporator part (Nie et al., 2017).

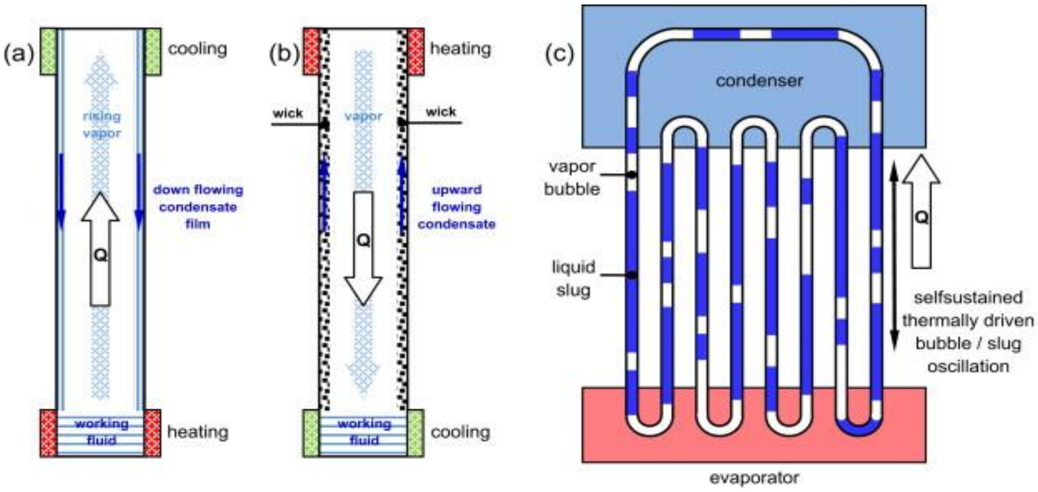

Figure 2. U-pipe ETSC (a) heating (evaporator), (b) cooling (adiabatic), and (c) condenser processes.

1.2.3. Heat pipe

This type is characterized by very high thermal conductivity and a low level of vaporizable fluid. The mechanism of this type is released to the evaporation condensation cycle. In the evaporation mechanism, the sun radiation is released to the collector and fluid to make the phase of evaporation. The condensation mechanism, which ensures the flow of heat, is transferred to the heat sink (Daghigh & Shafieian, 2016; Hayek et al., 2011). The design of a typical direct solar thermal absorption collector using a nanofluid as the working fluid is shown in Figure 3(a). Figure 3(b) shows a typical direct solar thermal absorption system with a separate freshwater circuit and a closed-loop nanofluid circuit. Figure 3 represents the heat pipe solar water heater (Daghigh & Shafieian, 2016).

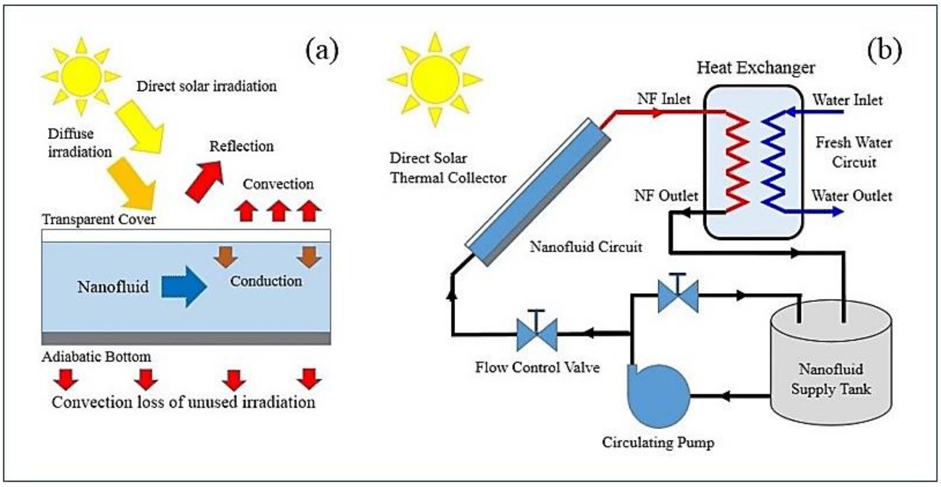

Figure 3. Heat Pipe solar collectors.

2. THERMOPHYSICAL PROPERTIES OF NANOFLUIDS

Nanofluid is a liquid or suspension mixture that is prepared by mixing certain fluids such as water, oil, and glycol with metallic (Cu, Al, Zn, Ni, Si, Fe, Ti, Au, Ag) or non-metallic (Al_2O_3, CuO, SiC, ZnO, TiO_2) nanoparticles ranging in size from 1–100 nm in diameter.

Several previous studies have made attempts to improve the thermal-physical properties of the nanoparticle, including thermal conductivity, specific heat, and viscosity. The nanoparticle is then mixed with a fluid. Nanoparticles are used to improve the thermal properties of fluids and the enhancement of the properties of nanofluid depends on several factors, e.g., the concentration of nanoparticles, the shape and size of nanoparticles, and the temperature of the working fluid (Lee et al., 2008).

Nanofluids exhibit several properties, including the thermal conductivity of nanoparticles, which is one of their most significant properties, nanofluid dispersion rate, nanofluid concentration, and nanoparticle size. Al_2O_3 thermal conductivity and nanofluid concentration were found to be linearly related (Hong et al., 2005). For copper to have a higher thermal conductivity value, it is essential to increase the surface area of nanoparticles (Alsboul et al., 2022a, 2022b; M. S. Liu et al., 2006).

Nanoparticles have different specific heats depending on their type and concentration. Specific heat (C) is defined as the amount of heat needed to increase a unit mass by one degree Celsius. According to the results, the specific heat decreased as the volume fraction of Al_2O_3 increased (Sajadi & Kazemi, 2011).

A critical characteristic of any heat transfer system is the convective transfer of heat. Heat transfer coefficient values must be determined in terms of how nano properties and volume fractions change over time. The value of the heat transfer coefficient increases by 47% when the nanoparticle size of Al_2O_3 is 27–56 nm in diameter and volume fractions of 0.6–1.6% (Wen & Ding, 2004). Water enhanced by TiO_2 nanoparticles delivers a 22% higher heat transfer coefficient than pure water when TiO_2 nanoparticles are added (Zhou & Ni, 2008).

2.1. Potential of nanofluids

In recent years, nanofluids have attracted much more attention. Improving thermal properties is the main goal of using metallic and non-metallic nanoparticles in various applications. Nanofluids are used in many applications including heat transfer applications such as the extraction of geothermal power, heating building, and nuclear system cooling; biomedical applications such as sensing and imaging and nano drug delivery; and energy applications such as Energy Storage and Solar Absorption (Al-Rawashdeh et al., 2021; Chand, 2017; Gomaa et al., 2022; Marashli et al., 2022).

There are many advantages of applying nanofluids in the solar system. As a result of their small size and large surface area, nanoparticles possess many characteristics, which increase the absorption of solar energy. In addition, nanofluids are characterized by their high density, high heat transfer coefficient, and high conductivity, enhancing the effectiveness of thermal properties (Elsheikh et al., 2018). Nanofluids have disadvantages including restricted use and high costs, the latter being the most important. In addition, they require certain chemicals and manufacturing conditions as well as advanced equipment (Wang et al., 2022).

2.2. Nanofluid-based performance of an evacuated tube solar collector

In the same operating conditions, ETSC enjoys higher efficiency, which is defined as the proportion of heat energy that a solar thermal collector produces to the total solar energy it receives, than FPC (Tong & Cho, 2015), and it is important to note that the efficiency of ETSC varies from type with type. It was found that the heat pipe type was more efficient than the U-pipe type by approximately 8% on sunny days, whereas the U-pipe type performed better on cloudy days (Zambolin & Del Col, 2010). Many studies have investigated the incorporation of nanofluid in different types of ETSC extensively. These research studies pursued the objective of identifying the impact of nanofluid on the performance and efficiency of the ETSC.

The thermosyphon ETSC efficiency increased when TiO_2 was used as a nanofluid with a 30-50 nm diameter at a flow rate of 2.7 liters per minute, approximately 16.7% more efficient than water (Mahendran et al., 2012). The enhancement of maximum thermal performance and energy efficiency of the U-shaped pipe ETSC can be achieved at 12.2% and 5.4%, respectively, by incorporating TiO_2 as a heat transfer fluid (Muhammad, 2016). The thermal conductivity of the nanofluid increases as the TiO_2 volume fraction increases in thermosyphon ETSC (Hosseini & Shafiey Dehaj, 2021). The use of CuO nanoparticles improves the efficiency of the U-tube ETSC. The highest efficiency of ETSC was determined to be 69.1% when 400 nm of CuO was added as a nanoparticle (Hussein, 2016). The addition of CuO to the thermo-syphon ETSC increases the temperature of the outside air used in heating operations and this method improves the efficiency by as much as 14 percent, compared to the water-based method (Sharafeldin & Gróf, 2019).

The maximum efficiency of the thermosyphon ETSC was achieved at 57.63% with a 40 nm diameter by incorporating Al2O3 as a nanoparticle (Kim et al., 2017). Adding Al_2O_3 to the U-tube ETSC yielded a maximum efficiency of 72.4% at a diameter of 20 nm (Ghaderian & Sidik, 2017). The addition of WO3 as a nanoparticle to the thermosyphon ETSC resulted in a 21% increase in the nanofluid temperature difference (Z. H. Liu et al., 2013). Generally, the utilization of WO_3 nanoparticles in ETSCs is restricted (Kang et al., 2019). Moreover, the inclusion of CeO_2 as a nanoparticle in the thermosyphon ETSC elevated the temperature difference for nanofluids by up to 37.3% compared to pure water (Sharafeldin & Gróf, 2018). Introducing Ag nanoparticles into the thermosyphon ETSC raised energy efficiency from 20.7% to 40% compared to pure water (Ozsoy & Corumlu, 2018). In the U-tube ETSC, ZnO/Ethylene-glycol nanoparticles achieved a maximum efficiency of 62.87%, and increasing nanoparticle volume concentration enhanced the thermal conductivity of ZnO/Ethylene-glycol with water nanofluids (Kaya & Arslan, 2019). Implementing nanofluids in heat pipe ETSCs reduced fuel consumption by approximately 67.7%, with CuO nanoparticles and TiO_2 nanoparticles increasing system performance by 12% and 5%, respectively (Daghigh & Zandi, 2019). A mixture of Ag nanoparticles (30 nm), ZrO_2 nanoparticles (50 nm), and water as a base fluid in the thermosyphon ETSC improved thermal performance compared to pure water due to the high thermal conductivity of Ag and ZrO_2 (Hussain et al., 2015). The use of MgO/water nanofluid exhibited superior thermal performance in heat pipe ETSCs compared to pure water (Dehaj & Mohiabadi, 2019).

To enhance the heat transfer rate, hybrid nanofluids with high thermal conductivity are employed. The addition of $ZnFe_2O_4$ and water as a hybrid nanofluid led to a 42.99% increase in the convective heat transfer coefficient (Gupta et al., 2020). Assessing different concentrations of Al_2O_3 and CuO nanoparticles on the thermal performance of ETSC heat pipes revealed optimal conditions resulting in thermal performance enhancement of 20-54% and energy efficiency improvement of 15-38% (Eidan et al., 2018). For U-tube ETSCs, Ag, ZnO, and MgO nanoparticles were tested in various concentrations alongside ethylene glycol-pure water (EG-PW). The highest collector efficiency, 68.7%, was achieved with Ag/EG-PW as a heat transfer fluid, while pure water yielded an efficiency of 26.7%. Additionally, reductions of 855.5 kg and 7.2 kg per year in CO_2 and SO_2 generation were observed (Kaya & Arslan, 2019).

Increasing nanoparticle concentration improved thermal conductivity, leading to a more efficient solar collector. Among MWCNT, CuO, Al_2O_3, TiO_2, and SiO_2 nanofluids, the greatest efficiency enhancement of 62.8% compared to pure water was attained with MWCNT nanofluid in U-tube ETSCs (Kim et al., 2016). Heat pipe ETSCs with varying volumes of Al_2O_3 and CuO nanoparticles demonstrated better heat transfer with CuO/H_2O as the nanoparticle volume to water ratio increased, showing a 6.70% improvement over Al_2O_3/H_2O under the same conditions (Mercan & Yurddaş, 2019). In thermo-syphon ETSCs, the addition of SiO2/water nanofluids enhanced heat transfer and heat flux, with the increased mass fraction of SiO_2 resulting in higher thermal conductivity (Yan et al., 2017). Utilizing TiO_2/water as a nanofluid enhanced the performance of thermosyphon ETSCs, where higher mass flow rates led to increased thermal efficiency and reduced entropy generation (Gan et al., 2018). For U-tube ETSCs, MWCNT combined with water improved efficiency by 4%, and CO_2 and SO_2 emissions were reduced by 1600 kg and 5.3 kg, respectively (Tong et al., 2015). The utilization of SWCNT with water as a nanofluid in heat pipe ETSCs led to enhanced collector efficiency, with a maximum efficiency of 93.43% (Sabiha et al., 2015). The addition of MWCNT/water nanofluid to thermosyphon ETSCs improved thermal efficiency by over 20% (Shanbedi et al., 2014). Heat transfer was enhanced by approximately 1.23% with CuO/water nanofluid in thermo-syphon ETSCs (Z. H. Liu et al., 2007). Similarly, the use of Fe_2O_3/Water nanofluid in thermo-syphon ETSCs led to a heat transfer coefficient increase of about 1.15% (Huminic & Huminic, 2013). The application of GNP-COOH/Water nanofluid in thermo-syphon ETSCs increased heat transfer coefficients by over 66%, and CuO/water nanofluid led to a more than 160% increase (Amiri et al., 2015; Yang & Liu, 2012).

When Iron oxide/water, TiO_2/water, Graphene/Acetone, and SiC/water nanofluid are used in thermosyphon ETSC, the thermal resistance will be reduced by about 35% (Huminic & Huminic, 2011), 24% (Buschmann & Franzke, 2014), 70.3% (Asirvatham et al., 2015), and 6.1% (H. jie Li et al., 2018), respectively.

3. RESULTS AND DISCUSSION

3.1. Comparison of Nanofluids Used In The Evacuated Tube Solar Collector

In the initial stages, prior research undertook a comparison of the performance of distinct ETSC designs across various liquids and nanofluids, a depiction of which can be observed in Figure 4.

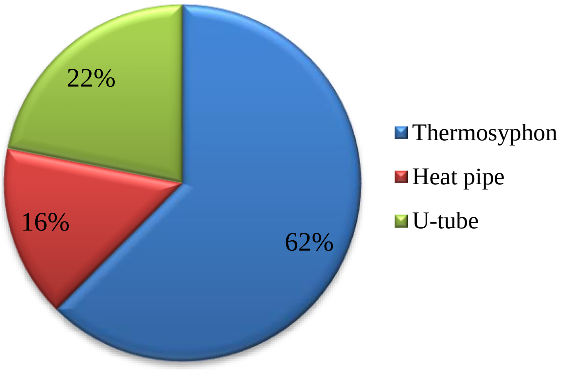

Figure 4. Prior studies have used nanofluids in a variety of ETSCs.

Based on the insights presented in Figure 4, it becomes evident that the Thermo-syphon ETSC design holds the dominant position, while the U-tube configuration is preferable when compared to the heat pipe design. This analysis has yielded the following distribution: approximately 62% of the previous research centered around the implementation of thermo-syphon ETSCs, 22% focused on U-tube variations, and the remaining 16% explored heat pipe configurations, each coupled with diverse nanofluid formulations in an endeavor to enhance thermal efficiency. Further investigation into previous research reveals the utilization of a diverse array of nanofluids, some of which have been employed repeatedly, as shown in Figure 5.

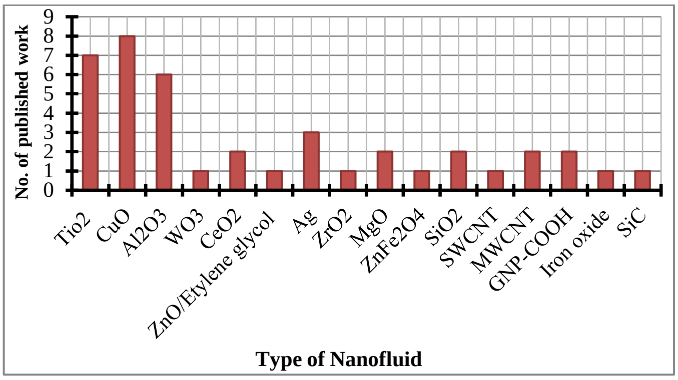

Figure 5. Nanofluids were used in previous ETSC studies.

Figure 5 visually presents the distinct contributions of various nanofluid types within prior research endeavors. Among these, TiO_2, CuO, and Al_2O_3 emerge as the most prevalent choices for integration into ETSC designs. Conversely, nanofluids like WO_3, ZrO_2, SWCNT, and SiC were utilized less frequently. As reported by Ref. (Sabiha et al., 2015). A noteworthy achievement was noted in Ref. (Sabiha et al., 2015), attesting to a maximum efficiency improvement of 93.43% in heat pipe ETSCs through the utilization of SWCNT/water nanofluids.

For a comprehensive comparison of the outcomes stemming from Nanofluid application in ETSCs aimed at enhancing thermal performance through various approaches, refer to Table 1.

Table 1. Analyses of past studies of the effects of nanofluids on ETSCs.

Type of ETSC	Nanofluid	Size (nm)	Thermal Enhancement	Ref.
Thermosyphon	Tio_2/Water	30–50	The efficiency increased by about 16.7% compared to water, which equals 73%.	(Mahendran et al., 2012)
U-tube	Tio_2/Water	40-60	Thermal conductivity and maximum efficiency were achieved at up to 5.4% and 12.2%, respectively.	(Muhammad, 2016)
Thermosyphon	TiO_2/Water	30-50	The thermal conductivity of a nanofluid increases with increasing TiO_2 volume fractions.	(Hosseini & Shafiey Dehaj, 2021)
U-tube	CuO/Water	400	The efficiency at a maximum of about 69.1% was achieved.	(Hussein, 2016)
Thermosyphon	CuO/Water	50	The temperature of the outside air used in heating operations increased and the efficiency was improved by up to 14% when compared to water.	(Sharafeldin & Gróf, 2019)
Thermosyphon	Al_2O_3/Water	40	Maximum efficiency reached 57.63% when the Al_2O_3 nanoparticle was added to water as a nanofluid.	(Kim et al., 2017)
U-tube	Al_2O_3/Water	20	Maximum efficiency reached 72.4% when the Al_2O_3 nanoparticle was added to water as a nanofluid.	(Ghaderian & Sidik, 2017)
Thermosyphon	WO_3/Water	90	The temperature difference between nanofluids and pure water was improved by as much as 21%.	(Z. H. Liu et al., 2013)
Thermosyphon	CeO_2/Water	25	The temperature difference was improved for a nanofluid maximally by 37.3% compared to pure water.	(Sharafeldin & Gróf, 2018)
Thermosyphon	Ag/Water	-	The ratio of enhancement in temperature between nanofluids and pure water reached 37.3%.	(Ozsoy & Corumlu, 2018)
U-tube	ZnO/Ethylene-glycol	30	The maximum efficiency of ZnO/Ethylene-glycol was 62.87%, and an increase in nanoparticle volume concentration was associated with an increase in thermal conductivity.	(Kaya & Arslan, 2019)

Type of ETSC	Nanofluid	Size (nm)	Thermal Enhancement	Ref.
Heat pipe	CuO/Water TiO_2/Water	-	The thermal performance of the system increased by about 12% by using CuO and by using TiO_2, it increased by 5%.	(Daghigh & Zandi, 2019)
Thermosyphon	Ag/water ZrO_2/water	30 50	The high thermal conductivity of Ag and ZrO_2 improved the thermal performance of the system in comparison with pure water.	(Hussain et al., 2015)
Heat pipe	MgO/water	20	As compared with pure water, MgO/water nanofluid enhanced the thermal performance of heat pipe ETSCs.	(Dehaj & Mohiabadi, 2019)
Thermosyphon	$ZnFe_2O_4$/water	-	There was a 42.99% increase in the convective heat transfer coefficient.	(Gupta et al., 2020)
Heat pipe	Al_2O_3/water CuO/water	25 50	The thermal performance and efficiency were enhanced by 20–54 and 15–38 percent, respectively.	(Eidan et al., 2018)
U-tube	Ag/ EG-PW ZnO/EG-PW MgO/ EG-PW	-	According to the results, the highest collector efficiency was achieved with Ag/EG-PW, which was higher than 26.7% than pure water and EG-PW. As a result, the maximum value of reducing CO_2 and SO_2 generation was 855.5 kg and 7.2 kg per year, respectively.	(Kaya & Arslan, 2019)
U-tube	MWCNT/water	-	The maximum efficiency reached 62.8 %, in comparison to 20 % with pure water.	(Kim et al., 2016)
Heat pipe	Al_2O_3/water CuO/water	-	Better results were obtained for CuO/H_2O, and increasing the nanoparticle volume ratio increased heat transfer. In contrast, Al_2O_3/H_2O demonstrated a 4.13% increase in heat transfer.	(Mercan & Yurddaş, 2019)
Thermosyphon	Sio_2/water	50	The thermal conductivity of SiO_2/water nanofluids increased with an increase in the mass fraction of SiO_2.	(Yan et al., 2017)
Thermosyphon	TiO_2 /water	21	In general, the higher the mass flow rate, the greater the thermal efficiency and the lower the generation of entropy.	(Gan et al., 2018)
U-tube	MWCNT/water	10-20	This increase in efficiency was accompanied by a reduction in CO_2 and SO_2 emissions of 1600 kg and 5.3 kg, respectively.	(Tong et al., 2015)
Heat pipe	SWCNT/water	-	The maximum efficiency of the collector was found to be 93.43 %.	(Sabiha et al., 2015)
Thermosyphon	MWCNT/water	10-20	The thermal efficiency was enhanced by more than 20%.	(Shanbedi et al., 2014)
Thermosyphon	CuO/water	50	Heat transfer was enhanced by about 1.23%.	(Z. H. Liu et al., 2007)
Thermosyphon	Fe_2O/Water	4-5	Heat transfer was enhanced by about 1.15%.	(Huminic & Huminic, 2013)
Thermosyphon	GNP-COOH/Water	-	This led to a more than 66% increase in the heat transfer coefficient.	(Yang & Liu, 2012)
Thermosyphon	CuO/water	30	This led to a more than 160% increase in the heat transfer coefficient.	(Amiri et al., 2015)
Thermosyphon	Iron oxide/water	4-5	The thermal resistance was reduced by about 35%.	(Huminic & Huminic, 2011)
Thermosyphon	TiO_2/water	42	The thermal resistance was reduced by about 24%.	(Buschmann & Franzke, 2014)
Thermosyphon	Graphene/Acetone	-	The thermal resistance was reduced by about 24%.	(Asirvatham et al., 2015)
Thermosyphon	SiC/water	30-50	The thermal resistance was reduced by about 6.1%.	(H. jie Li et al., 2018)

Table 1 illustrates a comparative analysis of the impact of employing distinct nanofluid variants in ETSC applications. The utilization of nanofluids leads to a notable enhancement in both efficiency and overall performance. This phenomenon is attributed to the diverse selection of nanofluids integrated into different ETSC protocols. While certain nanofluid types contribute to efficiency improvement, others augment thermal conductivity or refine temperature differentials. Some nanofluids result in reduced fuel consumption across varying degrees, whereas others engender escalated heat transfer coefficients or decreased thermal resistances.

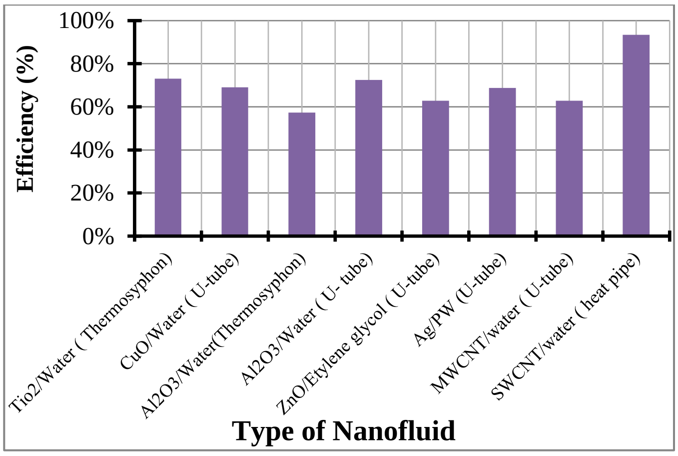

Figure 6. Efficiency of ETSC under various types of Nanofluid.

Figure 6 showcases the varied impact of nanofluids on the efficiency values of ETSCs. The highest alleged efficiency enhancement of 93.43% originated from SWCNT/water (Sabiha et al., 2015), followed by 72.4% achieved by Al_2O_3 in U-tube ETSCs (Kim et al., 2017), and subsequently 62.87% for ZnO/Ethylene-glycol nanofluids (Ozsoy & Corumlu, 2018). In contrast, the lowest efficiency, noted as 57.63%, was recorded in previous research using Al_2O_3 in Thermosyphon ETSCs (Ghaderian & Sidik, 2017). It's evident from Figure 6 that the use of Al_2O_3/water in U-tube ETSCs achieves greater effectiveness compared to its application in Thermosyphon ETSCs.

Enhancing the heat transfer coefficient stands as a paramount objective in employing nanofluid materials within ETSCs. Table 1 exhibits diverse nanofluid types with varying concentrations and sizes, each contributing to the improvement of the heat transfer coefficient. Notably, CuO/water with a size of 30 nm led to a remarkable increase of over 160% in the heat transfer coefficient, as depicted in Table 1 (Amiri et al., 2015). Furthermore, when utilizing the same nanofluid (CuO/water) but with a size of 50 nm, heat transfer is enhanced by approximately 1.23% (Yang & Liu, 2012). The reduction of thermal resistance was also a key target of nanofluid implementation in ETSCs. Employing TiO_2/water with a size of 42 nm led to a reduction in thermal resistance by around 24% (Buschmann & Franzke, 2014). Conversely, using SiC/water with a nearly identical volume size contributed to a reduction in thermal resistance by 6.1% (H. jie Li et al., 2018).

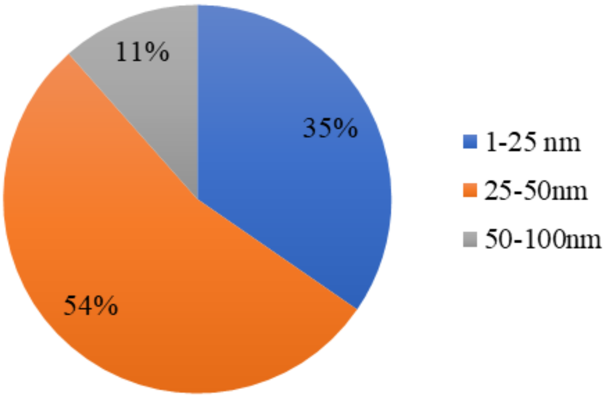

Figure 7. Used of different sizes of Nano Particle.

One of the most formidable challenges confronting researchers while engaging with nanofluids pertains to the size of nanoparticles. Consequently, the judicious selection of nanofluid sizes holds paramount significance for this study. Illustrated in Figure 7 is the application of nanoparticles of varying sizes in ETSCs. Within the spectrum of sizes studied, the range spanning 25-50 nm emerges as the most frequently employed. Throughout the research experiments, it was discerned that approximately 35% and 54% of nanofluids, characterized by sizes within the intervals of 1-25 nm and 25-50 nm respectively, were subjected to investigation. Furthermore, 11% of the selected nanofluids possessed sizes within the 50-100 nm range.

4. CONCLUSION

The research encompasses a collection of papers delving into the applications of nanofluids in ETSCs. These studies encompass a variety of nanofluid types, each characterized by a diverse range of sizes, and employed across different ETSC configurations. Each distinct nanofluid type has successfully achieved its designated objective within a particular context - the enhancement of thermal performance and system efficiency.

- ETSCs exhibit superior thermal efficiency compared to FPCs due to their operation at elevated temperatures.
- Three classifications of ETSCs were investigated, with Thermo-syphon emerging as the most prominent, accounting for 62% of the total research, followed by U-tube at 22%, and heat pipe at 16%.
- Prevalent nanofluids employed in ETSCs consist of Al_2O_3, CuO, and TiO_2, whereas Ag, WO_3, and CeO_2 are less commonly utilized.
- Nanoparticle size significantly influences the efficiency of various solar collectors. Research indicates that 54% of the studied nanofluids maintained an average size ranging from 25 to 50 nm, 25% fell within the 1 to 25 nm range, and 11% had sizes between 50 and 100 nm.
- Prior research identified the highest efficiency enhancement as 93.43% achieved by SWCNT/water in a heat pipe configuration, followed by 72.4% through the utilization of Al_2O_3 in U-tube ETSCs.

Nanofluids exhibit considerable potential in enhancing heat transmission, attributed in part to the heightened heat conductivity stemming from the inclusion of suspended ultrafine particles. Enhancing the heat transfer coefficient stands as a pivotal objective in adopting nanofluid materials within ETSCs. Previous endeavors demonstrated a 160% increase in the heat transfer coefficient using water/CuO (30 nm).

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Funding: This research was funded by the Deanship of Scientific Research, Al-Hussein Bin Talal University, Maan, Jordan, grant number 268/2023.

Data Availability Statement: The manuscript has no associated data.

6. ACKNOWLEDGEMENT

We would like to thank the reviewers and the editor-in-charge for spending their valuable time on the article and we are grateful to all the foundations that supported us.

REFERENCES

1. Al-Bawwat, A. K., Cano, A., Gomaa, M. R. & Jurado, F. (2023). Availability of Biomass and Potential of Nanotechnologies for Bioenergy Production in Jordan. In *Processes* (Vol. 11, Issue 4, p. 992). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/pr11040992
2. Al-Bawwat, A. K., Jurado, F., Gomaa, M. R. & Cano, A. (2023). Availability and the Possibility of Employing Wastes and Biomass Materials Energy in Jordan. In *Sustainability (Switzerland)* (Vol. 15, Issue 7, p. 5879). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/su15075879
3. Al-Rawashdeh, H., Hasan, A. O., Al-Shakhanbeh, H. A., Al-Dhaifallah, M., Gomaa, M. R. & Rezk, H. (2021). Investigation of the effect of solar ventilation on the cabin temperature of vehicles parked under the sun. *Sustainability (Switzerland)*, *13*(24), 13963. https://doi.org/10.3390/su132413963
4. Alsboul, M., Ghazali, M. S. M., Gomaa, M. R. & Albani, A. (2022a). Experimental and Theoretical Investigation of the Thermophysical Properties of Cobalt Oxide (Co3O4) in Distilled Water (DW), Ethylene Glycol (EG), and DW–EG Mixture Nanofluids. *Nanomaterials*, *12*(16), 2779. https://doi.org/10.3390/nano12162779
5. Alsboul, M., Ghazali, M. S. M., Gomaa, M. R. & Albani, A. (2022b). Experimental and Theoretical Investigations of the Thermal Conductivity of Erbium Oxide/Ethylene Glycol Nanofluids for Thermal Energy Applications. *Chemical Engineering and Technology*, *45*(12), 2139–2149. https://doi.org/10.1002/ceat.202200159
6. Amiri, A., Sadri, R., Shanbedi, M., Ahmadi, G., Chew, B. T., Kazi, S. N. & Dahari, M. (2015). Performance dependence of thermosyphon on the functionalization approaches: An experimental study on thermo-physical properties of graphene nanoplatelet-based water nanofluids. *Energy Conversion and Management*, *92*, 322–330. https://doi.org/10.1016/j.enconman.2014.12.051
7. Arunkumar, T., Velraj, R., Denkenberger, D. C., Sathyamurthy, R., Kumar, K. V. & Ahsan, A. (2016). Productivity enhancements of compound parabolic concentrator tubular solar stills. *Renewable Energy*, *88*, 391–400. https://doi.org/10.1016/j.renene.2015.11.051
8. Asirvatham, L. G., Wongwises, S. & Babu, J. (2015). Heat transfer performance of a glass thermosyphon using graphene-acetone nanofluid. *Journal of Heat Transfer*, *137*(11). https://doi.org/10.1115/1.4030479
9. Ayompe, L. M. & Duffy, A. (2013). Thermal performance analysis of a solar water heating system with heat pipe evacuated tube collector using data from a field trial. *Solar Energy*, *90*, 17–28. https://doi.org/10.1016/j.solener.2013.01.001
10. Budihardjo, I., Morrison, G. L. & Behnia, M. (2007). Natural circulation flow through water-in-glass evacuated tube solar collectors. *Solar Energy*, *81*(12), 1460–1472. https://doi.org/10.1016/j.solener.2007.03.002
11. Buschmann, M. H. & Franzke, U. (2014). Improvement of thermosyphon performance by employing nanofluid. *International Journal of Refrigeration*, *40*, 416–428. https://doi.org/10.1016/j.ijrefrig.2013.11.022
12. Chand, R. (2017). Nanofluid technologies and thermal convection techniques. In *Nanofluid Technologies and Thermal Convection Techniques*. IGI Global. https://doi.org/10.4018/978-1-68318-006-7
13. Daghigh, R. & Shafieian, A. (2016). An experimental study of a heat pipe evacuated tube solar dryer with heat recovery system. *Renewable Energy*, *96*, 872–880. https://doi.org/10.1016/j.renene.2016.05.025
14. Daghigh, R. & Zandi, P. (2019). Improving the performance of heat pipe embedded evacuated tube collector with nanofluids and auxiliary gas system. *Renewable Energy*, *134*, 888–901. https://doi.org/10.1016/j.renene.2018.11.090
15. Das, S. K. (2008). *Nanofluids : science and technology*. 397. https://www.wiley.com/en-sg/Nanofluids%3A+Science+and+Technology-p-9780470074732
16. Dehaj, M. S. & Mohiabadi, M. Z. (2019). Experimental investigation of heat pipe solar collector using MgO nanofluids. *Solar Energy Materials and Solar Cells*, *191*, 91–99. https://doi.org/10.1016/j.solmat.2018.10.025
17. Eidan, A. A., AlSahlani, A., Ahmed, A. Q., Al-fahham, M. & Jalil, J. M. (2018). Improving the performance of heat pipe-evacuated tube solar collector experimentally by using Al2O3 and CuO/acetone nanofluids. *Solar Energy*, *173*, 780–788. https://doi.org/10.1016/j.solener.2018.08.013
18. Elsheikh, A. H., Sharshir, S. W., Mostafa, M. E., Essa, F. A. & Ahmed Ali, M. K. (2018). Applications of nanofluids in solar energy: A review of recent advances. In *Renewable and Sustainable Energy Reviews* (Vol. 82, pp. 3483–3502). Pergamon. https://doi.org/10.1016/j.rser.2017.10.108
19. Estellé, P., Mahian, O., Maré, T. & Öztop, H. F. (2017). Natural convection of CNT water-based nanofluids in a differentially heated square cavity. *Journal of Thermal Analysis and Calorimetry*, *128*(3), 1765–1770. https://doi.org/10.1007/s10973-017-6102-1
20. Gan, Y. Y., Ong, H. C., Ling, T. C., Zulkifli, N. W. M., Wang, C. T. & Yang, Y. C. (2018). Thermal conductivity optimization and entropy generation analysis of titanium dioxide nanofluid in evacuated tube solar collector. *Applied Thermal Engineering*, *145*, 155–164. https://doi.org/10.1016/j.applthermaleng.2018.09.012
21. Ghaderian, J. & Sidik, N. A. C. (2017). An experimental investigation on the effect of Al2O3/distilled water nanofluid on the energy efficiency of evacuated tube solar collector. *International Journal of Heat and Mass Transfer*, *108*, 972–987. https://doi.org/10.1016/j.ijheatmasstransfer.2016.12.101
22. Gomaa, Mohamed R., Al-Dhaifallah, M., Alahmer, A. & Rezk, H. (2020). Design, modeling, and experimental investigation of active water cooling concentrating photovoltaic system. *Sustainability (Switzerland)*, *12*(13), 5392. https://doi.org/10.3390/su12135392
23. Gomaa, Mohamed R., Al-Dmour, N., AL-Rawashdeh, H. A. & Shalby, M. (2020). Theoretical model of a fluidized bed solar reactor design with the aid of MCRT method and synthesis gas production. *Renewable Energy*, *148*, 91–102. https://doi.org/10.1016/j.renene.2019.12.010
24. Gomaa, Mohamed R., Murtadha, T. K., Abu-jrai, A., Rezk, H., Altarawneh, M. A. & Marashli, A. (2022). Experimental Investigation on Waste Heat Recovery from a Cement Factory to Enhance Thermoelectric Generation. *Sustainability (Switzerland)*, *14*(16), 10146. https://doi.org/10.3390/su141610146
25. Gomaa, Mohamed R., Mustafa, R. J., Al-Dhaifallah, M. & Rezk, H. (2020). A low-grade heat Organic Rankine Cycle driven by hybrid solar collectors and a waste heat recovery system. *Energy Reports*, *6*, 3425–3445. https://doi.org/10.1016/j.egyr.2020.12.011

26. Gomaa, Mohamed Ramadan, Matarneh, G. A., Shalby, M. & AL-Rawashdeh, H. A. (2020). A State of the art Review on a Thermochemical Conversion of Carbonaceous Materials: Production of Synthesis Gas by Co-Gasification Process-Part I. *Current Alternative Energy*, *4*(1), 26–46. https://doi.org/10.2174/2405463104999200904115100

27. Gupta, M., Singh, V. & Said, Z. (2020). Heat transfer analysis using zinc Ferrite/water (Hybrid) nanofluids in a circular tube: An experimental investigation and development of new correlations for thermophysical and heat transfer properties. *Sustainable Energy Technologies and Assessments*, *39*, 100720. https://doi.org/10.1016/j.seta.2020.100720

28. Hayek, M., Assaf, J. & Lteif, W. (2011). Experimental investigation of the performance of evacuated-tube solar collectors under eastern mediterranean climatic conditions. *Energy Procedia*, *6*, 618–626. https://doi.org/10.1016/j.egypro.2011.05.071

29. Hong, T. K., Yang, H. S. & Choi, C. J. (2005). Study of the enhanced thermal conductivity of Fe nanofluids. *Journal of Applied Physics*, *97*(6). https://doi.org/10.1063/1.1861145

30. Hosseini, S. M. S. & Shafiey Dehaj, M. (2021). Assessment of TiO2 water-based nanofluids with two distinct morphologies in a U type evacuated tube solar collector. *Applied Thermal Engineering*, *182*, 116086. https://doi.org/10.1016/j.applthermaleng.2020.116086

31. Huminic, G. & Huminic, A. (2011). Heat transfer characteristics of a two-phase closed thermosyphons using nanofluids. *Experimental Thermal and Fluid Science*, *35*(3), 550–557. https://doi.org/10.1016/j.expthermflusci.2010.12.009

32. Huminic, G. & Huminic, A. (2013). Numerical study on heat transfer characteristics of thermosyphon heat pipes using nanofluids. *Energy Conversion and Management*, *76*, 393–399. https://doi.org/10.1016/j.enconman.2013.07.026

33. Hussain, A. H., Jawad, Q. & Sultan, K. F. (2015). Experimental analysis on thermal efficiency of evacuated tube solar collector by using nanofluids 2 . Preparation of Silver and Zirconium. *Internatonal Journal of Sustainable and Green Energy*, *4*(3–1), 19–28. https://doi.org/10.11648/J.IJRSE.S.2015040301.14

34. Hussein, A. K. (2016). Applications of nanotechnology to improve the performance of solar collectors - Recent advances and overview. In *Renewable and Sustainable Energy Reviews* (Vol. 62, pp. 767–792). Pergamon. https://doi.org/10.1016/j.rser.2016.04.050

35. Kang, W., Shin, Y. & Cho, H. (2019). Experimental investigation on the heat transfer performance of evacuated tube solar collector using CuO nanofluid and water. *Journal of Mechanical Science and Technology*, *33*(3), 1477–1485. https://doi.org/10.1007/s12206-019-0249-6

36. Kaya, H. & Arslan, K. (2019). Numerical investigation of efficiency and economic analysis of an evacuated U-tube solar collector with different nanofluids. *Heat and Mass Transfer/Waerme- Und Stoffuebertragung*, *55*(3), 581–593. https://doi.org/10.1007/s00231-018-2442-z

37. Kim, H., Ham, J., Park, C. & Cho, H. (2016). Theoretical investigation of the efficiency of a U-tube solar collector using various nanofluids. *Energy*, *94*, 497–507. https://doi.org/10.1016/j.energy.2015.11.021

38. Kim, H., Kim, J. & Cho, H. (2017). Experimental study on performance improvement of U-tube solar collector depending on nanoparticle size and concentration of Al2O3 nanofluid. *Energy*, *118*, 1304–1312. https://doi.org/10.1016/j.energy.2016.11.009

39. Kolsi, L., Alrashed, A. A. A. A., Al-Salem, K., Oztop, H. F. & Borjini, M. N. (2017). Control of natural convection via inclined plate of CNT-water nanofluid in an open sided cubical enclosure under magnetic field. *International Journal of Heat and Mass Transfer*, *111*, 1007–1018. https://doi.org/10.1016/j.ijheatmasstransfer.2017.04.069

40. Lee, J. H., Hwang, K. S., Jang, S. P., Lee, B. H., Kim, J. H., Choi, S. U. S. & Choi, C. J. (2008). Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al2O3 nanoparticles. *International Journal of Heat and Mass Transfer*, *51*(11–12), 2651–2656. https://doi.org/10.1016/j.ijheatmasstransfer.2007.10.026

41. Li, H. jie, Jiang, F., Qi, G. peng, Zhao, P. li, Jiang, T., Li, N., Chen, X. ling & Li, X. lun. (2018). Effect of particle size and solid holdup on heat transfer performance of a SiC/water three-phase closed thermosyphon. *Applied Thermal Engineering*, *132*, 808–816. https://doi.org/10.1016/j.applthermaleng.2017.12.114

42. Li, L. & Dubowsky, S. (2011). A new design approach for solar concentrating parabolic dish based on optimized flexible petals. *Mechanism and Machine Theory*, *46*(10), 1536–1548. https://doi.org/10.1016/j.mechmachtheory.2011.04.012

43. Li, X., Xu, E., Ma, L., Song, S. & Xu, L. (2019). Modeling and dynamic simulation of a steam generation system for a parabolic trough solar power plant. *Renewable Energy*, *132*, 998–1017. https://doi.org/10.1016/j.renene.2018.06.094

44. Liu, M. S., Lin, M. C. C., Tsai, C. Y. & Wang, C. C. (2006). Enhancement of thermal conductivity with Cu for nanofluids using chemical reduction method. *International Journal of Heat and Mass Transfer*, *49*(17–18), 3028–3033. https://doi.org/10.1016/j.ijheatmasstransfer.2006.02.012

45. Liu, Z. H., Hu, R. L., Lu, L., Zhao, F. & Xiao, H. S. (2013). Thermal performance of an open thermosyphon using nanofluid for evacuated tubular high temperature air solar collector. *Energy Conversion and Management*, *73*, 135–143. https://doi.org/10.1016/j.enconman.2013.04.010

46. Liu, Z. H., Yang, X. F. & Guo, G. L. (2007). Effect of nanoparticles in nanofluid on thermal performance in a miniature thermosyphon. *Journal of Applied Physics*, *102*(1). https://doi.org/10.1063/1.2748348

47. Mahendran, M., Lee, G. C., Sharma, K. V. & Shahrani, A. (2012). Performance of Evacuated Tube Solar Collector using Water-Based Titanium Oxide Nanofluid. *JOURNAL OF MECHANICAL ENGINEERING AND SCIENCES*, *3*, 301–310. https://doi.org/10.15282/jmes.3.2012.6.0028

48. Marashli, A., Alfanatseh, E., Shalby, M. & Gomaa, M. R. (2022). Modelling single-effect of Lithium Bromide-Water (LiBr-H2O) driven by an evacuated solar tube collector in Ma'an city (Jordan) case study. *Case Studies in Thermal Engineering*, *37*, 102239. https://doi.org/10.1016/j.csite.2022.102239

49. Marmoush, M. M., Rezk, H., Shehata, N., Henry, J. & Gomaa, M. R. (2018). A novel merging Tubular Daylight Device with Solar Water Heater – Experimental study. *Renewable Energy*, *125*, 947–961. https://doi.org/10.1016/j.renene.2018.03.031

50. Mercan, M. & Yurddaş, A. (2019). Numerical analysis of evacuated tube solar collectors using nanofluids. *Solar Energy*, *191*, 167–179. https://doi.org/10.1016/j.solener.2019.08.074

51. Morrison, G. L., Tran, N. H., McKenzie, D. R., Onley, I. C., Harding, G. L. & Collins, R. E. (1984). Long term performance of evacuated tubular solar water heaters in Sydney, Australia. *Solar Energy*, *32*(6), 785–791. https://doi.org/10.1016/0038-092X(84)90253-6

52. Muhammad, M. J. (2016). Thermal Performance of Thermosyphon Evacuated Tube Solar Collector using TiO2/Water Nanofluid Thermal Rating of underground Power Cables View project CFD simulation of SARS-CoV-2 airborne transmission View project. In *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* (Vol. 20, Issue 1). https://www.akademiabaru.com/submit/index.php/arfmts/article/view/2067

53. Muhammad, M. J., Muhammad, I. A., Sidik, N. A. C., Yazid, M. N. A. W. M., Mamat, R. & Najafi, G. (2016). The use of nanofluids for enhancing the thermal performance of stationary solar collectors: A review. In *Renewable and Sustainable Energy Reviews* (Vol. 63, pp. 226–236). Pergamon. https://doi.org/10.1016/j.rser.2016.05.063

54. Nie, X., Zhao, L., Deng, S. & Lin, X. (2017). Experimental study on thermal performance of U-type evacuated glass tubular solar collector with low inlet temperature. *Solar Energy*, *150*, 192–201. https://doi.org/10.1016/j.solener.2017.04.030

55. Ozsoy, A. & Corumlu, V. (2018). Thermal performance of a thermosyphon heat pipe evacuated tube solar collector using silver-water nanofluid for commercial applications. *Renewable Energy*, *122*, 26–34. https://doi.org/10.1016/j.renene.2018.01.031

56. Papadimitratos, A., Sobhansarbandi, S., Pozdin, V., Zakhidov, A. & Hassanipour, F. (2016). Evacuated tube solar collectors integrated with phase change materials. *Solar Energy*, *129*, 10–19. https://doi.org/10.1016/j.solener.2015.12.040

57. Rezk, H., Gomaa, M. R., Marmoush, M. M., Shehata, N. & Henry, J. (2019). Theoretical and experimental performance investigation of a newly combined TDD and SWH system. *Applied Thermal Engineering*, *161*, 114156. https://doi.org/10.1016/j.applthermaleng.2019.114156

58. Sabiha, M. A., Saidur, R., Hassani, S., Said, Z. & Mekhilef, S. (2015). Energy performance of an evacuated tube solar collector using single walled carbon nanotubes nanofluids. *Energy Conversion and Management*, *105*, 1377–1388. https://doi.org/10.1016/j.enconman.2015.09.009

59. Sajadi, A. R. & Kazemi, M. H. (2011). Investigation of turbulent convective heat transfer and pressure drop of TiO2/water nanofluid in circular tube. *International Communications in Heat and Mass Transfer*, *38*(10), 1474–1478. https://doi.org/10.1016/j.icheatmasstransfer.2011.07.007

60. Sayed, E. T., Rezk, H., Olabi, A. G., Gomaa, M. R., Hassan, Y. B., Rahman, S. M. A., Shah, S. K. & Abdelkareem, M. A. (2022). Application of Artificial Intelligence to Improve the Thermal Energy and Exergy of Nanofluid-Based PV Thermal/Nano-Enhanced Phase Change Material. *Energies*, *15*(22), 8494. https://doi.org/10.3390/en15228494

61. Selimefendigil, F. & Öztop, H. F. (2019). Corrugated conductive partition effects on MHD free convection of CNT-water nanofluid in a cavity. *International Journal of Heat and Mass Transfer*, *129*, 265–277. https://doi.org/10.1016/j.ijheatmasstransfer.2018.09.101

62. Selvakumar, P., Somasundaram, P. & Thangavel, P. (2014). Performance study on evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough. *Energy Conversion and Management*, *85*, 505–510. https://doi.org/10.1016/j.enconman.2014.05.069

63. Shanbedi, M., Heris, S. Z., Amiri, A. & Baniadam, M. (2014). Improvement in Heat Transfer of a Two-Phased Closed Thermosyphon Using Silver-Decorated MWCNT/Water. *Journal of Dispersion Science and Technology*, *35*(8), 1086–1096. https://doi.org/10.1080/01932691.2013.833101

64. Sharafeldin, M. A. & Gróf, G. (2018). Evacuated tube solar collector performance using CeO2/water nanofluid. *Journal of Cleaner Production*, *185*, 347–356. https://doi.org/10.1016/j.jclepro.2018.03.054

65. Sharafeldin, M. A. & Gróf, G. (2019). Efficiency of evacuated tube solar collector using WO3/Water nanofluid. *Renewable Energy*, *134*, 453–460. https://doi.org/10.1016/j.renene.2018.11.010

66. Tang, R., Cheng, Y., Wu, M., Li, Z. & Yu, Y. (2010). Experimental and modeling studies on thermosiphon domestic solar water heaters with flat-plate collectors at clear nights. *Energy Conversion and Management*, *51*(12), 2548–2556. https://doi.org/10.1016/j.enconman.2010.04.015

67. Tang, R. & Yang, Y. (2014). Nocturnal reverse flow in water-in-glass evacuated tube solar water heaters. *Energy Conversion and Management*, *80*, 173–177. https://doi.org/10.1016/j.enconman.2014.01.025

68. Tong, Y. & Cho, H. (2015). Comparative study on the thermal performance of evacuated solar collectors with U-Tubes and heat pipes. *International Journal of Air-Conditioning and Refrigeration*, *23*(3). https://doi.org/10.1142/S2010132515500194

69. Tong, Y., Kim, J. & Cho, H. (2015). Effects of thermal performance of enclosed-type evacuated U-tube solar collector with multi-walled carbon nanotube/water nanofluid. *Renewable Energy*, *83*, 463–473. https://doi.org/10.1016/j.renene.2015.04.042

70. Wang, X., Huang, K., Yuying, Y. & Cen, H. (2022). Heat transfer enhancement with nanofluids in automotive. In *Advances in Nanofluid Heat Transfer* (pp. 229–263). https://doi.org/10.1016/B978-0-323-88656-7.00016-7

71. Wen, D. & Ding, Y. (2004). Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions. *International Journal of Heat and Mass Transfer*, *47*(24), 5181–5188. https://doi.org/10.1016/j.ijheatmasstransfer.2004.07.012

72. Yan, S., Wang, F., Shi, Z. G. & Tian, R. (2017). Heat transfer property of SiO2/water nanofluid flow inside solar collector vacuum tubes. *Applied Thermal Engineering*, *118*, 385–391. https://doi.org/10.1016/j.applthermaleng.2017.02.108

73. Yang, X. F. & Liu, Z. H. (2012). Flow boiling heat transfer in the evaporator of a loop thermosyphon operating with CuO based aqueous nanofluid. *International Journal of Heat and Mass Transfer*, *55*(25–26), 7375–7384. https://doi.org/10.1016/j.ijheatmasstransfer.2012.07.026

74. Zambolin, E. & Del Col, D. (2010). Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions. *Solar Energy*, *84*(8), 1382–1396. https://doi.org/10.1016/j.solener.2010.04.020

75. Zhou, S. Q. & Ni, R. (2008). Measurement of the specific heat capacity of water-based Al2 O3 nanofluid. *Applied Physics Letters*, *92*(9). https://doi.org/10.1063/1.2890431