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Effects of using nanofluids in solar collectors

Güneş kolektörlerinde nanoakışkanların kullanılmasının etkileri

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Effects of Using Nanofluids in Solar Collectors

Highlights

- *Alternative solutions have been tried to be presented against fossil fuels*
- *Utılızatıon of Nanofluıds In Solar Collectors*
- *Applications of Nanofluids in Flat Plate Solar Collectors*
- *Nanofluid Applications in Heat Pipe Solar Collectors*

Graphical Abstract

With the advancing technology, the use of heat pipes in solar collectors has come to the agenda and as a result of the studies conducted, it has been determined that the use of heat pipe improves efficiency. In addition, the use of nanofluids in solar collectors and heat pipes has become quite common, and many studies have been carried out especially on this subject recently. The main goal is always to improve the performance of the system and achieve efficiency. In this way, solar energy will be used in the most effective way and world energy supply demand will be met by using renewable resources.

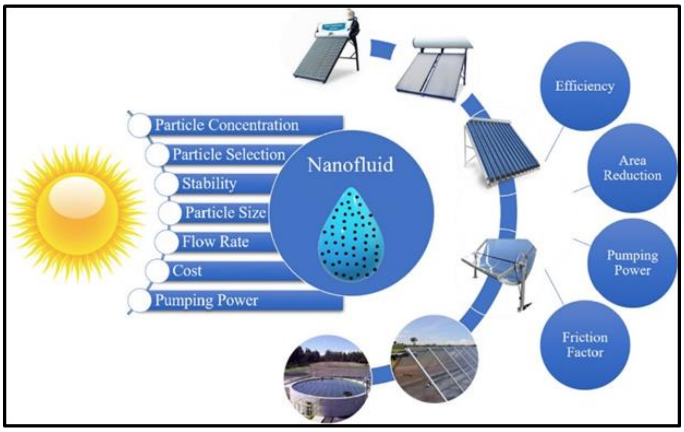

Figure. The use of nanofluids in solar collectors

Aim

The main goal is always to improve the performance of the system and achieve efficiency. In this way, solar energy will be used in the most effective way and world energy supply demand will be met by using renewable resources. Due to the availability of a wide variety of solar collectors, the studies done by the researchers have been summarized and the importance of the subject has been tried to be conveyed and attention has been paid to make this study a guide for future research. Although FPSCs are the most widely used among solar collectors, then ETSCs and heat pipe solar collectors were produced and focused on the solution of existing problems.

Design & Methodology

Early studies of nanofluids have been investigated. The solar energy applications of nanofluids have been researched and compared. Comparisons are given in tables.

Originality

The working characteristics of nanofluids have been determined. Its effects have been revealed by comparisons made in the solar energy applications. Experimental resılts were evaluated and cross checked.

Findings

Solar energy will be used in the most effective way and world energy supply demand will be met by using renewable resources.

Conclusion

The effects of nanofluids used in solar collectors on the system performance are positive. Apart from this, the use of new nanofluids to be produced should also be examined and their effects on performance should be investigated. Accordingly, new studies should be carried out and nanofluids that are more effective on the system should be produced.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Effects of Using Nanofluids in Solar Collectors

Derleme Makalesi / Review Article

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ABSTRACT

The importance of using solar energy, one of the renewable energy sources, has started to be understood more recently. The negative environmental effects and limited amounts of fossil fuels have led to increased demand for renewable energy sources worldwide and the production of various models and devices has accelerated to take advantage of solar energy, which is the basis of all energy sources. Using solar collectors as a way to benefit from solar energy has been used for many years. Although solar collectors are generally divided into 4 types as flat plate (FPSC), evacuated tube (ETSC), parabolic (PSC) and heat pipe (HPSC), these types can also be divided into separate types with many different features. The most commonly used solar collector type in the world is Flat Plate Solar Collector. The most important reasons for this are being cheap, easily produced and applied in various ways. Yet, the thermal productivity of FPSCs decreases below 40% in non-ideal climate conditions with low surrounding temperature. The existence of such disadvantages of FPSCs led to the production of Evacuated Tube Solar Collectors. With the advancing technology, the utilization of heat pipes in collectors has come to the agenda and as a result of the studies conducted, it has been determined that the use of heat pipe improves efficiency. In addition, the use of nanofluids in solar collectors and heat pipes has become quite common, and many studies have been carried out especially on this subject recently. The primary objective is always to improve the performance of the system and achieve efficiency. In this way, solar energy will be used in the most effective way and world energy supply demand will be met by using renewable resources.

Keywords: Solar collectors, solar energy, energy, nanofluids, heat pipes.

Güneş Kolektörlerinde Nanoakışkanların Kullanılmasının Etkileri

ÖZ

Yenilenebilir enerji kaynaklarından olan güneş enerjisinden faydalanmanın önemi son yıllarda daha fazla anlaşılmaya başlanmıştır. Fosil yakıtların olumsuz çevre etkileri ve miktarlarının sınırlı olması dünya genelinde yenilenebilir enerji kaynaklarına olan talebin artmasına yol açmış ve tüm enerji kaynaklarının temeli olan güneş enerjisinden yararlanmak için çeşitli modellerin ve cihazların üretilmesi hız kazanmıştır. Güneş enerjisinden yararlanmanın en önemli yolu güneş kolektörlerinin kullanılmasıdır. Güneş kolektörleri genel olarak düzlem yüzeyli (DYGK), vakum tüplü (VTGK), parabolik (PGK) ve ısı borulu (IBGK) olmak üzere 4 tipe ayrılmakla birlikte bu tipler de kendi aralarında birçok farklı özelliğe sahip ayrı türlere ayrılabilmektedir. Dünya üzerinde en fazla kullanılan güneş kolektörü tipi Düzlem Yüzeyli Güneş Kolektörü'dür. Bunun en önemli nedenleri arasında ucuz olması, kolayca üretilebilmesi ve çeşitli şekillerde uygulanabilmesi gibi parametreler yer almaktadır. Bununla birlikte düşük ortam sıcaklığı ile ideal olmayan iklim koşullarında DYGK'ların termal verimliliği %40'ın altına düşer. DYGK'ların bu tür dezavantajlarının bulunması Vakum Tüp Güneş Kolektörlerinin üretilmesine yol açmıştır. İlerleyen teknolojiyle birlikte güneş kolektörlerinde ısı borularının kullanılması durumu gündeme gelmiş ve yapılan çalışmalar sonucunda ısı borusu kullanımının verimi iyileştirdiği tespit edilmiştir. Ayrıca güneş kolektörlerinde ve ısı borularında nanoakışkan kullanılması durumu da oldukça yaygınlaşmış olup son dönemlerde özellikle bu konu ile ilgili birçok çalışma yürütülmüştür. Temel amaç her zaman için sistemin performansını iyileştirmek ve verimlilik elde etmektir. Bu sayede güneş enerjisinden en etkili şekilde yararlanılacak ve dünya enerji arzı talebi de yenilenebilir kaynaklar kullanılarak karşılanacaktır.

Anahtar Kelimeler: Güneş kolektörleri, güneş enerjisi, enerji, nanoakışkan, ısı boruları.

1. INTRODUCTION

The increasing need of energy, day by day, causes the depletion of fossil fuel resource reserves, which are limited in quantity, on the world. In addition, with the increase in the use of fossil fuels after the industrial revolution, the density of gases (greenhouse gases) that create greenhouse effects, carbon dioxide (CO_2), especially, has increased to a significant rate in the atmosphere and cause a global warming. Given the increasing energy demand and the negative effects of fossil fuels, the trend towards clean and efficient energy sources has started to be increased worlwide [1].

The concept of renewable energy sources includes solar energy, hydroelectricity, wind energy, geothermal energy and biomass energy. The rate of solar energy among renewable energy sources is 25.21%. [2]. The fact that, the solar energy source can be used by converting it into electricity and heat energy makes this source more important. This source, which is especially important in hot water production, can also be used in solar drying systems [3].

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The solar source can be used through photovoltaic modules or thermal collectors [4]. While photovoltaic conversion allows direct electricity generation, thermal collectors produce heat that can be used depending on the operating temperatures in various executions, such as air conditioning-cooling, hot water production, desalination and power generation, depending on the thermodynamic cycle [5].

Despite the fact that the solar energy source is found in significant amounts, fossil fuels such as petrol, natural gas and coal are still used to obtain energy, woldwide. A Research show that fossil-derived fuel use is around 80% in the world [6].

This study provides a comprehensive literature review on the effect of using nanofluids on solar collectors. The literature review includes studies on flat plate solar collectors, direct absorption solar collectors, wavy solar collectors, parabolic trough solar collectors, heat pipe solar collectors and other solar collectors. These studies are detailed with tables and explanations.

1.1. NanofluidTechnologies

The nanofluid concept can be characterized as solid-liquid composite materials containing nanometer-sized solid particles. Carbides, nitrites, pure metals and metal oxides are examples of solid materials used to form nanofluid, while water, ethylene glycol, and engine oil are also examples of base fluids. Although nanofluids are used in many fields such as nuclear reactors, biomedicals, transportation etc. their first outputs were realized in studies conducted for the purpose of increasing thermal conductivity. With these features, its use in solar energy systems is also very common [7-10]. Nanofluids, first introduced by Choi [9], have great potential for increasing heat absorption and carrying capacity. When a material changes from macro form to nano form, a number of parameters required for improved thermal performance are greatly changed. These parameters are; heat transfer coefficient ,thermal conductivity, electrical conductivity , optical extinction coefficient, density and viscosity [11]. Heat transfer can change with magnetic and electric fields applied on the fluid. In this study, the cooling time of the liquid is investigated in a laminar constant flow condition while a fluid to which a liquid metal is added flows in a pipe applied with a magnetic or electrical field. ANSYS Fluent software MHD module was used in the calculations. As a result, it has been observed that depending on the direction of the magnetic or electric field applied on a liquid fluid, heat transfer can be increased or weakened [12]. In order to increase the amount of heat transfer, there are options to increase the heat transfer coefficient, increase the temperature difference and increase the area based on the Fouirer equation. In many cases, where the last two are not possible for both technical and economic reasons, increasing the heat transfer coefficient remains the only option. In these cases, it is possible to use nanofluid, and both the transmission and transport coefficients of metal or metal oxide nanoparticles and suspensions prepared using water as the basic fluid can be increased [13]. There are some factors that affect the viscosity and thermal conductivity of nanofluids. These factors are the shape and size of the nanoparticles, the volumetric concentration ratio of the nanoparticles, the working temperature, the pH parameter and the quantity of surfactant in the medium [14]. In a similar study, the combined effect of an electrical (E = 0 V / m to ± 9e - 6 V / m) and magnetic field (B = 0 T - 0.15 T) on the thermophysical and hydrodynamic properties of steady-state magnetic viscous flow of incompressible liquid lithium contained in the enclosure was investigated. It has been reported that increasing the applied electrical and magnetic field decreases the flow rate and also increases the temperature, heat flux, shear stress, and Nusselt number. In addition, with the increase of the positive electric field, the flux field of the magnetic field has increased the thermophysical and hydrodynamic properties of the fluid. However, it has been observed that the electric field applied by increasing in the negative direction reduces the effect of the magnetic field [15]. Within the study, a 30.63% increase in heat transfer was shown by using CNT-water nanofluid prepared with 0.15% pure water. They also displayed that the small size (10 nm) of the nanoparticles within the nanofluid does not cause intemperate pressure loss. [16]. In another study, the effects of the magnetic field applied on an immiscible fluid on the hydrodynamic flow characteristic of its flow were analyzed analytically. For this, a model with two different flow states is used. In the first, a low electrical conductivity liquid (gasoline) was placed in the inner core and a high conductivity liquid (brine) was placed in the outer flow zone. The effects of the applied electrical field on the flow in fluids have been observed. The resulting flow models are expressed with theoretical equations on a differential basis and solved using the Laplace Transform method. These equations are modeled in such a way that flow velocities are dependent on magnetic field induction, pipe radius, pressure, and gradient. It has been observed that the general velocity of the magnetic forces formed in the inner core where the low conductive liquid is located decreases more than the flow velocity in the outer region where the highly conductive liquid is located [17].

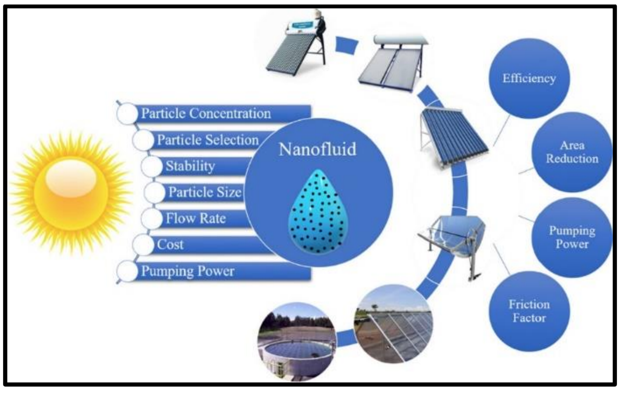

Figure 1.1. The Use of Nanofluids in Solar Collectors [18]

1.2. Solar Collectors

There are many ways to benefit from solar energy, as the most effective methods; converting it to electrical energy (such as PV cells) and converting it to heat energy (such as solar collectors).

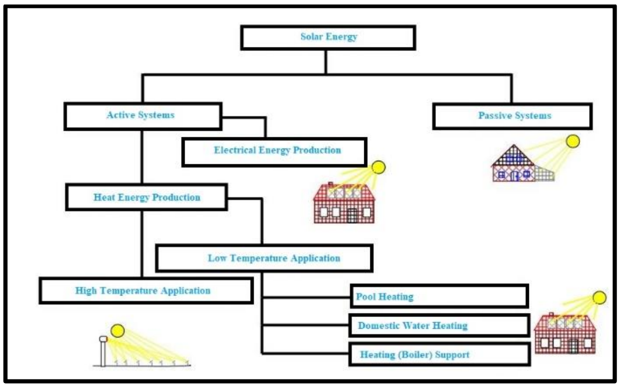

Figure 1.2. Using of Solar Energy [7]

Basically, the flat plate solar collectors are the most used among the solar collectors that can be divided into four groups. The advantages of this type of collectors are inexpensiveness, easyness in manufacturing and flexibility of structure. However, it has some technical and, especially, economic disadvantages during high temperature applications and during very cold weather conditions. An example of this is the low thermal efficiency of flat plate solar collectors at below 40% in non-ideal climatic conditions [19].

Figure 1.3. Flat Plate Solar Collectors [20]

Evacuated Tube Solar Collectors were designed to eliminate the disadvantages of flat plate solar collectors. In these collectors, in order to create favorable conditions for high temperature applications, the air in the ambient was removed to create a vacuum cavity [21]. Thanks to this application, in line with the use of selective absorbent material, thermal efficiency was increased even in cold climatic conditions with low solar radiation [22].

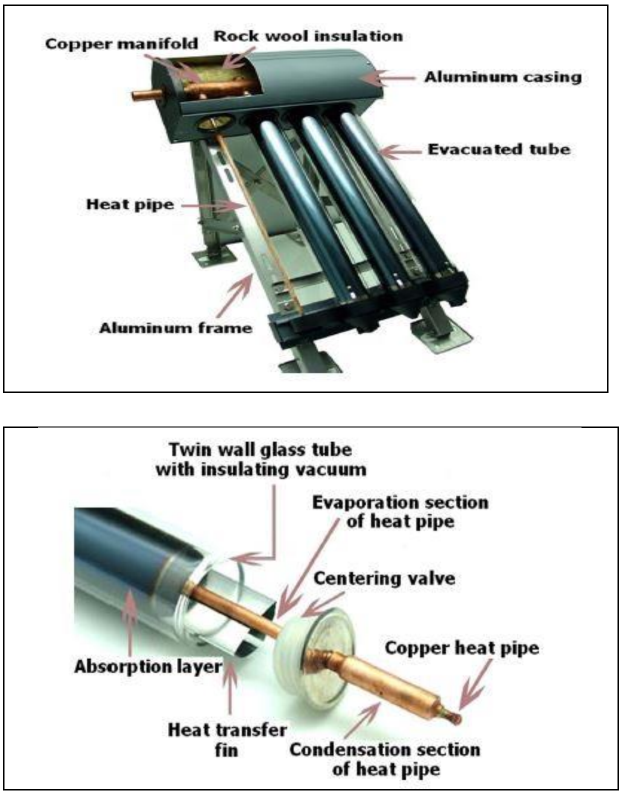

Figure 1.4. Evacuated Tube Solar Collector and Components [20]

Parabolic Trough Solar Collectors (PTSCs) are utilized in the production of steam by solar energy. In addition, it is used effectively in areas such as hot water supply, heating the places, air conditioning-cooling works, industrial processes and electrical energy production. Concentrated sun rays come to the receiving pipe surface in the center of the collector and heat the water in the pipe; in this case, solar radiation turns into useful energy [23].

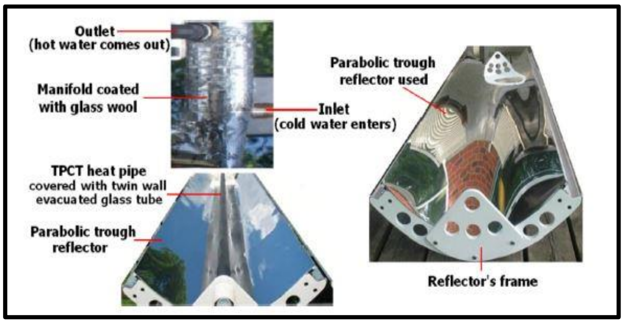

Figure 1.5. Design of the Parabolic Trough Solar Collector [24]

Heat pipe solar collectors were produced based on both heat pipe and evacuated tube applications, thus creating a new type of collector that can create advantages. The advantages of this type of collector include low thermal resistance, high heat removal and low hydraulic resistors [25]. The heat transfer processes of the heat pipes in the collector are based on the phase change, which significantly reduces the temperature drop. This situation creates high heat transfer capacity and low heat transfer area [26].

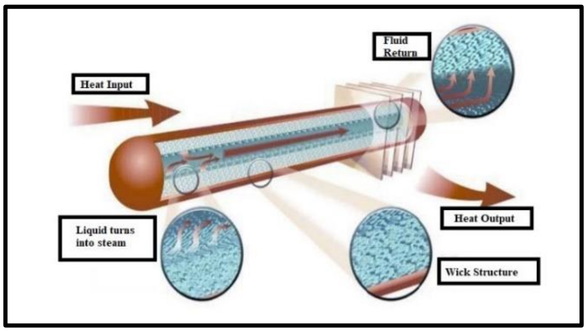

Figure 1.6. General working principle of heat pipes [27]

1.3. Advantages of Nanofluid Usage in Solar Collectors and Effects on Efficiency

Compared to conventional fluids, it is observed that nanofluids have considerable benefits on the effectiveness of solar collectors. Some of these benefits are summarized below [28].

- The flexible structure of nanoparticles and easy change in the volume fraction make them effective for maximum absorption of solar energy.
- Solid nanoparticles have small particle sizes, so they have the properties to increase the heat capacity property and surface area width of the liquid.
- Nanofluid has low emission properties in the infrared range and high suction properties in the solar interval. Thanks to these properties, the optical parameters of a base liquid can be increased using nanofluid, which is a positive condition for system performance.
- As the temperature and concentration of the nanofluid in the system increases, also the thermal conductivity increases and this significantly increases the productivity of solar collector.
- A nanofluid has a relatively high suction coefficient compared to base liquid. At the same time, it has excellent absorbent fluid ability due to its good stability.
- Nanofluids have the ability to improve the radiation features of base fluids, and thus tend to improve the productivity of solar collectors.
- The way to increase the outlet temperature applied to improve collector productivity in conventional solar collectors leads to an Increase in the heat transfer field, which increases the collector's cost and size. On the other hand, the application of nanofluid in the system increases the outlet temperature and does not have a negative effect on situations such as cost and size increase.

2. MATERIAL and METHOD UTILIZATION OF NANOFLUIDS IN SOLAR COLLECTORS

2.1. Applications of Nanofluids in Flat Plate Solar Collectors

There are many studies in the literature regarding the utilization of nanofluids in flat plate solar collectors. With the use of nanofluid, factors such as collector efficiency, collector size and area, heat transfer coefficient, inlet and outlet temperatures were evaluated and various results were achieved.

An experimental study was carried out by Kalkan [29] to determine the thermal performance of a two-phase thermosiphon solar water heater utilizing two distinctive nano-fluid and pure water-filled warm pipes. Al_2O3-H_2O, CuO-H_2O nanofluids and pure water were used in the tests. In addition, a latent heat storage unit filled with $CaCl_2.6H_2O$ was integrated into the condensing unit of this two-phase thermosiphon solar water heater system. The highest thermal performance has been obtained for CuO-H_2O nanofluid while the lowest thermal performance has been obtained for pure water. In thier study, Balcıoğlu [30] aimed to improve the performance of heat pipe using nano-fluid obtained by adding alumina (Al_2O_3) metal oxide nanoparticles instead of water used as working fluid in thermosyphon heat pipe. As a result of experiments, %2 improvement was observed in the experiments carried out with nano-fluid than the experiments carried out with water. Yousefi et al. [31] studied the effects of nanofluids on system performance in an FPSC and evaluated the consequences. The experiments were carried out in twq different ways. It has been determined that the medium using nanofluids as working fluid increases efficiency compared to water. Improved efficiency for 0.2% by weight was found to be 28.3%. Yousefi et al. [32] experimentally examied the effect of MWCNT-water nanofluid as the absorbent medium on the effectiveness of the FPSC. The results showed that there was a important improvement in productivity by rising the fraction to 0.4%. Besides, utilization of surfactant caused an improvement in productivity. Yousefi et al. [33] examined the status of the pH variation on the effectiveness of an FPSC and used the MWCNT-H_2O nanofluid for this purpose. The experiments were carried out by using different pH merits as additives, also 0.2% by weight MWCNT with Triton X-100. The consequences showed that the effect of the existing nanofluid in the system on the collector productivity increases positively with the increase-decrease method according to the pH value at the isoelectric point. Tora and Moustafa [34] developed a model to quantify feat of a typical FPSC and plate and tube geometry by using nanofluids. The model was verified by comparison with published experimental results on the behavior of nanofluids. Correspondingly, they determined that the collector which using nanofluid has loftier efficiency. Jamal-Abad et al. [35] used a direct synthesis method to prepare the Cu-water nanofluid for use as a working fluid in the solar collector. According to the results obtained, as the nanoparticle concentration increased, so did the collector efficiency, and the collector productivity at 0.05% by weight was about 24% higher for certain conditions. Faizal et al. [36] analyzed the size reduction potential of the solar collector by using MWCNT nanofluid as absorbent medium. For the same outlet temperature, it has been observed that when applying MWCNT nanofluid as working fluid, the collector size reduced by up to 37%, thereby reducing the overall cost of the system. Gangadevi et al. [37] conducted studies to demonstrate that the efficiency of an FPSC could be increased by increasing the volume fraction of nanoparticle and thermal conductivity of the nanofluid. By using Al_2O_3-water nanofluid as working fluid, efficiency has increased up to about 30%. Chaji et al. [38] manufactured a small FPSC and tested it to examine the effects of different nano particle size TiO_2 concentrations in water as base liquid. The addition of nanoparticles to water allowed of FPSC initial efficiency to increase between 3.5% and 10.5%, and the total efficiency of the collector showed an improvement of 2.6% to 7%. Tiwari et al. [39] examined the thermal production of the system using Al_2O_3 / water nanofluid in a FPSC for water heating application. In addition, the effects of parameters such as particle fraction and mass flow rate on system productivity have been investigated. Consequently, it was determined that 1.5% nanofluid volume fraction increased thermal productivity by 31.64%. Faizal et al. [40] conducted research on an FPSC using various nanofluids on parameters such as efficiency, cost, reducing collector size and energy savings. As a result of their work, they determined that the nanofluid-based collector could compensate 170 kg less CO_2 emissions and 220 MJ of energy could be saved. In addition, they determined that 2.4 year time saving could be achieved during the payback period, which was a big problem in collector applications. Said et al. [41] added nanofluids they prepared to the system to investigate the thermophysical properties of nanofluids and conducted experiments. They also investigated the effect of viscosity and density parameters on the collector's pumping power. Consequently, the thermal conductivity increased due to the increasing concentration rate, and the viscosities of the nanofluids decreased with increasing temperature. During the experiments, the researchers also determined that the nanofluid in the system exhibited Newtonian behavior. Colangelo et al. [42] tested different nanofluids on the prototype panel, and after they chosed water - Al_2O_3 nanofluid as the heat transfer fluid. All tested nanofluids were prepared as groups and their thermal conductivity and convective heat transfer coefficients were measured before using them as heat transfer fluid in the solar panel. In the system, conductivity improved and convective transfer coefficient also increased. Nasrin and Alim [43] applied alumina and copper nanoparticles to the riser tube of an FPSC and also executed a numerical study to obtain information about the heat transfer of the system using various nanofluids. It has been found that a significant improvement in heat loss occures when double nanoparticles are used. The researchers determined that Cu-water nanofluid is more useful in terms of improving the heat loss parameter. Ekramian et al. [44] executed studies to evaluate parameters such as thermal transfer coefficients and thermal efficiency in a FPSC system using different nanofluids. The states of temperature and flow rate parameters on nano-liquids and pure water were examined and the results were compared. It has been determined that the thermal productivity and heat transfer coefficient of CuO / water nanofluid were higher than other working fluids. Moghadam et al. [45] added the Cu-water nanofluid which they prepared to assess the productivity and performance of the FPSC, and also experimentally examined and interpreted the effects on the system. Based on their experimental studies, they found that the use of nanofluid in the system gave positive results and significantly improved system performance. Mahian et al. [46] used the nanofluids they synthesized in a solar collector and worked on heat transfer and entropy production based on these fluids. They included nanofluids with different particle sizes and different volume concentrations in the system and used them as working fluids. In the study, the mass flow rate was considered perpetual for all working fluids, and as a result, it was determined that the heat transfer coefficient and Nusselt number showed different properties. In thermophysical models, uncertainties and pipe roughness have been found to have important effects. The findings showed that the outlet temperature increased with an increase in the volume fraction of the nanofluid, and a very trivial lessen in the temperature when increased nanoparticle size. Roy et al. [47] executed an experimental study to investigate the heat properties of the nanofluid in a FPSC. Radiation heat flux, mass flow rate of nanofluid, inlet temperature to solar collector and convective heat transfer coefficient of the particle and volume concentration effect on collector efficiency were investigated. Both parameters improved when particle volume concentration and flow rate increased. The optimum percent increase achieved in the convective heat transfer coefficient was determined as 18.4% for the volume concentration of 0.04%, the Reynolds number of which is 25000. Said et al. [48] carried out studies by including the nanofluids they prepared for increase the productivity of the collector. Different volume fractions and mass flow rates were used in the study and the effects of these parameter changes on performance were examined. As a result of the study, high levels of energy and exergy productivity were determined. Shareef et al. [49] investigated the effect of using nanofluid in solar collector on system efficiency and performance. The experimental test setup consisted of a solar collector, closed working fluid system and measuring devices (flow meter, thermocouples, temperature meter and digital solar energy meter). While the maximum difference between the inlet and outlet temperatures of the solar collector was 14.4 ℃, the solar radiation was about 788

Table 2.1. Summarizing the Studies Using Nanofluid in Flat Plate Solar Collectors Using Various Parameters

References	Years	Types of Nanofluids	Explanations
[31]	2012	Al_2O_3-H_2O	It was determined that efficiency was increased by using nanofluid in the system.
[32]	2012	MWCNT-H_2O	The productivity of the system has increased when used nanofluid and surfactant, and the efficiency of the system has decreased when there is no surfactant.
[33]	2012	MWCNT-H_2O	It has been determined that pH change has an important effect on collector efficiency.
[34]	2013	Al_2O_3-H_2O	The collector efficiency and the thermal conductivity of the nanofluid showed better performance as the particle size increased.
[35]	2013	Cu-H_2O	It has been determined that the productivity of the collector, which contained 0.05% nanofluid by weight, was higher.
[36]	2013	MWCNT	When applying MWCNT nanofluid, the collector size can be reduced to 37% of its original size.
[37]	2013	Al_2O_3-H_2O	It has been determined that the nanofluid used in the system increased collector efficiency by approximately 30%.
[38]	2013	TiO_2-H_2O	Thanks to the nanofluid used, collector efficiency has been increased by approximately 7%.
[39]	2013	Al_2O_3-H_2O	The use of nanofluid in the system significantly increased thermal efficiency and it was determined that this rate was approximately 31.64% in the measurements.
[40]	2013	CuO, SiO_2,TiO_2, Al_2O_3-H_2O	Solar collector area reduction of 25.6%, 21.6%, 22.1% and 21.5% was achieved by using nanofluids.
[41]	2013	Al_2O_3-H_2O-EG	It was determined that the pumping power of nanofluids at low volume concentration was almost equal to the base liquid.
[42]	2013	Al_2O_3-H_2O	The heat transfer coefficient was improved at a given volume concentration.
[43]	2014	Ag, Cu, CuO, Al_2O_3-H_2O	The use of nanofluid has been very beneficial in terms of transmitting the heat parameter through the pipe in the collector.
[44]	2014	MWCNT, CuO, Al_2O_3-H_2O	CuO-water nanofluid was superior to other nanofluid in the evaluation of the thermal efficiency parameter.
[45]	2014	CuO-H_2O	The collector productivity improved by approximately 21.8%.
[46]	2014	Al_2O_3-H_2O	When mass flow rate is considered constant for all working fluids, the Nusselt number and heat transfer coefficient have been found to have different trends.
[47]	2015	Ag-H_2O	It has been determined that the maximum efficiency of the solar collector was close to 70%.
[48]	2015	TiO_2-H_2O	The highest energy efficiency was 76.6% and the highest exergy efficiency was 16.9%.
[49]	2015	Al_2O_3-H_2O	It was determined that there was a difference between the inlet and outlet temperatures of the collector.
[50]	2015	SiO_2-H_2O	It revealed that the use of nanofluids increased the outlet temperature and reduced the rate of entropy production.
[51]	2016	SiO_2-H_2O	The productivity of the collector increased with increasing flow rate.
[52]	2017	MgO-H_2O	9.34% thermal efficiency increase was achieved in the system.
[53]	2017	CeO_2-H_2O	When using CeO2-water nanofluid, higher collector efficiency was obtained compared to the results obtained with water application.
[54]	2018	TiO_2-H_2O	Instantaneous productivity was determined as 48.67% for nanofluid and 36.20% for pure water.
[55]	2018	Al_2O_3-H_2O	The use of nanofluid increased the outlet temperature by 7.20%.
[56]	2018	Al_2O_3-H_2O	The maximum friction factor for 0.3% nanofluid at Re = 13500 was 1.25 times.
[57]	2018	Al_2O_3, ZnO-H_2O	When using nanofluid in the system, it has been determined that there was a 15.13% increase in efficiency.
[58]	2019	Al_2O_3-Distilled H_2O	By increasing the volume fraction of the nanofluid, an increase of approximately 21.32% in the collector efficiency was achieved.
[59]	2019	Alumina-H_2O	There was a decrease in efficiency from 47% to 41.5%.
[60]	2020	CeO_2-H_2O	It was determined that collector productivity increased with the use of nanofluid.
[61]	2020	TiO_2-H_2O	It has shown that collector efficiency for volume fractions of 5% and 2.5% TiO_2 nanoparticles was increased by approximately 45% and 17%, respectively, using nanofluids as working fluid.

research on heat transfer parameter and entropy production in the FPSC using nanofluid with 1% volume concentration. In the research, the effects of two particular pH values and two different sizes of nanoparticles on the entropy production rate in turbulent flow were investigated. In calculations made using the Brinkman model, a high thermal efficiency value and heat transfer coefficient value were obtained. The consequences showed that the use of nanofluids increases outlet temperature, reduces rate of entropy production. Noghrehabadi et al. [51] examined the productivity of square FPSC using nanofluid. In the study, SiO_2 / water nanofluid was used as a coolant and its impact on the performance of the FPSC was experimentally researched. The efficiency of the square FPSC was increased by increasing the flow rate. The results revelaed that the SiO_2 / water nanofluid increased thermal productivity and temperature performance. Kumar Verma et al. [52] examined the performance of the system using MgO / water nanofluid in the flat plate solar collector. The tests implemented were based on different particle sizes and different particle volume concentrations. Experimental observation provided an increase in thermal efficiency of 9.34% for a concentration of 0.75% particle volume at a flow rate of 1.5 lpm. Exergetic efficiency improve was observed as 32.23% for the same concentration and flow rate. Sharafeldin and Gróf [53] conducted experiments to examine the effect of three different volumes of CeO_2 nanoparticles of 0.0167%, 0.0333% and 0.0666% on FPSC productivity, keeping the average particle size constant. A number of processes have been applied to keep the stability of the nanofluid constant. Evaluations were made at 3 different mass flow rates. The utilization of nanofluid enabled the system to achieve high collector productivity. Kılıç et al. [54] executed a comprehensive work to assess the feat of the system using TiO_2 / water nanofluid in the FPSC. It is aimed to eliminate the agglomeration problem by adding Triton X-100 surfactant to the mixture. It has been discovered that the utilization of nanofluid has an enhancing effect on system performance. Genc et al. [55] carried out a study based on the heat transfer approach and accordingly carried out studies in a nano-liquid based flat plate solar collector. In their analysis, Al_2O_3 nanoparticles and water in different volumetric concentrations were used. It was determined that the highest thermal efficiency value was obtained in October. Sundar et al. [56] followed the way to increase the thermal conductivity and flow turbulence of the working fluid in order to examine the development techniques of passive heat transfer in the FPSC. Al_2O_3 nanofluid and twisted tape splices have been used to improve heat transfer and thus the thermal efficiency of the solar water heater. The Reynolds number for 13000 showed that the heat transfer increase for the concentration of 0.3% volume nanofluid was 21% for the flat tube and increased to 49.75% when H / D = 5 had a twisted band. The thermal productivity of the flat collector improved to 58% when using 0.3% nanofluid and increased to 76% with a twisted H / D = 5 tape at a mass flow rate of 0.083 kg / s. Arıkan et al. [57] studied to investigate the status of EG and nanofluids on collector productivity, and they added these substances to the system to examine the situation. The use of EG in the system increased efficiency and an improvement in mass flow rate was also determined. Rajput et al. [58] evaluated the performance of the system by using nanofluid in the solar water heater collector. They used SDS as a surfactant and improved the dispersion quality.

Table 2.2. Summarizing the Studies Using Nanofluid in Direct Apsorption Solar Collectors Using Various Parameters

References	Years	Types of Nanofluids	Explanations
[62]	2012	Aluminium-H_2O	The use of Al-water nanofluid has been the right choice for improving the performance of the system and the efficiency has improved with the improve in particle size.
[63]	2013	Al_2O_3-H_2O	The use of nanofluid in the system increased the collector efficiency by approximately 5%.
[64]	2013	Graphene-Aluminium/Therminol VP-1	It was concluded that the DARS diameter should be reduced in order to reach high outlet temperatures.
[65]	2014	TiO_2-Al_2O_3-Ag-Cu-SiO_2/Texatherm oil	The use of nanofluid in the system increased efficiency by approximately 2.5% and increased the outlet temperature by 30-100 K.
[66]	2014	Cu-H_2O	In line with the increasing Reynolds number and the increasing volume fraction, the efficiency has increased approximately twice as much.
[67]	2014	CNT-H_2O	Nanofluid was proposed to increase the overall efficiency of direct absorption solar collectors.
[68]	2015	Carbon-nanohorn	By developing three-dimensional models, heat losses occurring at the borders were calculated and the performance of the system was evaluated with the use of nanofluid.
[69]	2015	Al_2O_3-H_2O	The collector productivity was increased more than pure water for all four concentrations of the nanofluid.
[70]	2019	SiO_2 / Ag-CuO	The stability of nanofluids vigorously influenced the optical and thermal properties of the nanofluid.

By increasing the volume fraction of the nanofluid, system productivity improved. Mondragón et al. [59] conducted studies to evaluate the effect of nanofluid use and nanoparticle concentration on efficiency in the flat plate solar collector. A reduction in efficiency has been achieved since the nanofluids they used could not increase the conductivity parameter of the nanoparticle concentration. However, it was determined that the amount of nanofluid used has an effect on productivity. Sharma et al. [60] investigated the effects of nanofluid use on thermal performance in an FPSC. Thermophysical parameters of the nanofluid were measured at different concentrations using a particle size of 30 nm. As a result of the studies, determined that the collector productivity increased up to 57.1%. Ahmadlouydarab et al. [61] have made efforts to increase productivity for public use by making a change in the laboratory scale on flat plate solar collector structure. For this purpose, a nanofluid containing TiO_2 particles was used as working fluid in FPSC. In addition, an N-TiO_2 particle layer was applied on the outer side of the glass surface of FPSC. The collector productivity for volume fractions of 5% and 2.5% TiO_2 nanoparticles improved by approximately 45% and 17%, respectively by using nanofluid.

2.3. Parabolic Trough Solar Collectors and Nanofluid Usage in These Systems

Research on the implementation of nanofluids in parabolic trough collectors are generally carried out to examine the performance and thermal productivity of the collector.

Khullar et al. [71] investigated the issue of deposition of solar radiation using parabolic trough solar collectors and analyzed this situation numerically. The nanofluid collector has been observed to have approximately 10% higher productivity than the traditional parabolic collector. De Risi et al. [72] used gas-based nanofluids to quantify the optimization of the PTSC. It was determined that transparent receptors integrated with nanofluids can immediately absorb radiation owing to the very high total surface of the nanoparticles. The maximum thermal productivity for the nanofluid outlet temperature of 650 °C was determined to be approximately 62.5%. Ghasemi and Ahangar [73] conducted numerical studies to examine the effect of using nanofluid on the parabolic solar collector. In particular, thermal efficiency and outlet temperatures were calculated and the results were compared. In addition, parameters such as volume ratios and concentration ratios of nanoparticles were evaluated. It has been determined that collector performance increases when the volume ratio of nanoparticles are increased. Sokhansefat et al. [74] numerically investigated the improve in the PTSC with nanofluid and investigated its effect on heat transfer rate. It has been determined that the transfer coefficient improves when nanoparticles used in. It was also determined that thermal conductivity is significantly increases by using nanofluid in the system. Mwesigye et al. [75] manufactured a parabolic trough solar collector and carried out thermodynamic analysis of the system using synthetic oil - Al_2O_3 nanofluid. As a result, it was found that thermal efficiency improves 7.6%. Kaseian et al. [76] investigated the productivity of a PTSC by experimental tests and evaluated their results. 0.2% and 0.3% multi-walled carbon nanotube (MCNT) / oil-based nanofluids were prepared and used as working fluids. The results showed that when using nanofluid in the system, the collector efficiency achieves a maximum value of approximately 7%. Khosravi et al. [77] analyzed the heat transfer parameter with the nanofluid used under a certain magnetic field and made calculations using the CFD law. In the study, nanofluids and some liquids was used and these parameters were evaluated as working fluid for the collector. The numerical analysis performed was primarily confirmed with theoretical results and extra studies were performed to determine how the magnetic field affects the system. As a result, it was determined that the magnetic field has an effect on the collector heat

Table 2.3. Summarizing the Studies Using Nanofluid in Parabolic Trough Solar Collectors Using Various Parameters

References	Years	Types of Nanofluids	Explanations
[71]	2012	Aluminium-Therminol VP-1	The collector which using nanofluid showed greater efficiency/productivity.
[72]	2013	Ni-CuO	The optimum thermal productivity for a nanoparticle volume concentration of 0.3% was about 62.5%.
[73]	2014	Cu-H_2O	The productivity of the system decreased as the length of the receiver increased and the collector performance increased in direct proportion with the volume fraction of the nanoparticles.
[74]	2014	Al_2O_3-synthetic oil	The coefficient of the heat transfer parameter in the system increased with the use of nanoparticles.
[75]	2015	Al_2O_3-synthetic oil	The thermal productivity of the receiver provided 7.6% improvement thanks to the nanofluid used.
[76]	2015	MCNT-mineral oil	When using MCNT / mineral oil nanofluid, efficiency increased 4-5% at 0.2% and 5-7% at 0.3%.
[77]	2018	Fe_3O_4-Therminol 66	It is determined that the magnetic field parameter could change various properties of the collector.

productivity and exit temperature of the system can be increased with this parameter.

2.4. Using nanofluid in wavy solar collectors

The wavy solar collector includes an undulating glass top surface and a flat steel bottom surface exposed to the ambient atmosphere. The researches carried out in wavy solar collectors to improve heat transfer. Nasrin and Alim [78] have examined the effects of the heat transfer parameter using Ag, CuO-water nanofluids and have made comments by numerically examining the performance of the system. Various parameters of nanofluids related to system performance have been examined in detail. It has been determined that heat transfer in the collector showes better performance when using nanofluid. Alaeian et al. [79] scrutinized the production of a wavy collector and used MWCNT-oil nanofluid in different concentration values. Also, the condition of the heat transfer coefficient, which is an important parameter for the system, was examined in this direction. Nanofluid was used in the system and heat transfer increased by 56%.

2.5. Nanofluid Applications in Heat Pipe Solar Collectors

The studies conducted using nanofluid in the heat pipes have been towards to increasing the collector efficiency and the efficiency increase with the applications. Sözen et al. [80] In the study, using 0.2% by weight of Triton X-100, various proportions of fly ash / water nanofluids were obtained. Experiments were carried out with these prepared nanofluidics in a two-phase closed water heater at different water flow rates (5, 7.5 and 10 g / s) and at different heating powers (200, 300 and 400W). It provided a 26.39% increase in the system efficiency of 4% fly ash / water nanofluid mixture at 5 g / s flow and 200 W heat power for the best performance. Sözen et al. [81] studied using fly ash and alumina nanofluids to evaluate the performance of two-phase closed thermosiphon heat pipe. In their study, they used various metal oxide containing nanoparticles such as SiO_2, TiO_2, Al_2O_3, Fe_2O_3, CaO and MgO obtained from the cyclones of Yatağan Thermal Power Plant. The tests were implemented at three different heating powers (200 W, 300 W and 400 W) and three different coolant flow rates (5 g / s, 7.5 g / s and 10 g / s). It has been determined that using nanofluid instead of water at 400 W heating power and 5 g / s cooling water flow provided a 30.1% reduction in heat resistance. Lu et al. [82] examined the competence of an open thermosiphon using nanofluid and made interpretations based on data obtained through experiments. The results showed that the heat transfer coefficient improves by 30% and the nanofluid used improves the performance of the evaporator in the system. It was also determined that the wall temperatures decreases after adding nanoparticle to the water. Çaylıoğlu [83] evaluated R134a, R22 and methanol working fluids and different wick structures in heat pipe solar collectors designed and manufactured in his study. As a result of the experiments carried out, it was determined that the efficiency values of R134a and R22 fluids, which were selected as working fluids in heat pipe solar collectors, are lower than conventional systems. It has been determined that the heat transmission coefficients of R134a and R22 gases, selected as working fluids in heat pipe solar collectors, are low, and that the efficiency values of the HPSCs are also low. Moorthy et al. [84] evaluated the performance and efficiency of the system utilizing nanofluid in a evacuated tube solar collector containing a heat pipe. It was concluded that the productivity of the collector using 0.3% concentration of TiO_2 nanofluid was about 73% more efficient than those using about 58% pure water. Chougule et al. [85] solar suppository in outsourced test conditions for water and CNT at various concentrations and at various inclination angles investigated the performance of a non-solar wick HPSC experimentally. They found that HPSC at 63% CNT concentration had a maximum yield of 73% at a 50 ° tilt angle. Liu et al. [86] carried out several studies on the system integrated with an open thermosiphon using CuO-water nanofluid. As a result of the studies, it has been determined that the efficiency of the collector with nanofluid performs better. Ersöz and Yıldız [87] manufactured heat pipe evacuated tube solar collectors with heat pipe diameters of 16, 22 and 18 mm. As working fluid in the thermosiphon type heat pipe ethanoland as heated fluid, air which isrequired industrial drying an building heating have been used. In the days when the average daily solar radiation fell below 775.45 W / m^2, the condensate of ethanol, which was the working fluid in the heat pipe evacuated tube solar collector with a heat pipe Ø 28, has increased, so the thermal efficiency has decreased because the solar radiation intensity was not sufficient for evaporation. In the days when the average daily solar radiation was over 775.45 W / m^2, in the heat pipe evacuated tube solar collector with heat pipe Ø16, the working fluid ethanol has completely evaporated and the heat transfer has decreased as a result of this, since the heat transfer has decreased. Saravanan and Karunakaran [88] compared the performance of the integrated state of the V-type collector with the heat pipe using nanofluids and distilled water. Using nanofluid in the system has led to an increase in thermal efficiency. Aruna et al. [89] experimentally analyzed the productivity of the HPSC using two different working fluids with a constant nanoparticle concentration and size of 80 ml / l and 40 nm, respectively. The nanofluid has been found to provide better performance than propanol. Menlik et al. [90] investigated how the MgO / water nanofluid affected the performance of a closed thermosiphon heat pipe in different operating conditions. Triton X-100 nonionic surfactant was used to produce 5% (volume) MgO / water nanofluid by direct synthesis. When nano liquid was loaded into the system instead of water, a heating power of 200 W and a level of improvement of 26% were determined for the effectiveness of the heat pipe used in the study at a flow rate of 7.5 g / s. Çiftçi et al. [91] worked on improving the thermal performance of a dualphase closed thermosiphon (heat pipe) using nanofluid containing nano-sized TiO_2 (Titanium dioxide) particles. The experiments were carried out separately for water and nanofluid, and the results were compared. The best result was achieved at 200 W heater power and 5 g / s coolant flow rate, using nanofluid as the working fluid, providing 16.5% improvement in thermal performance. Pise et al. [92] conducted studies to investigate the thermal performance of the serpentine-shaped thermosiphon HPSC under real operating conditions. The observed increase for the collector was found to be 0.05% by weight, 0.25% by weight, 0.5% by weight, compared to purified water, respectively 3.79%, 10.72%, 15.24%. Water-Al_2O_3 + surfactant performed better than pure water, an increase was observed for the collector compared to pure water and nanofluids, and the increase was 20% compared to water. Sözen et al. [93] used nanofluids and fly ash as working fluids in the system. In the study, the effects of nanofluids and fly ash on the performance of a closed thermosiphon heat pipe were investigated. It has been determined that there was a decrease in thermal resistance. The use of fly ash reduced thermal resistance more than the nanofluid. Eidan et al. [94] carried out an experimental study to improve the performance of the heat pipe vacuum tube solar collector using various nanofluids. The improvement percentages of the system were up to about 36%, 64%, 32% and 56%, respectively, using Al_2O_3 and CuO acetone-based nanofluids in different fractions. All the cases which examined showed that the average water tank temperature was higher for two types of nanofluid than acetone. In their experimental study, Ozsoy and Corumlu [95] determined the thermal efficiency of the thermosiphon heat pipe vacuum tube solar collector by utilizing silver-water nanofluid for commercial applications. It has been observed that the thermosiphon heat pipe loaded with silver-water nanofluid maintains its improved heat transfer property. Nanofluid working fluid

Table 2.4. Summarizing the Studies Using Nanofluid in Heat Pipe Solar Collectors Using Various Parameters

References	Years	Types of Nanofluids	Explanations
[82]	2011	CuO-H_2O	The use of nanofluid considerably improved the performance of the evaporator part of the collector.
[83]	2011	R134a, R22 ve methanol	The low heat transfer coefficients of R134a and R22 gases caused the productivity values of the HPSCs to be low.
[84]	2012	TiO_2-H_2O	Thanks to the use of nanofluid, system efficiency is increased by 16.7%.
[85]	2013	Carbon nanotube (CNT)	An optimum value has been obtained for the nanofluid in the system and this has been proven by experiments.
[86]	2013	CuO-H_2O	The collector efficiency and the air outlet temperature that contain nanofluid were determined to be higher.
[87]	2013	Ethanol	Since the working fluid, ethanol, cannot completely absorb heat in the evaporated condenser, heat transfer has decreased and thereby thermal efficiency has decreased.
[88]	2014	TiO_2-Distilled H_2O	The thermal productivity of the collector was improved by using nanofluid.
[89]	2014	TiO_2-Distilled H_2O	The nanofluid used in the system provided the best performance.
[90]	2015	MgO-H_2O	An improvement level of 26% was detected at 200 W heating power and 7.5 g / s flow rate.
[91]	2016	TiO_2-H_2O	The best thermal performance was provided at 200 W heater power and 5 g / s coolant flow rate.
[92]	2016	Al_2O_3-H_2O	The increase in performance compared to water was found to be 20%.
[93]	2016	H_2O, alumina nanofluid and fly ash	The use of fly ash reduced thermal resistance more than nanofluid.
[94]	2018	Al_2O_3 and CuO/acetone	HP-ETSC productivity has always been better than acetone in nanofluids under the same test conditions.
[95]	2018	Ag-H_2O	Nanofluid improved the productivity of the solar collector.
[96]	2018	Graphene-H_2O	There was a reduction in start-up time on the system.
[97]	2019	AuNPs MWCNT	The increase in the nanofluid concentration provided more radiation absorption in OHP.
[98]	2019	CuO-methanol	Thermal properties have increased and better performance has been achieved.
[99]	2019	CuO-H_2O	Copper oxide nanofluid and deionized water increased the productivity of the collector.
[100]	2019	TiO_2-H_2O	The highest efficiency was 49,214% when the cooling water flow was 7 g / s and nanofluid was used.

increased solar collector efficiency by 20.7% to 40% compared to pure water. Zhao et al. [96] conducted an experimental study on the thermal initiation performance of the gravity-assisted heat pipe by synthesizing graphene / water nanofluid. The concentrations of different GNPs were measured at different temperatures in different analyzes, including the thermophysical properties-thermal conductivity and viscosity of the nanofluid. In addition, based on the operational evaluation on the start-up process of a single heat pipe, the performance of solar gravity-assisted heat pipes enriched with nanofluids using different concentrations of GNP. The results showed that the use of nanofluid instead of water could lead to a reduction in start-up time. Jin et al. [97] produced transparent-shaped OHPs and added nanofluids to them and studied the performance of the system. Thanks to the nanoparticles added to the system, radiation absorption has significantly increased and performance has improved. OHPs containing nanofluids had very high thermal conductivity, and thus a serious improvement in the system was detected. Kaya et al. [98] conducted studies on the energetic and exergetic analysis of a concentrated air collector with evacuated tube heat pipe at different air rates. For this purpose, CuO-methanol nanofluid was used in the study.

Experimental results have clearly demonstrated that nano-liquid application improves thermal properties and provides better performance for heat pipe applications. Dehaj and Mohiabadi [99] studied the performance and productivity of the system using nanofluid in the HPSC. The optical and structural properties of the nanostructure were analyzed using various parameters and the results were evaluated. The collector productivity and pumping power were calculated for nanofluids. As a result of the experiments, it was determined that the use of nanofluid in 0.017 volume fraction and a certain flow rate provides an increase in efficiency. Su [100] prepared nanofluid by using two-step method using amorphous TiO_2 nanoparticles and preferring water as the basic fluid. Afterwards, pure water was charged to one ETHPC and the nanofluid which prepared to the other was charged. The inlet and outlet temperatures were measured in the cooling water tank and the thermal efficiencies were calculated by measuring the temperature changes at different cooling water flow rates. As a result of the experiments, it was observed that the low heat resistance, high thermal conductivity, high operating temperatures in the ETHPCs reach to the desired temperature values in a short time and the efficiency increases. The highest outlet temperature was realized at 3 g / s water flow rate and using nanofluid and was 28.1 ^oC. In the same conditions, when there was pure water in ETHP, it was 26.1 ^oC. While the highest efficiency cooling water flow was 7 g / s and nanofluid was used, it was 49,214%, whereas pure water was used, it was calculated as 37,496%.

2.6. Applications of Nanofluid in Evacuated Tube Solar Collectors

The use of nanofluid in vacuum tube solar collectors positively affected important parameters such as heat transfer, collector efficiency and thermal efficiency.

Mahendran et al. [101] conducted studies to assess the efficiency of the evacuated tube solar collector. To improve the performance of the system, they conducted experimental studies using 30-50 nm sized TiO_2 nanoparticles. As a result efficiency increases by a maximum of 16.7% compared to a water-only system. Ghaderian and Sidik [102] experimentally investigated the effect of using nanofluid as working fluid on the thermal productivity of the inner spherical coil ETSC inside the horizontal tank. In this experimental study, Triton X-100 was used as a surfactant. Collector efficiency increased more with increasing volume fractions and flow rate of Al_2O_3 nanoparticles. Iranmanesh et al. [103] analyzed the impacts of the utilization of nanofluid on the system performance in the ETSC water heater system and evaluated the system efficiency by making experiments. In addition, by determining various parameters, they examined the physical and thermal properties of nanofluids in the system. Consequently, they determined that the efficiency of the collector improves up to 90.7%. Yang Gan et al. [104] carried out studies to evaluate thermal efficiency in an ETSC they designed and determined the results. It has been determined that the efficiency of ETSC increases with increasing use of nanofluids. In contrast, entropy production decreases. Sharafeldin and Gróf [105] evaluated the productivity of the system using CeO_2 nanoparticles. The tests were done by utilizing three different volumes of CeO_2 (Cerium oxide) nanoparticle concentrations. As a result, it was seen that by using nanofluids, the temperature difference between the inlet and outlet flow and the absorbed energy increases. In their experimental study, Mahbubul et al. [106] analyzed the impact of the Single Walled Carbon Nanotube nanofluid on the collector performance. The results showed that efficiencies up to 56.7% and 66% were observed when the collector was operated with water and 0.2% nanofluid, respectively. Researchers have determined that when using nanofluid, system performance improves. Mercan and Yurddaş [107] performed numerical analysis at the ETSC using nanofluids. Different volume fractions, different mass flow rates and collector angle parameters of nanofluids were evaluated. The increase in heat transfer for the Al_2O_3 / H_2O nanofluid containing Al_2O_3 nanoparticle in the 5% volume fraction for the 24 tube collector was 4.13%, while it was determined as 6.80% for the CuO / H_2O nanofluid under the same conditions. Sharafeldin and Gróf [108] used WO3 nanoparticles to evaluate system performance in the evacuated tube solar collector and tested their experiments at different mass flux rates. It has been determined that the nanoparticles used in the study increase the beneficial heat gain. The thermal efficiency of the evacuated tube solar collector has been up to 72.83%. Sadeghi et al. [109] synthesized and used copper oxide-water nanofluid to study the thermal properties of the evacuated tube solar collector at different volumetric flow rates. The effect of the different volume fractions of the nanofluid used on the properties of convective heat transfer coefficient, Nusselt number and collector useful heat gain were tested. It was concluded that there is an increase in both the flow rate and the concentration of the nanofluid results in an improve in the thermal performance of the solar collector.

Table 2.5. Summarizing the Studies Using Nanofluid in Evacuated Tube Solar Collectors Using Various Parameters

References	Years	Types of Nanofluids	Explanations
[101]	2012	TiO_2-H_2O	When compared with the water-only system, TiO_2 nanoparticles have increased efficiency by a maximum of 16.7%.
[102]	2017	Al_2O_3-distilled H_2O	The utilization of nanofluid in the system has increased productivity.
[103]	2017	GNP-distilled H_2O	It is determined that the thermal energy gain increased when the mass percentage of nanoparticles increased.
[104]	2018	TiO_2	The efficiency of the system has increased when using nanofluid.
[105]	2018	CeO_2-H_2O	It has been determined that the use of nanofluid in the system increased the difference of inlet and outlet temperatures.
[106]	2018	Carbon nanotube	10% higher efficiency was observed for nanofluids.
[107]	2019	Al_2O_3-H_2O CuO-H_2O	The increase in heat transfer for the Al_2O_3 / H_2O nanofluid was 4.13%, while it was 6.80% for the CuO / H_2O nanofluid under the same conditions.
[108]	2019	WO_3-H_2O	The thermal-optical efficiency of the ETSC reached 72.8%.
[109]	2020	Cu_2O-H_2O	Thermal properties of ETSC have been improved with Cu_2O / water nanofluid.

2.7. Nanofluid Applications in Different Types of Solar Collectors

Studies on solar collectors, which are structurally different from other collectors, were also carried out on heat transfer properties and collector performance. In their study Li et al. [110], it was determined that the heat performance of the tubular collector with different nanoparticles. According to the experimental results, it was seen that the heat transfer productivity of all nano-liquid types increases compare to distilled water. Based on their low viscosity and excellent heat transfer performance, they concluded that the 0.2% volume concentration of ZnO nanofluid was a true choice in solar energy system. Taylor et al. [111] examined the effects of utilizing nanofluid in high intelligent solar collectors and tried to determine what effects they have on the system. In their study, they made evaluations by using various nanoparticles together with Terminol VP-1. They have determined that it is appropriate to use nanofluid in the system and efficiency increases to, approximately, 10%. Rahman et al. [112] In this study, a triangular shaped solar collector with a grooved base with water-based nanofluids in its enclosure was investigated. In this application, the corrugated base is kept constant at high temperature and the side walls of the triangular housing are kept at a low temperature and processed. The effect of three types of nanoparticles (Cu, Al_2O_3 and TiO_2) on solid volume fraction (ϕ) was investigated numerically using the Galerkin weighted finite element method in the range of Grashof number (Gr) 104-106. It has been found that both the Grashof number and the flow lines in the enclosure have a significant effect on the isotherms and the solid volume fraction. It was determined that the heat transfer on heated surfacesincreased by 24.28% as the volume fraction increased from 0% to 10% for copper water nanofluid at ϕ, Gr = 106 and τ = 1 '. Goudarzi et al. [113] have constructed a cylindrical solar collector with a helical tube and used various nanofluids and experimentally examined the effects of these nanofluids on efficiency. During the experiments, the weight ratios of the nanoparticles and the mass flow rates of the liquid were added to the system at different values and the results were compared. It was observed that thermal efficiency improved 25.6% by using nanofluid in the system. Rahman et al. [114] In this study, quarter circular solar thermal collectors whose cavity is carbon nanotube (CNT) - water nano-fluid are investigated. The angle of inclination of this type of collector plays an important role in heat transfer, and with a certain angle of inclination of the collector, the solid volume fraction of the nanofluid can be maximized. In such a case, the results were improved by applying the Galerkin weighted FEM residue independence test and code verification. In addition, the large solid volume fraction (= 0 to = 0.12) was studied for the Rayleigh number (Ra = 105-108) and the slope angle (= 0 to = 60 °) at varying times. As a result, it has been shown that both collector inclination angle and solid volume fraction have an important role in increasing heat transfer. Tong et al. [115] used copper fins to provide a constant heat flow in a U-tube solar collector which they designed and filled the system with nanofluid to increase collector efficiency. In this way, it was determined that the collector productivity improved by 4% and it was determined that the use of copper fins is appropriate. Colangelo et al. [116] designed a flat panel solar collector and examined its effectiveness using various parameters. They determined that the collector productivity improved by 11.7% thanks to the nanofluid they put into the system. They also concluded that the nanofluid is more effective than high-temperature water. Younis et al. [117] conducted thermodynamic analyzes to improve the thermal, electrical and exergy efficiency of the solar photovoltaic / thermal (PV / T) hybrid collector system. The two liquids examined were water, and Al_2O_3-ZnO-H_2O was mixed with Ethylene Glycol as a nanofluidic surfactant. The average increase in total efficiency for the mass fraction of nanoparticles 0.05% by weight is 4.1% and the total available energy (exergy) efficiency is 4.6%.

2.8. Use of Nanaofluid in Solar Collectors

Various literature studies on the use of nanofluids in solar collectors are also shown in Table 2.7 and their results are explained. Sruthi [118] conducted a study on the use of nanotechnology in solar water heater systems and also examined the relationship with solar panels and evaluated the current situation. With this study, he stated the benefits of using nano materials in solar water heater systems. Among these advantages; there were parameters such as easy and safe usage, usage in a wide range of commercial applications thanks to its wireless features, energy saving and electricity saving.

Khanafer and Vafai [119] worked on the use of nano materials in the desalination and solar energy sectors and on the benefits of these materials. They have studied and compared the most important developments in various solar collectors and desalination technologies. As a result, they stated that the radiation parameter should be converted to heat in the working fluid to ensure optimum performance, so that parameters such as cost and heat losses can be minimized. Javadi et al. [120] examined the studies conducted in the literature to determine the effect of the use of nanofluids on solar collectors and made a situation assessment by comparing the studies they determined. As a result, they determined that it is more accurate to use two-stage methods in the preparation of nanofluid and suggested that such studies should be conducted by stating that the parameters such as extinction coefficient and permeability of nanofluids were missing in the literature studies conducted. Al-Shamani et al. [121] conducted studies on the efficiency and environmental effects of the use of nanofluidics in solar collectors. They also conducted reviews on the research, performance and development of photovoltaic / thermal (PV / T) collector systems. In order to serve as a guide for the researchers, they evaluated such studies and stated their results, especially, on efficiency in their studies. Chaudhari and Walke [122] made comparisons by examining the studies indicating the benefits of using nanofluid in applications such as solar cells, solar collectors, thermal energy storage systems. In particular, they determined that the particle size had an effect on efficiency and stated that the studies conducted on this subject were incomplete and determined that new studies should be done in this regard. Kasaeian et al. [123] examined and evaluated the applications of nanofluids on solar cells, energy storage systems and different types of solar collectors. It has been determined that the volumetric absorption parameter of the nanofluid reduces thermal resistance and increases the efficiency in that direction. It was emphasized that studies on particle size and nanofluid studies should be increased to minimize cost in collector systems. Verma and Tiwari [124] conducted studies to investigate the effects of using nanofluids in collectors. It has been determined that the use of nanofluids significantly increased efficiency in photovoltaic systems. They stated that the surface

Table 2.6. Summarizing the Studies Using Nanofluid in Different Solar Collectors Using Various Parameters

References	Years	Nanofluid/collector type	Explanations
[110]	2011	Al_2O_3, ZnO, MgO-H_2O Tubular Solar Collector	It has been determined that the use of nanofluid has a positive effect on system performance.
[111]	2011	Aluminium-Copper-Graphite-Silver-Therminol VP-1 Solar tower collector	With a nanofluid receiver, a 5-10% efficiency increase was possible.
[112]	2014	Cu, Al_2O_3, TiO_2-H_2O Curved bottom wall triangular solar collector	System performance has shown better results when using Cu-water nanofluid.
[113]	2014	CuO-H_2O Cylindrical solar collector with receiver helical tube	Productivity increased by approximately 25.6%.
[114]	2014	CNT-H_2O Quarter Circular Solar Collector	Inclination angle and volume fraction were effective in increasing the heat transfer of the system.
[115]	2015	MWCNT-H_2O Evacuated U-tube solar collector	With the use of nanofluid in the system, an increase in productivity was achieved.
[116]	2015	Al_2O_3-distilled H_2O Modified flat panel solar collector	1.Nanofluid improved productivity by up to 11%. 2. Nanofluid was more powerful than high temperature water.
[117]	2018	Al_2O_3, ZnO-H_2O PV / T solar collector	The average increase in overall efficiency for the mass fraction of 0.05% by weight of the nanoparticles was 4.1% and the total available energy (exergy) efficiency was 4.6%.

Table 2.7. Literature Review of Nanofluid Applications in Solar Collectors

Refecence	Number of articles	Years	Applications	Explanations
Sruthi [118]	5	2012	Solar cells Solar water heater systems	It has been determined that making use of nanotechnology has many advantages in such systems.
Khanafer ve Vafai [119]	104	2013	Photovoltaic systems Solar desalination	It has been determined that absorption of radiation should be absorbed at minimum wavelength in order to obtain optimum performance in solar collector systems.
Javadi ve ark. [120]	134	2013	DASC	Further research should focus on two-phase analysis of nanofluids.
Al-Shamani ve ark. [121]	100	2014	PV / T collector systems	It has been determined that nanofluids can be used as coolants in photovoltaic systems.
Chaudhari ve Walke [122]	20	2014	Solar collector Solar cell Thermal energy storage	The temperature difference decreased with the use of nanofluid.
Kasaeian ve ark. [123]	127	2015	Solar collector Solar thermoelectric devices Solar cells	It has been determined that particle production and cost should be reduced in order to improve the research on nanaofluid.
Verma ve Tiwari [124]	172	2015	PV / T collector systems	The efficiency of photovoltaic systems could be increased by using nanofluid.
Hussein ve ark. [125]	48	2016	DASC	The use of nanofluid in DASC systems increased productivity.

absorption capacity parameter of the absorbent plates needs further investigation and also the optical properties of the nanofluidics should be detailed. Hussein et al. [125] evaluated the effects of using nanotechnology in their investigations on the productivity of DASCs. For this purpose, they made comparisons by examining experimental, numerical and theoretical studies. As a result, they concluded that using nanofluid in these systems significantly increases system efficiency.

3. DISCUSSION AND SUGGESTIONS

In this study, which explains the importance of solar collectors and nanofluids, alternative solutions have been tried to be presented against fossil fuels. Due to the availability of a wide variety of solar collectors, the studies done by the researchers have been summarized and the importance of the subject has been tried to be conveyed and attention has been paid to make this study a guide for future researches. Although FPSCs are the most widely used among solar collectors, then ETSCs and heat pipe solar collectors were produced and focused on the solution of existing problems. By using various nanofluids, as working fluid, the performance and efficiency of the collectors were increased and positive results were obtained.

SYMBOLS

wt : Weight

SiO_2 : Silisium dioksit

TiO_2 : Titanium dioxide

WO_3 : Tungsten trioxide

CeO_2: Cerium oxide

ABBREVIATIONS

ANOVA : Analysis of Variance
ASHRAE : American Society of Heating, Refrigerating and Air-Conditioning Engineers
CFD : Computational Fluid Dynamics
CNT : Carbon Nano Tube
DARS : Direct Absorption Refrigeration System
DASC : Direct Absorption Solar Collectors
EG : Ethylene Glycol
ETSC : Evacuated Tube Solar Collector
FPSC : Flat Plate Solar Collector
HPSC : Heat Pipe Solar Collector
MWCNT : Mono Wall Carbon Nano Tube
OHP : Oscillation Heat Pipe
PTSC : Parabolic Trough Solar Collector
PV : Photovoltaic
SDS : Sodium Dodecyl Sulfate
SEM : Scanning Electron Microscope
XRD : X Ray Diffraction

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods they use in their studies do not require ethics committee permission and / or legal-specific permission.

AUTHORS' CONTRIBUTIONS

Sinan ÜNVAR: Bought the materials. Prepared the experimental designs. Performed the experiments and analyse the results. Wrote the manuscript.

Tayfun MENLİK: Performed the analyse the results. Wrote the manuscript. Spell check done.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Owusu P.A., Asumadu-Sarkodie S., "A review of renewable energy sources, sustainability issues and climate change mitigation", ***Cogent Engineering***, 3:1, 1167990, DOI: 10.1080/23311916.2016.1167990, (2016).

[2] Lee N. A., Gilligan G. E., Rochford J., "Solar Energy Conversion", ***Green Chem. An Incl. Approach***, 60 : 3, 981-918, (2018).

[3] Faizal M., Saidur R., Mekhilef S., Alim M., "Energy, economic and environmental analysis of metal oxides nanofluid for flat plate solar collector", ***Clean Technologies and Environm. Policy***, 17 :6, 1457-1473, (2013).

[4] Allouhi A., Kousksou T., Jamil A., Bruel P., Mourad Y., Zeraouli Y., "Solar driven cooling systems: An updated review", ***Renewable and Sustainable Energy Reviews, Elsevier***, 44 (C), 159-181, (2015).

[5] Islam Md. T., Huda N., Abdullah A. B., Saidur R., "A comprehensive review of state-of- the art concentrating solar power (CSP) technologies", ***Renewable and Sustainable Energy Reviews***, 91 (C), Elsevier, 987-1018, (2018).

[6] Thirugnanasambandam M, Iniyan S, Goic R. "A review of solar thermal technologies", ***Renew. Sustain. Energy Rev.***, 14:312–22, (2010).

[7] Bejan A., Kraus, A. D., "Heat Transfer Handbook", ***John Wiley&Sons Inc***., (2013).

[8] Hussein A. K., Li D., Kolsi L., Kata S., Sahoo B., "A Review of Nano Fluid Role to Improve the Performance of the Heat Pipe Solar Collectors", ***Energy Procedia***, 109: 417-424, (2017).

[9] Choi S., "Enhancing thermal conductivity of fluids with nanoparticles-Developments and Applications of Non-Newtonian Flows", ***ASME, FED, 231/MD-66***, 99-105, (1995).

[10] Li Y., Zhou J., ang S., Schneider E., Xi S., "A review on development of nanofluid preparation and characterization", ***Powder Technology***, 196: 89-101, (2009).

[11] Kumar V. S.,Kumar T.A.,Singh C. D., "Experimental evaluation of flat plate solar colector using nanofluids", ***Energy Conversion and Management***, 103-115, (2017).

[12] Selimli, S., Recebli, Z. Impact of electrical and magnetic field on cooling process of liquid metal duct magnetohydrodynamic flow. Thermal Science, 22, 263-271, (2018).

[13] Saidur R., Leong K. Y., Mohammad H. A., "A review on applications and challenges of nanofluids", ***Renewable and Sustainable Energy Reviews***, 15: 1646:1668, (2011).

[14] Khairul M. A.,Shah K., Doroodchi E., Alizian R., Moghtaderi B., "Effects of surfactant on stability and thermo-physical properties of metal oxide nanofluids", ***International Journal of Heat and Mass Transfer***, 98: 778-787, (2016).

[15] S. Selimli, Z. Recebli, E. Arcaklioglu, "Combined effects of magnetic and electrical field on the hydrodynamic and thermophysical parameters of magnetoviscous fluid flow**"** ***Int J Heat Mass Tran***, 86 , 426-432, (2015).

[16] Chougule S.S., Nirgude V.V., Gharge P.D., Modak M.,Sahu S. K., "Heat Transfer Enhancements of Low Volume Concentration CNT/Water Nanofluid and Wire Coil Inserts in a Circular Tube" ***Energy Procedia***, Volume 90, December 2016, 552-558, (2016).

[17] Recebli, Z., Selimli, S., and Ozkaymak, M. , "Theoretical Analyses of Immiscible MHD Pipe Flow," ***International Journal of Hydrogen Energy***, 40 (44), 15365–15373, (2015).

[18] Wahab A., Hassan A., Muhammad A. Q., Ali H. M., Babar H., Sajid M. U., "Solar energy systems-Potential of nanofluids", ***Journal of Molecular Liquids***, 289:111049, (2019).

[19] Rassamakin B., Khairnasov S., Zaripov V., Rassamakin A., Alforova O., "Aluminium heat pipes applied in solar collectors", ***Solar Energy***, 94: 145-154, (2013).

[20] Fathabadi H., "Novel low-cost parabolic trough solar collector with TPCT heat pipe and solar tracker: Performance and comparing with commercial flat-plate and evacuated tube solar collectors", ***Solar Energy***, 195: 210-222, (2020).

[21] Window B., Hardin G.L., "Progress in the materials science of all glass evacuated collectors", ***Solar Energy***, 32: 609-623, (1984).

[22] Brunold S., Frey U., "A comparison of 3 different collectors for process heat applications", ***Solar energie Pruf and Forschungsstelle Ingenieurschule***, ITR, 15 p., (2007).

[23] Ercoşkun G. T., Keskin A., Gürü M., Altıparmak D., " Investigation of Design, Production and Performance of Double Trough Parabolic Trough Type Solar Collector", ***Gazi University Journal of Engineering and Architecture Faculty.***, Volume 28, No: 4, 855-863, (2013).

[24] Fathabadi H., "Novel solar collector: Evaluating the impact of nanoparticles added to the collector's working fluid, heat transfer fluid temperature and flow rate", ***Renewable Energy***, 148: 1165-1173, (2020).

[25] Azad E., "Theoretical and experimental investigation of heat pipe solar collector", ***Exp. Therm. Fluid Sci.***, 32 : 8, 1666-1672, (2008).

[26] Bejan A., Kraus, A. D., "Heat Transfer Handbook", ***John Wiley&Sons Inc***., (2013).

[27] Gernert N. J., "Heat Pipe Sink Tech Improves 6 Kw Cooling, Engineering and Technology Thermacore, ***Inc. Lancaster PA***, (2009).

[28] Sukhatme S., Nayak K. "Solar energy principles of thermal collection and storage", ***Tata McGraw Hill Education Private Limited***; (2009).

[29] Kalkan G., "Performance of latent heat stored nano fluid solar water heater" ***Fırat Üniversity, Institute of science, Energy Systems Engineering Depeartment, Master's Thesis,*** (2019).

[30] Balcıoğlu B., "Experimental investigation on the effect of the heat pipe performance using alumina nanofluid" ***Gazi Üniversity, Institute of science, Energy Systems Engineering Depeartment, Master's Thesis***, (2014).

[31] Yousefi T., Veysi F., Shojaeizadeh E., Zinadini S., "An experimental investigation on the effect of Al_2O_3–H_2O nanofluid on the efficiency of flat-plate solar collectors", ***Renewable Energy***, 39:293–8, (2012).

[32] Yousefi T., Veysi F., Shojaeizadeh E., Zinadini S., "An experimental investigation on the effect of MWCNT–H2O nanofluid on the efficiency of flat-plate solar collectors", ***Exp. Thermal Fluid Sci.***, 39:207–12, (2012).

[33] Yousefi T., Shojaeizadeh E., Veysi F., Zinadini S., "An experimental investigation on the effect of pH variation of MWCNT–H_2O nanofluid on the efficiency of a flat-plate solar collector", ***Solar Energy***, 86:771–9, (2012).

[34] Tora E., Moustafa T., "Numerical simulation of an Al_2O_3–H_2O nanofluid as a heat transfer agent for a flat-plate solar collector", ***Int J. Sci. Eng. Res.***, 4:762–73, (2013).

[35] Jamal-Abad M., Zamzamian A., Imani E., Mansouri M. "Experimental study of the performance of a flat-plate collector using Cu–water nanofluid", ***J. Ther-mophys Heat Transf.***, 27:756–60, (2013).

[36] Faizal M., Saidur R., Mekhilef, S. "Potential of size reduction of flat-plate solar Collectors when applying MWCNT nanofluid", ***In: Proceedings of the4th International Conferenceon Energy and Environment (ICEE2013)***, 1–4, (2013).

[37] Gangadevi R., Senthilraja S., Imam S. "Efficiency analysis of flat plate solar collector using Al2O3–water nanofluid", ***Methods Enrich Power Energy Dev (MEPED'13)***, 1-4, (2013).

[38] Chaji H., Ajabshirchi Y., Esmaeilzadeh E., Heris S., Hedayatizadeh M., Kahani M., "Experimental study on thermal efficiency of flat plate solar collector using TiO_2/water nanofluid", ***Modern Appl Sci.***, 7:60–9, (2013).

[39] Tiwari A., Ghosh P., Sarka rJ. "Solar water heating using nanofluids – a comprehensive overview and environmental impact analysis", ***Int. J. Emerg. Technol. Adv. Eng.***, 3:221–4, (2013).

[40] Faizal M., Saidur R., Mekhilef S., Alim M., "Energy, economic and environmental Analysis of metal oxides nanofluid for flat-plate solar collector", ***Energy Convers. Manag.***, 76:162–8, (2013).

[41] Said Z., Sajid M., Alim M., Saidur R., Rahim N., "Experimental investigation of the Thermophysical properties of Al_2O_3-nanofluid and its effect on a flat plate solar collector", ***Int. Commun. Heat Mass Transf.***, 48:99–107, (2013).

[42] Colangelo G., Favale E., DeRisi A., Laforgia D., "A new solution for reduced sedimentation flat panel solar thermal collector using nanofluids", ***Appl. Energy***, 111:80–93, (2013).

[43] Nasrin R., Alim M. "Finite element simulation of forced convection in a flat plate solar collector: influence of nanofluid with double nanoparticles", ***J. Appl. Fluid Mech.***, 7:543–56, (2014).

[44] Ekramian E., Etemad S., Haghshenasfard M. "Numerical investigations of heat transfer performance of nanofluids in a flat plate solar collector", ***Int. J. Theor. Appl. Nanotechnol.***, 2:30–9, (2014).

[45] Moghadam A., Farzane-Gord M., Sajadi M., Hoseyn-Zadeh M. "Effects of CuO/Water nanofluid on the efficiency of a flat-plate solar collector", ***Exp. Thermal Fluid Sci.***, 58:9–14, (2014).

[46] Mahian O., Kianifar A., Heris S., Wongwises S., "First and second laws analysis of a minichannel-based solar collector using boehmite aluminana nofluids: effects of nanoparticle shape and tube materials", ***Int. J. Heat Mass Transf.***, 78:1166–76, (2014).

[47] Roy S., Asirvatham L., Kunhappan D., Cephas E., Wongwises S. "Heat transfer performance of silver/water nanofluid in a solar flat –plate collector", ***J. Thermal Eng.***, 1:104–12, (2015)

[48] Said Z., Sabiha M., Saidur R., Hepbasli A., Rahim N., Mekhilef S., "Performance enhancement of a flat plate solar collector using titanium dioxide nanofluid and polyethylene glycol dispersant", ***J. Clean Prod.***, 92:343–53, (2015).

[49] Shareef A. S., Abbod M. H., Kadhim S. Q., "Experimental investigation on a flat plate solar collector using Al2O3 nanofluid as a heat transfer agent", ***Int. Journal of Energy and environment***, 6:4, 317-330, (2015).

[50] Mahian O., Kianifar A., Sahin A. Z., Wongwises S., "Heat Transfer, Pressure Drop, and Entropy Generation in a Solar Collector Using SiO_2/Water Nanofluids: Effects of Nanoparticle Size and pH", ***J. Heat Transfer.***, 137 (6): 061011, (2015).

[51] Noghrehabadi A., Hajidavalloo E., Moravej M., "Experimental investigation of efficiency of square flat-plate solar collector using SiO_2-water nanofluid", ***Case Studies in Thermal Engineering***, 8: 378-386 (2016).

[52] Kumar V. S., Kumar T. A., Singh C. D., "Experimental evaluation of flat plate solar colector using nanofluids", ***Energy Conversion and Management***, 103-115, (2017).

[53] Sharafeldin M. A., Grof G., " Experimental investigation of flat plate solar collector using CeO_2-water nanofluid", ***Energy Conversion and Management***, (2017).

[54] Kiliç F., Menlik T., Sözen A., "Effect of titanium dioxide/water nanofluid use on thermal performance of the falat plate solar collector", ***Solar Energy***, 164: 101-108, (2018).

[55] Genc A. M., Ezan M. A., Turgut A., "Thermal performance of a nanofluid-based flat plate solar collector: A transient numerical study", ***Applied Thermal Engineering***, 130: 395-407, (2018).

[56] Sundar, S., Manoj, K., Singh, V. Punnaiah, Sousa, Antonio C.M., "Experimental investigation of Al_2O_3/water nanofluids on the effectiveness of solar flat-plate collectors with and without twisted tape inserts", ***Renewable Energy***, 119, 820–833, (2018).

[57] Arıkan E., Abbasoğlu S., Gazi M., "Experimental Performance Analysis of Flat Plate Solar Collectors Using Different Nanofluids", ***Sustainability***, 10 (6): 1794, (2018).

[58] Rajput N. S., Shukla D. D., Rajput D., Sharm S. K., "Performance Analysis of Flat Plate Solar Collector using Al_2O_3/Distilled Water Nanofluid: An Experimental Investigation", ***Materialstoday Proceedings***, 10: 52-59, (2019).

[59] Mondragón R., Sánchez D., Cabello R., Llopis R., Juliá J. E. "Flat plate solar collector performance using alumina nanofluids: Experimental characterization and efficiency tests", ***PLOS ONE***, 14 (2), (2019).

[60] Sharma S., Tiwari S., Tiwari A. K., Nandan G., Prakash R., "Thermal Performance Enhancement of Flat-Plate Solar Collector Using CeO_2–Water Nanofluid", ***Advances in Solar Power Generation and Energy Harvesting***, 109-118, (2020).

[61] Ahmadlouydarab M., Ebadolahzadeh M., Ali H., "Effects of utilizing nanofluid as working fluid in a lab-scale designed FPSC to improve thermal absorption and efficiency", ***Physica A: Statistical Mechanics and Its Applications***, 540, (2020).

[62] Saidur R., Meng T., Said Z., Hasanuzzaman M., Kamyar A., "Evaluation of the effect of nanofluid-based absorbers on direct solar collector", ***Int. J. Heat Mass Transf.***, 55:5899–907, (2012).

[63] Verma V., Kundan L., "Thermal performance evaluation of a direct absorption flat plate solar collector (DASC) using Al_2O_3–H_2O based nanofluids", ***IOSRJ Mech Civil Eng.***, 6:29–35, (2013).

[64] Hector A., Singh H., "Development of a nano-heat transfer fluid carrying direct absorbing receiver for concentrating solar collectors", ***Int. J. Low-Carbon Technol.***, 1-6, (2013).

[65] Luo Z., Wang C., Wei W., Xiao G., Ni M., "Performance improvement of a nanofluid solar collector based on direct absorption collection (DAC) concepts", ***Int. J. Heat Mass Transf.***, 75:262–71, (2014).

[66] Parvin S., Nasrin R., Alim M., "Heat transfer and entropy generation through nanofluid filled direct absorption solar collector", ***Int. J. Heat Mass Transf.***, 71:386–95, (2014).

[67] Karami M., Akhavan Bahabadi M., Delfani S., Ghozatloo A., "A new application of carbon nanotubes nanofluid as working fluid of low-temperature direct absorption solar collector", ***Solar Energy Mater Solar Cells***, 121:114–8, (2014).

[68] Moradi A., Sani E., Simonetti M., Francini F., Chiavazzo E., Asinari P., "Carbon- nanohorn based nanofluids for a direct absorption solar collector for civil application", ***J. Nanosci. Nanotechnol.***, 15:3488–95, (2015).

[69] Gupta H., Agrawal G., Mathur J., "An experimental investigation of a low temperature Al2O3–H2O nanofluid based direct absorption solar collector", ***Solar Energy***, 118:390–6, (2015).

[70] Joseph A., Sreekumar S., Sujith Kumar C. S., Thomas S., "Optimisation of thermo-optical properties of SiO_2/Ag-CuO nanofluid for direct absorption solar collectors", **Journal of Molecular Liquids**, 296:111986, (2019).

[71] Khullar V., Tyagi H., Phelan P., Otanicar T., Singh H., Taylor R., "Solar energy harvesting using nanofluids-based concentrating solar collector", ***ASME J. Nanotechnol. Eng. Med.***, 3:031003, (2012).

[72] De Risi A., Milanese M., Laforgia D. "Modelling and optimization of transparent parabolic trough collector based on gas-phase nanofluids", ***Renewable Energy***, 58:134–9, (2013).

[73] Ghasemi S., Ahangar G "Numerical analysis of performance of solar parabolic trough collector with Cu-water nanofluid", ***Int. J. NanoDimens***, 5:233–40, (2014).

[74] Sokhansefat T., Kasaeian A., Kowsary F. "Heat transfer enhancement in parabolic trough collector tube using Al_2O_3/synthetic oil nanofluid", ***Renewable Sustain Energy Rev.,*** 33:636–44, (2014).

[75] Mwesigye A., Huan Z., Meyer J., "Thermodynamic optimisation of the performance of a parabolic trough receiver using synthetic oil–Al_2O_3 nanofluid", ***Applied Energy***, 156:398–412, (2015).

[76] Kasaeian A., Daviran S., Azarian R., Rashidi A., "Performance evaluation and nanofluid using capability study of a solar parabolic trough collector", ***Energy Convers Manag.***, 89:368–75, (2015).

[77] Khosravi A., Malekan M., Assad M. E. H., "Numerical analysis of magnetic field effects on the heat transfer enhancement in ferrofluids for a parabolic trough solar collector", ***Renewable Energy***, (2018).

[78] Nasrin R., Alim M., "Performance of nanofluids on heat transfer in a wavy solar collector", ***Int. J. Engineering Sci. Technol.***, 5:58–77, (2013).

[79] Alaeian M., Sedaghat A., Bahabadi M., "Heat transfer enhancement of MWCNT/ HT-Oil nanofluid in U-bend wavy tubes for use in solar collectors", ***J. energy Power Sources***, 1:134–40, (2014).

[80] Sözen A., Menlik T., Gürü M., Irmak A. F., Kılıç F. & Aktaş M., "Utilization of Fly Ash Nanofluids in Two-phase Closed Thermosyphon for Enhancing Heat Transfer", ***Experimental Heat Transfer***, 29:3, 337-354, DOI: 10.1080/08916152.2014.976724 To link to, (2016).

[81] Sözen A., Menlik T., Gürü M., K., Kılıç F., Aktaş M., M. Tarık Çakıra, "A comparative investigation on the effect of fly-ash and alumina nanofluids on the thermal performance of two-phase closed thermo-syphon heat pipes", ***Applied Thermal Engineering***, Volume 96, 5 March 2016, Pages 330-337, (2014).

[82] Lu L., Liu Z., Xiao H., "Thermal performance of an open thermosyphon using nanofluids for high-temperature evacuated tubular solar collectors Part1: indoor experiment", ***Solar Energy***, 85:379–87., (2011).

[83] Çaylıoğlu E., "The Use of Different Types of Heat Pipes in Solar Collectors and Investigation of Their Thermal Efficiency", ***Ege University Institute of Science, Master's Thesis***, 93 p., (2011).

[84] Moorthy M., Chui L., Sharma K., Anuar S., "Performance evaluation of evacuated tube solar collector using water-based titaniumoxide (TiO_2) nanofluid", ***J. Mech Eng. Sci.***, 3:301–10, (2012).

[85] Chougule S., Sahu S., Pise A., "Thermal performance of two phase thermosyphon on flat plate solar collectors using nanofluid", ***J. Solar Energy Eng.***, 136:1–5, (2013).

[86] Liu Z., Hu R., Lu L., Zhao F., Xiao H., "Thermal performance of an open thermosyphon using nanofluid for evacuated tubular high temperature air solar collector", ***Energy Convers Manag.***, 73:135–43, (2013).

[87] Ersöz M. A., Yıldız A., " Determination of Optimum Pipe Diameter in Evacuated Tube Solar Collectors ", ***Plumbing Engineering***, sayı: 133, (2013).

[88] Saravanan M., Karunakaran N., "Experimental analysis of heat pipe with V-trough solar collector", ***Int. J. Res. Advent. Technol.***, 13–7, (2014).

[89] Aruna V., Channakaiah D., Murali G., "A study on a flat plate type of solar water heater with an thermosyphon

using different working fluid", ***Singaporean J. Sci. Res.***, 6:132–5, (2014).

[90] Menlik T., Sözen A., Gürü M., Öztaş S., " Heat transfer enhancement using MgO/water nanofluid in heat pipe", ***Journal of the Energy Institute***, 88: 247-257, (2015).

[91] Çiftçi E., Sözen A., Karaman E., "Experimental Investigation of the Effect of Using Nanofluid Containing TiO_2 on Heat Pipe Performance", ***Politeknik Magazine***, 19 (3), 367-376, (2016).

[92] Pise G. A., Salve S. S., Pise A. T., Pise A. A., "Investigation of Solar Heat Pipe Collector Using Nanofluid and Surfactant", ***Energy Procedia***, 90: 481-491, (2016).

[93] Sözen A., Menlik T., Gürü M., Boran K., Kılıç F., Aktaş M., Çakır M. T., " A comparative investigation on the effect of fly-ash and alumina nanofluids on the thermal performance of two-phase closed thermo-syphon heat pipes", ***Applied Thermal Engineering***, 96: 330-337, (2016).

[94] Eidan A. A., AlSahlani A., Ahmed A. Q., Al-fahham M., Jalil J. M., " Improving the performance of heat pipe-evacuated tube solar collector experimentally by using Al_2O_3 and CuO/acetone nanofluids", ***Solar Energy***, 173:780-788, (2018).

[95] Ozsoy A., Çorumlu V., " Thermal performance of a thermosyphon heat pipe evacuated tube solar collector using silver-water nanofluid for commercial applications", ***Renewable Energy***, 122: 4, (2018).

[96] Zhao S., Xu G., Wang N., Zhang X., " Experimental Study on the Thermal Start-Up Performance of the Graphene/Water Nanofluid-Enhanced Solar Gravity Heat Pipe", ***Nanomaterials***, 8: 2, (2018).

[97] Jin H., Lin G., Zeiny A., Bai L., Cai J., Wen D., " Experimental study of transparent oscillating heat pipes filled with solar absorptive nanofluids", ***International Journal of Heat and Mass Transfer***, 139: 789-801, (2019).

[98] Kaya M., Gürel A. E., Ağbulut Ü., Ceylan İ., Çelik S., Ergün A., Acar B., " Performance analysis of using CuO-Methanol nanofluid in a hybrid system with concentrated air collector and vacuum tube heat pipe", ***Energy Conversion and Management***, 199:111936, (2019).

[99] Dehaj M. S., Mohiabadi M. Z., " Experimental study of water-based CuO nanofluid flow in heat pipe solar collector", ***Journal of Thermal Analysis and Calorimetry***, 137: 2061-2072, (2019).

[100] Su U. Ö., "Improvement of Performance with Nano Solution in Heat Pipe Solar Collectors", ***Gazi University Institute of Science and Technology, Department of Energy Systems Engineering, Ph.D. Thesis***, 96, (2019).

[101] Mahendran M., Lee G. C., Sharma K. V., Shahrani A., Bakar R. A., "Performance Of Evacuated Tube Solar Collector Using Water-Based Titanium Oxide Nanofluid", ***Journal of Mechanical Engineering and Sciences (JMES)***, 3: 301-310, (2012).

[102] Ghaderian J., Che Sidik N. A., "An experimental investigation on the effect of Al_2O_3/distilled water nanofluid on the energy efficiency of evacuated tube solar collector", ***International Journal of Heat and Mass Transfer***, 108: 972-987, (2017).

[103] Iranmanesh S., Chyuan Ong H., Bee Chin Ang, Sadeghinezhad E., Esmaeilzadeh A., Mehrali M., "Thermal performance enhancement of an evacuated tube solar collector using graphene nanoplatelets nanofluid", ***Journal of Cleaner Production***, 162: 121-129, (2017).

[104] Yang Gana Y., Chyuan Onga H., Chuan Ling T., Zulkiflia N.W.M., Chin-Tsan Wang, Yang Y., "Thermal conductivity optimization and entropy generation analysis of titanium dioxide nanofluid in evacuated tube solar collector", ***Applied Thermal Engineering***, 145: 155-164, (2018).

[105] Sharafeldin M. A., Gróf G., "Experimental investigation of flat plate solar collector using CeO2-water nanofluid", ***Energy Conversion and Management***, 155: 32-41, (2018).

[106] Mahbubul I. M., Mohammad Mumtaz A. K., Nasiru I. I., Ali H. M., Fahad A., Saidur R., "Carbon nanotube nanofluid in enhancing the efficiency of evacuated tube solar collector", ***Renewable Energy***, 121: 36-44, (2018).

[107] Mercan M., Yurddaş A.., "Numerical analysis of evacuated tube solar collectors using nanofluids", ***Solar Energy***, 191:167-179, (2019).

[108] Sharafeldin M. A., Grof G., " Efficiency of evacuated tube solar collector using WO3/Water nanofluid", ***Renewable Energy***, 134: 453-460 (2019).

[109] Sadeghi G., Najafzadeh M., Ameri M., "Thermal characteristics of evacuated tube solar collectors with coil inside: An experimental study and evolutionary algorithms", ***Renewable Energy***, 151: 575-588, (2020).

[110] Lie Y., Xie H., Yu W. J, "Investigation on heat transfer performances of nanofluids in solar collector", ***Mater. Sci. Forum.***, 694:33–6, (2011).

[111] Taylor R., Phelan P., Otanicar T., Walke rC., Nguyen M., Trimble S., "Applicability of nanofluids in high flux solar collectors", ***J. Renew. Sustain. Energy***, 3:1–15, (2011).

[112] Rahman M., Mojumder S., Saha S., Mekhilef S., Saidur R., "Augmentation of natural convection heat transfer in triangular shape solar collector by utilizing water based nanofluids having a corrugated bottom wall", ***Int. Commun Heat Mass Transf.***, 50:117–127, (2014).

[113] Goudarzi K., Shojaeizadeh E., Nejati F., "An experimental investigation on the simultaneous effect of CuO–H2O nanofluid and receiver helical pipe on the thermal efficiency of a cylindrical solar collector", ***Appl. Thermal Eng.***, 73:1236–43, (2014).

[114] Rahman M., Mojumder S., Saha S., Mekhilef S., Saidur R., "Effect of solid volume fraction and tilt angle in a quarter circular solar thermal collectors filled with CNT-water nanofluid", ***Int. Commun Heat Mass Transf.***, 57:79–90, (2014).

[115] Tong Y., Kim J., Cho H., "Effects of thermal performance of enclosed-type Evacuated U-tube solar collector with multi-walled carbon nanotube/water nanofluid", ***Renewable Energy***, 83:463–73, (2015).

[116] Colangelo G., Favale E., Miglietta P., DeRisi A., Milanese M., Laforgia D., "Experimental test of an innovative high concentration nanofluid solar collector", ***Applied Energy***, 154:874–81, (2015).

[117] Younis A., Elsarrag E., Alhorr Y. M., Onsa M. H., "The Influence of Al_2O_3-ZnO-H_2O Nanofluid on the Thermodynamic Performance of Photovoltaic-Thermal Hybrid Solar Collector System", ***Innov. Ener. Res.***, 7(1): 187, (2018).

[118] Sruthi B. "Nanotechnology in solar water heater", ***Coimbatore: National Conference on Developing Scenario in Applied Sciences and Communicative English, Kumaraguru College of Technology***, 27–9, (2012).

[119] Khanafer K., Vafai K., "Applications of nanomaterials in solar energy and desalination sectors", ***Adv. Heat Transf.***, 45:303–29, (2013)

[120] Javadi F., Saidur R., Kamalisarvestani M., "Investigating performance improvement of solar collectors by using nanofluids", ***Renew. Sustain. Energy Rev.***, 28:232–45, (2013).

[121] Al-Shamani A., Yazdi M., Alghoul M., Abed A., Ruslan M., "Nanofluids for improved efficiency in cooling solar collectors-a review", ***Renew. Sustain Energy Rev.***, 38:348–67, (2014).

[122] Chaudhari K., Walke P, "Applications of nanofluid in solar energy-a review", ***Int. J. Eng. Res. Technol.***, 3:460–3, (2014).

[123] Kasaeian A., Eshghi A., Sameti M., "A review on the applications of nanofluids in solar energy systems, ***Renew. Sustain. Energy Rev.***, 43:584–98, (2015).

[124] Verma S., Tiwari A., "Progress of nanofluid application in solar collectors: a review", ***Energy Convers Manag.***, 100:324–46., (2015).

[125] Hussein A., Walunj A., Kolsi L., "Applications of nanotechnology to enhance the performance of the direct absorption solar collectors., ***J. Thermal Eng.***, 2:529–40, (2016).