RESEARCH ARTICLE | DECEMBER 15 2023

Characterization of a flat plate solar water heating system using different nano-fluids FREE

Falah Zarda Mohammed; Adnan M. Hussein; Suad H. Danook; Barhm Mohamad

AIP Conf. Proc. 2901, 100018 (2023)
https://doi.org/10.1063/5.0178901

Characterization of a Flat Plate Solar Water Heating System Using Different Nano-Fluids

Falah Zarda Mohammed [1, a], Adnan M. Hussein [1, b], Suad H. Danook [1, c], Barhm Mohamad [2, d]

[1] *Kirkuk Technical Engineering College, Northern Technical University, Kirkuk, Iraq*
[2] *Department of Petroleum Technology, Koya Technical Institute, Erbil Polytechnic University, 44001 Erbil, Iraq*

[a] *Corresponding Author: falahzardaoa@ntu.edu.iq*
[b] *dradnan_hwj@ntu.edu.iq*
[c] *suaddanook@ntu.edu.iq*
[d] *barhm.mohamad@epu.edu.iq*

Abstract. Flat-plate solar collectors (FPSCs) are the most effective and environmentally friendly heating systems available. They are frequently used to convert solar radiation into usable heat for a variety of thermal applications, because of their superior thermo-physical features, the use of Nano-fluids in FPSCs is a useful technique to improve FPSC performance. Nano-fluids are advanced colloidal suspensions containing Nano-sized particles that have been researched over the last two decades and identified a fluid composed of strong nanoparticles with a diameter of smaller than (100 nm). These micro-particles aid in improving the thermal conductivity and convective heat transfer of liquids when mixed with the base fluid. The current study provides an in-depth review of the scientific advances in the field of nano-fluids on flat-plate solar collectors. Previous research on the usage of nano-fluids in FPSCs shows that nano-fluids can be used successfully to improve the efficiency of flat-plate collectors. Though several nano-fluids have been reviewed as solar collector operating fluids. Nano-fluids have greater pressure drops than liquids, and their pressure drops and hence pumping power rise as the volume flow rate increases. Additionally, the article discusses the concept of nano-fluids, the different forms of nanoparticles, the methods for preparing Nano-fluids, and their thermos-physical properties. The article concludes with a few observations and suggestions on the usage of Nano-fluids in flat-plate solar collectors. This article summarizes the numerous research studies conducted in this region, which may prove useful for future experimental studies.

Keywords: Flat-plate solar collectors; Nano-fluid; Pressure drop; Friction factor.

INTRODUCTION

Solar energy is the primary option for reducing the use of fossil fuels and the critical impact on the environment in several technical and manufacturing areas of developing countries. In many developed countries' manufacturing and industries, solar energy is a significant option for reducing the use of fossil fuels and their negative environmental effects. A solar thermal collector is an important component for collecting and converting solar energy into thermal energy. Solar water heating (SWH) is an efficient method of producing hot water/steam for heating processes that use thermal solar energy transmitted from the sun to water or working fluids. The most common types of solar water heating systems are evacuated tube collectors, flat plates, and unglazed plastic collectors. Among these various types, flat plate solar collectors (FPSCs) are a common piece of equipment in solar systems used to generate hot water for everyday use. FPSCs are advantageous systems because of their low maintenance costs and lack of sun monitoring, but they are also difficult to grow widely because of their low thermal performance.

Solar water heating can be active or passive, with active systems being the most common. Pumps are used in active structures to move liquid within the collector and accommodation vessel, whereas passive operations rely on

Third International Conference on Advances in Physical Sciences and Materials: ICAPSM 2022
AIP Conf. Proc. 2901, 100018-1–100018-10; https://doi.org/10.1063/5.0178901
Published by AIP Publishing. 978-0-7354-4765-3/$30.00

gravity and the normal flow of heated water [1]. Several approaches have been used to improve the FPSC's performance. However, using Nano-fluid instead of conventional heat transfer liquid to improve the rate of heat transfer of the collector's absorber plate is a modern and simple approach to improving the performance of current and established FPSCs [2–4]. Nano-fluids are referred to as next-generation working fluids because of their superior thermo-physical properties compared to base fluids [5]. Choi and Eastman [6] coined the term "Nano-fluid" in 1995, describing it as a colloidal mixture of nanoparticles and base fluid (with a dimension less than 100nm).

Nanofluids made from these suspended liquids were discovered to improve the thermal conductivity (k) and convective thermal transfer efficiency of the basic liquids. They are typically traditional heat transfer liquids. Many experiments have been conducted to improve thermal conductivity using Nano-fluids. The inclusion Yang et al. [7] presented in laminar flow convective heat transfer coefficient developments in comparison to the job fluid that the use of nanoparticles significantly increases the absorption of incident radiation by more than nine-fold compared to plain water. The use of nano-fluids includes ventilation and air conditioning, electrical cooling, heat exchangers, heavy oil regeneration, heat pipes, medication distribution systems, diesel-electric generators, and heat pumps. Nano lubricants, heating, and pollution reduction [8–12]. Theoretically, Said et al. [13] investigated the formation of entropy, the increase in thermal transference, and the pressure drop in flat-plate solar collectors using nano-fluid absorbing media (SWCNTs) as single-wall carbon nanotubes (SWC).

Solar collectors have low thermal efficiency because the absorber plate has a low convective heat transfer coefficient compared to the heat transfer mechanism, resulting in high absorber plate temperatures and increased heat losses to the atmosphere [14]. Low heat loss coefficients boost net exergy flow, lowering pressure drop. Using Nano-fluids on FPSCs provides benefits such as cost-effectiveness, environmental friendliness, compactness, and lightweight, according to Pandey and Chourasia [15]. In the case of a thermal system, the three goals in designing a thermal device are typically improved heat transfer, reduced pressure drop, and maximum flow, with cost being a commonly used standard used to evaluate designs [16]. Verma et al. [17] carried out an empirical study on a variety of oxide nanoparticles to determine their efficiency and pumping power. Mahian et al. [18] investigated how the mini channel FPC on nano-fluid affected heat transfer and pressure loss.

The use of nanofluids in such laboratory settings resulted in an improvement. Furthermore, simulations for Computational Fluid Dynamics (CFD) were carried out to numerically estimate thermal performance, and this work was done to solve the necessary equation of CFD cases because the fluid flow within the collector needs to be defined precisely in this investigation. The primary property of nano-fluids is to achieve the highest possible thermal conductivity while maintaining the lowest possible nanoparticle convergence.

This paper pointed to examining the current advancements and the potential prospects of Nano-fluids in Flat plate solar collectors (FPSCs). Additionally, this analysis article discusses additional performance criteria such as effectiveness, pumping power, and the impact of nanoparticle concentration on the thermo- physical properties of Nano-fluids. The remainder of the article reads as follows: section 2 defines the preparation of Nano-fluids. The Nano-fluid thermo- physical characteristics are described in section 3. The section 4 and 5 are presented the Pressure drops, pumping power and Friction Factor, as well as FPSC respectively. Although, the conclusions, current challenges and future work are reported in section 6.

PREPARATION OF NANO-FLUIDS

The term “Nano-fluid” has been described in various forms in research, however, most experts agree that it is a combination of nanoparticles with a diameter range between 1 and 100 nm that has been effectively distributed in a base fluid. Air, ethylene glycol and oil are all instances of common base fluids. Through incorporating nanoparticles into a base fluid, thermal and physical properties such as thermal conductivity, mass diffusivity, and radiative heat transfer may be altered. Nano-fluid is a combination of a liquid (base fluid) and a nanoparticle (nanoparticle) [19-21]. To accomplish significant efficiency, Nano-fluids require a good preparation stage that warrants the stabilization and uniformity of the suspended particles inside the base fluid. Nano-fluid preparation can be carried out in 2 ways: a one-step technique and a two-step technique.

Single-step technique

In this phase, nanoparticles are dispersed and produced at the same stage. Either physically or chemically, this process can be carried out. The ultrasonic-assisted submerged arc method is applied in the physical method to synthesize nanoparticles. To fusion nanoparticles and to vaporize the decayed water, the power provided by titanium electrodes fused in the dielectric liquid is used. The Nano-fluid, which is a mixture of melting nanoparticles and deionized water, is then produced in the vacuum chamber. Only a decreasing agent in the mixture of nanoparticles and base liquid followed by a mix and heating is required to make the chemical process more dependent [22-24].

Two-step technique

Nanoparticles are formed in a separate phase before being distributed in the base fluid in the two-step system. Stabilizing chemicals, such as surfactants, should be applied to the solution to decrease the interfacial forces among the nano-particles and the base fluid's molecules. Following that, the solution can be combined mechanically utilizing a homogenizer, stirrer, or ultrasonicate. The two-step procedure is the largest frequently utilized process for preparing Nano-fluids, as it is relatively less labor-intensive and cost-efficient [25-29].

NANO-FLUID THERMO-PHYSICAL CHARACTERISTICS

The presence of nanoparticles in the base fluid has a strong impact on the thermo-physical characteristics of the Nano-fluid, such as thermal conductivity, specific heat, and density [30]. Table 2 shows the models and associations used to estimate the nano-fluid properties.

TABLE.1. Correlations for predicting the properties of Nano-fluids.

Property	correlation	Ref.
Thermal conductivity	$\mathrm{K_{nf}} = \frac{K_{bf}\left(K_{nf+}2K_{bf} - 2\varphi\left(K_{bf} - K_{np}\right)\right)}{K_{np} + 2K_{bf} + \varphi\left(K_{bf} - K_{np}\right)}$	[27]
Specific heat	$cp_{nf} = \frac{(1-\varphi)(\rho[\![cp)]\!]_{bf} + \varphi(\rho[\![cp)]\!]_{p}}{\rho_{nf}}$	[28]
Mass density	$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np}$	[29]

Viscosity

The viscosity of nano-fluids is critical for carrying thermal energy in various engineering applications such as cooling systems or heat exchangers. The viscosity of the nano-fluid increased with increasing mass concentration and a high fraction of particulate volume but decreased with increasing temperature. The fluid density and friction factor increase as the volume of nanoparticles combined increases. The effect of particle concentration on the friction factor is stronger at high densities. This increase in friction is caused by the increased viscosity of the nano-fluids, which is caused by the addition of larger solid-size nanoparticles to the base fluids [31-33]. The Prandtl number increases while the Reynolds number decreases, affecting heat transfer and pumping capacity. The Nano-fluid viscosity is determined by using the following formula [34]:

$$\mu_{nf} = \frac{\mu_{bf}}{1-34.87\left(\frac{d_{np}}{d_{bf}}\right)^{-0.3}\varphi^{1.03}} \varphi \leq 10\% \tag{1}$$

Where d_{bf} denotes the base fluid's molecular diameter:

$$d_{bf} = 0.1\left(\frac{6M}{\pi N \rho_{bf0}}\right)^{\frac{1}{3}} \tag{2}$$

Where N, M, and ρbfo denote the Avogadro quantity, the base fluid's molecular weight, and the density of the base fluid at 294K, sequentially.

Thermal performance of the solar collector

In steady-state conditions, the efficacy of FPSCs can be assessed using energy balance, which can be measured using a solar incident radiation equilibrium, which is split into usable energy gains, thermal losses, and optical losses. Wong [35] proposed the first statistical model for measuring the effectiveness of FPSCs, which was later expanded by ASHRAE to provide a standard for assessing the performance of FPSCs. The following segment evaluates the primary theoretical equations for estimating the FPSC performance. The quantity of solar radiation that the collector receives is [36-44]:

$$Q_i = I.A_c \tag{3}$$

The following equation describes the useful heat gain of a heat transfer fluid:

$$Q_u = \dot{m}C_p(T_{out} - T_{in}) \tag{4}$$

$$Q_U = F_R A_c[I\tau\alpha - U_L(T_i - T_a)] \tag{5}$$

Where:
F_R: Collector heat removal factor.
A_c: Collector area (m^2).
I: Intensity of solar radiation (W/m^2).
τ: Transmittance.
α: Absorptance.
U_L: Overall heat transfer coefficient (W/m^{2}K).
T_i: Absorber plate temperature (℃).
T_a: Ambient temperature (℃), and this equation is identified as the "Hotel-Hillier-Bliss equation".
F_R Value is specified as the ratio of real heat transfer to maximum potential heat transfer.

$$F_R = \frac{\dot{m}C_P}{A_c U_L}\left[1 - exp\left(-\frac{A_c U_L F^`}{\dot{m}C_p}\right)\right] \tag{6}$$

Where:
F': Collector efficiency factor. In the following calculation, the thermal efficiency of the solar flat plate collector can be estimated:

$$\eta_{th} = \frac{Q_u}{Q_I}(\%) \tag{7}$$

As a result, the instant efficiencies may be written in various formulations, as shown by East. (8-10):

$$\eta = \frac{Q_u}{IA_c} \tag{8}$$

$$\eta = \frac{F_R A_c[G_{SC}\tau\alpha - U_L(T_i - T_a)]}{IA_C} \tag{9}$$

$$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right) \tag{10}$$

For the collector and the volume flow rate, the value off, τ, α, and U_L are constant, so the efficiency of the collector's capacity is a linear function with three functional variables: Ambient air temperature (T_a), Fluid inlet temperature (T_i), and Solar irradiance (I).

PRESSURE DROPS, PUMPING POWER AND FRICTION FACTOR

A mechanical pump was used to drive the flat plate solar collector (FPSC), as well as it is desired to flow water within the device [45]. The pump would necessitate electrical energy, and a section of the solar cell's electrical yield would be utilized to drive the pump. Thus, the cumulative energy needed for pumping to sustain a steady flow into the collector must be known to calculate the net electric energy possible from the combination machine. The whole machine needs a pump to mix nano-fluids. Pumping capacity and the solar collector's pressure drop (p) are calculated as follows in [46]:

$$\Delta P = f\frac{\rho V^2}{2}\frac{\Delta l}{D_i} + K\frac{\rho V^2}{2} \quad (11)$$

The loss coefficient (K) due to entry and exit impact, bends, elbows, pipes, and so on the loss coefficient K is frequently chosen from tables obtained from experiments or determined with equations that are unaffected by the density and kinematic viscosity of the heat transfer fluid. The flow velocity [V] in unit of (m/sec) of the system's nano-fluids, as described by:

$$V = \frac{\dot{m}}{\rho_{nf}\pi Di^2/4} \quad (12)$$

Di: Hydraulic diameter (m)
ρ_{nf}: Density of the fluid was calculated from:

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np} \quad (13)$$

f: Friction factor

$$f = \frac{64}{R_e} \quad \text{For laminar Flow (14)}$$

$$f = \frac{0.079}{Re^{0.25}} \quad \text{For turbulent Flow (15)}$$

The Reynolds number is determined using the following equations:

$$R_e = \frac{\rho V D_i}{\mu} \quad (16)$$

Presently, the pumping power is obtained as follows:

$$\text{Pumping power} = \left(\frac{\dot{m}}{\rho}\right)\Delta P \quad (17)$$

The pressure drop is primarily determined by the friction factor and the density of the nano-fluids. The fluid density and pressure drop increase as the volume concentration of nanoparticles increases. The dynamic viscosity is normally increased by strong nanoparticles with basic fluid opposed to the base fluid. Due to the direct relation of dynamical viscosity with pressure drop, the higher viscosity value drives an increased pressure decrease. Another factor contributing to the pressure drop seems to be the migration and disorderly movement of nanoparticle. Additionally, enhancing the rate of fluid inlet volume movement consequences in an improvement in pressure drop, which grows by pumping power. The viscosity is higher in Nano-fluids than in water, so it is assumed that the friction factor would be more powerful than water. Despite this, the total head loss is affected not only by the friction factor, but also by density, which is an important parameter. The extent of overall head loss is determined by the balance of friction factor and density [47-49].

TABLE 2. Experimental investigations of friction factor and pressure drop of different Nano- fluid.

Darzi et al.	SiO_2 /water	0, 0.5, 1.0%	Increase in friction with increased concentration of particle volume	Pressure drop reduction	[53]
Maddah et al.	Al_2O_3 /water	0.2-1.0%	The friction factor has been slightly increased	Pressure drop is inversely proportional to particle volume concentration.	[54]
Almada et al.	Al_2O_3/water	0.3-2.0%	Friction factor development	pressure drop decrease	[55]

FLAT PLATE SOLAR COLLECTOR SYSTEM (FPSCS)

The flat plate collector absorbs the ultraviolet radiation emitted by the Sun. Convection is used to move thermal heat to the copper tubes through the front glass and collector. Because of its higher thermal conductivity than water, nano fluid was utilized as a working fluid in this case. The working fluid was circulated through the pipe, absorbing heat from incident radiation on the covering. A heat exchanger transfers the thermal heat from the nano-fluid into the base fluid, which is water. The flow of the working fluid is controlled by a Rotameter. The K-type thermocouple was used to measure the temperature of the fluids at various stages. As the hot fluid goes into the flat plate collector, it returns to its original temperature. A pump is used to transfer the operating fluid to the collector in this case. Valves are utilized to regulate the flow path. The heat exchanged in tank water may be applied for a variety of purposes [50-56]. The usage of Nano-fluids in FPSCs has a number of benefits, including the following: Nanoparticles greatly enhance accelerated mixing and turbulence in nano-fluid flows [57]. Increased heat transfer potential due to its thermal conductivity being significantly greater than that of the base fluid, as a function of the Brownian passage of the attached nanoparticles [58]. Nano-fluids have a high heat transfer coefficient, which results in an improvement in the thermal performance of FPSCs [59]. The nanoparticles are tiny in size but have a wide covering region, which results in a meaningful improvement in the heat potential and absorption of the Nano-fluid. As a result, the FPSCs' energy losses can be reduced [60].

A review of the different Nano-fluids used in FPSC

The analysis of solar flat plate collectors' performance was recorded by Shamshirgaran et al. [46]. They also employ MATLAB's computer software for simulating the efficiency of a solar collector under steady-state laminar cases. The findings indicate that when Cu nano-fluid is utilized preferably than pure water as the working solvent, the thermal performance of the collector could be increased by 2.4 percent at a 4 percent volume concentration. The spread of nano-particles within the water leads to a more powerful pressure drop and, thus, more powerful power usage in the collector for pumping the nano-fluid. It is predicted that the collector understudy would result in a 30% rise in pressure drop and pumping power. Mahian et al. [18] examined the heat transfer, pumping capacity, and entropy production of an FPSC-based 1.0 wt% SiO_2/water Nano-fluid following turbulent flow conditions theoretically. Two nanoparticle sizes were examined, namely 16 and 12 nm, and two pH values, namely 6.5 and 5.8. Their studies revealed that, as opposed to water, utilizing nano-fluid increases thermal power, outlet temperature, coefficient of heat transfer, and pressure drop while decreasing entropy production. Additionally, improving the pH of the Nano-fluid improved entropy production for 16 nm nanoparticles but reduced it for 12 nm nano-particles [61]. To enhance the performance of a Flat Plate Solar Collector, Titanium dioxide Nano-fluid and Polyethylene Glycol (PEG400) dispersant was applied. They studied the collector device's energy and exergy usingTiO_2. The volume fractions between 0.1 and 0.3 percent were applied, and the mass flow rate ranged between 0.5 and 1.5 kg/min. With ft = 0.3 percent TiO_2, an enhance in thermal conductivity of approximately 6% was perceived. The viscosity reduced with growing temperature and enhanced with increasing particle filling. The energy performance of the system increased as the volume fraction and mass flow rate increased. The energy performance of the system reduced as the volume fraction or mass flow rate was raised. Energy effectiveness improved by 76.6% at 0.1 vol. percent and 0.5 kg/min, while the nano-fluid used had a maximum possible energy efficiency of 16.9% when opposed to water at 0.1 vol. percent and 0.5 kg/min. Additionally, the pumping capacity of TiO_2 nano-fluid was found to be equal to that of base fluid at low volume fractions.

Said et al. [13] investigated heat transfer, pressure decrease, pumping capacity, the performance of exergy, also nano-fluid dependent single-wall carbon nanotubes for a flat platform solar collector (SWCNTs). The region of absorption included in the study was 1.51 m^2. The real heat CP of SWCNTs was discovered to decrease with increasing volume fraction, implying that less heat is needed at more powerful volume fractions, because of a rise in volume fraction and mass flow rates, the entropy generation declined. In contrast to other nano-fluids, SWCNTs nano-fluids exhibit a higher Nusselt number and thermal conductivity for rising volume flow rate. The heat transfer coefficient of SWCNTs Nano-fluid was observed to increase linearly with the volume flow rate. In contrast to other nano-fluids, SWCNTs needed the lowest pumping power. SWCNTs Nano-fluid was determined to be capable of reducing entropy production by 4.34 percent and increasing the heat transfer coefficient by 15.33 percent. Additionally, Said et al [62]. examined the thermo-physical properties of water/Al_2O_3 and ethylene glycol (EG)-water/Al_2O_3 Nano-fluids, as well as their impact on the pumping capacity of an FPSC. A two-step process utilizing 13 − nm Al_2O_3 nanoparticles, an ultrasonic probe, and a high-pressure homogenizer is applied to create nano-fluids with volumetric concentrations of

0.05 − 0.1 percent. Water/ Al_2O_3 nano-fluid had higher stability than EG-water/ Al_2O_3 nano-fluid had higher stability than EG-water/Al_2O_3 nano-fluid. The findings indicated that the calculated thermal conductivity increased approximately linearly with concentration. The nano-fluid's determined viscosity remained greatly depending on the base fluid utilized, the volume concentration, as well as the temperature. In different thermal transfer utilization, nano-fluids were consequently decided to improve heat transfer rates. It is important to note that no knowledge was given about the stability of the nano-fluids planned.

To increase heat transfer and hence the thermal efficiency of solar water heaters, Sundar et al. [63] applied nan-fluids of Al_2O_3 and wrapped tape inserts. In this analysis, a tube including or without twisted tape in which water movement and Nano-fluids are mainly imitated by the collector in the solar water heating device. The results of the heat transfer tests show that, for a Reynolds count of 13000, the thermal transmission increase is 21% for the flat pipe, at 0,3% volume, and that it is added up to 49,75% for twisted H/D = 5 tubes. For 0.3 percent nano-fluid 24 with H/D = 5 as opposed to water in a simple collection, the gross friction penalty of 1.25 times was noted. When the 0.3 percent Nano-fluid is applied and further up to 76 percent with a twisted band H/D = 5 at a mass flow rate of 0.083 kg/s, the thermal performance of the plain panel is improved to 58 percent. Thermal performance increases in solar water heaters, in which collectors have twisting tape insertions and Nano-fluids, broadly exceed pressure losses.

TABLE.3. Investigations into various forms of Nano-fluids dependent on FPSCs

Novelist	**Process**	**Required fluid**	**Species**	**Size (nm)**	**Fraction (%)**	**Increased efficiency (%)**	**Form of flow**
Michael and Lniyan	Experimental	Water	CuO	21 nm	0.05%	6.3%	Turbulent
Tora and Mustafa	Numerical	Water	Al_2O_3	-	0.5%	27%	Turbulent
He et al.	Experimentali	water	Cu	10 nm	23.8%	0.1%	Turbulent
Faizal et al.	Experimental	Water	SiO_2	10 nm	27%	0.4%	Laminar
said et al.	Experimental	Water	SWCNT	20 nm	53%	0.3%	Laminar

CONCLUSION, CURRENT CHALLENGES AND FUTURE WORK

This review article discusses the most recent advancement of solar energy technology, the flat plate solar collector (FPSCs). Nano-fluids will significantly improve the efficiency of flat-plate collectors. For the last two decades, researchers have been investigating the usage of nano-fluid as an absorber fluid in FPSC. Although numerous Nano-fluids have been examined as functioning fluids in solar collectors, further research is required to determine the impact of utilizing certain recently formed nanoparticles with high thermal conductivities on solar collector efficiency. Because of their abnormal increase in thermal conductivity, nano-fluids demonstrated a promising improvement in the thermal performance of FPSCs. Numerous published papers demonstrate that nano-fluids have a far higher heat transfer coefficient than conventional base fluids and suffer little to no pressure drop penalty; furthermore, it is demonstrated that pressure drop, and pumping capacity rise as volume flow rate increases. It is decided that, as opposed to pure water, the various forms of Nano-fluid improve the thermal efficiency of solar collectors. The key problems with Nano-fluids for solar devices are primarily associated with| their great cost, instability, agglomeration of nanoparticles, and increased viscosity, which increases frictional pressure drop and pumping capacity. Higher nano-fluid concentrations would then have higher dispersal stability, and lower costs, with only a slight development in viscosity, pressure drop, and pumping capacity. Furthermore, the experiment may be replicated with different base fluids when preparing Nano- fluid. The results of base fluids such as transformer oil and ethylene glycol could be detected. Besides, the FPSC test of nanostructure of carbon, copper oxide, and aluminum oxide nano liquids can be compared under the same circumstances with comprehensive economic analysis.

REFERENCES

1. A. Jamar, Z.A.A. Majid, W.H. Azmi M. Norhafana and A.A. Razak *A review of water heating system for solar energy applications*. International Communications in Heat and Mass Transfer 76:178–187 (2016).
2. W. Xiaowu and H. Ben *Exergy analysis of domestic-scale solar water heaters*. Renewable and Sustainable Energy Reviews 9:638–645 (2005).
3. N.J. Vickers *Animal communication: when i'm calling you, will you answer too?* Current biology 27:R713–R715 (2017).
4. C.D. Ho and T.C. Chen *The recycle effect on the collector efficiency improvement of double-pass sheet-and-tube solar water heaters with external recycle*. Renewable Energy 31:953–970 (2006).
5. X.Q.Wang and A.S. Mujumdar *Heat transfer characteristics of nanofluids: a review.* International journal of thermal sciences 46:1–19 (2007).
6. S.US.Choi, J.A. Eastman *Enhancing thermal conductivity of fluids with nanoparticles*. Argonne National Lab.(ANL), Argonne, IL (United States) (1995).
7. Y.Yang, Z.G.Zhang and E.A. Grulke *Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow.* International journal of heat and mass transfer 48:1107–1116 (2005).
8. D.Tripathi and O.A. Bég *A study on peristaltic flow of nanofluids: Application in drug delivery systems.* International Journal of Heat and Mass Transfer 70:61–70 (2014).
9. D.P. Kulkarni, D.K. Das, R.S.Vajjha *Application of nanofluids in heating buildings and reducing pollution.* Applied Energy 86:2566–2573 (2009).
10. O.A. Alomair, K.M.Matar and Y.H. Alsaeed *Nanofluids application for heavy oil recovery*. Society of Petroleum Engineers - SPE Asia Pacific Oil and Gas Conference and Exhibition, APOGCE 2014 - Changing the Game: Opportunities, Challenges and Solutions 2:1346–1363 (2014).
11. D.P.Kulkarni, R.S.Vajjha, D.K.Das, D.Oliva *Application of aluminum oxide nanofluids in diesel electric generator as jacket water coolant*. Applied Thermal Engineering 28:1774–1781(2008).
12. K.J. Park K-J, D.Jung *Boiling heat transfer enhancement with carbon nanotubes for refrigerants used in building air-conditioning*. Energy and Buildings 39:1061–1064 (2007).
13. Z.Said, R.Saidur, N.A. Rahim and M.A. Alim *Analyses of exergy efficiency and pumping power for a conventional flat plate solar collector using SWCNTs based nanofluid*. Energy and Buildings 78:1–9 (2014).
14. A. Layek, J.S. Saini, S.C. Solanki *Second law optimization of a solar air heater having chamfered rib-groove roughness on absorber plate*. Renewable Energy 32:1967–1980 (2007).
15. K.M. Pandey and R. Chaurasiya *A review on analysis and development of solar flat plate collector.* Renewable and Sustainable Energy Reviews 67:641–650 (2017).
16. M.A.Alim, Z.Abdin, R.Saidur A. Hepbasli, M.A. Khairul and N.A. Rahim *Analyses of entropy generation and pressure drop for a conventional flat plate solar collector using different types of metal oxide nanofluids.* Energy and Buildings 66:289–296 (2013).
17. S.K.Verma, A.K.Tiwari, D.S.Chauhan *Experimental evaluation of flat plate solar collector using nanofluids.* Energy conversion and Management 134:103–115 (2017).
18. O.Mahian, A.Kianifar, A.Z. Sahin and S.Wongwises *Heat Transfer, Pressure Drop, and Entropy Generation in a Solar Collector Using SiO_2/Water Nanofluids: Effects of Nanoparticle Size and pH*. Journal of Heat Transfer 137 (2015).
19. S.K.Das, S.US.Choi, H.E.Patel *Heat transfer in nanofluids—a review.* *Heat transfer engineering* 27:3–19 (2006).
20. K.Khanafer and K.Vafai *A review on the applications of nanofluids in solar energy field*. Renewable Energy 123:398–406 (2018).
21. E.Bellos, Z.Said and C.Tzivanidis *The use of nanofluids in solar concentrating technologies*: A comprehensive review. Journal of Cleaner Production 196:84–99 (2018).
22. H.A. Mohammed, A.A. Al-Aswadi, N.H. Shuaib, R. Saidur *Convective heat transfer and fluid flow study over a step using nanofluids: A review*. Renewable and Sustainable Energy Reviews 15:2921–2939 (2011).
23. A.N. Kozitsina, T.S. Svalova, N.N. Malysheva, A.V. Okhokhonin, M.B.Vidrevich, K.Z. Brainina *Sensors based on bio and biomimetic receptors in medical diagnostic, environment, and food analysis.* Biosensors 8:35 (2018).
24. H. Chang, C.S. Jwo, P.S. Fan, S.H. Pai *Process optimization and material properties for nanofluid manufacturing*. The International Journal of Advanced Manufacturing Technology 34:300–306 (2007).

25. P Raj and S. Subudhi *A review of studies using nanofluids in flat-plate and direct absorption solar collectors.* Renewable and Sustainable Energy Reviews 84:54–74 (2018).
26. S.A. Angayarkanni and J. Philip *Review on thermal properties of nanofluids: Recent developments.* Advances in colloid and interface science 225:146–176 (2015).
27. W.Yu and S.US. Choi *The role of interfacial layers in the enhanced thermal conductivity of nanofluids: A renovated Maxwell model.* Journal of Nanoparticle Research 5:167–171 (2003).
28. Y. Xuan and W. Roetzel *Conceptions for heat transfer correlation of nanofluids.* International Journal of heat and Mass transfer 43:3701–3707 (2000).
29. B.C. Pak and Y.I. Cho *Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles.* Experimental Heat Transfer an International Journal 11:151–170 (1998).
30. M.A.Sharafeldin and G. Gróf *Experimental investigation of flat plate solar collector using CeO_2-water nanofluid*. Energy Conversion and Management 155:32–41(2018).
31. M. Ghanbarpour, E.B. Haghigi and R.Khodabandeh *Thermal properties and rheological behavior of water based Al_2O_3 nanofluid as a heat transfer fluid.* Experimental Thermal and Fluid Science 53:227–235. (2014).
32. P. Naphon, P. Assadamongkol and T. Borirak *Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency*. International Communications in Heat and Mass Transfer 35:1316–1319 (2008).
33. I. Gherasim, G. Roy, C.T. Nguyen and D. Vo-Ngoc *Experimental investigation of nanofluids in confined laminar radial flows*. International Journal of Thermal Sciences 48:1486–1493 (2009).
34. M. Corcione *Empirical correlating equations for predicting the effective thermal conductivity and dynamic viscosity of nanofluids.* Energy Conversion and Management 52:789–793 (2011).
35. H.Y. Wong *Handbook of essential formulae and data on heat transfer for engineers*. Addison-Wesley Longman Limited (1977).
36. J.A. Duffie and W.A. Beckman *Solar engineering of thermal processes*. John Wiley & Sons (2013).
37. S.A. Kalogirou, S. Karellas K. Braimakis, C. Stanciu and v. Badescu *Exergy analysis of solar thermal collectors and processes. Progress in Energy and Combustion Science* 56:106–137 (2016).
38. A.A.R. Darzi, M. Farhadi, K. Sedighi, R. Shafaghat and K. Zabihi *Experimental investigation of turbulent heat transfer and flow characteristics of SiO 2/water nanofluid within helically corrugated tubes.* International Communications in Heat and Mass Transfer 39:1425–1434 (2012). https://doi.org/10.1016/j.icheatmasstransfer.2012.07.027
39. Q. He, S. Zeng and S. Wang Experimental investigation on the efficiency of flat-plate solar collectors with nanofluids. Applied Thermal Engineering 88:165–171 (2015).
40. D.A. Stewart, H.P. Dudel and L.J. Levitt *Solar Radiation in Saudi Arabia*. ARMY MISSILE COMMAND REDSTONE ARSENAL AL WEAPONS SCIENCE DIRECTORATE (1993).
41. S. Farahat, F. Sarhaddi, H. Ajam *Exergetic optimization of flat plate solar collectors*. Renewable energy 34:1169–1174 (2009).
42. A.M. Hussein, K. Kadirgamma, M.M. Noor and L.K. Aik *Palm oil based nanofluids for enhancing heat transfer and rheological properties*. Heat and Mass Transfer 54:3163–3169 (2018).
43. K.A. Mohammed, A.F. Hameed and A.M. Hussein *Nanofluid heat transfer augmentation in a double pipe heat exchanger.* In: AIP Conference Proceedings. AIP Publishing LLC, 2213(1):20059 (2020). https://doi.org/10.1063/5.0000243
44. M.S. Kamel, F. Lezsovits, A.M. Hussein, O. Mahian and S. Wongwises *Latest developments in boiling critical heat flux using nanofluids: A concise review*. International Communications in Heat and Mass Transfer 98:59–66 (2018).
45. M.B. Nejad, H.A. Mohammed, O. Sadeghi and S.A. Zubeer *Influence of nanofluids on the efficiency of Flat-Plate Solar Collectors (FPSC)*. In: E3S Web of Conferences. EDP Sciences, p 123 (2017).
46. S.R. Shamshirgaran, M.K. Assadi, H.H. Al-Kayiem and K.V. Sharma *Investigation of thermal behaviour, pressure drop, and pumping power in a Cu nanofluid-filled solar flat-plate collector*. MATEC Web of Conferences 131:1–6 (2017).
47. H.P. Garg and R.K. Agarwal *Some aspects of a PV/T collector/forced circulation flat plate solar water heater with solar cells*. Energy Conversion and Management 36:87–99 (1994).
48. W.S. Saric, H.L. Reed and E.B. White *Stability and transition of three-dimensional boundary layers*. Annual Review of Fluid Mechanics 35:413–440 (2003).
49. F.M. White *Advanced Fluid Dynamics*. McGraw-Hill Book Company Inc., New York, pp. 135-136 (1991).
50. N.A.C. Sidik, H.A. Mohammed, O.A. Alawi, S. Samion *A review on preparation methods and challenges of nanofluids.* International Communications in Heat and Mass Transfer 54:115–125 (2014).

51. A.F. Niwalkar, J.M. Kshirsagar, K. *Kulkarni Experimental investigation of heat transfer enhancement in shell and helically coiled tube heat exchanger using SiO_2/ water nanofluids*. Materials Today: Proceedings 18:947–962 (2019).
52. O. Mahian, A. Kianifar, A.Z. Sahin, S. Wongwises *Heat transfer, pressure drop, and entropy generation in a solar collector using SiO2/water nanofluids: effects of nanoparticle size and pH*. Journal of Heat Transfer 137:61011 (2015).
53. A.A.R. Darzi, M. Farhadi, K. Sedighi, R. Shafaghat and K. Zabihi *Experimental investigation of turbulent heat transfer and flow characteristics of SiO_2/water nanofluid within helically corrugated tubes.* International Communications in Heat and Mass Transfer 39:1425–1434 (2012).
54. H. Maddah, M. Alizadeh, N. Ghasemi, S.R.W. Alwi *Experimental study of Al_2O_3/water nanofluid turbulent heat transfer enhancement in the horizontal double pipes fitted with modified twisted tapes.* International Journal of Heat and Mass Transfer 78:1042–1054 (2014).
55. J. Albadr, S. Tayal and M. Alasadi *Heat transfer through heat exchanger using Al_2O_3 nanofluid at different concentrations*. Case Studies in Thermal Engineering 1:38–44 (2013).
56. S. Arockiaraj and P. Jidhesh *Effect of nano fluids in solar flat plate collector systems*. Int J Eng Comput Sci 5:18404–18412 (2016).
57. W. Chen, C. Zou and X. Li *An investigation into the thermophysical and optical properties of SiC/ionic liquid nanofluid for direct absorption solar collector.* Solar Energy Materials and Solar Cells 163:157–163 (2017).
58. K.Y. Leong, K.Z.K Ahmad, H.C. Ong, M.J. Ghazali and A. Baharum *Synthesis and thermal conductivity characteristic of hybrid nanofluids–a review*. Renewable and Sustainable Energy Reviews 75:868–878 (2017).
59. A.H. Elsheikh, S.W. Sharshir, M.E Mostafa, F.A. Essa and M.K.A. Ali *Applications of nanofluids in solar energy: A review of recent advances.* Renewable and Sustainable Energy Reviews 82:3483–3502 (2018). https://doi.org/10.1016/j.rser.2017.10.108
60. M. Mehrali, E.Sadeghinezhad, M.A. Rosen, S.T. Latibari, M. Mehrali, H.S.C. Metselaar and S.N. Kazi *Effect of specific surface area on convective heat transfer of graphene nanoplatelet aqueous nanofluids.* Experimental Thermal and Fluid Science 68:100–108 (2015).
61. Z. Said, M.A.Sabiha, R. Saidur, A. Hepbasli, N.A. Rahim, S. Mekhilef and T.A. Ward *Performance enhancement of a flat plate solar collector using titanium dioxide nanofluid and polyethylene glycol dispersant.* Journal of Cleaner Production 92:343–353 (2015).
62. Z. Said, M.H. Sajid, M.A. Alim, R. Saidur and N.A. Rahim *Experimental investigation of the thermophysical properties of AL2O3-nanofluid and its effect on a flat plate solar collector.* International Communications in Heat and Mass Transfer 48:99–107 (2013).
63. L.S. Sundar, M.K. Singh, V. Punnaiah and A.C.M. Sousa *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).