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Performance Improvement of Solar Water Distillation System Using Nanofluid Particles

H. H. El-Ghetany,[a] H. M. Elgohary, [b] and Y. M. Mohammed [c]

[a] *Solar Energy Department, National Research Centre, Dokki, 12622, Giza, Egypt*
[b] *Mechanical Power Engineering Department, Faculty of Engineering, Suez University, Suez, Egypt*
[c] *Engineering Sciences Department, Faculty of Petroleum & Mining Eng. Suez University, Suez, Egypt*

Abstract
The aim of this work is to utilize nanofluid particles (Titanium dioxide, TiO2) to enhance the heat transfer characteristics of the Heat Transfer Fluid (HTF) of the solar heating system to improve its thermal performance. It is found that using the nanofluid particles like TiO2 improves the heat transfer characteristics of the HTF of the solar water distillation system and consequently increases the rate of daily water productivity. It is found also that the system can produce distilled water of 5616 liters//day, 6048 liters//day, 6134 liters//day, and 7128 liters//day in case of using TiO2 with a concentration of 0 mg/l, 75 mg/l, 80 mg/l, and 100 mg/l respectively. The experimental pilot unit was installed in Solar Energy Department, National Research Centre, and Giza, Egypt. Several test runs are performed to measure all assigned parameters that affect the system performance. The tested system can positively contribute in water desalination units especially in rural and isolated communities.

Keywords— Nano fluid particle, efficiency improving, solar water desalination system; rate of water productivity.

1. Introduction

Nano-fluids are effective heat transfer fluids for various industrial and thermal applications because of their excellent thermal performance. Nanoparticles have several advantages; as large surface area to volume ratio, dimension-dependent physical properties, and lower kinetic energy, Nanoparticles better and more stably dispersed in base fluids. It is investigated both theoretically and experimentally that mixing nanoparticles in a liquid (a Nanofluid) improves the thermo-physical properties of the carrier fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. Nanofluids have novel properties that enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid. Choi [1] introduced ultra-fine nanoparticles (<50 nm in diameter) dispersed in the base fluid and thereby introduced Nanofluid. Nanofluids, a more efficient type of working fluid, are achieved by dissolving nanometer-sized particles/fibers between 1 and 100 nm with the conventional heat transfer fluids. The size of those suspended particles was of the order of a few nanometers. Some of the commonly used nanoparticles are Al_2O_3, CuO, TiO_2, ZnO and SiO_2. Yousefi et al. [2] tested Al_2O_3/water as a coolant in a flat-plate collector. They showed that the nanofluid increased both the outlet temperature and the efficiency of collector. The weight fraction of nanoparticles was 0.2% and 0.4% and the particles dimension was 15 nm. Experiments were performed with and without Triton X-100 as surfactant. The mass flow rate of nanofluid varied from 1 to 3 L/min. The results show that, in comparison with water as absorption medium using the nanofluids as working fluid increase the efficiency. For 0.2 wt. % the increased efficiency was 28.3%. Lu et al. [3] investigated the thermal performance of an open thermosyphon for high-temperature evacuated tubular solar collectors employing deionized water and water-based CuO nanofluid as coolants. They showed that the nanofluid enhanced the collector performance and increased the evaporating heat-transfer coefficients by ~30%. Grimm [4] dispersed aluminum metal particles (1–80 nm) into water and claimed 100% increase in thermal conductivity of the nanofluid for 0.5–10wt%. Natarajan and Sathish [5] investigated the thermal conductivity enhancement of base fluids using carbon nanotube (CNT) and suggested efficiency enhancement of the

*Corresponding author e-mail: hamdy.elghetany@gmail.com.; (H. H. El-Ghetany).
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conventional solar water heater by using CNT based nanofluids as a heat transport medium. Nanoparticles also offer the potential of improving the radiative properties of liquids, leading enhanced efficiency of direct absorption solar collectors. Sheikholeslami et al. [6–10] recently used nanofluid and simulated nanofluid flow and heat transfer by different methods for different kinds of problems to enhance the heat transfer rate. S. Lee et al [11] prepared Oxide nanofluids and measured their thermal conductivities by a transient hot-wire method. Their experimental results showed that the nanofluids, containing a small amount of nanoparticles, have significantly higher thermal conductivities than the same liquids without nanoparticles. They showed that the model can predict the thermal conductivity of nanofluids containing large agglomerated Al_2O_3 particles. A.E. Kabeel et al [12] performed laboratory experiments with a thermal solar water heater consisting of a flat-plate solar collector and helical coil heat exchanger using Al_2O_3 Nanoparticles dispersed in water as a working. The experiments were carried out for various nano-particle concentrations, from 0% to 3% (by volume), through forced convection cooling under the climatic conditions of Tanta University, Egypt in August 2013. The experiments have an emphasis on the main parameters with impact on the water production temperature, as the solar radiation, the feed water mass flow rate and the nano-particle volume fraction. The outlet water temperature is increased with increasing of nanoparticle concentration by 5.46% for concentration 2%. Lenert and Wang [13] presented a model and experimental study of concentrated solar power application using carbon-coated cobalt (C-Co) nanoparticles and Therminol VP-1 base fluid and concluded that the efficiency is more than 35% with nanofluid and the efficiency will increase with increasing nanofluid height. Lu, Liu and Xiao [14] shown that the application of Copper Oxide (CuO) nanoparticles in evacuated tubular solar collector will significantly enhance the thermal performance of evaporator and evaporating heat transfer coefficient increased by 30% compared to water as working fluid. 5% improvement in efficiency. Faizal et al. [15] studied the effects of various nanofluids on the thermal efficiency, and size reduction of the flat plat solar collectors. They found that by using the nanofluid as working fluid the efficiency of the collector increases. Said et al. [16] performed some experiments for investigation on the nanofluid heat transfer on the flat plate solar collectors. Al_2O_3/water nanofluid with various concentrations has been used in that work and the effect of density and viscosity of nanofluid on the pumping power of solar collector were studied experimentally. El-Maghlany et al. [17] numerically investigated the effects of nanofluid on the thermal performance of ribbed flat plate using cu-water nanofluid. Teamah et al. [18] numerically and experimentally investigated flow structure and heat transfer of jet cooling over flat plat utilizing nanofluids (Al_2O_3). The mathematical model was derived and numerically solved using Finite volume with SIMPLER algorithm. Manjunath et al. [19] developed a CFD model to study the effect of surface geometry of solar collector on the thermal performance. The results of this configuration were compared to a dimple absorber plate. The CFD prediction showed that the average temperature of absorber plate and outlet water temperature for dimple configuration are higher than temperatures in flat plate solar collector. Mintsa Do Ango et al. [20] Adopted numerical simulations for optimizing the design of polymeric flat plate solar collectors. Effects of operating conditions and geometrical parameters on thermal behavior of polymeric flat plate collector were studied. It was observed that the length of collector does not influence the collector performance and the efficiency of collector increases by increasing the air gap thickness up to 10 mm and then decreases slowly. Basavanna and Shashishekar [21] developed numerical simulations to study the thermal performance of triangular tube configuration on a flat plate solar collector. The special configuration of tubes makes larger contact area between the tube and the plate, which causes more energy to be absorbed. The numerical analysis had also been used by another researcher such as Karanth et al. [22], Selmi et al. [23], Turgut and Onur [24]. for prediction of thermal performance of flat plate solar collectors. In those studies, the CFD technique is presented as a powerful, reliable, and cost saving tool for design and optimization of the solar collectors. Jabari Moghadam et al. [25] studied the effect of CuO–water nanofluid on the performance and the efficiency of a flat-plate solar collector experimentally. The experimental results of their study revealed that utilizing the nanofluid increases the collector efficiency in comparison to water as an absorbing medium. The nanofluid with mass flow rate of 1 kg/min increases the collector efficiency about 21.8%. Gupta et al. [26] investigated the effect of Al_2O_3– H_2O nanofluid flow rate on the efficiency of direct absorption solar collector. Using an experimental setup, they reported that collector efficiency enhancement of 8.1% and 4.2% has been achieved for 1.5 and 2 l/min flow rate of nanofluid, respectively. They also reported the optimum flow rate of 2.5 and 2 l/min to maximum collector efficiency for water and nanofluid, respectively. M.A. Sharafeldin et al [27] performed experiments to study the effect of using CeO_2- water on the efficiency of flat-plate solar collector by three different volume fractions of CeO_2 nanoparticles of 0.0167%, 0.0333% and 0.0666%, while the mean particle dimension was kept constant at 25 nm. An ultrasonic process was used for maintaining the stability of the CO_2-water nanofluid. The working fluid mass flux rates were 0.015, 0.018 and 0.019 kg/s m^2. Higher collector efficiency was achieved when using CeO_2-water nanofluid compared to results achieved with water application. They recommended that the efficiency of the collector is directly proportional with the mass flux rate and with the nanofluid volume fraction. Experiments indicated that the highest rise in efficiency of the collector at zero value of $[(T_i - T_a)/G_T]$ is 10.74%, for volume fraction (φ) 0.066%, and for mass flux rate of 0.019 kg/s m^2 compared to water. Iqbal A. et al [28] provided a research study that has focused on the role of nanofluids to improve heat transfer. And consequently to enhance the productivity and energy utilization efficiency of the solar stills. They concluded that utilization of nanofluids in small fraction enhanced the thermal conductivity compared to base fluid alone and found that Alumina was found to be the most suitable nanoparticle used as nanofluids inside the solar stills due to its availability and lower cost. Kalpesh V. M. et al. [29], provided a Comparative Performance Study of Double Basin Single Slope Solar Still with and Without Using Al_2O_3 nanoparticles. They concluded the use of nanoparticles in solar still increases the distilled output by 17.6%, 12.3%, 7.2%, and 2.6% for weight concentrations of 0.01%, 0.05%, 0.10%, and 0.20%, respectively, in comparison to the solar still without nanoparticles. Youngho L. et al. [30] provided experimental investigation on evaluation of thermal performance of solar heating system using Al_2O_3 Nanofluids. They concluded that the thermal conductivities of the nanofluids of the 0.1, 0.3, and 0.5 wt% alumina nanofluids were 0.32%, 0.62%, and 0.95% higher, respectively, than that of distilled water and the temperature increases by 3.1%, 12.5%, and 13.9% higher, respectively, than that of distilled water.

System Description

The purpose of the current system is to produce fresh water from saline water. Solar energy is used as renewable energy provider of the single effect water desalination process to produce fresh water as shown in Fig. 1. The water desalination system consists mainly of two loops; Heat transfer fluid (HTF) loop and water loop respectively. The heat transfer fluid is chosen a synthetic thermal heating oil to carry the thermal energy from the heat pipe evacuated tube collector to the thermal oil storage tank. It has good heat transfer efficiency, high resistance to thermal cracking, excellent heat transfer properties, long life, and minimum maintenance costs. The HTF loop consists of four components; evacuated tube collector with storage tank, hot oil stainless steel coil immersed in thermal hot water storage tank acting as heat exchanger, backup electric heater as auxiliary heating sources, and hot oil circulating pump. The HTF is heated in the solar evacuated tube collector and the gained thermal energy is transferred to the 100 liters' hot water storage tank after passing the backup electric heater. The pumped HTF temperature increased in the evacuated tube collector up to the range of 75-90 ^oC and then it is heated in the hot oil auxiliary heater up to 200 ^oC. The system operation shown in Fig. 2 is mentioned in detailed in the authors previously published work El-Ghetany H. H. et al, [31].

Experimental procedure

The effect of a nanoparticle concentrations of TiO_2 mixed with hot oil loop was examined on solar water distillation system to investigate the daily water productivity with different concentrations of TiO_2. The technical specification of the used TiO_2 is shown in Table 1.

Three TiO_2 concentrations were studied (75 mg/l, 80 mg/l, and 100 mg/l respectively) to find out the effect of its concentration on the daily water productivity compared to the reference case 0 mg/l. several experimental runs were made while the hourly hot oil temperature in each concentration was measured and the hourly and daily distilled water was measured in each experiment.

Table 1. TiO_2 technical specification

No.	Item	Specification
1	Product name	Titanium dioxide, anatase, nanopowder, <25 nm particle size, 99.7% trace metals basis
2	Product number	637254
3	Formula weight	79.87 gm/mol
4	Appearance	White color
5	type	powder
6	X-Ray Diffraction	Confirm to structure
7	Trace metal analysis	≤ 4000 ppm
8	Surface area	45-55 m^2/g

Results and Discussions

Based on the previously mentioned experimental procedure, the temperature distribution of the hot oil outlet from the heat pipe evacuated tube solar collector and auxiliary heater with different nanoparticle concentrations was measured throughout the experiment day and plotted versus amount of energy consumed per day as shown in Fig. 3 and Fig. 4 respectively.

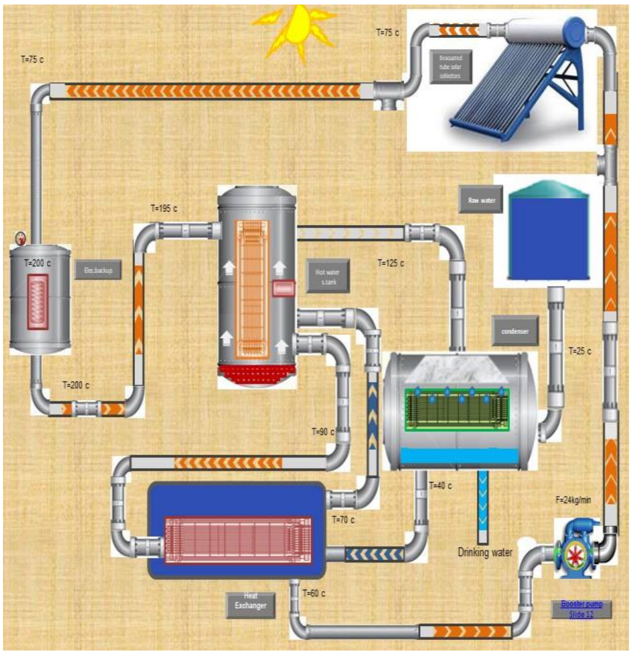

Fig. 1 Schematic diagram of the solar water desalination system

Fig. 2 Photographic view of a solar water desalination system using evacuated tube collector **[31]**

It is clear that for the same energy consumed, the higher the nanoparticle concentration, the higher hot oil temperature achieved. The hot oil temperature difference across the heat pipe evacuated tube solar collector is illustrated in Fig. 5.

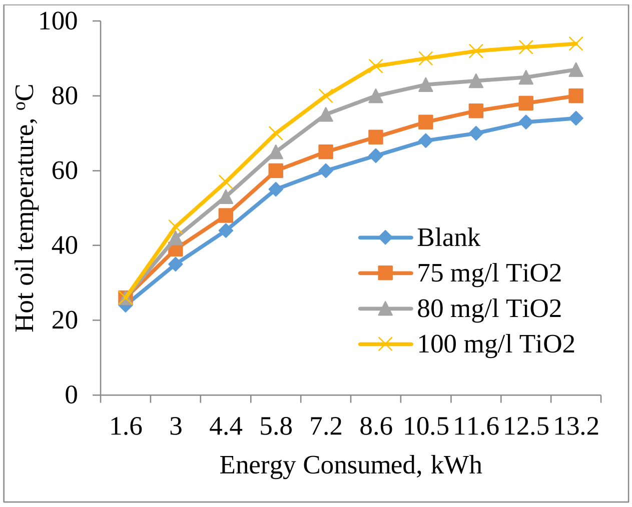

Fig. 3 Temperature distribution of the hot oil outlet from the heat pipe evacuated tube solar collector with different nanoparticle concentrations

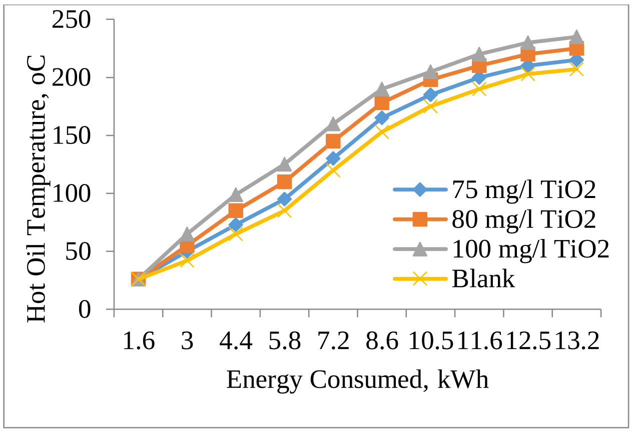

Fig. 4 Temperature distribution of the hot oil outlet from the auxiliary heater with different nanoparticle concentrations

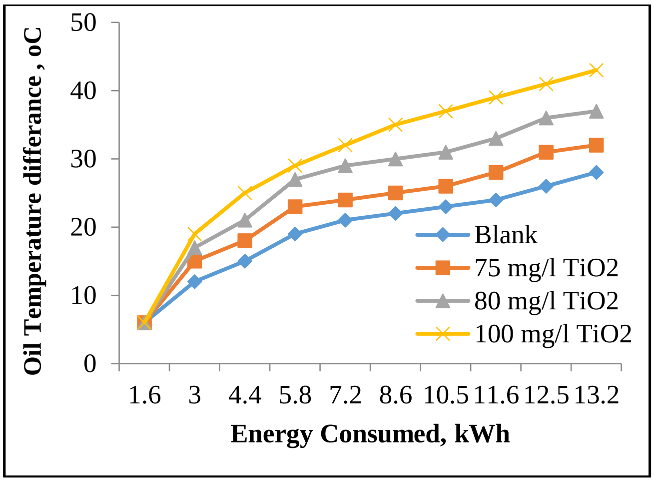

Fig. 5 The hot oil temperature difference across the heat pipe evacuated tube solar collector

It is clear that increasing the concentration of the nanoparticles improve the convective and conductive heat transfer characteristics and consequently increase the collector outlet temperature that yield to increase the temperature difference across the collector. The hot oil temperature distribution inlet, outlet the solar collector and outlet from the auxiliary heater tank versus energy consumed, kWh for nanoparticle concentration 0 mg/l (without nanoparticles) is shown in Fig. 6.

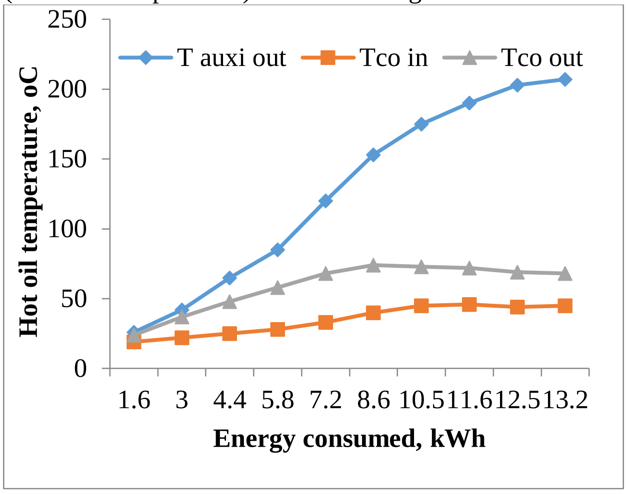

Fig. 6 The hot oil temperature distribution of inlet, outlet the solar collector and outlet from the auxiliary heater tank versus energy consumed, kWh without nanoparticles

While the hot oil temperature distribution inlet, outlet the solar collector and outlet from the auxiliary heater tank versus energy consumed, kWh for nanoparticle concentration 100 mg/l is shown in Fig.7. The hourly distilled water for three different nanoparticle concentrations was observed from several runs with different concentration as shown in Fig. 8.

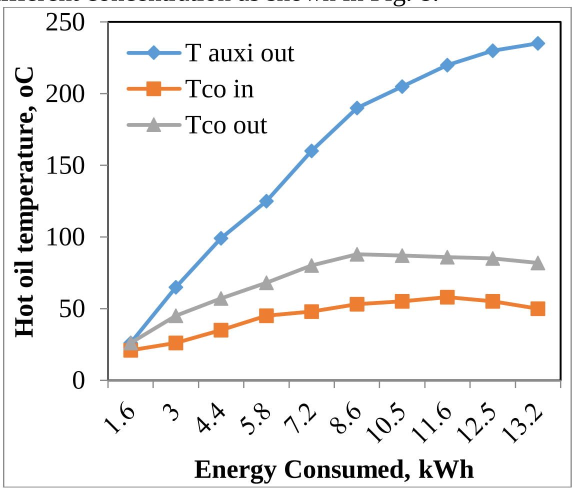

Fig. 7 The hot oil temperature distribution of inlet, outlet the solar collector and outlet from the auxiliary heater tank versus energy consumed, kWh with 100 mg/l nanoparticles

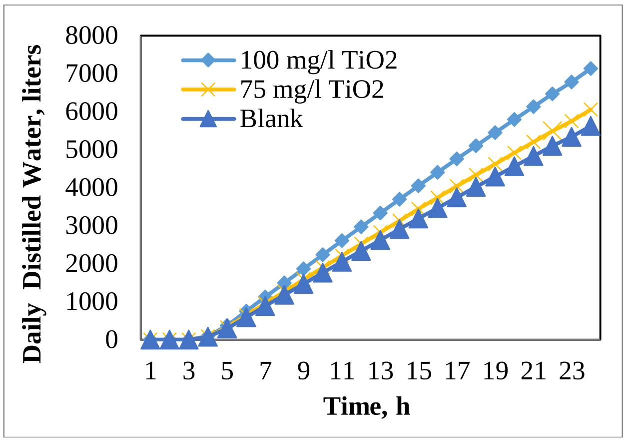

Fig. 8 Accumulated distilled water for three different nanoparticle concentrations

It is found that the higher nanoparticle concentration, the higher distilled water productivity that referred to improving the heat transfer characteristics of the heat transfer fluid. The daily distilled water for all studied cases (different nanoparticle concentration) was observed from several runs with different concentration. It is found that the presented system can produce 5616 liters per day for the reference case (Blank, without nanoparticle) while it can produce 7128 liters per day in case of using 100 mg/l TiO_2 nanoparticle concentration as shown in Fig. 9. It can be concluded that using TiO_2 nanoparticle with a concentration of 100 mg/l increase the daily distilled water productivity by 26.9%.

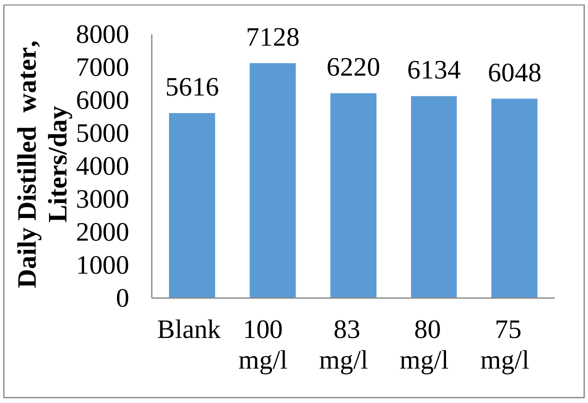

Fig. 9 Daily distilled water productivity for different nanoparticle concentrations

Conclusion

It can be concluded that using the nanofluid particles like TiO_2 improves the heat transfer characteristics of the heat transfer fluid of the solar water distillation system and consequently increases the rate of daily water productivity. The presented system can produce 5616 liters per day for the reference case (without nanoparticle) while it can produce 7128 liters per day in case of using 100 mg/l TiO_2 nanoparticle concentration. It can be concluded that using TiO_2 nanoparticle with a concentration of 100 mg/l increase the daily distilled water productivity by 26.9%. this performance improvement will enhance the utilization of nanofluids in the heat transfer loops to increase the daily rate of productivity. The presented system can produce two types of water, the first one distilled water and can be used for medical and industrial sectors while the second one is the potable or drinking water to cover the water demand needed for human being to life in sustainable life. It is found also that the system can produce distilled water of 5616 liters/day, 6048 liters//day, 6134 liters//day, and 7128 liters//day in case of using TiO_2 with a concentration of 0 mg/l (blank) , 75 mg/l, 80 mg/l, and 100 mg/l respectively.

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