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Effect of Nanoparticles and Phase Change Materials in Enhancement of Solar Stills: A Review

Rasha Hayder Hashim [1], Muna Hameed Alturaihi [2], Saddam K. Al-Rahhem [3], Angham Fadil Abed [4]

[1,2,3,4] *Department of Mechanical Engineering, Faculty of Engineering, University of Kufa, Al-Najaf Governorate, Iraq*

Abstract: *Clean water is becoming increasingly difficult to come by, particularly for those who live in rural and coastal locations. The water must be treated before use, even for individuals who discover subterranean water. The solar still is a free, environmentally responsible gadget that uses green energy to turn salty water into drinking water. Researchers have tried a number of methods to increase the productivity of solar distillers because their daily output is so low. Owing to their advantageous optical and thermophysical qualities, some researchers have employed the nanoparticles alone or in combination with phase-changing materials. Among other approaches, using nanoparticles and solid particles with a diameter between 1 and 100 nm has been used for the past 20 years. Utilizing nanoparticles alone or in combination with phase change materials in active and passive desalination systems, the current review paper explores which nanoparticles are most appropriate for solar stills. After review, it was discovered that the still's use of nanoparticles and phase change materials enhanced both its daily productivity and efficiency.*

Keywords: *Solar desalination, solar still, Review, Nanotechnology, Phase change materials*

I. Introduction

As a result of the growing expense and lack of clean water, solar-powered energy and water desalination has become increasingly important for human existence in recent decades. It has also significantly accelerated efforts to reduce the greenhouse gas emissions associated with burning fossil fuels [1]. In order to produce fresh water, impure (salty or brackish) water has been desalinated using solar energy, a free and abundant energy source [2,3]. Because islands and continents make up 29% of the earth's surface, 71% of it is covered in water. Three percent is made up of fresh water from lakes and frozen water, whereas the rest ninety-seven percent of the planet's water is found in the ocean and salty seawater [4]. Therefore, everyone faces a great problem in meeting the need for clean drinking water. The most effective way to turn salty water into pure, potable form is solar desalination. A straightforward contraption called a solar still transforms saltwater into clean, drinking form. However, the main issue with solar stills is their poor productivity and efficiency [5]. As a result, researchers are working to improve everyday output by developing condensation, evaporation, or both using various forms of nanofluids, including nano with PCM, added fin to the still basin, wicks, stepped design, pyramid design and perforated plate [6-11]. Different metrological parameters are investigated by other researchers to see how they affect the performance of SSs. The glass cover is subject to meteorological elements such as cloud cover and dust, as well as sun intensity [12], air temperature [13], wind speed [14], and relative humidity [15] which that not under control. The most popular approach for decades has been the traditional basin solar still technique, which is trouble-free in terms of ease and upkeep. In order to maximize radiation, the see-through basin with salty water inside that is exposed when solar radiation is present is typically painted black [16]. Water that has changed form (by evaporation) will cause its particles to condense as soon as they come into contact with the cover. Finally, using the appropriate channels, the leftover water is then distributed to various facilities.

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The impact of employing different kinds of nanoparticles and phase change materials on the functionality of solar stills (SSs) has been the subject of many studies recently. On the other hand, SSs with nanoparticles (NPs) and phase change materials (PCM) do not have a specific, achievable review. This study presents a documentary investigation of the application of NPs alone and NPs in conjunction with PCM to enhance the efficiency of SSs.

II. Types of Solar Stills

The low productivity of solar stills has prompted several improvements, which categorize the SSs operating concept in two categories: passive and active. Types of SSs are shown in Figure 1 [17-19] :-

I– Passive: Passive solar stills can either be simple stills or have been enhanced so they just need the sun's radiation for power. These types of passive SSs are less productive and have a simple design without any moving parts, meaning they require less maintenance.

II - Active: The improvements to the active solar stills include preheating the input water using a separate electrical heater or solar collector. To maximize the condensation process, external condensers or fans may be employed in certain situations. There are instances where industrial facilities utilize the energy that is squandered. Such kind of solar still produces more and does so with greater efficiency.

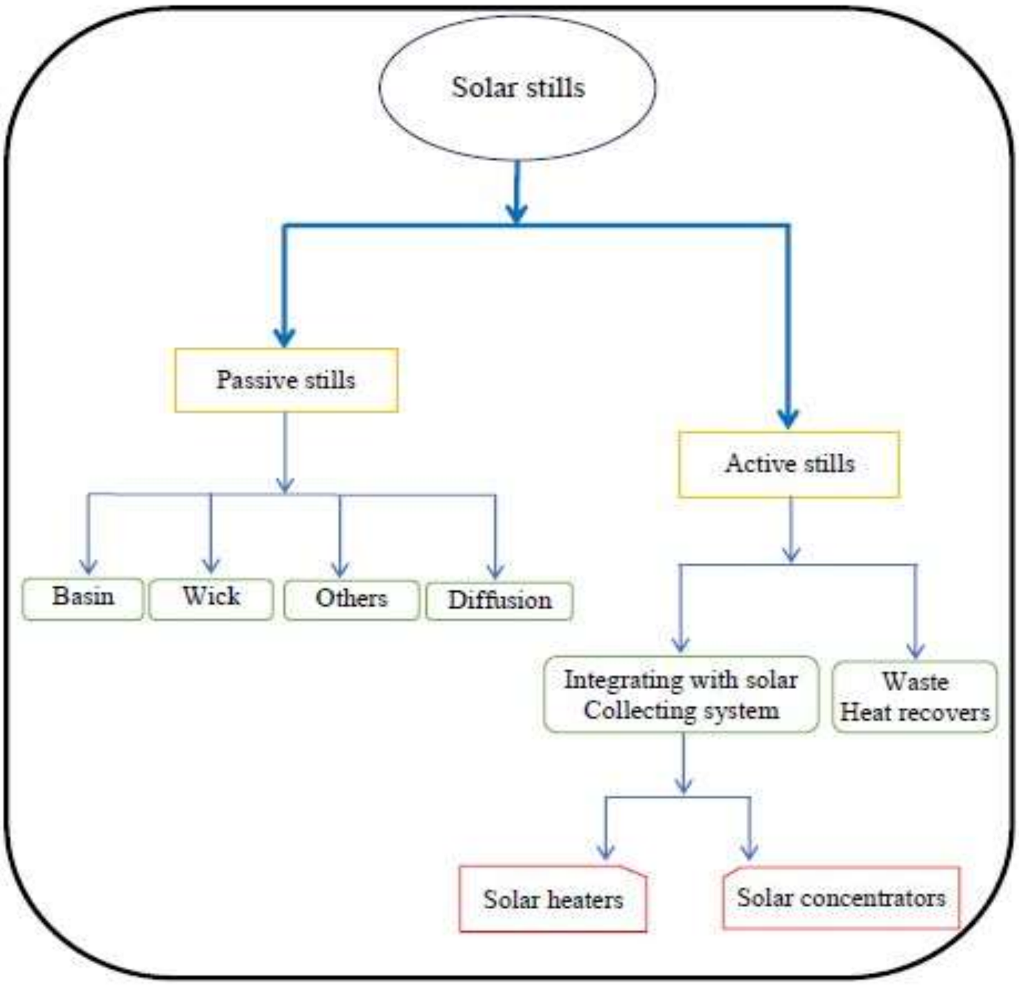

Figure 1 Solar stills systems Sorting **[18]**.

III. Nano particles types

Nanoparticles, which are solid particles with a diameter between 1 and 100 nm, have been utilized for the past 20 years to increase the performance of SS in terms of yield of fresh water. This is undoubtedly a novel method among others. One of the main areas of research in the solar still is the capacity to achieve the necessary thermo-physical properties of NPs through variations in particle concentration, size, and shape. The thermal conductivity and price of the various NPs utilized in the SSs are displayed in Table 1[4].

Table 1. The thermal conductivity and cost of various NPs[20]

Sr. No.	Nano powders	Thermal conductivity (W/m °K)	Quantity	Cost/Rs
1	Aluminium oxide (Al_2O_3)	40	25g	2000
2	Zinc oxide (ZnO)	29	100 g	1500
3	Tin oxide (SnO_2)	36	25g	1500
4	Iron oxide (Fe_2O_3)	7	25g	1750
5	Gold Nano powder (Au)	315	1 g	35,029
6	Titanium dioxide (TiO_2)	8.5	100 g	12,859
7	Copper oxide (CuO)	76	5g	3111
8	Carbon nanotubes	3000-6000	250 mg	19,521
9	Zirconium (IV) oxide (ZrO_2)	2	100 ml.	10,611
10	Silicon nitride (Si_3N_4)	29 30	25g	11,434
11	Boron nitride (BN)	30 33	50 g	4911
12	Aluminium nitride (AIN)	140-180	50 g	5193
13	Diamond Nano powder (C)	900	1 g	8755
14	Silver Nano powder (Ag)	424	5 g	12,917

The sun radiation, which peaks between 11 am and 2 pm, affects how well the solar screen performs. The solar still (SS) reaches its maximum level of freshwater productivity during this time. Additionally, during this time, a significant amount of solar radiation causes the temperature of the glass and the dirty water inside the SS to rise. There will be more water vapor inside the SS as well. Additionally, since it mostly depends on the temperature differential between the basin water and the inside layer of the glass cover, the distillate water will be enhanced. This is because the rate of condensation on the interior surface of the glass cover and the still's increased natural air circulation are to blame. Stated differently, the addition of NPs improves SS performance because of its increased thermal conductivity.

IV. Review of solar still with different types of Nano particles and Nano particles with PCM

Madhu et al. [21] conducted an experimental investigation to determine how the concentration of nanoparticles affected the solar still's performance. Al_2O_3, CuO, and TiO_2 at concentrations ranging from 0.05 to 0.2% were employed in his research. The addition of alumina nanoparticles to the base fluid resulted in a 20% increase in daily energy efficiency, a 7% rise in maximum water temperature, and a 50% increase in still productivity.

The experimental examination was carried out on a conventional solar still that contained nanoparticles and was outfitted with a vacuum pump by Kabeel et al. [22]. They employed CuO and aluminum oxide NPs with (76.5 and 46 W/m.K) thermal conductivities, respectively, for their experiments. Through experimentation, they discovered that, for CuO and aluminum oxide NPs with fans to keep a vacuum, 133.64% and 125% efficiency of still was obtained, respectively. This decreased to 93.87% and 88.97% for CuO and aluminum oxide NPs without fans. Gupta et al. [23] conducted an experimental investigation to increase the productivity of potable water by employing CuO 0.12% weight at two different water depths (5 and 10) cm with white painted side walls. Comparing the results to a traditional solar still, the greatest productivity gain was found to be 30% at a water depth of 10 cm**.** In order to investigate the impact of Al_2O_3 NPs on a solar still with double slope, Sahota et al. [24] conducted an experiment with varying concentrations of particles. In comparison to still not using nanoparticles, the yield obtained when 0.12% volume of Al_2O_3 was employed was (12.2% for 35 kg)of water and (8.4%) for (80 kg) of water.

An experimental study was provided by Sain and Godhraj [25] to increase the productivity of potable water. They investigated how mixing (Al_2O_3) nanoparticles with black paint affected the performance of solar stills. Several stills are examined at varying water depths of 0.01, 0.02, and 0.03 meters. In compared to conventional solar still findings, the highest results showed a 38.09% increase in production and a 12.18% improvement in thermal efficiency at a water depth of 0.01 meters. In a different study, Modi et al. [26] used Al_2O_3 nanoparticles to conduct experiments on a double basin SS of single slope. The mass of Al_2O_3 NPs was changed during the experiment, from 0.01% to 0.20%. In comparison to a still without nanoparticles, the distilled output at 0.20 % mass of Al_2O_3 is 2.6% whereas at 0.01% mass of NPs is 17.6% . Using nano-composite PCM, Rajasekhar et al. [27] experimented on a single slope solar still in this manner. Nanoparticles of aluminum oxide (Al_2O_3) were combined with paraffin wax. The total yield of 2800 mL per day was discovered. There was a (60% and 44.40%) increase in daily efficiency when PCM with Al_2O_3 and PCM were utilized, respectively. When PCM and PCM NPs were present, water yielding increased by (49.82% and 72.85%), respectively. Rashidi et al. [28] used varying volume fractions of (Al_2O_3) nanoparticle materials combined with pure water to focus their numerical work on improving water absorptivity of solar radiation. The findings indicate that a solid volume fraction of 5% for nanoparticles still resulted in a 25% increase in productivity. Sharshir et al. [29] conducted an experiment utilizing nanoparticles on a pyramid solar still fitted with an evacuated tube in a different study. Three types of pyramid solar stills are employed in experiments: the standard pyramid SS, the modified pyramid SS with evacuated tube, and the modified pyramid SS with NPs. Two distinct nanoparticles, such as carbon black and copper oxide, with a 1.5% weight concentration, are used in this experiment. Comparing the modified SS to the conventional pyramid SS and the classic SS, the yield of pure water raised by 4.77% and 26.6%, respectively. The yield of water rose by 27.85% and 54.85%, respectively, when a modified SS containing CuO was utilized instead of a traditional solar still or a standard pyramid solar still. Comparing a modified sun still with carbon black nanoparticles to a regular pyramid SS and a classic SS, respectively, showed increases in fresh water output of 33.59% and 57.098%. The results also showed that the SS with modification had a daily efficiency of 50%, which rose to 61% for the modified SS when CuO was added, and 64.5% when carbon black was added. Two distinct solar stills with the same dimensions were used for the experiment by Elavarasi et al. [30]. In the first, paraffin wax was still used, but in the second, silicon oil and CuO NPs were combined. Using copper oxide nanoparticles with silicon oil resulted in a 25% increase in output.

An additional strategy to boost effectiveness Elfasakhany et al. [31]experiment, which used PCM (paraffin wax) as and a single basin SS to contain copper oxide nanoparticles, was carried out. Three distinct examples were used for the experiments: case 1 involved continuing without PCM, case 2 involved continuing with PCM, and case 3 involved continuing with PCM and copper oxide nanoparticles. They showed that, in comparison to cases 1 and 2, case 3's overall daily output increased by 125% and 106%, respectively. When PCM and a combination include PCM and CuO NPs were added to the still, respectively, the still's operating duration increased to five and six hours, respectively. The experiment conducted by Nazari et al. [32] was conducted on a single slope SS and used CuO NPs and a thermoelectric cooling channel. They discovered that 81% more pure water was produced and 80.6% greater energy efficiency was produced in a SS with a thermoelectric cooling of channel when 0.08% of CuO NPs were utilized. Dsilva et al. [33] numerical analysis on a solar still using latent heat storage material and nanoparticles was conducted. Paraffin wax was utilized as a medium for latent heat storage, while TiO_2 was utilized as NPs. When titanium oxide was mixed with paraffin wax instead of just paraffin wax, the output increased to 6.6 L/m^2 per day. Compared to a conventional solar still, an energy storage material including nanoparticles produced an 88% increase in production from the still. The experiment was carried out on a single slope solar still by Somanchi et al. [34] using two distinct PCM, such as magnesium sulfate hexahydrate and sodium sulfate mixes with titanium oxide (TiO_2) NPs. They discovered that magnesium sulfate hexahydrate is more efficient than a combination of titanium oxide nanoparticles and sodium sulfate. Using NPs, Panchal et al. [35] carried out the experiment on a stepped solar still. For the experiments, different concentrations of titanium and magnesium oxide were utilized. The concentration range of nanoparticles utilized in the experiments was 0.1% to 0.2%. According to the results, 33.33% more fresh water was obtained at a concentration of 0.1% magnesium oxide, while 45.38% more was obtained at a concentration of 0.2%. In a similar vein, titanium oxide produced 4.1% fresh water at a concentration of 0.1% and 20.4% at a concentration of 0.2%. Higher fresh water output from a still is a result of magnesium oxide's low specific heat capacity and strong thermal conductivity as compared to titanium oxide. Using fumed silica nanoparticle in black paint, Sathyamurthy et al. [36] conducted the experiment on a stepped solar still layer. The range of nanoparticle concentrations is 10–40%, and it has been observed that an increase in nanoparticle concentration beyond 20% has no discernible impact on the final product. In comparison to regular black paint, the output rose by 27.2% when 10% concentration of nanoparticles was utilized in the experiment. Similarly, compared to regular black paint, the production increased by 34.2%, 18.3%, and 18.4% when 20%, 30%, and 40% concentrations of nanoparticles were employed.

Using a combination of paraffin wax PCM with CuO and Al_2O_3 NPs, Shoeibi et al. [37] modified a solar distiller. They found that the productivity enhancement for CuO and Al_2O_3 nano-based PCM was 55.8% and 49.5%, respectively. The use of graphene nano-powder dispersed in ratios (0.2, 0.4, and 0.6) wt% with pure paraffin wax and placed underneath the absorbent surface of a solar still was the practical study presented by Safaei et al. [38]. The results showed that the daily yield of the SS contain PCM with nano, 0.6 wt.% was 2.5 L/0.4 m^2 and an average 25% enhancement as compared to the SS with PCM only**.**

Thakkar and Hitesh [39] conducted an experimental investigation on the use of PCM (paraffin wax) and aluminum oxide NPs to increase SS productivity utilized three sun stills for their research. The first is a traditional still; the second uses only nanoparticles (Al_2O_3); and the third uses composite PCM (paraffin wax) with nanoparticles (Al_2O_3). The output of the second and third stills was found to be 92% and 106%, respectively, greater than that of the traditional solar still.

Nanoparticles of carbon black (NPs -CB) combined with PCM were used by Abdelaziz et al. [40] to fill the cavity beneath a v-corrugated trough of a tubular SS. In addition, the system included a wick material as well as CB-NF(nano fluid). It was examined using PCM alone initially, and later PCM based on CB-NPs. For pure PCM and (CB-NPs) combined with PCM, respectively, the productivity grew by (73.56% and 88.84%), with a thermal efficiencies climbed by (70.28% and 82.16%). A study conducted by Rajasekhar and Eswaramoorthy [41] used (Al_2O_3) distributed in paraffin wax to improve the productivity of solar stills. As a consequence of the final analysis, the daily efficiency of the solar still was calculated to be 45% when it included NPCM, 40% when it included PCM alone, and 38% when it did not include any thermal storage. Experimental research indicates that solar stills integrated with phase-changing nanocomposite materials perform better than those with and without the materials on their own. Several nano-based additives were employed by Kandeal et al. [42] to improve the double-slope distiller's performance. After submerging CuO-NF and copper chips in saline water, the SS was tested twice: first with PCM alone and again with PCM combined with nanotechnology. For pure PCM and NPs-PCM, respectively, the productivity rose by (83.7% and 113%,) the thermal efficiencies by (97% and 112.5%). Miqdam and Kazem [43] conducted an experimental study to improve the productivity of solar stills utilizing aluminum nanopowder and paraffin wax. According to the results, during the examined time, distiller productivity was 1.91 L/m^2.day, 2.347 L/m^2.day, and 2.7875 L/m^2.day for conventional, still with PCM, and still with NPCM, respectively.

PCM combined with CuO-NPs and reflectors was employed by Abdullah et al. [44] to improve a tray distiller. With a 51.5% thermal efficiency and a daily yield of 5 L/m^2/day, the yield jumped by 108%**.** CuO, TiO_2, and GO nanoparticles with a 0.3% weight concentration were the three types of nanoparticles that Rufuss et al. [45] used to study the impact of enhancing the thermal characteristics of PCM on the productivity of SS. The outcomes were contrasted with the traditional SS. In order to assess the SS's performance with and without PCM, four SS were designed and produced. Additionally, the scientists investigated how PCM with nanoparticles affected the production of freshwater, water temperature, and storage temperature. The findings showed that, for the SS with PCM integrated with CuO, TiO_2, and GO, respectively, the freshwater production was approximately 5.28, 4.94, and 3.66 L/m^{2}d. Conversely, the CSS's freshwater production was roughly 3.92 L/m^{2}d.

Methre and Eswaramoorthy [46] carried out experiments to look at how nano-composite PCMs affected the performance of the SS. Al_2O_3 nanomaterials (50 nm in a two concentrations, 4% and 2% for Nano PCM type 2 and Nano PCM type 1, respectively) combined with paraffin wax. Additionally, the thermo-physical characteristics of nano-composite PCMs are examined. It was discovered that when Al_2O_3 NPs (NPs- PCM type1 (2%) and NPs- PCM type 2 (4%) are used in bigger weight fraction ratios than paraffin wax alone, the SS energy and energy efficcies are improved. Furthermore, (4.17 L/day, 30.42%, and 4.93%), respectively, are the daily average production, energy efficiency, and energy efficiency.

V. Conclusions

The employment of PCM and NPs has increased recently in an effort to boost the SS's performance and output. From theory to the production model, this examination has addressed several essential facts and ideas regarding solar stills. The article discusses many methods of improvement, such as nanotechnology and storage materials.

In order to enhance the performance of SSs, we reviewed the research conducted on them that uses various NPs or NPs combined with PCM. The primary findings and conclusions are emphasized as follows:

1- The yield of a solar still is affected by a number of uncontrollable elements, including solar radiation intensity, air temperature, air velocity and relative humidity.

2- 2. Compared to a conventional solar still, the still's overall efficiency was raised by employing nanoparticles since they improve thermal conductivity.

3- The output from the still increased when the Phase Change Material (PCM) and NPs were combine because PCM increases latent heat.

4- Finally, it is discovered that, when compared to other nanoparticles, aluminum oxide NPs are the most appropriate for solar water desalination.

VI. References

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