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## Application of Nanomaterials in Water Desalination to Enhance Solar Still Productivity

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**Abstract**

Much care is being given for the issue of sustainable development in the last few years. Among these efforts, researchers are giving much interest to saving water resources, energy conservation and protecting the environment from pollution resulting from the use of fossil fuel. Zinc oxide (ZnO) nanoparticle integration in solar water desalination systems is a novel way to increase freshwater output using solar energy. Compared to traditional solar stills, this technique shows a notable increase in productivity and efficiency. The application of utilizing ZnO nanoparticles in solar water desalination has been investigated in this study. The prepared materials have been characterized using SEM technique. Different operating parameters have been examined such as, The parameters of ambient temperature, basin temperature, glass temperature and solar intensity. the results of applying ZnO nano particles have been compared to that of utilization of $TiO_2$ and $TiO_2$ nano particles in solar water desalination. A total productivity amounting to 1645ml, 1560 ml and 1115 ml was obtained per day from stills having nano-ZnO, nano-$TiO_2$ or $TiO_2$ particles (0.6 g/l), respectively. The still efficiency is calculated to be 34.93%, 48.87% and 51.53% when $TiO_2$, $TiO_2$ NPs and ZnO NPs are used, respectively. Thus, ZnO showed the best productivity, followed by $TiO_2$ and finally by $TiO_2$ particles.

**Keywords**: Solar still productivity; Soar water desalination productivity; Application of Nanomaterials

## 1. Introduction

Numerous delamination techniques have been modified, Research and development is now on for a few of them. For desalination, the two primary technologies that are utilized are membrane and thermal desalination method. In addition to the various processes that are part of both technologies, there are other, less common technologies like freezing and ion exchange. Energy is required for all of these devices to function. Conventional energy or renewable energy is generally used in these methods [1], fig (1).

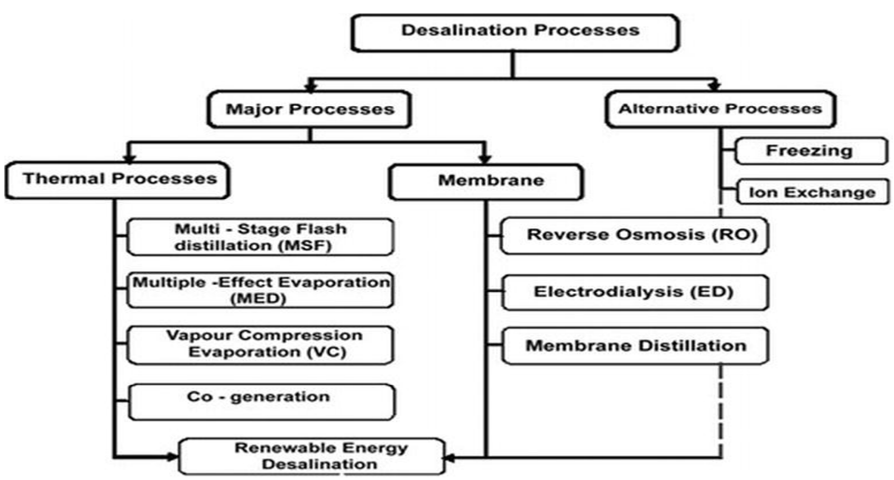


**Figure (1): Types of Water Desalination Techniques [1]**

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One of the most significant ways to get clean water using a simple and cheap technique is solar distillation of salt water [2-4].In recent years, solar distillation has emerged as a leading solution for addressing global water scarcity [5-7]. Researchers are always looking for new methods to harness energy [8-11]. Solar energy, whether used for thermal cooking, reflecting lenses, or cells, can reduce the amount of energy needed to burn fuel by over ten thousand times [12, 13]. Conventional solar distillation units are among the most basic; they can achieve thermal efficiencies of up to 50% and generate water at rates ranging from 1 to 4 liters/$m^2$/day [14]. Solar distillation's efficiency is conditional on a number of variables, some of which are inherent to the distillery's design and others of which are influenced by external influences, such as the surrounding temperature and the quantity of sunlight [15, 16]. Active solar stills and passive solar stills are the two primary categories of solar stills[17,18]. Solar stills with additional components, including concentrators or collectors, have been considered in some research [19]. Nanofluids containing nanoparticles such graphite, CuO, $SiO_2$, $TiO_2$, and $Al_2O_3$ have been the subject of current research aimed at improving the solar collector's performance [20-23]. Energy storage and exchange materials, such as nanostructures with efficient steam generation, nanofluids and nanoparticles, nano-embedded PCMs (Phase Change Materials), and sensible heat storage materials for solar desalination, were covered in a review article [24].The incorporation of non-metallic nanofluids into the base fluid as a means to improve solar still performance was the subject of another review[25] . Alluvial, Cu, Zn, and $TiO_2$ nanoparticles are covered in this review. Incorporating $Al_2O_3$ into a solar-still desalination system improved efficiency, decreased energy consumption, decreased heat loss, and increased distillate yield, according to many studies. A hybrid nanofluid consisting of cerium oxide ($CeO_2$) nanoparticles and multi-walled carbon nanotubes (ratio of 80:20) has been utilized. The productivity of conventional still (CS) has been recorded to be 920 ml, whereas the modified still (MS) reached a whopping of 1430 ml. Reduction in TDS levels of salt water using MS are (96.38%) lower than those of CS (92.55% )[26] . The characteristic features of nanoparticles and the recent developments, in the usage of nano-based PCM and pure nanoparticles as a thermal storage medium in solar stills, were discussed in a review paper[27] . The study demonstrated the utilization of both pure nanoparticles and nanoparticles integrated with PCM. This method has been selected as the most effective way to increase still productivity because it increases PCM thermal conductivity compared to base fluids. Using nanoparticles in a solar still enhanced its efficiency and daily productivity, according to a review report published in 2021[28] . The effects of using copper oxide (CuO) nanoparticles on a single-slope solar still's performance has been proposed. CuO converted solar still to a thermal energy storage unit. According to the experimental results, compared to the standard solar still, the combined use of nanoparticles increased accumulated production by 26.77%[29] . There was a discussion of the latest advancements in using micro/nano-materials to create high-performance solar stills [30]. Particle concentration, material type, system setup, and sun intensity are among the several variables that could affect the efficiency and productivity gains reported in the evaluated research. Furthermore, a novel fundamental ideas like nanofluid operating principle, heat transmission in nanofluid, and various preparation methods were covered in a recent study [31]. One significant finding is that, up to a certain point, the thermal conductivity of nanofluids is directly proportional to the concentration of nanoparticles. To maximize the yield of pure water, it is necessary to use the optimal concentration of each nanoparticle, which is determined by their thermal conductivity. In order to enhance the performance of the solar still, some researchers [32] created a new layering 2-D MXene from 3-D MAX phase and used it as a covering material. The thermal conductivity and solar absorption of the turpentine oil/black paint solution were greatly enhanced with more MXene loading. An increase of 6% in water temperature and a total water yield of 2.07 kg were caused by the absorber's increased heat transfer rate to the water, which was made possible by the 0.1 wt% MXene coating. With 0.1 weight percent MXene in the absorber black paint layer, the SS had an average energy efficiency of 36.31%.

The primary objective of a recent study[33] was to examine the most noteworthy advancements in energy-related desalination nanotechnology. In light of the achievements and outstanding issues, several findings and recommendations for further study are put forth. Moreover, Several novel materials have been investigated in the literature for effective water generation by solar stills[34] . Among the novel materials that have recently attracted attention are nanoparticles, nanofluids, composite phase change materials (PCMs), PCMs incorporating porous materials, and PCMs incorporating heat pipes. According to the results of the review, modern energy storage materials have a major impact on how much more productive solar stills are than older models. Using PCM/porous materials can also increase solar desalination productivity; research shows that solar still water production can be boosted by 40 to 70%. An integrated model comprising conventional solar still (CSS), flat plate collector (FPC), and parabolic trough collector (PTC) was put through its paces in order to produce drinkable water using nanomaterials such as ZnO, $Al_2O_3$, $TiO_2$, and CNTs, according to a study [35]. The integrated system involvng CSS, FPC, and PTC employing CNT based nanofluid had the greatest water production rate of 0.478 $lm^{-2}$ $h^{-1}$ (LMH), which was 153% greater than the rate of CSS without nanoparticles, according to the testing data. At a concentration of 0.1 wt%, the integrated system produced 0.458 LMH of water from ZnO nanofluids, 0.466 LMH from $TiO_2$, and 0.466 LMH from $Al_2O_3$ nanofluids. Zinc oxide composite has been applied in solar desalination to enhance solar desalination process, a sponge-like CuO/ZnO-PVA/PSS hydrogel (CZO-HH) has been synthesized by incorporating CuO/ZnO (CZO) heterojunction nanoparticles, that possess an excellent photothermal properties, into poly(vinyl alcohol) (PVA) and polystyrene sulfonic acid

(PSS). A novel integration between the nonradiative relaxation effect in semiconductor photothermal materials and the unique structural properties of hydrogels has been identified. The importance of energy management and energy mass transfer in the process of solar energy utilization has been revealed to enhance the efficiency of photothermal conversion [36]

This research tries to find ways to use various nanomaterials to make solar distillers more efficient. Materials such as ZnO nanoparticles, $TiO_2$ particles, and $TiO_2$ nanoparticles are investigated. The study presents the consequences of their incorporation and compares the various materials in terms of productivity and efficiency. Moreover, Zn oxide has been impeded on carbonized oil palm fiber (ZnO-CF) to investigate effect on water desalination performance. Water evaporation rate and efficiency of ZnO-CF are reported to be 1.739 kg $m^{-2}h^{-1}$ and 98.96 %, respectively. ZnO-CF possesses an excellent desalination and bactericidal properties in treating lake water and seawater. Because of its many uses, ZnO-CF is a good option for upcycling biomass waste from the oil palm sector, which advances environmentally friendly water desalination technology [37].

## 2. Materials and Method:

### *2.1. Materials:*

Analytical grade materials are used in the present study and it were obtained from Sigma Aldrich, as follows: sodium chloride for the preparation of salt water with 2000 ppm salt concentration, titanium oxide $TiO_2$ with a purity of 94%, titanium oxide nanoparticles (99.5% trace metals basis, particle size 21 nm (TEM), surface area 35-65 $m^2/g$ (BET), density 4.26 g/ml at 25°C), zinc oxide nanoparticles (ZnO NPs) (particle size: less than 100 nm) and anatase $TiO_2$ catalyst with specifications (fine white powder, particle size: 0.05 mm and density: 0.94 $g/cm^3$).

### *2.2. Method:*

#### *2.2.1. Experimental setup:*

The experimental setup consists of a series of basin type solar stills with stainless steel basins and an area of 1 $m^2$. It is covered with a 0.003 m thick glass pane and its bottom is blackened to absorb the maximum solar radiation. The water distillate is collected on the lower side of the glass cover, moved through a water passage and ultimately collected in a graduated cylinder. All experiments are performed in batch mode and at room temperature. Stills are fitted with thermometers to measure: basin temperature, vapour temperature and inside glass cover temperature. The experimental setup has been displayed in Fig (2.a) and the experimental scheme has been illustrated in fig (2.b).


**Figure (2.a): Experimental Setup**

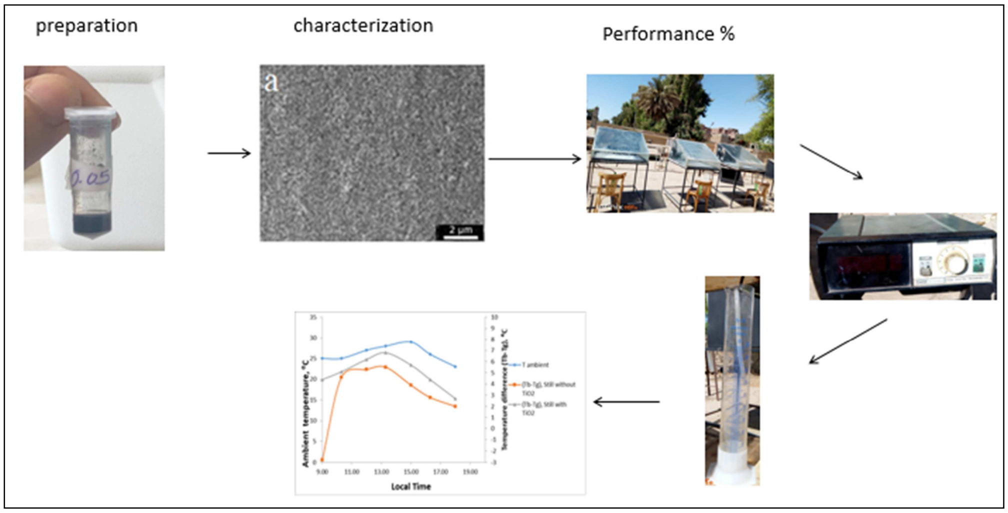



**Figure (2.b): The Experimental Scheme**

### *2.2.2. Solar desalination experiments:*

Equal volumes of saline water are prepared and an energy storage material $TiO_2$ particles (800 ppm), $TiO_2$ NP (15 %) or ZnO Np (15%) is added to saline water and mixed well in a mixing vessel then poured into the solar still. Concentration of the added materials have been expressed in ppm and wt% , in comparison section the concentrations of added materials have been expressed in terms of wt/vol (0.15, 0.6, 1.0, and 1.2 g/l) The fourth still is being used as a reference still for the object of comparison. The hourly distillation rate (ml/h/m$^2$), solar intensity (W/m$^2$), and temperatures (basin temperature, glass cover temperature, vapor temperature, and ambient temperature) are recorded ($^O$C). The internal glass temperature and the water temperature in the basin were measured with the digital multipoint meter (Fluke) "2166A" with thermocouples. Ambient temperature was measured using a standard thermometer. The volume of distillate was measured by collecting it in 1000 ml graduated cylinders, and solar intensity was measured using the "Eppley Black and White Pyranometer", model 8-48 with a sensitivity (conversion factor) of 8 µV/Wm$^µ$. The hourly collected distillate from each still is measured, recorded and used later on for calculating daily still productivity and efficiency of different stills. Temperatures readings are also recorded hourly and its change with time is plotted together with the values of solar intensity. The utilized measuring devices have been illustrated in table (1). All experiments were conducted in the Faculty of Engineering, Minia University, Egypt (30.45' east longitude), in 2021, on several consecutive days between 9 am and 6 pm during the summer months (July and August 2021).

**Table (1): apparatus and measuring devices**

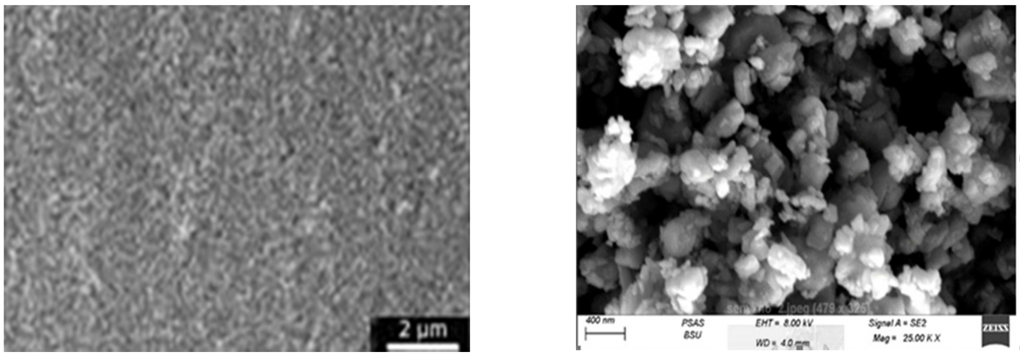
| No. | Device | Company & model | Use |
|---|---|---|---|
| **1** | Solar radiometer | Eppley Black and White Pyranometer", model 8-48 | Measuring solar intensity in watt/m$^2$ with a sensitivity (conversion factor) of 8 µV/Wm$^µ$ |
| **2** | Electronic weighing balance | Advenrurer DHAUS | Weighing purposes |
| **3** | Agitator of varying speed | | For mixing |
| **4** | digital multipoint meter with thermocouples | (Fluke) "2166A" | To measure temperature in side still |
| **5** | Thermometer | | Ambient temperature measurement |
| **6** | viscometer | | Measuring vicosity |

## 3. Results and discussion:

This section has been divided into two parts, the first part is characterization of prepared nano material and the other pat is estimation of solar desalination behavior, All experiments were conducted in the Faculty of Engineering, Minia University, Egypt (30.45' east longitude), in 2021, on several consecutive days between 9 am and 6 pm during the summer months (July and August 2021).

### *3.1. Characterization of material*

Characterization of utilized catalysts has been performed and the results are displayed in Figs (3.a) & (3.b)




a b

**Figure (3.a): SEM Characterization of $TiO_2$ Nanoparticles, Fig(3.b): SEM Characterization of ZnO Nanoparticles**

From fig (3.a) it is clear that, a catalyst possess a uniform surface poses and homogeneous grains has been produced. On the other hand, fig (3.b) represents SEM image of nano-ZnO nanoparticles. A homogeneous and consistence surface has been synthesized. Consequently the physical properties of the utilized nanomaterial have been summarized in table (2).

**Table (2): The physical properties of the utilized nanomaterial**

| Physical properties | ZnO nanoparticles | Ref | $TiO_2$ nanoparticle | ref |
|---|---|---|---|---|
| Morphology and Crystal Structure | ZnO nanoparticles have been synthesized as, nanorods, nanowires, nanospheres, its crystal structure is a hexagonal wurtzite. | [38-40] | Titanium dioxide nanoparticles exist in three main crystal structures, also known as polymorphs:Anatase, Rutile and Brookite: This is another | [41] |
| Size and Surface Area | Its nano designation refers to particles with diameters of less than 100 nanometers, ZnO nanoparticles have a large surface area to volume ratio. | [42, 43] | MolecularWeight: 79.89 g/mol, Melting Point: 1750 °C., Density: The relative density is around 4.27 g/cm³ at 25°C. | [45], [47] |
| Electrical properties | ZnO is an n-type semiconductor. The electrical properties, including AC conductivity and dielectric constants, can be explained by the Maxwell-Wagner model. | [38], [44] | Titanium dioxide is an n-type semiconductor, The electrical conductivity of $TiO_2$ nanoparticles is influenced by factors like temperature and the presence of defects. | [45] |
| Thermal properties | Bulk ZnO has a relatively high thermal conductivity. | [46] | | |

### 3.2. Effect of adding $TiO_2$ particles in the still basin:

Two solar stills with one basin and one inclined surface are used. $TiO_2$ (800 ppm) was added to one still, while the other still served as a reference. Fig.4 shows the hourly productivity of the reference still and the solar still with $TiO_2$. It can be seen that the effect of adding $TiO_2$ is more evident around noon due to the high solar intensity and the consequent activation of the photothermal properties of $TiO_2$ [48, 49]. When thermally activated, $TiO_2$ acts as an energy sink absorbing solar energy and transferring it to the basin water thus heating it. The daily productivity of a single-basin solar still without $TiO_2$ addition was 870 ml/m$^2$ /day, and with $TiO_2$ addition was 1245 ml/m$^2$ /day. Thus, the addition of $TiO_2$ increases the productivity of the distillation system by 43.1%. These productivity values correspond to a system efficiency of 28% for the reference still and 39% for the still with $TiO_2$. The cumulative production of both stills has been recorded in table (3).

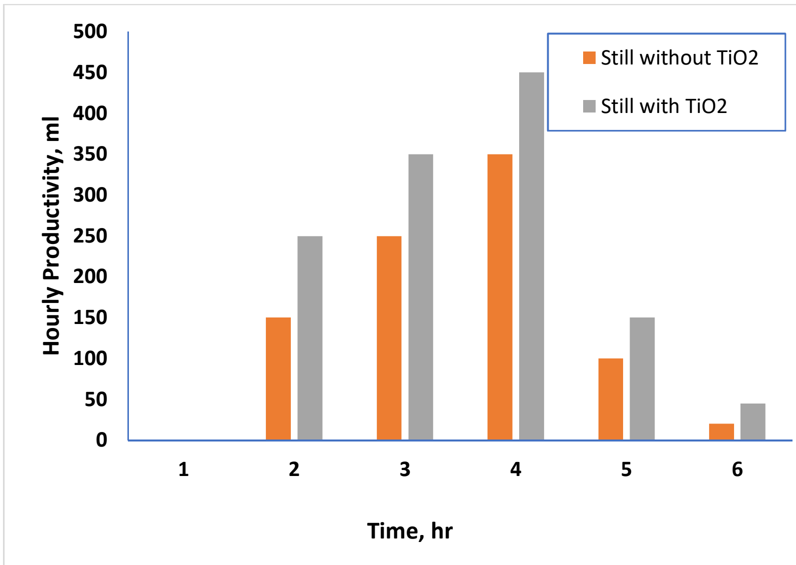



**Figure (4): Effect of Adding $TiO_2$ on Hourly Still Productivity, (4/07/2021)**

**Table (3): Cumulative Production of Both Stills**

| Still without $TiO_2$ | Still with $TiO_2$ |
|---|---|
| 0 | 0 |
| 180 | 250 |
| 250 | 350 |
| 350 | 450 |
| 100 | 250 |
| 50 | 45 |
| sum | Sum |
| 870 ml/m$^2$/day | 1580 ml/m$^2$/day |

#### 3.2.1. Effect of temperature gradient (Tb-Tg) in presence of $TiO_2$ particles:

An important factor in the advancement of distillate production is the temperature gradient that exists between the inner glass cover (Tg) and the basin (Tb). Figure 5 shows the water distillation unit with $TiO_2$ and the reference unit with respect to the temperature gradient. Evidently, the $TiO_2$-added still outperforms the reference still in terms of productivity due to its greater temperature gradient values [26]. The fact that the temperature gradient is negative first thing in the morning is an intriguing observation. One possible explanation is that the glass cover is heated by the sun's rays first thing in the morning, creating a negative temperature gradient between the glass and the basin [50]. Positive temperature gradient values are the outcome of the pool's heating up over time. Hence, since the temperature gradient was negative in the morning, no harvest was accomplished.

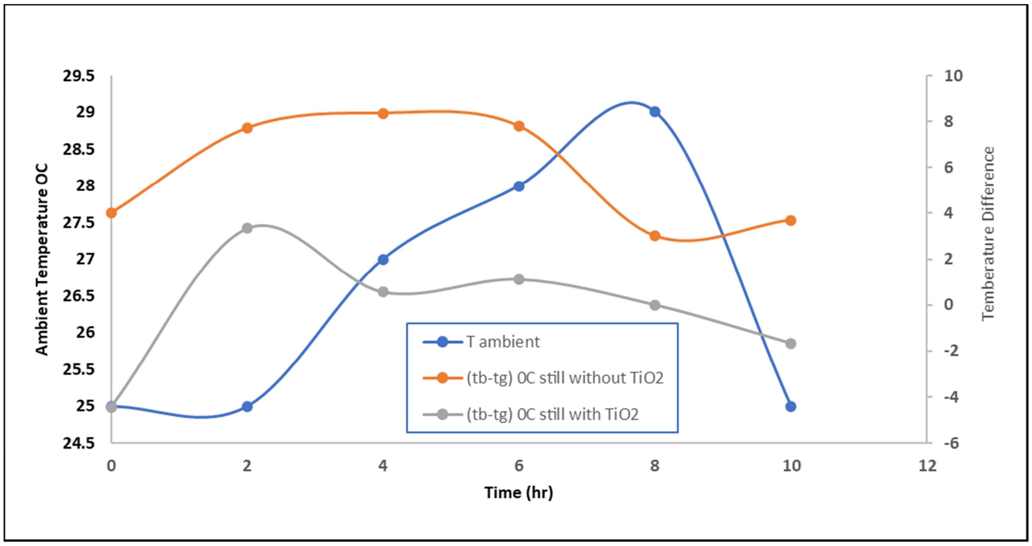



**Figure (5): Change of Temperature Gradient (Tb-Tg) with Time for Stills with and Without $TiO_2$ (4/4/2021)**

### 3.2.2. Effect of Solar Intensity (SI) in presence of $TiO_2$ particles:

The effect of change in solar intensity during the day on the hourly productivity of the distillery is shown in Fig. 6. From this figure, it can be seen that both the SI curve and the distillers' productivity curve have the same trend, i.e., lower values at the beginning and end of the day and maximum values at midday. Thus, distillation productivity is proportional to solar intensity [51]. The maximum hourly productivity of the stills with and without $TiO_2$ is 550 and 340 ml/h/m$^2$, respectively, with a maximum solar intensity value of 690 W/m$^2$ at solar noon.

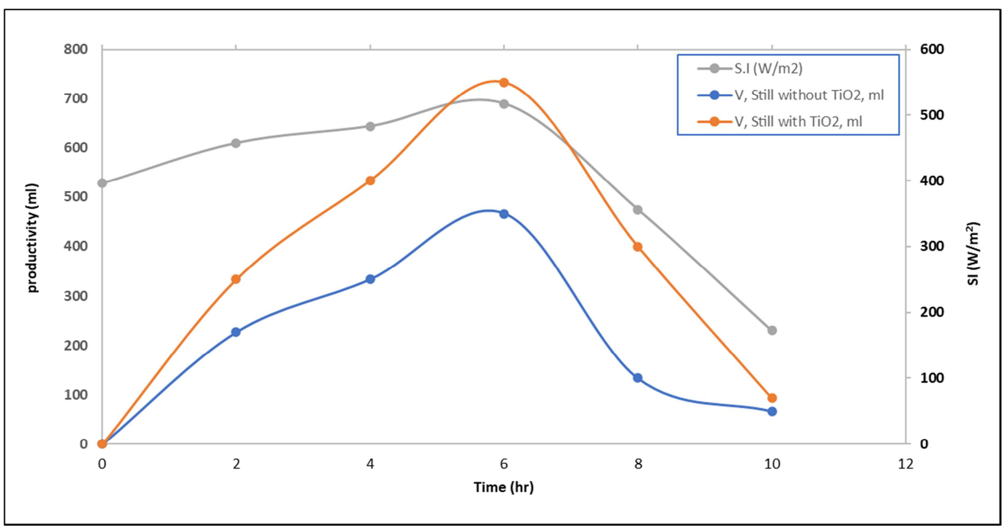



**Figure (6): Effect of Solar Intensity (SI) on Hourly Still Productivity,(4/07/2021)**

## 3.3. Effect of using Nano particles on solar still productivity:

### 3.3.1. Effect of using $TiO_2$ and Nano $TiO_2$:

In the present experiments, the effect of using $TiO_2$ as nanoparticles on solar still performance is experimentally investigated. Two solar stills were used; $TiO_2$ particles were added to the salt water in one still and nano-$TiO_2$ was used in the other still. The same catalyst concentration is used in both stills (0.15 wt%). Fig. 7 shows the hourly productivity of both stills. It is clear that the use of $TiO_2$ nanoparticles leads to an increase in solar still performance compared to solar still with $TiO_2$ particles. This is due to the photothermal activation of $TiO_2$ NP when exposed to solar radiation, an action which results in solar energy being stored in the nano-material, and is consequently transferred to the basin water causing an elevation in its temperature and enhancing its evaporation. Fig. 7 shows that the effect of using nanomaterials to increase the productivity of stills becomes more pronounced around noon, and that this effect diminishes as we approach the sunset hour. A maximum increase of 30.1% in distillation productivity is achieved at 13:00 by using nano-$TiO_2$.

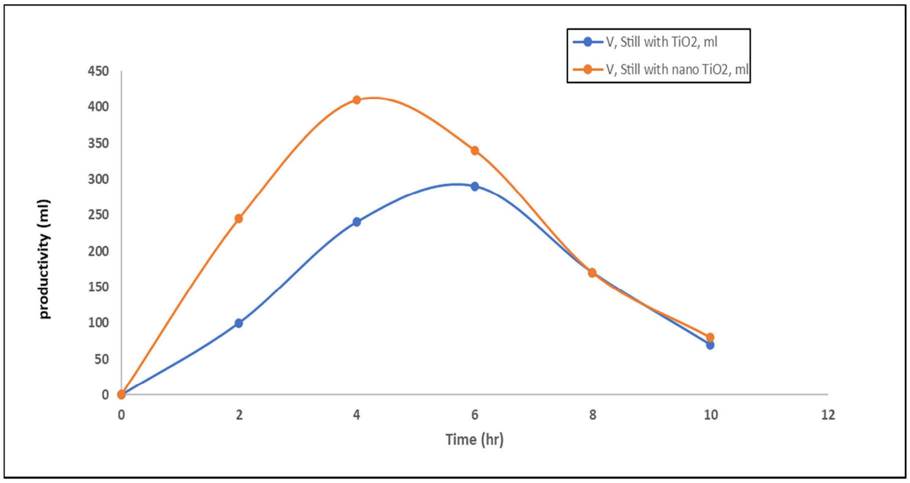



**Figure (7): Effect of Using $TiO_2$ NPs on Hourly Still Productivity, (1/08/2021)**

Moreover, the pool temperature of the still with nano-$TiO_2$ is higher than that of the still with $TiO_2$ particles, as shown in Fig. 8. This is related to the photothermal properties of $TiO_2$, which are supported by the higher solar intensity at noon [52]. This increase in pool temperature is one explanation for the higher productivity of stills with $TiO_2$ NPs [53].

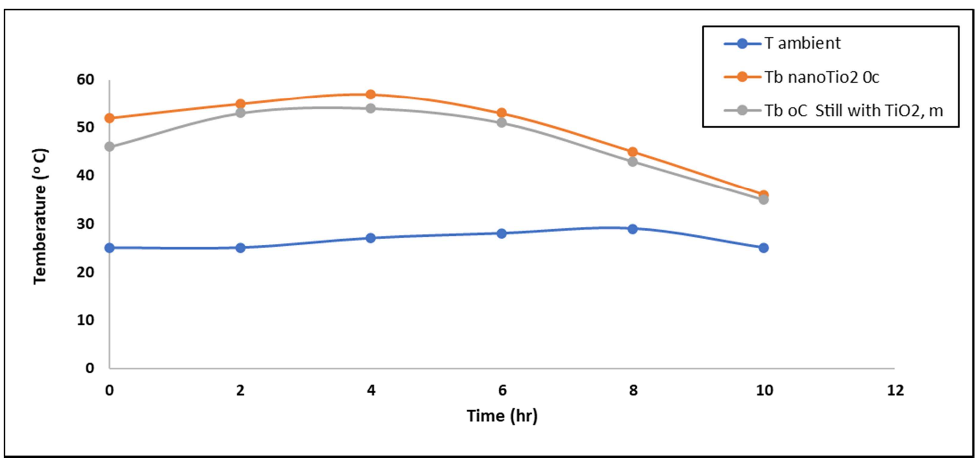



**Figure (8): Change of Basin Temperature with the Addition of $TiO_2$ NPs, (1/08/2021)**

Figure 9 shows the variation of hourly distillation power with solar intensity for stills with $TiO_2$ and $TiO_2$ NPs. This figure shows that all curves have almost the same trend, i.e., low values at the beginning of the day and at sunset and maximum values at solar noon. The positive effect of the addition of $TiO_2$ in the form of nanoparticles is more evident in the morning region and reaches its maximum value at noontime. This is due to the photocatalytic effect of $TiO_2$ particles, which becomes more evident in the presence of sunlight [54, 55]. The maximum hourly distillation productivity of 410 ml/h/$m^2$ is obtained for the distillation unit with $TiO_2$ NPs compared to 290 ml/h/$m^2$ for the distillation unit with $TiO_2$ particles; both at a maximum solar intensity of 710 $W/m^2$ at solar noon. The daily productivity of the stills with $TiO_2$ and $TiO_2$ NPs is shown in Fig. 10 (with values of 1570 and 920 $ml/h/m^2$ for still with $TiO_2$ NPs and still with $TiO_2$, respectively). Thus, the daily productivity of the stills is increased by 70.7% by using $TiO_2$ NPs.

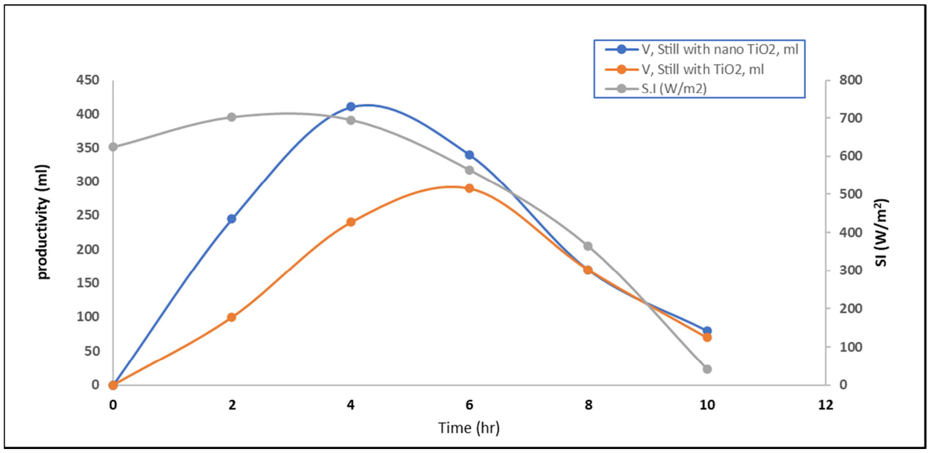



**Figure (9): Change of Still Hourly Productivity with Solar Intensity**

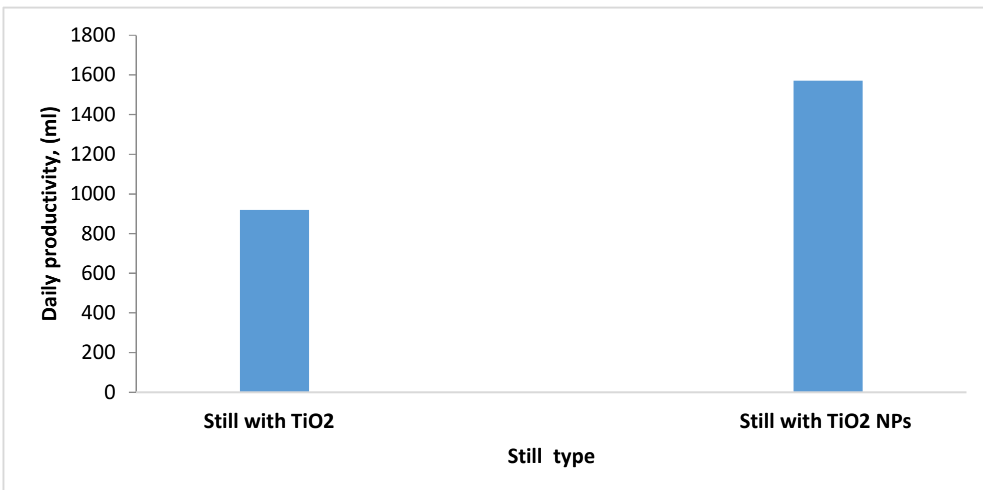



**Figure (10): Effect of Using $TiO_2$ and $TiO_2$ NPs on Daily Still Productivity, (1/08/2021)**

**3.2.2. Effect of using different Nano-materials: ($TiO_2$ NPs and ZnO NPs):**

Here, we look at how two distinct nanomaterials affect solar distillers' efficiency. Titanium dioxide and zinc oxide are the solid nanoparticles that were examined. Researchers tested the system at 0.15, 0.6, 1.0, and 1.2 g/l of nanoparticles in pool water to see how it performed. The cumulative productivity of stills including $TiO_2$ particles, $TiO_2$ NPs, or ZnO NPs is illustrated in Figure 11. When compared to $TiO_2$ particles, ZnO NPs and $TiO_2$ NPs together significantly improve still productivity. The distillation productivity was shown to rise with increasing catalyst concentration up to 0.6 g/l, after which it dropped again. This might be because there is a limit to how much energy the water can receive from the sun's rays when the catalyst concentration is too high, which reduces the distillation unit's productivity [56, 57].

The still containing ZnO NPs outperformed the one containing $TiO_2$ NPs by 5.4% at a catalyst concentration of 0.6 g/l. The second one outperformed the still containing $TiO_2$ particles by 39.9 percent. While 0.6 g/l of catalyst concentration yields the best productivity, the performance gap between $TiO_2$ NPs and Zn NPs becomes more pronounced with increasing catalyst doses (at 1.2 g/l of catalyst dose, the productivity of still with ZnO NPs is 22.7% greater than that with $TiO_2$ NPs). This might be because ZnO NPs are more valuable because of their metallic character as the key advantage of ZnO nanoparticles lies in their thermal properties. Which in turn facilitates more efficient heat transfer within the water. This leads to a faster increase in water temperature and, consequently, a higher evaporation rate. In comparative studies, solar stills containing ZnO nanoparticles have demonstrated a greater daily output of distilled water compared to those with $TiO_2$ nanoparticles [59] and the distillation pool water's heat capacity grows as the catalyst concentration does [58]. Distillation productivity is proportional to sun intensity, according to experiments conducted using $TiO_2$ particles, $TiO_2$ nanoparticles, and ZnO nanoparticles at a catalyst concentration of 0.6 g/l. Midday is when hourly productivity peaks, as illustrated in Figure 8. Based on these hourly productivity estimates, the overall productivity for the stills containing nano-ZnO, nano-$TiO_2$, and $TiO_2$ particles is 1645 ml, 1560 ml, and 1115 ml, respectively. As for the stills' efficiency, it's 34.93% with $TiO_2$ particles, 48.87% with nano-$TiO_2$, and 51.53% with nano-ZnO. Finally, table (4) displays a sample of recent studied utilizing ZnO nanoparticles in solar water desalination.

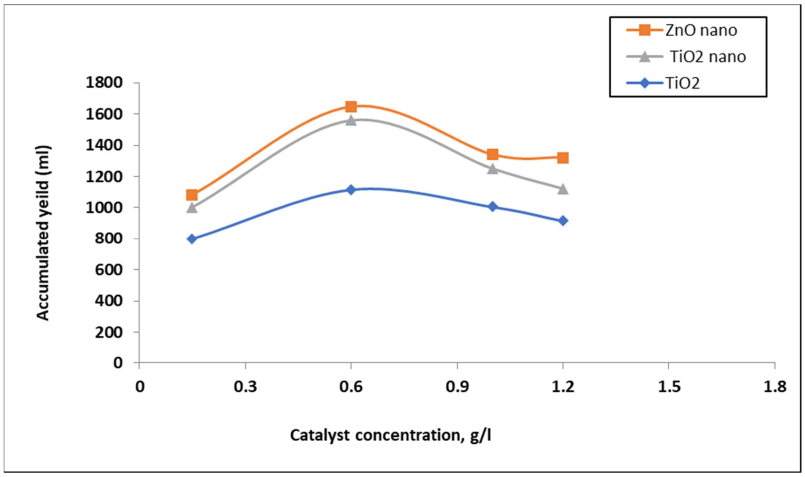



**Figure (11): Effect of Using Different Types of Nanoparticles, (4/8/2021- 7/08/2021)**

**Table (4): Findings of Other Researchers that Utilizing ZnO Nanoparticles in Solar Water Desalination**

| **Saline water concentration** | **ZnO Nanoparticle Concentration** | **Water production rate** | **Citation** |
|---|---|---|---|
| No specified | 0.3% | 4.5 l | [60] |
| Saline water | 0.1% | 3.3 | [61] |
| Brackish water | 5g/l | | [62] |
| Saline water | 0.6 g/l | 43% as compared to $TiO_2$ | THIS STUDY |

## 4. **Conclusion**

From the present study; it has been estimated that, the addition of $TiO_2$ to the distillation pool increases the distillation productivity by 43.1% compared to the reference distillation unit ie. distillation efficiency increases by 11% . The magnitude of the temperature gradient (Tb-Tg) is proportional to the magnitude of the distillation productivity. The maximum hourly distillation power is attained at noon (at maximum value of SI). Furthermore, the addition of $TiO_2$ NPs further increases the distillation productivity. A maximum increase of 30.1% is achieved at 13:00 by the addition of $TiO_2$ NPs. The positive effect of the addition of $TiO_2$ in the form of nanoparticles is more pronounced in the morning period and reaches its maximum value around noon time. The productivity of the stills is increased by 70.7% by using $TiO_2$ NPs. (compared to the still with $TiO_2$ particles. On the other hand, ZnO NPs have a better effect on increasing distillation productivity than $TiO_2$ NPs and both are better than $TiO_2$ particles. As the catalyst concentration increases, the distillation productivity increases up to a concentration of 0.6 g/l; then the distillation productivity decreases again. The difference between the performances of the two nano materials ($TiO_2$ NPs and ZnO NPs) becomes more evident when the catalyst dose is increased (ZnO NPs is 22.7% higher than $TiO_2$ NPs at a catalyst dose of 1.2 g/l). When $TiO_2$ particles, $TiO_2$ NPs and ZnO NPs were used, the efficiencies of stills were 34.93%, 48.87% and 51.53%, respectively.

**Conflict of Interest:**

There are no conflicts to declare.

**Acknowledgement:**

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