Chapter 30
A Review of the Applications of Nanomaterials to Augment Solar Still Productivity

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30.1 Introduction

Clean alternative energy, such as wind energy (Abdelkhalig et al. 2022; Cheng et al. 2021) and solar energy, is sustainable, clean source of energy for sustainable cities and communities (AlMallahi et al. 2022; Elgendi et al. 2022b; Obaideen et al. 2021). Solar energy has multiple uses involving photovoltaics, thermal energy, solar heating, and other typical solar energy-harvesting methods. Solar still technology is a convenient and simple method for acquiring potable water from saline water (Elgendi and Selim 2022). Saline water can be fed manually or automatically (Elgendi et al. 2022a). Water evaporates naturally from the salty water surface and flows to the solar still top cover (El-Gendi 2018a, b; El-Gendi and Aly 2017). Although solar still is an affordable and convenient method, its major drawbacks include low efficiency. Several techniques are applied to enhance the solar still performance and increase its efficiency, such as the wick materials (Khalifa 2011), external reflector (Khalifa and Ibrahim 2010), and solar collector (Sampathkumar and Senthilkumar 2012). A major objective in

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solar still fields is to enhance the distillate production of drinkable water. Solar still distillate yield is dependent on the availability of solar radiation, which is intermittent. The applicability of a solar still system is determined by meteorological parameters such as solar radiation, wind velocity, and ambient temperature. In addition, using nanomaterials in solar still significantly increases its productivity (Elgendi et al. 2021a). Nanomaterials can be mixed with saline water to form a nanofluid or coat the absorber or the cover (Chamsa-ard et al. 2020). Also, it can be doped in phase change materials to improve its thermal characteristics.

30.2 Bibliometric Analysis

With the growing attention on the solar stills field, a substantial volume of research literature has evolved. Bibliometric approaches are helpful for statistically analyzing large-scale research publications and determining a field's development state and research performance. The bibliometric analysis has been widely utilized to reveal the state of research in numerous study sectors. For instance, (Kandeal et al. 2022) reviewed recent water harvesting technologies with the help of bibliometric analysis. Similarly, (Ding et al. 2021) discussed the research status and development in the hybrid thermal energy storage systems field. This section presents a comprehensive bibliometric analysis of solar stills and PCM/nanomaterials. The data in this study were obtained from the Web of Science and Scopus databases. The document type and search language were not restricted, the period span is all years from (2010 to 2022) and data analysis was performed on 24 October 2022. A total of 262 were collected and exported for bibliometric analysis as demonstrated in Table 30.1. Figure 30.1 displays the publication trend of solar stills research from 2010 to 2022.

Table 30.1 Main information about the data obtained

Description	Results
Timespan	2010:2022
Documents	262
Annual growth rate %	42.31
Average citations per document	29.82
References	10,672
Research article	182
Book chapter	5
Conference paper	39
Conference review	5
Review paper	31

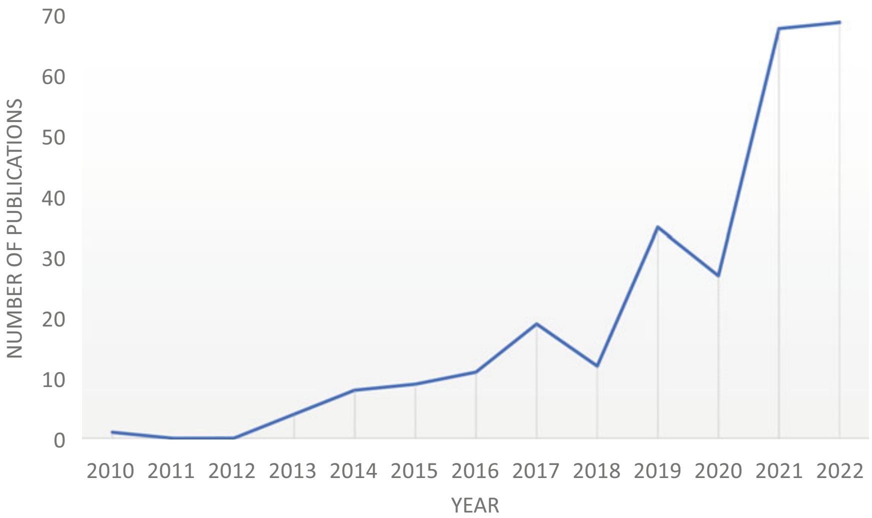

Fig. 30.1 Number of studies on solar stills and PCM/nanomaterials that have been published based on web of science and scopus databases

Figure 30.2 portrays the primary authors' collaborative network. The size of the circle symbolizes the author's number of publications; the connection between the authors reflects the strength of the collaboration. By examining the collaboration network of high-yield authors, we can rapidly grasp the primary research team in the field of solar stills cooperation and identify the research frontier.

Fig. 30.2 Collaboration networks of the most productive authors in this field

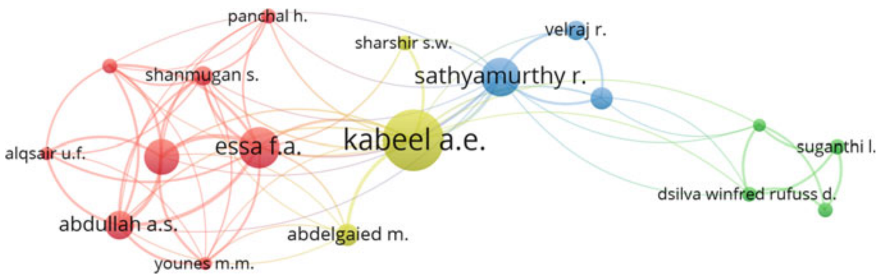

Fig. 30.3 Country collaboration network

The collaboration network among countries and the number of publications are demonstrated in Fig. 30.3. It can be shown that significant levels of collaboration occur between countries located in the same geographical area, such as India, Egypt, and neighboring countries.

The number of citations usually represents the academic significance of the article. Highly cited publications demonstrate that this paper's research material has been acknowledged by other researchers on the same subject and has a high reference value. Table 30.2 lists the top ten most referenced papers on the topic of solar stills and nanomaterials/PCM. The article with the most total citations (222) was Khanafer and Vafai (2018). Correspondingly, Table 30.3 shows the top 8 most repeated words in the search string set. Because many studies' end goals are applications, it is normal for researchers to be concerned about productivity. Scholars also appear to be concerned about paraffin wax and nanoparticles in this field.

The three most relevant global affiliations related to publications on solar stills and PCM/nanomaterials are Tanta University (Egypt), Kafrelshiekh University (Egypt), and Anna University (India). This implies that the majority of relevant research

Table 30.2 Top 10 most cited papers in the search string (2010–2022)

Sr.	Paper	Total citations
1	Khanafer 2018, Renew Energy (Khanafer and Vafai 2018)	222
2	Al-Harahsheh 2018, Appl Therm Eng (Al-harahsheh et al. 2018)	195
3	Omara 2015, Energy Convers Manag (Omara et al. 2015)	188
4	Sharshir 2017, Appl Energy (Sharshir et al. 2017)	179
5	Kabeel 2014, Energy Convers Manag (Kabeel et al. 2014)	177
6	Kabeel 2016, Desalination (Kabeel and Abdelgaied 2016)	172
7	Faegh 2017, Desalination (Faegh and Shafii 2017)	162
8	Sharshir 2016, Appl Therm Eng (Sharshir et al. 2016)	162
9	Arunkumar 2013, Desalination (Arunkumar et al. 2013)	159
10	Shalaby 2016, Desalination (Shalaby et al. 2016)	150

Table 30.3 Word repetition frequency

Sr.	Terms	Frequency
1	Solar still	131
2	Phase change material(s) OR PCM	130
3	Desalination	46
4	Productivity	26
5	Solar desalination	26
6	Solar energy	25
7	Paraffin wax	18
8	Nanoparticles	16

Table 30.4 Most relevant affiliations and countries

Sr.	Country	Affiliation	Articles
1	Egypt	Tanta University	58
2	Egypt	Kafrelsheikh University	31
3	India	Anna University	25
4	Saudi Arabia	Prince Sattam Bin Abdulaziz University	16
5	Iran	Islamic Azad University	15
6	Egypt	Delta University for Science and Technology	13
7	India	Hindustan Institute of Technology and SciencE	13

on solar stills comes from Middle East and South Asia countries. Table 30.4 demonstrates the most relevant affiliations and countries in this search string.

Cluster analysis showed that the terms naturally clustered into six clusters, as shown in Fig. 30.4a. Keywords from the same cluster are frequently found in the same body of literature. Each cluster might identify several research hotspots. On the other hand, word clouds are useful for providing an overview of the literature on any topic during a certain time. The magnitude of the term indicates how frequently authors used it in their publications. Figure 30.4b shows a word cloud of the most frequently used keywords selected by authors. Solar stills, heat storage, productivity, nanoparticles, energy efficiencies, and other words were identified.

The three-field plot in Fig. 30.5 demonstrates the best-performing country, source (journal), and finally research focus. The thicker rectangle is, the greater frequency is. The connecting nodes, inflows, and outflows show more connections and thicker nodes.

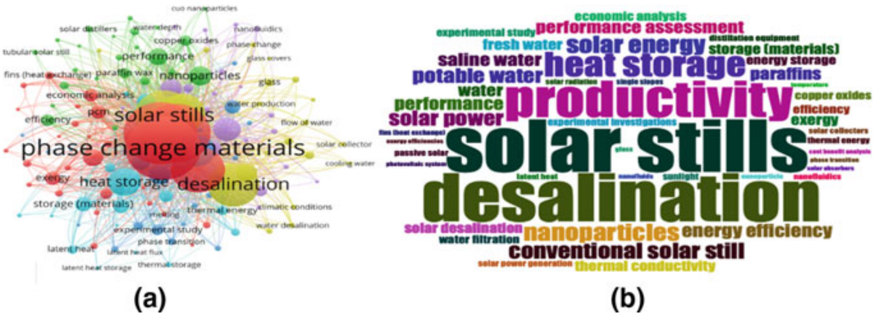

Fig. 30.4 **a** Network visualization of most used keywords, **b** word cloud on publications related to "solar stills" AND "phase change materials" OR "nanomaterials"

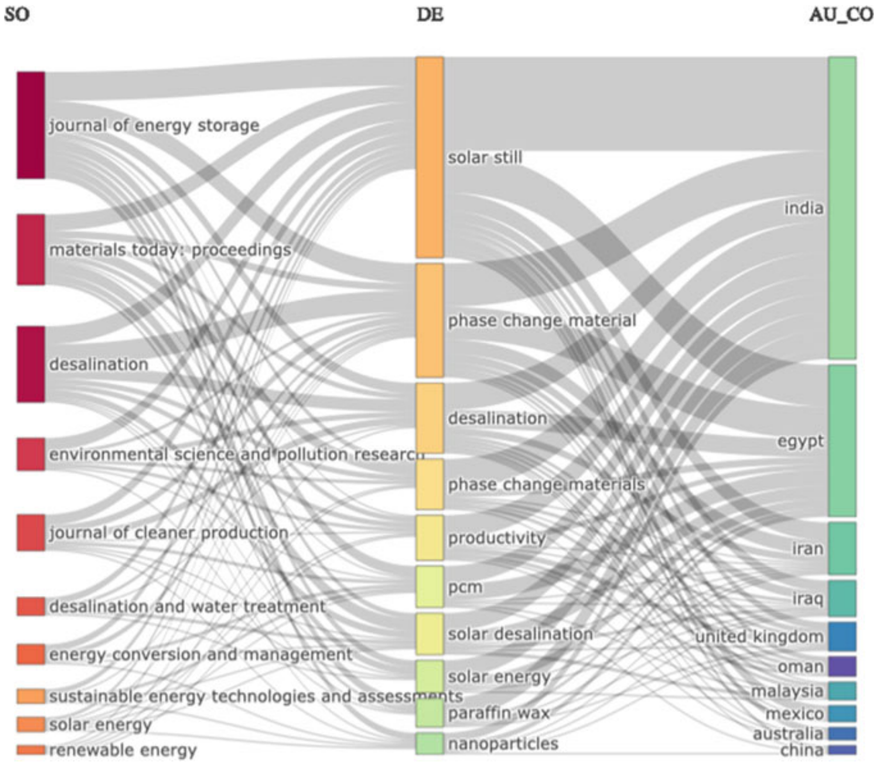

Fig. 30.5 Three-field plot of literature in the field of solar stills, PCM and nanomaterials, source (SO), keywords (DE), authors' countries (AU_CO)

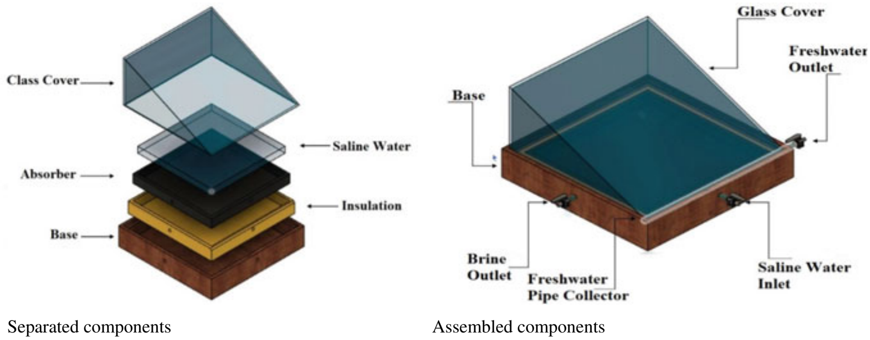

Fig. 30.6 Solar still components: (1) cover, (2) saline water, (3) absorber, (4) insulation, and (5) box

30.3 The Main Components of the Solar Still

The solar still has a simple design (Elgendi et al. 2021b). Figure 30.6 shows the primary features of the solar still:

A transparent cover, usually made from glass, allows the transmission of solar radiation. Also, the distilled water condenses on its inner surface. Nanomaterials can be applied to its inner surface to improve the wettability properties.

Saline water absorbs solar energy to evaporate. Nanomaterials can be added to saline water to improve its thermal characteristics. Therefore, the mixture will be a nanofluid.

Absorbers are usually coated with black paint and made from non-corrosive materials to hold the saline water and absorb solar energy. In addition, nanomaterials can cover the absorber to increase the absorbed energy.

Insulation hinders the dissipation of thermal energy. Phase change materials (PCM), thermal storage materials, can be added between the absorber and insulation. Nanomaterials can dope the PCM to improve its thermal characteristics.

Box or base usually made from wood includes solar still components.

30.4 Techniques to Enhance the Solar Still Performance

The productivity of the solar still can be affected by meteorological parameters, operational parameters, and design and fabrication parameters. As illustrated in Fig. 30.7, numerous factors impact solar still performance.

Several studies have been carried out in the literature to improve solar still performance. For example, a single-slope solar basin with a movable aluminum-suspended absorbent plate is proposed (El-Sebaii et al. 2000). The baffle-suspended absorber boosts the productivity of the solar still by 20% because the preheating time for water evaporation is reduced.

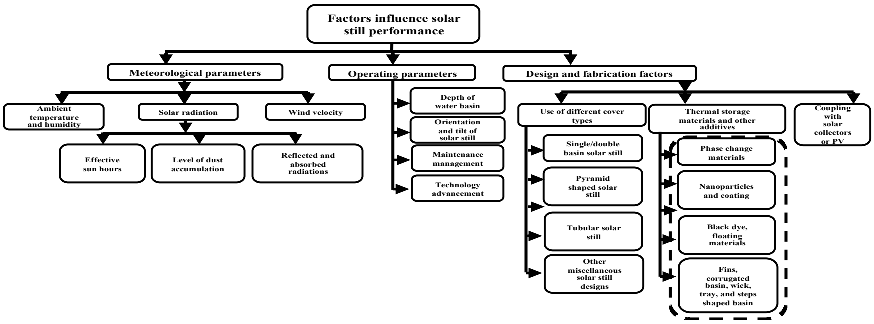

Fig. 30.7 Factors influence solar still performance

Naim and Abd El Kawi (Naim and Abd El Kawi 2003) proposed a solar still system that utilizes charcoal particles as the absorber medium. The effect of charcoal particle range, saline water flow rate, and glass cover inclination on productivity is examined. As a strong absorber medium, the charcoal particles increase solar still productivity by 15%. Correspondingly, a packed sheet mounted at the bottom of the solar still basin optimizes the performance of the solar still (Addel-Rehim and Lasheen 2005). The compressed layer's substance has superior thermal properties. The packed coating of glass balls aids in heating saline water during the day and night and raises freshwater productivity to 7.5%.

Heat can be stored in the phase change materials as latent heat. For example, heat is applied to a substance to change its phase from solid-state to liquid by preserving the heat as latent heat of fusion or from liquid to vapor by storing the heat as latent heat of vaporization. Energy storage materials (ESM) improve the efficiency of a solar still (Addel-Rehim and Lasheen 2005). The ESM is inserted in the solar still tray during the still assembly process. The combination of paraffin wax, paraffin oil, and water is an energy storage medium.

Jute fabric has a porous surface that improves its absorption property. Furthermore, jute thread is very solid and one of the least expensive natural fibers available (Sakthivel et al. 2010). It also has high insulating characteristics, low heat conductivity, and a limited capacity to recover moisture. In the regenerative solar still, the air-vapor mixture temperature is lowered and becomes lower than that in the traditional still. The latent heat generated by the glass cover is used to evaporate water from the jute cloth. It was discovered that yield potential was increased by 20%, and performance was increased by 8% compared to the traditional solar still.

Moreover, the influence of coated and uncoated metallic wiry sponges, as well as volcanic pebbles, on solar still production was explored. Compared to the traditional solar still, The yield of coated metallic wiry sponges, uncoated metallic wiry sponges, and volcanic rocks is improved by 28%, 43%, and 60%, respectively (Abdallah et al. 2009).

The glass cover inclination parameter mainly influences the efficiency of the solar still. In winter, increasing the inclination raises the yield, and vice versa in the summer (Khalifa 2011). On the other hand, increasing the inclination decreases the evaporation rate in the summer and winter. Moreover, an increased tilt angle increases heat losses from the cover while decreasing yield by increasing reflected radiation from the absorber.

Water quickly evaporates at much lower temperatures by creating a vacuum within the solar still, using less energy than traditional techniques. The productivity of a solar desalination device depends on the solar still pressure (Nassar et al. 2007). The experimental model is an elliptical, metallic container positioned in the focus of the concave reflector. The saline water is subjected to an absolute vacuum pressure of 25 kPa, and in a condenser, the distilled water is collected. Applying vacuum pressure improves the efficiency by 303% and the output ratio by 900% (Nassar et al. 2007). Table 30.5 presents a summary of the papers reviewed and their objectives.

30.5 Applications of Nanomaterials in Solar Still

Nanomaterials coat the absorber to increase the thermal conductivity and, thus, the hourly productivity of coated absorber using nano-Fe_2O_3 particles (Balachandran et al. 2020). The basin water temperature peak is 66 °C for nano-Fe_2O_3 coated solar still, which is 3 and 5 °C higher than those of micro-coated and conventional solar stills, respectively. The maximum efficiency of nano-Fe2O3 solar still was 68% and 55% for water depths equal to 5 mm and 10 mm, respectively (Balachandran et al. 2020).

Graphene oxide (GO) decreases the melting temperature of paraffin as phase-change materials (PCMs) (Safaei et al. 2019). Paraffin is an organic material and is considered the most futuristic PCMs because of its ideal characteristics, such as remarkable latent heat. Graphene oxide nanomaterial is applied to improve the thermal efficiency of PCM. The absorbed heat transfers to the paraffin/graphene oxide during the daytime. At a temperature of 45 °C, graphene oxide is dispersed into melted paraffin to maximize the solar still's yeild. Furthermore, the stored heat in the PCM as latent heat boosts solar efficiency at night. The solar still performance with GO/paraffin solar still has higher productivity by 25% than solar performance with PCM only. The daily yield of solar still was 5 kg/m^2 and 6.25 kg/m^2 for GO/PCM and PCM solar still, respectively (Safaei et al. 2019).

Because of the outstanding durability and inexpensive cost of oxide nanoparticles, oxide nanofluids are the most often utilized nanofluid in solar still (Elango et al. 2015). Al_2O_3 is a useful oxide nanoparticle among many others in passive solar stills. Al_2O_3, SnO_2, and ZnO nanofluids had thermal conductivities of 0.63556 W/(m^2+K), 0.6215 W/(m^2+K), and 0.6105 W/(m^2+K), respectively. The performance of the solar still is enhanced by 29.5%, 18.63%, and 12.67%, by Al_2O_3, SnO_2, and ZnO nanofluids, respectively.

Table 30.5 Objectives of the papers reviewed in brief

Reference	Main objectives and findings
Katekar and Deshmukh (2020a)	A review on PCMs and nanoparticles for solar stills. The authors found that CuO nanoparticles are the most suitable nanoparticles for mixing with paraffin wax
Singh et al. (2020)	A comparison study on solar stills and the impact of nanofluids on their performance are carried out. Adding nanoparticles to passive solar still with a double slope top cover boosted productivity
Singh et al. (2021)	Different types of nanofluid integrated with various types of solar collectors were studied. The carbon black-Ethelene glycol nanofluid improves total thermal conversion efficiency by 27.90% when applied to direct absorption solar collector
Katekar and Deshmukh (2020b)	The paper is categorized based on the design, slope, basin, passive, active, and other modifications. Nanoparticle coating was applied and studied for solar stills. The authors stated that the single basin cascade solar still is the most suitable for domestic uses, and tubular solar still with a wick is the optimum design for industrial uses
Arunkumar et al. (2021)	Capillary flow driven for water evaporation and nanoparticles were investigated. The highest evaporation rate found was achieved by Ti_2O_3-nanoparticles/polyvinyl alcohol absorber
Kaviti et al. (2021)	Solar desalination is generally studied, and it explicitly investigates solar still. Moreover, it focuses on nanomaterials applications in solar stills. Solar vapor generation materials outperform other efficient materials, with more than 96% absorption broadband wavelength
Sharshir et al. (2019)	The authors discussed the methods utilized to enhance tubular solar stills. One of these techniques include nanomaterials. The usage of ZnO nano-rod shape enhanced the production by 30%
Chauhan et al. 2021)	The paper discussed direct solar desalination, and the integration of PCM with nanocrystal can substantially increase the yield. This enhancement is due to the boost of overall thermal conductivity of the basin water
Naveenkumar et al. 2020)	The authors segregated the paper based on effect and impact of nanomaterial such as CuO, TiO_2, Al_2O_3, and ZnO. This survey provides a good information basis for researchers to use in selecting optimal nanomaterials to boost solar still production rates
Iqbal et al. (2021)	A review of nanofluid assisted solar still was performed, and several aspects of economic and environmental benefits were investigated. The researchers showed that using NF-based SSs was a highly efficient system with considerable economic and environmental benefits

(continued)

Table 30.5 (continued)

Reference	Main objectives and findings
Mevada et al. (2020)	The effect of fin configuration was investigated through a review. Fins are known to enhance the surface area, thus rate of heat transfer and the heat dissipation of the bottom of solar still is reduced
Arunkumar et al. (2018)	The thermal conductivities of Al_2O_3, CuO, Cu_2O, ZnO, SnO_2, TiO_2, SiO_2, Cu, Fe_2O_3, SiC, and multiwalled carbon nanotubes distributed in water with varying volume fractions are examined
Patel and Modi (2020)	The use of nanoparticles serves as a sensible energy storage material, accumulating energy throughout the day and releasing it at night. To increase performance, the authors analyzed different solar stills slopes and covers
Yang et al. (2020)	The paper showcases different studies that examine PCM and nano-PCM where nano-PCM outperformed PCMs by 8–11 times. Also, literature confirmed that the presence of nanoparticles could lower melting temperatures while increasing freezing temperatures

Black paint blended with titanium oxide nanoparticles is applied to the absorber of a solar still, a 0.25 m^2 mild steel basin formed into an equilateral triangle (Kabeel et al. 2019). To stop escaping heat to the outside environment, insulation was added on the bottom and sidewalls of the solar still. Black paint called TiO_2 nanoparticles raises water temperature by 1.5 °C compared to an absorber without them. As a result, TiO_2 nanoparticles enhance the solar still's production by 12% at the maximum water depth. For the absorber plate with and without a TiO_2 nanoparticle coating, the cumulative yield from the solar still is 6.6 and 6.2 kg/m^2, respectively (Kabeel et al. 2019).

The standard solar still was modified using flake graphite nanoparticles (FGN), phase change material (PCM), and film cooling (Sharshir et al. 2017). The still's productivity is 50.28%, 65%, 56.15%, and 73.8%, with FGN (modification A), FGN and PCM (modification B), FGN and film cooling (modification C), and FGN, PCM, and film cooling (modification D), respectively. As the water depth grows, the solar still performance of modificatoins A and B declines (Sharshir et al. 2017).

30.6 Conclusions

In this chapter, the main elements of the solar still are illustrated and the most common solar still systems are summarized and compared. The importance of utilizing nanotechnology to improve solar still efficiency using different techniques is discussed. Nanomaterials and saline water can be combined to create nanofluids. Some techniques include coating the absorber, coating the cover, or dispersing PCM.

The suggestions for future work can be summarized as follows:

- Combine two or three nanomaterials
- Combine new PCM with nanomaterials
- Coat the glass cover to decrease the temperature (previous research affects the wettability)
- Combine a nanomaterial and a sensible storage material (previous with PCM)
- Investigate the effect of nanomaterial morphology
- Coat both the absorber and glass.

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