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Review

Clean Water Production Enhancement through the Integration of Small-Scale Solar Stills with Solar Dish Concentrators (SDCs)—A Review

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Abstract: The conventional solar still, as a water treatment technique, has been reported to produce water at a low working temperature where various thermal resistance pathogens could survive in their distillate. In this work, the reviews of previous research on the quality of water produced by passive solar stills and their productivities in initial basin water temperatures were first presented and discussed. The next review discussed some recent studies on the performances of small-scale solar stills integrated with SDCs (with and without sun-tracking systems (STSs)) to observe the operating temperatures from early hours until the end of operations, daily water yield, and cost per liter. Based on these findings, it was revealed that SDCs with STSs indicated an instant increase in the absorber water temperature up to 70 °C at the starting point of the experiments in which this temperature range marked the unbearable survival of the pathogenic organisms and viruses, particularly the recent SARS-CoV-2. Furthermore, disinfection was also observed when the absorbers' water temperature reached beyond the boiling point until the end of operations. This indicates the effectiveness of SDCs with STS in reflecting a large amount of sun's rays and heat to the small-scale absorbers and providing higher operating absorbers temperatures compared to immobile SDCs. Daily productivities and costs per liter of the SDCs with STSs were found to be higher and lower than those of the other previous passive and active solar stills. Therefore, it is recommended that small-scale absorbers integrated with SDCs and STS can be used as a cost-effective and reliable method to produce hygienic pathogen-free water for the communities in remote and rural areas which encounter water scarcity and abundant annual bright sunshine hours.

Keywords: solar distiller; water temperature; pathogens removal; rural areas; sun-tracking system; cost-effective water production; water scarcity; SARS-CoV-2

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1. Introduction

The components of the environment and rich sources on Earth [1] which are essential for humans include water [2], plant life [3], and animal life [4]. However, 3% of water sources are fresh water and only 0.30% of that fresh water is surface water which is accessible by humans [5]. Of the total available water on earth, 97% is salty [5–8], whereby its consumption can cause health problems to human beings, such as hypertension, stomach upset, and stroke effects [9]. Freshwater shortages are now affecting more than three billion people around the world as the amount of fresh water available per capita has dropped by a fifth over two decades [10] due to the impacts of climate change, global population growth, and industrial developments which have resulted in increasing freshwater demand across the strips of the globe [10–13]. It has become more difficult than before to obtain safe, potable water for a healthy life [14]. The vast problems caused by the lack of potable water and the transmission of waterborne diseases have been reported in some parts of the world, particularly involving communities in rural areas [15–21], which have generated public health distress. Around one in four people suffered from lack of safely managed drinking water in their homes in 2020 [15]. A report by WHO/UNICEF in 2020 stated that 81% of the world population have access to safe drinking water and about 1.6 billion people will need to survive without hygienic drinking water by 2023 [15]. Based on the surveys from 45 developing countries, 82% of people who lack access to safe clean water reside in rural communities, while the rest live in urban areas; meanwhile, 140 million hours are spent daily by millions of women and children living in villages to collect water from distant and often polluted sources, such as groundwater and natural water resources, for their day-to-day water consumption [15,16]. The drinking of water from the above contaminated water sources pose health risks to the villagers if consumed without any further purification [15–21]. Various types of pathogens—categorized as bacteria, viruses, fungi, and protozoa—which are found in environmental sources (such as water bodies) are risky and could lead to various diseases for living organs, particularly human bodies. Waterborne diseases—such as cholera, dracunculiasis, infectious hepatitis, typhoid, bacillary dysentery, paratyphoid, colibacillosis, giardiasis, salmonellosis, filariasis, cryptosporidiosis, and amoebiasis—are mostly transmitted in contaminated fresh water due to pathogenic microorganisms in water sources from flowing rivers, groundwater, and runoff water from rooftops, as mostly consumed by the rural communities in Africa, India, and East Asia [20,21]. Skin keratosis is caused by high concentrations of arsenic in groundwater as reported in some rural areas of India, Pakistan, Nepal, and Bangladesh [17,19]. Many more bacterial and viral diseases can be caused by contaminated water [21]. Infection by viruses in untreated water—such as astrovirus, rotavirus, norovirus, and hepatitis A and B viruses—can result in a higher rate of mortality for vulnerable groups such as children, the elderly, and pregnant women, in which 6.3% of all causes of death in the world are attributed to the consumption of unsafe water and inadequate sanitation [22]. It was estimated that every year, one million people in developing countries could die due to contact with waterborne diseases [20–22]. In countries such as India, Bangladesh, Pakistan, and Nepal, there are certain regions where the arsenic concentration is more than 10 times that of the WHO drinking water quality standards of 0.01 mg/L [19]. In India alone, nearly 100 million people are at a health risk due to arsenic-rich water [19]. Some of them are suffering from arsenic-related diseases, such as skin burning and irritation, blackening of skin, paralytic attacks, and early greying of hair. Thus, the quality of drinking water has to be considered when evaluating the role of water in public health [20,22]. Reportedly, there are a number of water treatment methods for Arsenic removal from raw water. Oxidation reduction, adsorption, coagulation and precipitation, ion-exchange, membrane techniques and biological treatments, vapor compression distillation, reverse osmosis, and electro dialysis are some examples of desalination techniques which have been developed and tested by various researchers [17]. However, these methods require electricity and the observation of certain performance parameters on a steady basis; they also produce hazardous waste that restricts the sustained performance of these technologies, especially in rural areas which have restricted access to electricity and skilled manpower [17]. Over 10,000 desalination plants which exist in the world produce about 18.93 million cubic meters of treated water a day [23]. The required electricity for the above desalination methods is generated from coal and fossil fuel combustion as input energy which has contributed to the discharging of hazardous greenhouse gas emissions and increased global temperatures, thus leading to climate change and threatening the lives of millions of people on earth [24–26]. Meanwhile, some countries located in the middle east (e.g., Qatar, Lebanon, Iran, Jordan, Kuwait, Saudi Arabia, and UAE), South-East Asia (e.g., India, Bangladesh, Nepal, and some parts of China), and Africa (e.g., Libya, Egypt, Algeria, Sudan, Mali, Niger, and Nigeria), which are home to nearly a fourth of the world's population, have been facing extremely high levels of water stress and crisis recently [27]. All of these countries enjoy high levels of average daily solar irradiance and receive about 3000 bright sunshine hours annually [28]. Considering this, the application of solar energy to treat the contaminated surface or groundwater and the production of clean potable water can be used as an alternative to aid in eliminating water scarcity and stress issues for the local rural communities of the aforementioned countries.

Solar distillation still utilizing only solar energy is one of the most reported cost-effective, environmentally friendly, and sustainable water treatment technologies to supply high-quality drinking water which are safe from poor water sources for rural, remote, and coastal communities who lack access to other water treatment options [17,21,29–35]. Hence, the main aim of this work is to review the recent studies on performances of solar dish concentrators (SDCs) with different configurations which are integrated with the small-scale conventional solar stills (small absorbers) and a sun-tracking system. Specifically, the objectives of this work are to evaluate the capability of SDCs in the studies by: (1) eliminating the waterborne pathogens, bacteria, as well as SARS-CoV-2 virus from the absorbers water at the initial stages of the experimental work by achieving the initial absorber water temperatures at about 70 °C instantaneously; (2) disinfecting the water absorbers by increasing the water temperature to the boiling point and even at higher rates in continuous durations in the experiments; and (3) enhancing the production of hygienic, pathogen-free, and cost-effective fresh water for communities in remote and rural areas.

2. Performance of Passive Solar Desalination Still for Water Treatment

Solar stills are closed containers with different designs and configurations which are mainly comprised of basin/bed to keep the contaminated water and a transparent cover of the condensation to allow the sun's rays pass through it and heat the basin water [32–36] (Figure 1).

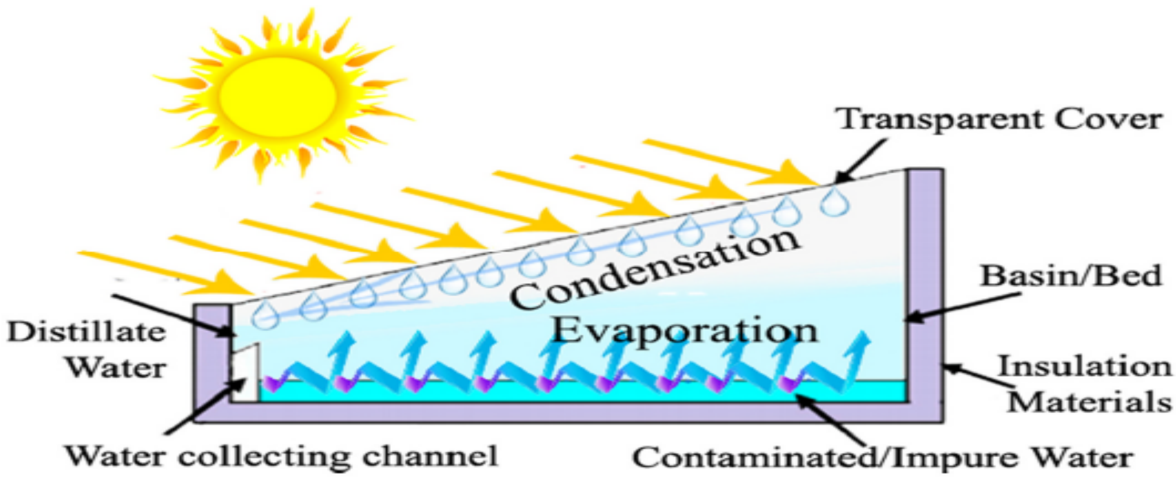


Figure 1. Sketch of a single slope passive solar still [36].

The basic process of the hydrological cycle—namely, evaporation and condensation phenomena—occurs inside a solar still between the surface water of the basin and inner cover of the solar still in order to produce clean water [37]. Solar distillation stills are categorized as passive and active solar stills [38]. The operation of passive solar stills depends greatly on the available direct solar irradiance to heat the basin water, while active solar stills are the similar to passive stills which are incorporated with additional external heat sources and receive direct solar irradiances [30,38–42]. The daily productivity of passive conventional solar stills (CSS) was investigated with different configurations in some countries, such as Malaysia [30,31,43], Saudi Arabia [44], India [45–48], Japan [49], Egypt [50,51], Jordan [52,53], Turkey [54] and Nigeria [21]; these productivity values were generally low—i.e., less than 5 L/m^2—due to failure in obtaining high basin water temperature which resulted in low evaporation rates and thus, low amounts of water production. Several researchers analyzed the quality of water produced by passive solar stills. In 2003, Hanson et al. [29] designed, fabricated, and studied the performance of a passive trapezoidal-shaped single basin single slope solar still in Southern New Mexico, USA in order to evaluate the treatment of samples of local tap water, brackish ground water, geothermal ground water, and diluted raw sewage. As proved in their study, 99% of non-volatile contaminants (such as salinity, total dissolved solids (TDS), total hardness (Caco3), electrical conductivity (EC), nitrate, fluoride), and 99.9% of *E.coli* and fecal coliform bacteria were successfully removed from the studied raw waters using the aforementioned passive solar distiller, and therefore it was concluded that the solar still produced high-quality hygienic drinking water [29]. In another study in Malaysia, lake water samples were treated using two passive glass (GSS) and polythene film (PSS) cover solar stills [30]. It was observed in the study that through both PSS and GSS (Table 1), the quality parameters of pH, TDS, salinity, nitrate, nitrite, iron, turbidity, and EC after the experiment were recorded within the acceptable ranges of WHO standards for drinking water [55]. Hence, the use of PSS was proposed as the economical means of production of healthy potable water for the benefit rural communities [30].

Table 1. Performances of several passive solar stills after the treatments of contaminated surface water [30], groundwater [17], and seawater [31] sample as recommended for the rural community consumption.

Water Quality Parameters	PSS [30]	GSS [30]	SSSB [17]	TrSS [31]	WHO Standards for Drinking Water [55]
pH	6.51	6.53	7.14	7.7	6.5–8.0
Total dissolved solids (TDS) mg/L	95	28	45	7.52	600
Total Arsenic (mg/L)	—-	—-	≤0.01	—-	0.01
Salinity (ppt)	0.1	0	Na	0.006	<0.25
Nitrate (mg/L)	0.6	0.4	0.74	—-	<50
Nitrite (mg/L)	0.03	0.01	Na	—-	<0.05
Fluoride (mg/L)	—-	—-	0.02	—-	1.5
Chloride (mg/L)	—-	—-	10.99	—-	250
Hardness (mg/L)	—-	—-	33.81	—-	200
Iron (mg/L)	0.03	0.02	0.00	—-	0.3
Sulfate (mg/L)	—-	—-	0.72	—-	250
Turbidity (NTU)	1.37	0.92	Na	—-	<5
Electrical conductivity (EC) (µS/cm)	52.5	15.66	Na	11.6	<250

In a study, a single-slope single-basin (SSSB) passive solar still was designed and constructed, and then its performance for groundwater treatment was investigated in a rural community area affected by high arsenic levels in India, namely Kaudikasa village [17]. It was perceived in the study that the parameters of pH, TDS, total arsenic, nitrate, fluoride, chloride, hardness, iron, sulphate, and total coliform after conducting the experiment using SSSB [17] conformed with the WHO drinking water guideline ranges [55], as given in Table 1. In another study in Malaysia [31], seawater samples were treated using a low-cost passive triangular solar still (TrSS), and the results showed that the quality parameters of pH, salinity, TDS, and EC were also in compliance with the WHO standards of drinking water [55] as in Table 1. The distillate water produced by the solar distillers is deficient in minerals and fluoride concentration and therefore, some minerals and fluoride salts may be added to the distillate [17] to be in accordance with the current requirements as per drinking water quality standards which stated 1.5 mg/L in WHO, 2008 [55] as the requirement of fluoride so that the produced distilled water can be consumed as potable water without negatively affecting health. However, some recent studies [36,56–61] expressed their concern that working water temperatures in passive solar stills play an important role for the viability of various viruses and pathogens in the distillate due to their transmission through vapor in solar stills. This is because water vapor was observed at an extensive range of temperatures, and solar stills were able to produce distilled water even at low working temperatures [36]. With various modifications of passive solar stills, their maximum water temperature can reach up to 70 °C, and the temperature is considerably higher in active solar stills due to the use of different external heat sources, such as solar collectors, pre-heating, etc. [62]. However, in a study conducted by Parsa et al., the initial working water temperature in the early experimental hours using most passive and active solar stills was usually low, which was observed between 20 °C and 50 °C [61]. In another study conducted by Parsa S.M. [36], most solar stills, including passive and active solar stills [31,39,40,42–44,46–51,53,63–73], had the productivity at low working temperatures. The passive solar stills tested in Malaysia [31,43], Saudi Arabia [44], India [46–48,64,65,70,71,73], and Japan [49], had their initial productivity in basin water temperatures of 32, 35, 37, 35, 34, 33, 49.2, 18, 19.3, 25, 39, and 20 °C, respectively and most the active solar stills investigated in Malaysia [39,40], India [42,63,66,68,71,72], Saudi Arabia [44], Egypt [50,51], Jordan [53], Oman [67], and Iran [69] had their early water production in water temperatures of 47, 49, 25.5, 18.9, 9.25, 25, 26.6, 49, 48, 36, 25, 34.6, and 21.6 °C, respectively (Table 2) [36]. Generally, these results were obtained in the beginning of their experiments at early morning hours, with exposure to the low rate of solar radiation intensity [36]. In one study, the concentration of biological colonies in the distillate water produced by a passive stepped solar still was extremely high [56]; while, in another study, the presence of *E. coli* was noticed in the water produced by a passive plastic type solar still [57]. Another study reported the capability of various pathogens of *E. coli*, *Klebsiella pneumoniae*, and *Enterococcus faecalis* in transferring via vapor in a solar still [58]. The transmission rate of *E. coli* in water temperatures in the 30–35 °C range was found to be higher than *Enterococcus faecalis*, while the transmission rate of *Enterococcus faecalis* was higher than *E.coli* at the 40–45 °C and 50–55 °C temperature ranges [58]. As a thermally resistant pathogen, *Enterococcus faecalis* was able to survive in water with temperature up to 65 °C [58]. It was recommended that exposing all parts of solar stills to sunlight with a high rate of radiation intensity throughout the experiment is also important to prevent the growth of bacteria and pathogens in the produced water by solar stills [58–60]. However, this recommendation is not completely practical due to some parts of solar stills possibly failing to catch the solar intensity in early experimental hours (usually in the morning), and the presence of pathogens in the productivity of solar stills seems to be unavoidable [36].

Table 2. Initial produced water by some passive and active solar stills corresponded to their basin water temperature [36].

Solar Still Type	Modified/Incorporated with	Basin Water Temperature of the Distiller (°C)	Initial Productivity (L/m^2) of the Distiller Corresponded to the Basin Water Temperature	Countries/ Year of Experiment	Ref.
Passive, double slope	Polythene film cover and black painted Perspex sheet basin	32 °C	0.01 L/m^2	Malaysia/2014	[31]
Active, double slope	Photovoltaic modules-AC heater	47 °C	0.138 L/m^2	Malaysia/2016	[39]
Active, double slope	A photovoltaic module-DC heater	49 °C	0.32 L/m^2	Malaysia/2019	[40]
Active, single slope	Hybrid PV/T with cover cooling method	25.5 °C	0.08 L/m^2	India/2018	[42]
Passive, double slope	Black soil heat absorption materials	35 °C	0.048 L/m^2	Malaysia/2015	[43]
Passive, double slope	Black painted basin	37 °C	0.15 L/m^2	Saudi Arabia/2012	[44]
Active, double slope	Two immersed AC water heaters	49 °C	0.50 L/m^2	Saudi Arabia/2012	
Passive, single slope	Fin and sand as heat storing materials	35 °C	0.05 L/m^2	India/2008	[46]
Passive, single slope	Marble pieces in basin	34 °C	0.035 L/m^2	India/2017	[47]
Passive, single slope	Glass cover with 4 mm thickness	33 °C	0.04 L/m^2	India/2016	[48]
Passive, tubular shape	Polythene film cylindrical cover	20 °C	0.02 L/m^2	Japan, 2012	[49]
Passive, single slope		39 °C	0.07 L/m^2	Egypt/2012	[50]
Active, single slope	Vacuum tube collector and stepped basin	48 °C	0.15 L/m^2		
Active, single slope	A photovoltaic module-Rotating shaft	36 °C	0.05 L/m^2	Egypt/2005	[51]
Active, pyramid shape	A photovoltaic module-DC fan	25 °C	0.06 L/m^2	Jordan/2012	[53]
Active, single slope	Hybrid PV/T and flat plate collector (FPC)	18.9 °C	0.08 L/m^2	India/2018	[63]
Passive, single slope	Porous absorber and carbon foam	49.2 °C	0.10 L/m^2	India/2018	[64]
Passive, double slope	Multi wicks heat storage materials	18 °C	0.062 L/m^2	India/2017	[65]
Active, single slope	PV/T	15 °C	0.04 L/m^2	India/2010	[66]
Active, single slope	Inverted absorber	34.6 °C	0.06 L/m^2	Oman/2011	[67]
Active, single slope	Hybrid PV/T and heat exchanger	9.25 °C	0.0014 L/m^2	India/2018	[68]
Active, single slope	Reflectors	21.6 °C	0.0017 L/m^2	Iran/2021	[69]
Passive, single slope		19.3 °C	0.03 L/m^2	India/2006	[70]
Passive, single slope		12.2 °C	0.007 L/m^2	India/2006	[71]
Active, single slope	Flat plate collector (FPC)	25 °C	0.016 L/m^2		
Active, double slope	Flat plate collector (FPC)	26.6 °C	0.032 L/m^2	India/2011	[72]
Passive, single slope	Micro coated and nano-ferric oxide particles in basin	39 °C	0.13 L/m^2	India/2020	[73]

Nowadays, another worldwide concern, as reported by Parsa S.M. [36], was the presence of SARS-CoV-2 in the environment [74–78] which is able to survive in various water bodies with 4 °C temperature, room temperature of 20–25 °C, and hot temperature of 33–37 °C for 14, 7, and 1–2 days, respectively [75]. However, it was also reported that the novel coronavirus is unable to survive more than 30 min at temperatures within the range of

50–70 °C [74,75]. As recently noted, the water temperature in the basin of solar stills is one the most crucial factors affecting the viability of waterborne pathogens and SARS-CoV-2 in basin water, vapor, and distillate of the solar stills [36]. Thus, the risk of transmitting some pathogens and SARS-CoV-2 is higher in the produced water by the solar stills if the productivity occurs at low initial water temperatures, i.e., within the ranges of 20–25 °C and 33–37 °C [36] (Table 2). It is recommended that the best solution for treating water using solar stills and preventing the transmission of pathogens and viruses is by increasing the initial temperatures of water in the basin of solar stills instantaneously to 70 °C, and then to the boiling point (100 °C). Next, the boiling point temperature is maintained until the end of the experiment by integrating the external heat sources (such as external solar heat collectors) to the small-scale conventional passive solar stills (small-scale CSS) called absorbers or (boilers) with low water capacity. This will help to avoid the transmission of waterborne pathogens and the viruses, particularly SARS-CoV-2, in the vapor and solar still productivity during the pandemic. There are two types of conversion modes which are incorporated into the passive solar distillation stills to enhance the water production; the first mode is the solar flat plate collectors' approach and the second mode is the application of solar dish concentrator (SDC) [79]. In one study, the former type was used to increase the solar still basin water temperature up to 100 °C; while the second one—which is composed of an SDC, a focal absorber, and a sunlight tracking system—was used to enhance the freshwater production of the passive solar desalination approaches by increasing the temperatures of their boiler water to more than 100 °C [79]. As reported in the study, the thermal efficiency of the SDC system is higher than the efficiency of the flat plate collector (FPC) system as the receiver area of the SDC losses less heat temperature compared to the area of the FPC [79]. As mentioned previously, due to the recent concerns regarding the existence of waterborne pathogens and SARS-CoV-2 virus in the solar still vapors and distillate which are produced at low basin water temperature [36], one of the best alternatives is through the immediate increase in the initial basin water temperature of small-scale CSS or absorber above 70 °C in the early stages of the experiment. Other than that, it is also recommended that the absorber water temperature can be increased to be higher than the boiling point in order to remove the bacteria and viruses in the boiler. These methods can be employed by integrating the CSS with the SDC and the sun-tracking system. As reported by several studies, a disinfection process occurs during the continuous boiling process using the SDC system with the explosion of the solution to the solar radiation ultraviolet waves [80–83]. The solar thermal parabolic dish concentrators were also noted as one of the most cost-effective paths for renewable energy to displace fossil fuels [84] which can be employed in producing freshwater for the rural communities. The reason for incorporating a sun-tracking system to the SDC was to increase the solar energy density at the focal point of the dish by reflecting most of the sunlight onto the solar still through absorber. This approach could lead towards achieving higher water temperatures [80–82,85,86], compared to the immobile solar reflectors which was reported to be unable to increase the basin water temperature up to the boiling point and thus increase the distillate yield significantly [87,88]. To ensure the specified accuracy and smoothness of the SDC surface, Sinitsyn, S. et al., 2020 proposed a method of fan-shaped geometric parquetting of the surface of a parabolic concentrator [89] and Panchenko, V., 2021 stated that the overall efficiency of a solar module increased and the uniform illumination was provided by using a composite concentrator (SDC) by concentrating the solar radiation on the surface of the module [90].

2.1. Description of Solar Dish Concentrator (SDC)

Generally, an SDC is a parabolic-shaped device which is covered with mirror strips to reflect and focus on the radiation of the sun towards a receiver or absorber mounted on the focal point of the parabolic dish, as depicted in Figure 2 [82]. A dual-axis direct current (DC) sun tracker system is required to maintain the orientation of the dish towards the sun [79–82,85,86]. As shown in Figure 2, the parabolic dish is characterized by the parameters of an aperture area, acceptance angle, rim angle, focal length, intercept factor, and the absorber area [91]. The curvature area of the dish that receives the sun's rays and reflects them to the absorber is called the aperture area (Figure 2). The acceptance angle (θ_{lim}) is defined as the angular limit to which the direction of the sun passes from point A to point B, and its rays deviate from the curvature, reflect on, and still touch the bottom of the absorber that is mounted on the focal point (Figure 2), where point A and point B symbolize the position of the sun in the sky. In order to use the sun-tracking system, the acceptance angle from point A to point B must always be equal to 0° [82]. The rim angle (φ_r) is the angle between the edge of the dish and the center of dish curvature from the focal point (absorber) (Figure 2); meanwhile, the intercept factor (γ) is defined as the ratio of the solar energy intercepted (cut off) by the absorber to the total energy that is reflected by the parabola of the SDC [82].

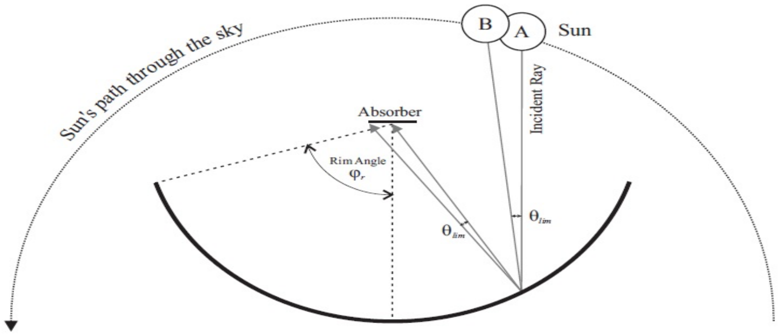


Figure 2. Acceptance and rim angles of an SDC [82].

The mathematical general equation for calculating the solar dish/parabolic concentrator (SDC) profile and the focal length (f) of the parabola of SDC was described by Johnston et al., 2003 [92] and Chaichan M.T. and Kazem H.A., 2015 [93] which is shown in Equation (1) when the coordinates of the parabola vertex (the point at the intersection of the parabola and its line of symmetry) is equal to (0, 0) (Figure 3).

$$y = x^2/(4f) \tag{1}$$

where y and x are the depth and radius of the SDC parabola, respectively, and f is the parabolic focal length (Figure 3) [92,93].

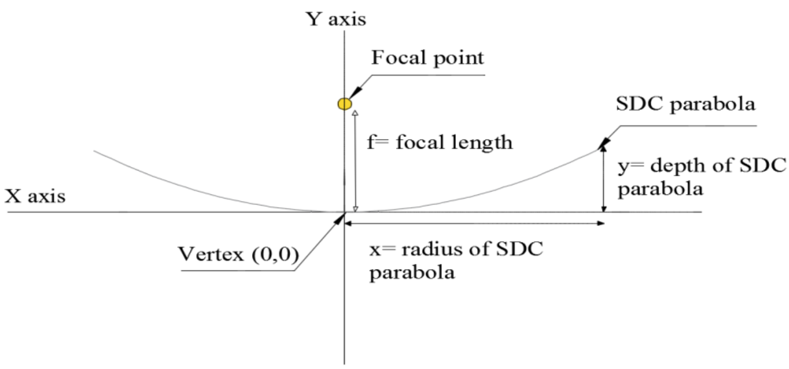


Figure 3. Sketch of an SDC parabola [92,93].

Maximized basin water temperature up to the boiling point and minimized thermal losses are among the advantages of SDCs compared to other heat sources which are coupled with passive solar distillation stills [94,95]. To achieve the above objectives, the quality of the SDC depends heavily on the quality of the reflecting surface; it is recommended that the surface be made using aluminum and stainless steel sheets for ensuring cost effectiveness and durability, as well as accuracy of the machining surface [94,95]. The solar still basin should be designed with small surfaces to ease its mounting at the focal point of the SDC for absorbing most of the reflected sunlight [79–82,85,86,94–96] as received from the optical concentration from tracking of the sun. As stated in a study, the typical temperature of the small-scale absorber integrated with the SDC and a dual-axis sun-tracking system ranges from 100 °C to 1500 °C [96].

2.2. Recent Findings on SDCs Integrated with Solar Stills

2.2.1. SDCs Integrated with Solar Stills and the Sun-Tracking System (STS)

The design and installation of an SDC that is integrated with a mini single-slope, air-tight solar still is called a 'modified receiver' (boiler) (Figure 4). This approach was presented and tested in a study [80] for the purpose of brackish water desalination under the climate in Egypt, in which the SDC performance was compared experimentally with the performance of a simple CSS. The dish-shaped concentrator (made of aluminum as a point-focus collector with an aperture diameter, depth, and focal length of 100, 20, and 40 cm, respectively) was selected and covered with highly reflective glass mirror strips (with 0.004 m of thickness) to reflect the intensity of the incoming solar insolation into the boiler located at the dish focal point. A tracking system was applied to the SDC to track the sun on two axes by using a 36 VDC tracking motor to move the SDC into the calculated positions. This was carried out throughout the day to maintain the focus of the sun's rays to the boiler in improving its water temperature, thermal efficiency, and distillate yield (Figure 4) [80]. The whole tracking system was powered by a 15 W amorphous silicon solar photovoltaic module, charge controller, battery, and inverter (Figure 4) [80]. Brackish water was preheated by a black hose which was exposed to solar irradiation throughout the day and supplied to both trapezoidal-shaped boiler and CSS. The boiler with a basin surface area of 0.046 m^2 had small dimensions (with the length, width, height from back, and front sides of 27, 16, 17, and 12 cm, respectively) to admit most of the reflected sunlight. The trapezoidal-shaped CSS with the basin area of 0.5 m^2 (with the high side and low side basin walls of 44 and 15 cm, respectively) was covered with a 30° inclined glass sheet (Figure 4). The experiments were conducted for nine hours, from 9:00 a.m. to 6:00 p.m. All of the boiler surfaces which were exposed to the sunlight (mainly UV) received some radiation from above as direct solar radiation, and most radiation of the sun's rays was reflected from the SDC surface to the sides and bottom surface of the boiler.

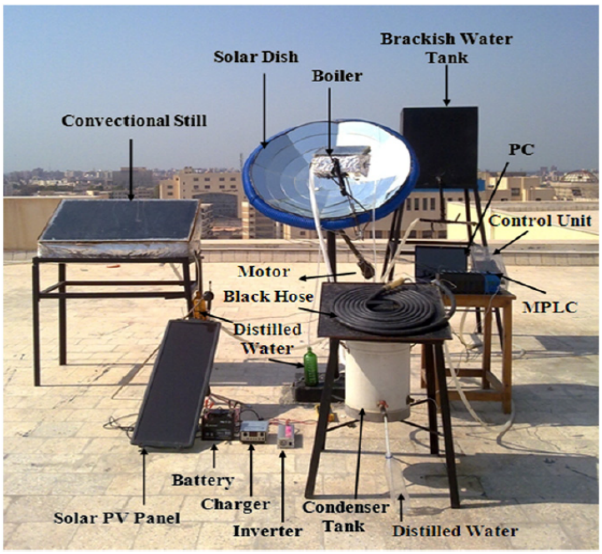


Figure 4. Experimental set-up photograph of the CSS and the solar still coupled with an SDC under Egypt's climate [80].

This process appeared to prevent the growth of bacteria and waterborne pathogens that could cause contamination of the distilled water [58–60] throughout the experiment.

However, this process is not completely practical in any other types of passive and active solar stills (CSS) which involve early experimental hours (usually in the morning) (Figure 5) [36]. The study results also showed that the water temperatures in the boiler were approximately 36–42 °C higher than the water temperatures in the basin of the CSS throughout the experiment (Figure 5). This occurred due to the additional concentrated sun's rays hitting the sides and bottom of the boiler as received from the SDC, which were about 230 w/m^2 at 9:00 a.m. in the first hour of the experiment, 100 w/m^2 at 12:00 p.m., and 600 w/m^2 at 5:00 p.m. in the day (Figure 5); it was also because the direct solar radiation intensity received from the top condensing surface of the boiler [80]. Meanwhile, the CSS only received direct intensities of solar radiation from its condensing cover which is located at the top (Figure 4). As can be observed from Figure 5, the starting (initial) brackish water temperature of the boiler, which was integrated with the SDC without preheating by the black hose, immediately reached 70 °C due to absorbing additional rate of solar intensities as reflected from the SDC. This rate was much higher than the temperature of the initial basin water of the CSS (which was recorded at about 45 °C) and solar stills in other studies [30,31,42–54,63–73], as presented in Table 2. The boiler water temperature increased to above 80 °C within an hour, reached approximately 105 °C at 11:00 a.m., and then continued to generate steam with a temperature of 105 °C for a three-and-a-half hour period until 2:30 p.m. Meanwhile, the maximum basin water temperature of the CSS was recorded at 63 °C at 12:00 p.m. (Figure 5) under similar climatic conditions. The produced steam from the boiler moved to a cylindrical tank, referred to as the 'condenser unit', that was filled with cold water which would be converted to fresh water droplets and collected in a graded container (Figure 4) [80].

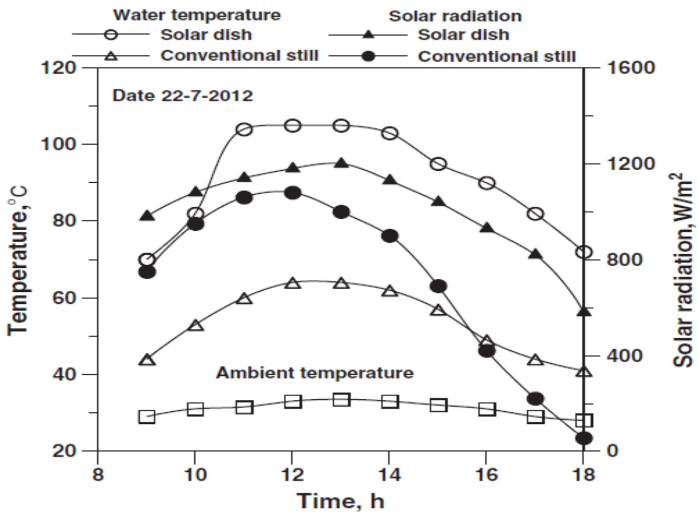


Figure 5. Diurnal hourly variations of direct and reflected intensities of solar radiation and water temperatures in the boiler and CSS and ambient temperature without pre-heating technique [80].

The study results showed that by integrating the SDC and small-scale solar still (boiler), the water temperature in the boiler drastically increased to above 70, 80, and 105 °C in the early experimental hours. This approach is seen as the most effective in removing any available waterborne pathogens, bacteria, and viruses—particularly SARS-CoV-2—from the boiler water and produced vapors while preventing the transmission of those impurities into the distillate (Figure 5). This is because the range of temperatures from 50 °C to 70 °C is the limit of the viability of waterborne pathogens and novel coronavirus, as recommended by several studies [74,75]. It was also stated in the study that the increased temperature of brackish water in the boiler by the SDC enhanced the amount of daily fresh water production, ranging from 0.65 and 0.55 L/h at 11:00 a.m. and 4:00 p.m., respectively (Figure 6) [80]. The boiler with SDC produced maximum water of 6.7 L/m^2 in a nine-hour period, while the CSS produced only 1.5 L/0.5 m^2 within the same period [80].

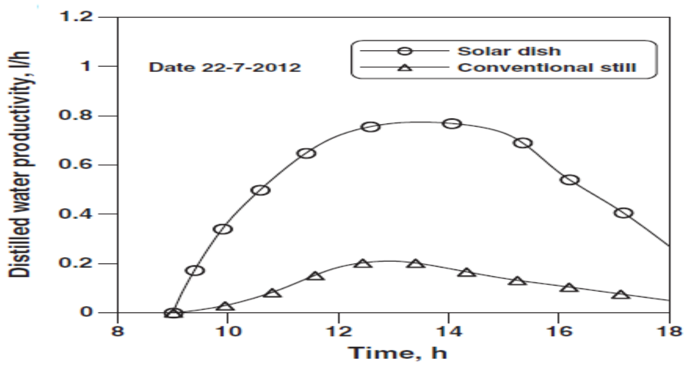


Figure 6. Hourly values of distilled water production of CSS and the boiler coupled with SDC without the preheating method [80].

In another study, a stand-alone point-focus parabolic solar still (PPSS) coupled with the sun-tracking system and a small-scale passive solar still as absorber or (boiler), was designed and fabricated for purification of the seawater and brackish water in Tehran, Iran (Figure 7) [81]. Salt with different masses (from 10 g to 40 g, with 5 g intervals) was dissolved into each kg of water sample before being fed into the boiler [81].

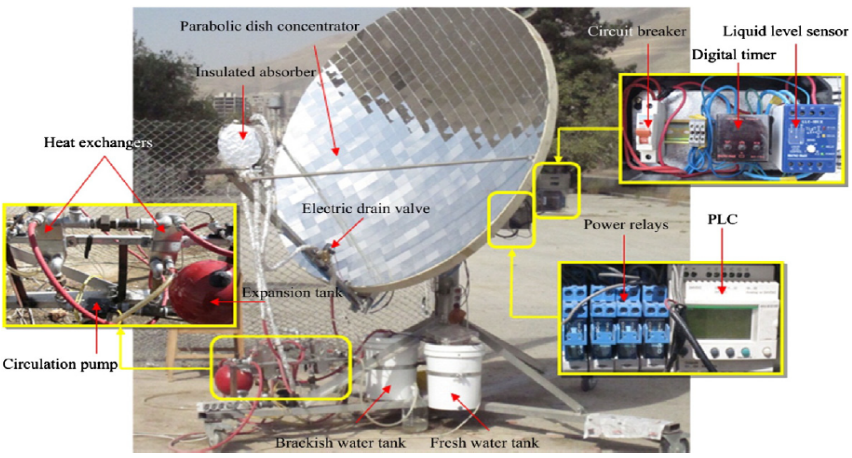


Figure 7. Photograph of the experimental set-up of an auto sun-tracking system SDC-solar still in Tehran, Iran [81].

The above-developed stand-alone system (PPSS) is comprised of several items, including a parabolic dish concentrator, a boiler mounted at the focal point of the dish collector, two plate heat exchangers (to condense the steam generated in the boiler and increase the brackish water temperature before entering the boiler, or the preheating process) and a brackish water level controller in the absorber (Figure 7) [81]. A programmable logic controller (PLC) was used to control the tracking motors to drive the SDC in two axes for tracking the sun based on the calculated positions [81] (Figure 7). The boiler had a receiving surface, which was as small as 0.031 m^2 and made of CK45 steel alloy, and the black chrome was coated at its bottom side to increase the absorptivity of the reflected sun's radiations [81]. The reflective area of the SDC was 3.142 m^2 with the aperture diameter of 2 m and the focal length of 0.693 m, and it was covered with silver-backed glass segments of 0.002 m thickness [81].

The study results showed that the initial boiler wall temperature (T_s) increased abruptly to about 70 °C (Figure 8) due to the reflection of solar radiation into the small-scale boiler [81]. All parts of the boiler were exposed to the sunlight in the early hours of the experiment, and the SDC-boiler system performed to produce water at temperatures higher than 70 °C, which is operative to prevent transmission of pathogens, bacteria, and viruses from the brackish water into the vapors and condensed vapors [74,75]. The boiler wall temperature increased drastically from 70 °C to about 100 °C in a short period of 30 min after the experiment started at 8:00 a.m. (Figure 8). Then it was maintained to reach above 100 °C (boiling point) for the remainder of the seven-hour experiment.

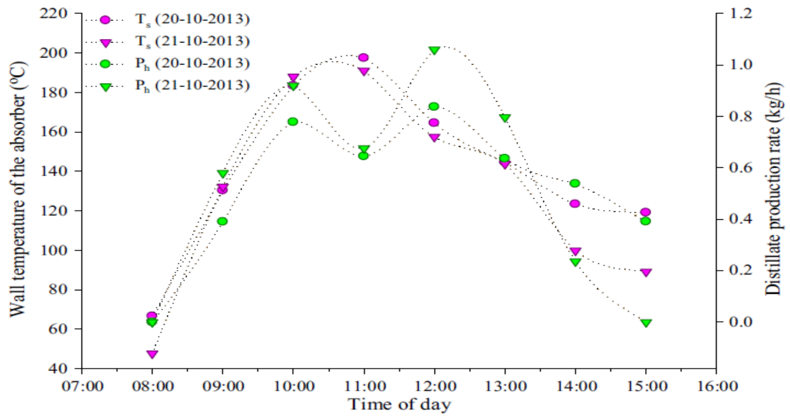


Figure 8. Hourly variations of temperature of absorber/or boiler wall of the PPSS versus the distillate production of the PPSS [81].

The maximum total daily water production (P_d) was reported on 18 and 22 October 2014 with values of 5.02 and 5.11 kg per 7 h, respectively. Meanwhile, the PPSS system was exposed to higher average solar radiation intensities ($(I_b)_{ave}$, more than 630 W/m^2) in these two days, causing the boiler wall temperatures $(T_s)_{ave}$ to reach maximum average values of about 140 °C and 150 °C, respectively. The highest average daily efficiency was reported as 36.7% on 22 October 2014 due to the highest average solar insolation, average absorber wall temperature, and total daily productivity [81]. However, it was reported that the average temperatures of air $(T_{air})_{ave}$, wind speed $(V_w)_{ave}$, and the salinity rates fed in water samples did not affect the daily water production considerably [81]. Water quality parameters of total dissolved solids (TDS) and electrical conductivity (EC) were also measured for feeding salt water into the boiler and discharging brine and distilled water from the boiler after the desalination process for the seven experimental days. As reported, the values of TDS and EC ranges for the distilled water produced by PPSS were the lowest and fell within the acceptable ranges of WHO standards for drinking water purposes [81]. The annual water production of the proposed PPSS system was calculated and stated as 2422.40 kg, while the cost of 1 kg of distilled freshwater produced by the system with an SDC coupled to a boiler was analyzed and reported as USD 0.012; under the Tehran climate, this cost was stated as sufficiently low and cost-effective for rural householders [81]. It was recommended that the photovoltaic modules can be employed as a useful alternative to supply power for the electrical components of the PPSS system, instead of consuming electricity directly in order to reduce the direct electricity consumption per kilogram as well as the operating costs of USD 6187.40 per year for the production of freshwater [81].

In another theoretical and experimental work [82], an SDC which was made from recyclable materials and coupled with a sun-tracking system and a boiler (evaporator) were designed, installed, and experimented for ground water and sea water desalination under the Brazil climate, as depicted in Figure 9. A recycled satellite dish antenna made from galvanized steel with two different aperture diameters (height of 68 cm and width of 62 cm) was selected, mirrored via an electrostatic chroming method, and then used as an SDC in the study [82].

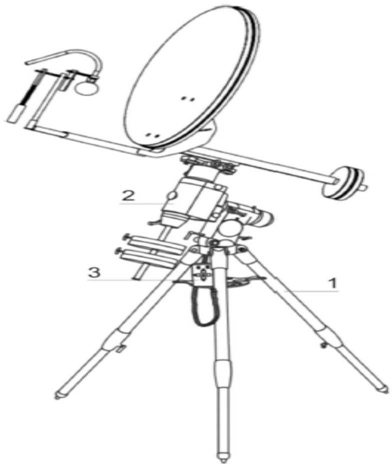


Figure 9. Sketch of a solar desalination unit of SDC coupled with a sun-tracking system [82].

Based on the experiment results as shown in Figure 10, an intermediate focal point in a focal region of the SDC which was determined between two different focus points of the reflected sun's rays was achieved at the best focal length of 51.5 cm [82]. A two-axis sun-tracking system was mounted on a steel tripod (1) and powered by two motors (2) which rotated the SDC in 64 steps per revolution with 1.8° in each step programmed through the control (3) (Figure 9) [82].

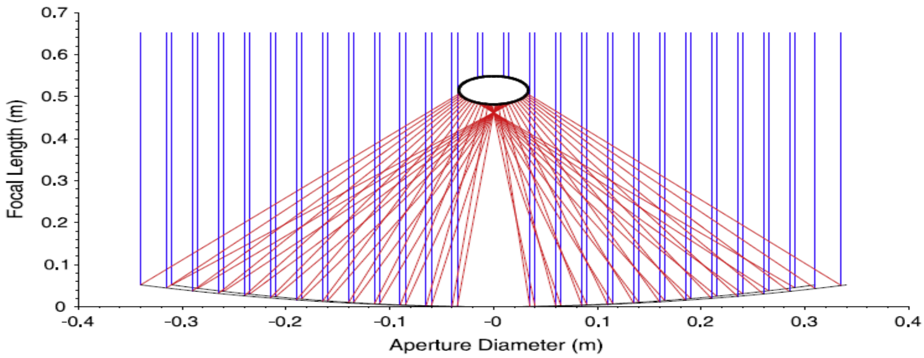


Figure 10. Simulation of the sun's rays (colored lines) as reflected from the two curvatures of the SDC had different diameters from the absorber which is located at the focal length of 51.5 cm [82].

The study's experiments were conducted from 9:00 a.m. to 4:00 p.m. for two months (September and October) [82]. As illustrated in Figure 11, a borosilicate glass sphere-shaped absorber called an evaporator absorber with the area of 0.1182 m^2 and the storage of 100 mL was filled with crushed basalt and coated with a matte black paint mounted at the focal point of the SDC. Samples of ground water and sea water with similar sea salt concentrations from 0% to 4% were pumped into the absorber from the storage tank (1). Next, the sun's rays' reflections were focused onto the sphere-shaped boiler to heat the sea water. Then, water vapor from the boiler passed through the copper tube with a length of 30 cm for the first phase of the condensing process (2) and was directed from a 1.5 m silicon tube for the second phase of condensation method (3) into the graduated container to store the produced water (4) [82].

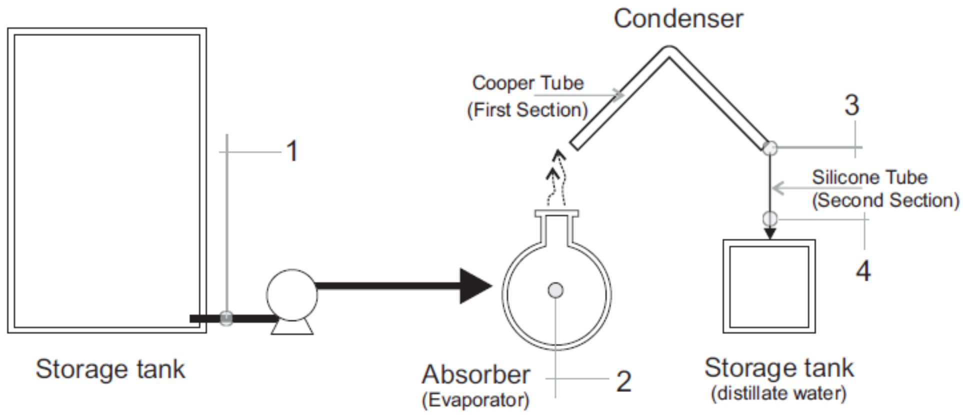


Figure 11. Processes of pumping brackish water into the absorber (1), evaporated from the absorber (2), and condensed in copper (3) and silicon (4) tubes [82].

As shown in Figure 12, two disk-shaped aluminum specimens, Specimen 1 and Specimen 2 (painted matte black with the effective areas of 0.1611, 0.1108 m^2, respectively) which were located at the focal region of the SDC acted as solar radiation absorbers and were tested theoretically and experimentally to determine their dynamic heating temperatures [82]. The intercept factors (γ) of Specimens 1 and 2 were experimentally investigated, analyzed, and recorded at 48.64 and 33.45 % respectively, which indicated that these factors were dependent on their diameters [82].

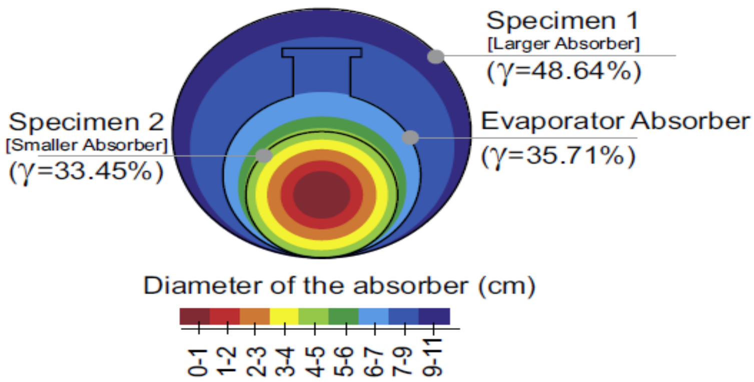
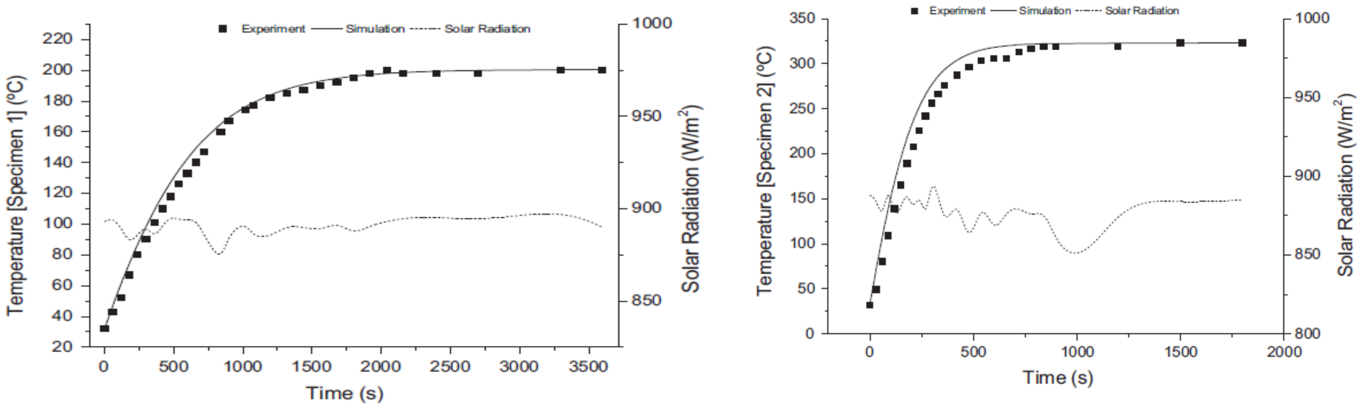


Figure 12. Relationship between absorbers' diameters and their intercept factors [82].

The temperature of the smaller absorber (Specimen 2) reached the maximum value of 319 °C in 840 s which was maintained until 1800 s, while the larger absorber (Specimen 1) experienced the maximum temperature of 198 °C at 1800 s which lasted until the end of experiment, i.e., at 3500 s. These results are shown in Figure 13a,b) [82]. It was also reported that the average boiling point temperature of the third absorber (called the 'evaporator absorber', with an optical efficiency of 0.273 and intercept factor of 35.71%) increased from 98.10 °C without sea salt concentration to 99.66 °C with 4% of salt concentration [82] during the desalination experimental works. This result indicated that a disinfection process occurs during the continuous boiling process with the explosion of the solution to the solar radiation ultraviolet waves [83]. It was observed during the study's experiments that all the three absorbers received ultraviolet waves (UV) of the sun's rays from their top sides and as reflected from the parabola of the SDC [82]. Thus, the reviews have proven the feasibility of using SDCs coupled with smaller absorbers of Specimen 2 and evaporator with the sun-tracking system in the study [82] for removing bacteria, waterborne pathogens, and viruses since the high initial temperatures of the absorber water were achieved. The highest yield of 4.95 kg/m^2 day of distilled water was attained under the average solar irradiances of 791 W/m^2 without adding salt in the sample [82].



(**a**) (**b**)

Figure 13. Experimental and simulated dynamic heating of Specimens 1 (**a**) and 2 (**b**) versus the values of solar radiation [82].

In a study conducted by Chaichan M.T. and Kazem H.A. in Baghdad, a solar distiller (absorber/receiver) was integrated with an SDC to heat the saline water (Figure 14) [93]. Then, hot water was transferred to a conical distiller by a heat exchanger to produce distilled water. The SDC had an aperture diameter of 1.5 m and a depth of 23 cm and the conical distiller was layered with paraffin wax, called 'PCM', as thermal energy storage material to expand the distillation process after daytime [93]. Aluminum foil was adhered to the parabola dish surface for reflecting the sunlight to the absorber.

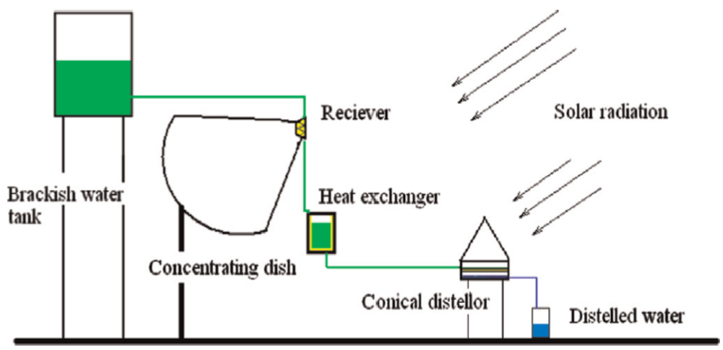


Figure 14. Sketch of the SDC with STS integrated with an absorber (receiver) with a conical distiller with PCM [93].

The experiments conducted for four cases consisted of the SDC without STS and PCM as Case 1, the SDC with STS and without PCM as Case 2, the SDC without STS and with PCM as Case 3, and the SDC with STS and PCM as Case 4. Using PCM with STS (Case 4) gave the highest temperatures compared to other three cases, especially for the period after 2:00 p.m. (Figure 15). However, the obtained temperature for Case 4 did not reach the boiling point of brackish water as the reflecting layer adhered to the surface of SDC was made of aluminum foils and had lower sun's rays reflectivity compared to the mirror. It can be seen that the water temperatures of the brackish water reached beyond 65 °C at about 2:00 p.m., and reduced significantly after 2:00 p.m. following the decrease in solar radiation intensity. Although the initial working temperatures of the absorber in Case 4 were between 10 °C and 40 °C in the early hours of the experiment (Figure 15). However, in the results obtained from the experiments conducted in [80–82], the initial temperature of the absorber was above 65 °C and it increased drastically beyond the boiling point immediately in a short period of time due to using glass mirror as the covered layer of the SDC surface. This can be resulted from covering the layer of the surface of the SDC with aluminum foil which has a lower solar radiation reflectivity as compared to mirror strips. Thus, it seems that the SDC layered with aluminum foil is unable to increase the absorber water temperature considerably (Figure 15) in order to remove bacteria, waterborne pathogens, and viruses due to the resulting low initial water temperatures in the absorber. Thus, it can be seen from the above results that the reflectivity of the cover layer of the SDC surface has a vital role in increasing the initial temperature of the brackish water in the absorber significantly.

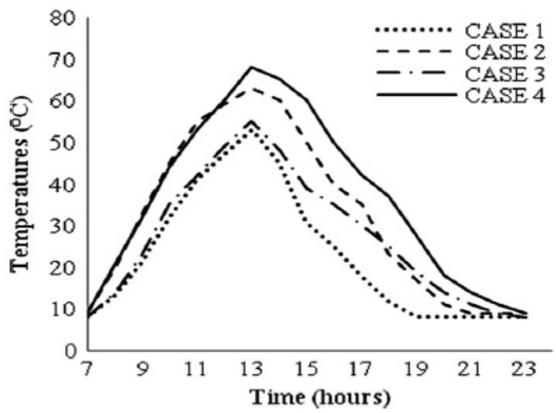


Figure 15. Variations of brackish water temperature versus time for the four studied cases [93].

In another study conducted by Bahrami et al., 2019 in Yasouj University, Iran, an SDC with an aperture diameter of 2.0 m integrated with an STS to reflect the solar radiation into an evaporator tank mounted on its focal point with a focal length of 1.4 m was designed, installed, and tested to desalinate saltwater (Figure 16) [97]. The evaporator had a base area of 0.2 × 0.2 m and saltwater in the range of 1.0 to 10 kg was fed into the evaporator during the experiment and maintained with the use of a float level controller (Figure 16).

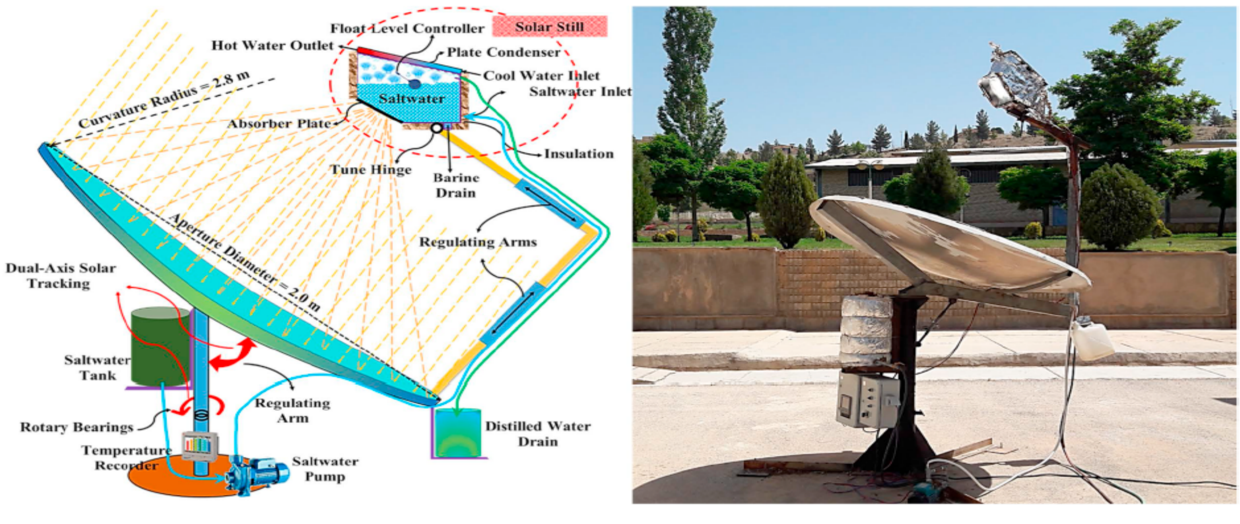


Figure 16. (**a**) Detailed sketch and (**b**) photograph of the experimental set up of the SDC and evaporator performed in Iran [97].

It has been stated by Bahrami et al. that the total amount of the produced distilled water increased from 11.5 to 50 kg by increasing the aperture diameter of the SDC from 1.5 to 3.0 m, respectively, and it increased twice while the optical efficiency of SDC increased from 0.5 to 0.8. The amount of produced water was also increased by more than double when the reflectivity of the evaporator base decreased from 0.7 to 0.4 [97]. They have also reported that the saltwater in the evaporator boils at earlier time for an SDC with larger aperture diameter. An SDC with an aperture diameter of 3.0 m was able to boil 8 kg of saltwater with a salinity rate of 30 (g salt/kg water) after about 20 min, while this took about 40 min for an SDC with a diameter of 2.0 m [97]. As depicted in Figure 17, the SDC with a diameter of 2.0 m was reported to boil 6.15 kg of saltwater with a salinity rate of 20 (g/kg) in the evaporator in a period of 1.0 h when the distillation process started from 11:40 a.m. and maintained the boiling point until 3:30 p.m. This highlighted that an SDC with larger aperture diameter [97] and smaller absorber area [82] is capable of reflecting more of the sun's rays to the evaporator (absorber) to reach the highest initial temperature and the boiling point in a shorter period.

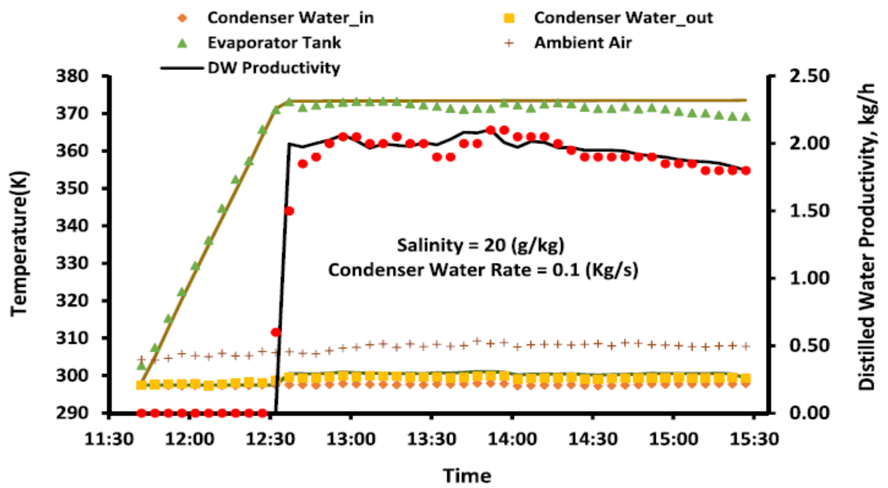


Figure 17. Hourly variation of saltwater temperature in the evaporator tank and the distilled water production of the SDC with aperture diameter of 2.0 m [97].

2.2.2. SDCs Integrated with Solar Stills without the Sun-Tracking System (STS)

In India, several studies investigated the performance of passive solar stills heated by SDCs and additional phase-change materials (PCM) in the still's basin using the cover cooling techniques, without employing the sun-tracking system [98,99]. In one of the studies [98], two passive single-slope solar stills (SSSS) were designed and fabricated, whereby each was mounted on a focal point of a fixed SDC (Figure 18) and stored the heat at their basins using six PCM copper balls filled with paraffin wax (Figure 19a,b); meanwhile, the cold water flow technique was employed at the top cover of one of the solar stills to improve the condensation rate. A black painted hemispherical copper bowl (with a diameter of 0.22 m and a thickness of 4 mm) was separately attached to each basin bottom of the passive SSSS mounted on the focal point of the SDC, which acted as receivers of the sun's rays' reflections to heat the basins water. Six hollow copper balls (each with a thickness of 1.2 mm, as in Figure 19a,b) filled with paraffin wax were used in the absorber of each solar still as the PCM. The balls acted as a heat source for the absorber water to maintain its temperature during the afternoon—i.e., when the solar irradiances started to decrease—and then continued to produce fresh water after sunset [98].

The performance of each solar still was strongly dependent on the intensities of solar absorption by the hemispherical copper bowl absorber from the concentrator, and the PCM balls located in the basin [98]. The temperatures of initial basin water temperatures in the early hours of the experiments with the solar stills with PCM and SDC using the top cover cooling techniques (with water flow rates of 40, 50, 60, 80, and 100 mL/min) were observed at 40, 43, 47, 47, and 48 °C at 9:00 a.m. and 56, 56, 56, 57, and 56 °C at 10:00 a.m. respectively; meanwhile, the temperatures recorded were 43 °C and 56 °C at 9:00 and 10:00 a.m., respectively, for the experiments without any water flow on the top cover [98].

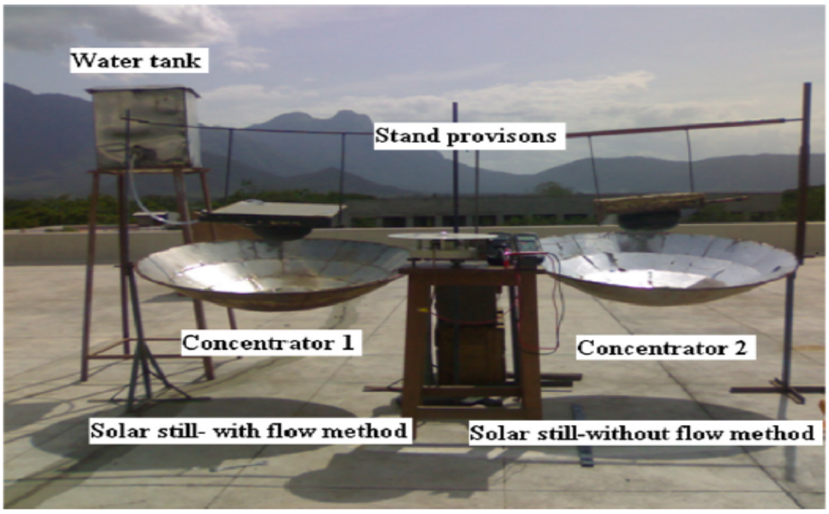
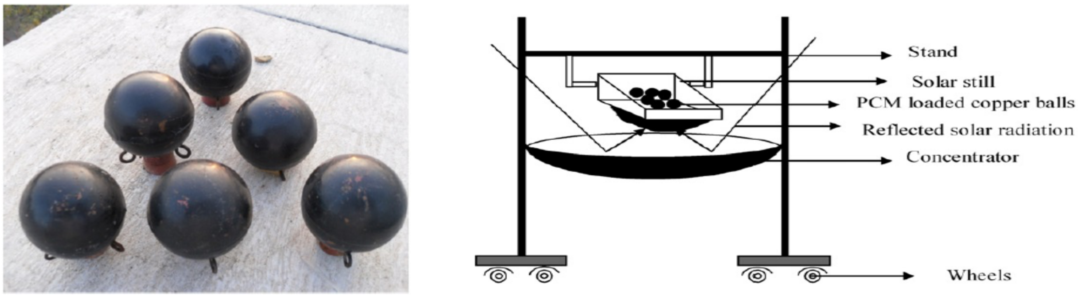


Figure 18. Photograph of two solar stills coupled two SDCs, with and without the cover cooling method [98].



(**a**) (**b**)

Figure 19. (**a**) Photograph of PCM copper balls used in a hemispherical SSSS; (**b**) sketch of a hemispherical SSSS with PCM balls in bowl-shaped copper basin while receiving the sun's rays from a fixed SDC [98].

As depicted in Figure 18, most parts of the solar still in the study included the top cover, basin bottom, and the sides which were exposed to the UV of solar radiation in the experiment from morning to evening [98], ranging from 580 to 1050 W/m^2. However, flowing water on the top cover and water droplets on the inner side of the solar still's cover reduced the inputs of the solar radiation to the basin water. Furthermore, as can be observed, there was a lack of coating of the mirrored layer on the SDC surface and no system to track the directions of the SDC and solar still towards the sun and to use the solar still to absorb the reflected sun's rays at a larger scale. As stated by Arunkumar et al., 2015, there were lower initial (ranging from 40 °C to 56 °C) and maximum (ranging from 92 °C to 88 °C) basin water temperatures and lower total yield (ranging from 3.557 to 3.80 L/m^2.day) in the solar stills throughout the experiment [98], compared to the use of solar stills with SDC, sun tracker system, and mirrored surfaces in other studies [80–82]. Meanwhile, as noted in other studies [36,74,75], it seems infeasible to produce water under low basin water temperatures with the use of solar stills coupled SDC and without the sun-tracking system [98], particularly in terms of removing bacteria, waterborne pathogens, and viruses due to the resulting low initial water temperatures (ranging 40 °C to 56 °C) in the basins of solar stills.

Another experimental study in India designed and fabricated a triple-basin solar distiller (TBSS) mounted on a focal point of an SDC [99]. Without engaging a sun-tracking system, it was heated by heat storing materials comprised of four triangular hollow fins filled with river sand (RS) and charcoal (CHAR) in the basins of the distiller which were exposed to the direct solar irradiances [99]. As depicted in Figure 20, a cover cooling (CC) approach using water with different flow rates (20 to 40 mL/s with the intervals of 5 mL/s) was also employed to decrease the still cover temperature and increase the condensation rate [99].

Figure 20. Photograph of a triple basin solar distillation still coupled with an immobile SDC [99].

As shown in Figure 21, the TBSS performed as an absorber whereby its three basins consisted of three basins (lower, middle, and upper basins) acting as an evaporator in the study [99]. Meanwhile, a trapezoidal-shaped glass casing (made of 4 mm thick window glass) was used as the condenser cover and placed at the top of the SDC (with a focal length of 50 cm) with no sun-tracking system to absorb the reflected sun's rays and direct solar intensities. The SDC had a diameter of 1.25 m and was made from a polished aluminum sheet with a thickness of 1 mm. The TBSS evaporator had an overall size of 0.3 × 0.36 m with a height of 0.33 m, while the three basins had a vertical gap of 0.12 m from each other to allow the water vapor to be directed into the inner surface of the condensing cover, as illustrated in Figure 21 [99]. The TBSS cover was constructed with the size of 0.4 × 0.46 m^2, heights of 0.4 m and 0.47 m at two different sides, and a 10° incline at the top. A plastic pipe with a diameter of 0.032 m and length of 0.46 m was punctured at regular intervals and then installed at the top of the outer surface of the condensing cover in order to cool the cover and maintain a uniform flow of water that was pumped over the outer glass of the condensing cover surface [99].

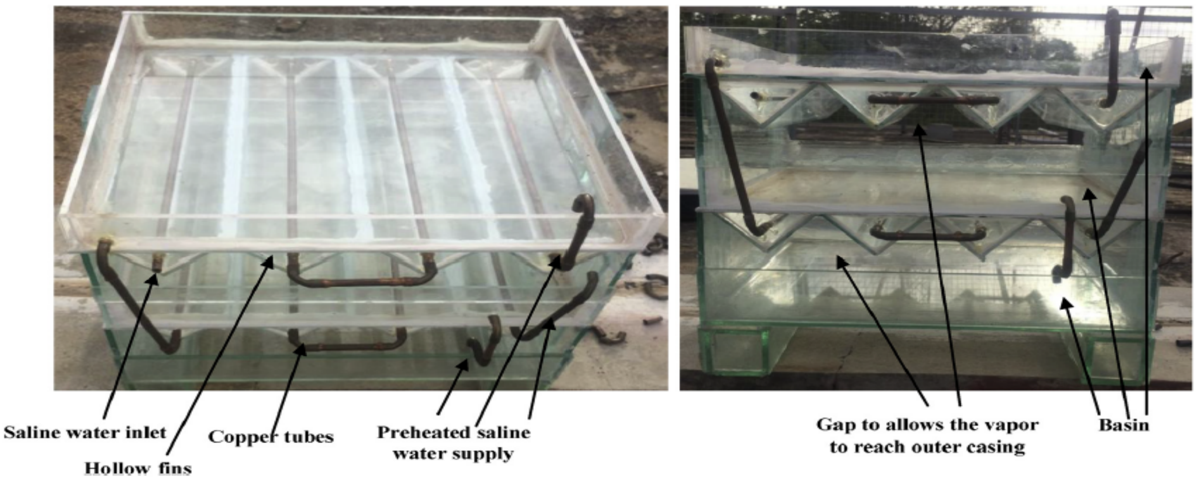


Figure 21. Photograph of a triple basin with triangular hollow fins [99].

The water temperatures in solar still basins of the TBSS, which was filled with charcoal and coupled with SDC without the sun-tracking system, were found to be 36 °C and

57 °C at the early experimental hours of experiment—i.e., at 9:00 a.m. and 10:00 a.m., respectively. As a result, about 0.30 kg/m^2 water was produced in the first hour of the experiment, as illustrated in Figure 22 [99]. These values are within the critical ranges for the transmission of pathogens and viruses in the produced water, as reported by several studies [36,74,75]. However, all parts of the TBSS were exposed directly to the reflected UV radiation of the sun. Hence, the competency of the TBSS which was coupled with SDC without a sun-tracking system as used in the study [99] seems to be impractical to remove bacteria, waterborne pathogens, and viruses. This was due to the water production at low basin water temperatures—i.e., ranged between 36 °C to 57 °C—as stated in other studies [36,74,75].

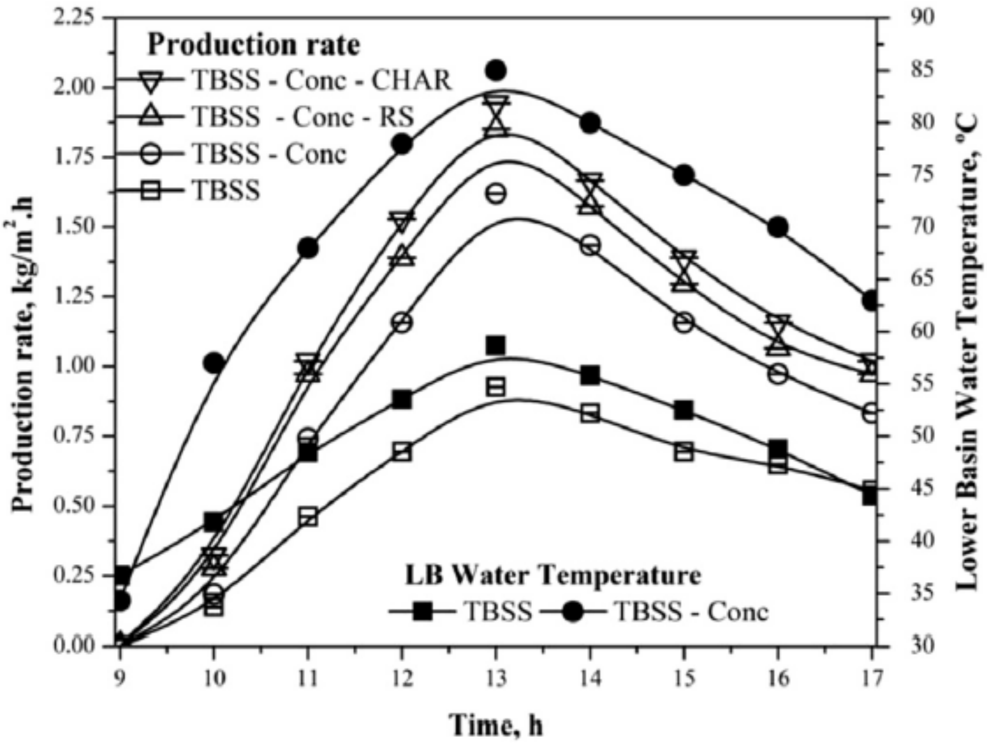


Figure 22. Hourly water temperatures and productivities of the TBSS (filled with and without heat storage materials in the basins) were affected by the use of SDC [99].

2.3. Cost Per Liter (USD) of Small-Scale Passive Solar Stills (Absorbers) Integrated with SDCs

In order to evaluate the economic benefits of passive solar stills (absorbers) integrated with SDCs for the remote and rural communities, it is essential to consider the cost per liter of the SDC distillation systems and their comparison against other passive and active solar stills. Previous studies revealed that the cost per liter (USD) of the small-scale solar stills (absorbers) coupled with SDCs and the sun-tracking system were USD 0.028 and 0.012 [80,81] and without the sun-tracking system were USD 0.0085 and 0.084 [98,99], respectively. As indicated in Table 3, these values were lower than the cost per liter of some conventional passive, and also active, solar stills used in several other studies [40,46,100–105]. Subsequently, the maximum water yields of the solar stills with both SDC and the sun-tracking system [80] and without the tracking system [99] were found to be higher than the maximum water production of passive and active solar stills tested in other studies [40,46,100–105] (Table 3).

Table 3. Cost per liter (USD) and maximum daily yield of the passive solar absorbers coupled with SDCs and the sun-tracking system in comparison with some other passive and active solar stills.

Types of Solar Still	Maximum Daily Water Production (L/m^2)	Cost per Liter (USD)
CSS with SDC with sun-tracking system and vapor condensing technique, Egypt [80]	6.70	0.028
CSS with SDC with sun-tracking system (PPSS) and vapor condensing method, Iran [81]	3.56	0.012
CSS with SDC with sun-tracking system and water heater/PV modules, Egypt [106]	13.63	0.25
SDC integrated with an evaporator and solar tracking system, Iran [97]	6.5	NA
Triple-basin solar still with SDC, charcoal in basins and cover cooling method without sun-tracking system, India [99]	16.94	0.084
SSSS with SDC, PCM balls, and cover cooling method without sun-tracking system, India [98]	3.80	0.0085
Conventional passive solar still, Egypt [80]	3.00	0.048
Conventional passive solar still, PSS, Malaysia [40]	3.21	0.015
Passive solar still (PSS) coupled with a PV module-DC heater, ACSS, Malaysia [40]	4.36	0.045
Single slope passive solar still, Pakistan [104]	3.25	0.063
Single slope hybrid (PV/T) active solar still, India [102]	1.91	0.14
Passive solar still coupled with a flat plate collector, Jordan [100]	4.69	0.103
Fin-type passive solar still, India [46]	4.00	0.054
Passive solar still with wick and fin in the basin, India [101]	4.06	0.065
Stepped passive solar still with fins and sponges in the basin, India [103]	3.03	0.064
Passive solar still with a shallow solar pond, Egypt [105]	4.65	0.08

3. Discussion

The limit of water temperatures ranging from 50 °C to 70 °C was reported as appropriate for the viability of some waterborne pathogens, bacteria, and viruses—particularly SARS-CoV-2—in water bodies [74,75]. The vast public health concern was pertaining to the existence of the aforementioned impurities during the pandemic, particularly SARS-CoV-2, in distilled water produced by passive and active solar stills, recently highlighted in previous studies [31,36,39,40,42–44,46–51,53,63–73], in which the solar stills were found to be able to generate the distillate in low initial operating water temperature. As can be observed from the reviews, using SDCs coupled with small-scale passive solar stills (i.e., absorbers or boilers) [80–82,97] and the sun-tracking systems could lead to drastic and instant increases in the initial water temperatures in the boilers until above 70, 80, and 105 °C in the early experimental hours. This was due to the high rates of the reflected sun's rays and heat from the SDC's mirrored surfaces onto the boiler outer surfaces, which is recommended as one of the most effective ways for removing any available waterborne pathogens, bacteria, and viruses—particularly SARS-CoV-2—from the absorber water in order to prevent the transmission of those impurities into the distillate.

However, initial basin water temperatures in the absorbers—which are coupled with SDCs, but without the sun-tracking systems as experimented in several studies [98,99]—were lower than 50 °C in the beginning of the experiments. Such conditions are an important factor for the viability and survival of water borne pathogens and viruses in the basins water and distillates, as noted by other studies [36,56–60].

Furthermore, as seen from the experimental works on the SDCs integrated with absorbers and sun tracking devices [80–82,97], all parts of the absorbers were exposed to the sunlight (mainly ultraviolet waves (UV)) and received direct radiation at the top surfaces and the reflected sun's radiation at the bottom and sides from the parabola surface of the SDCs throughout the experiments. Exposing all parts of the solar stills to the sun's rays is an efficient technique to prevent the growth of bacteria and pathogens in the distillate [58–60]. However, this method was not completely practical in the use of any other types of passive and active solar stills because the sun's rays were only received from the top condensing cover surfaces in the early experimental hours [21,29,31,39,40,42–44,46–51,53,63–73].

It was also stated in another theoretical and experimental study [80–82] that the absorbers with smaller surfaces areas and lower water capacity have experienced greater water temperatures, as compared to those with larger surfaces areas [97–99], when the SDCs and the boiler were used under the hourly sunlight periods. The water temperature of the small-scale absorbers coupled with SDCs and the sun-tracking systems as reported in several studies [80–82] increased drastically from about 70 °C to above 100 °C (i.e., the boiling point). The maximum values were achieved at 105, 150.7, and 319 °C, respectively, within a few minutes in the early morning after the daily experiments began, and then the condition was maintained for several hours until the evening. This indicated that a disinfection process occurred during the continuous boiling processes in the absorbers due to the explosion of the solution onto the solar radiation ultraviolet waves [83]. It was obtained from the results of the above studies [80–82,93,97] that an SDC with largest aperture diameter, greatest optical efficiency, and reflectivity with STS integrated with an absorber with smallest area and lowest reflectivity had a vital role in increasing the initial temperature of the brackish/saline water in the absorber around 70 °C, maintaining the water temperature beyond the boiling point and enhancing the amount of distillate significantly.

On the other hand, other studies [87,88,98,99] reported that solar stills with immobile solar reflectors were unable to significantly improve basin water temperature to reach the boiling point.

Furthermore, as reported in several studies [80–82], small-scale absorbers coupled with SDCs and dual-axis sun-tracking systems had better performance and were more effective in obtaining higher productivities with lower cost per liter, compared to passive and active solar stills investigated by others [40,46,100–105]. This was due to the resulting higher average water temperatures of the absorbers. Nevertheless, solar stills integrated with immobile SDCs and heat storage materials in their basins [98,99] had higher water productivities and lower costs per liter compared to the mobile SDCs—distillation systems [80–82]. Despite this, low initial absorber temperatures of the absorbers are highlighted as a public health concern in terms of preventing the transmission of pathogens and viruses into the distillate.

4. Conclusions

Based on the above reviews and discussions, SDCs with mirrored surfaces and sun-tracking systems were seen as capable of increasing the initial water temperature of the integrated small-scale absorbers until exceeding 70 °C. Furthermore, continuous increase in the absorbers' wall temperatures beyond the boiling point until the end of the operation is also recommended as another efficient technique to demolish the waterborne pathogens and viruses, especially SARS-CoV-2, at the same time to prevent transmitting these impurities to the produced water during the pandemic. Smaller scale absorbers were found to be more effective in terms of the SDC's surfaces' ability to absorb more heat from the reflected sun's rays, compared to those with larger areas. SDCs with and without the sun-tracking systems (STS) produced greater amounts of freshwater at a lower cost compared to the other previous passive and active solar stills. An SDC with larger aperture diameter, greater optical efficiency, and reflectivity with the STS integrated with an absorber with smaller area and lower reflectivity was perceived to be more operative in increasing the initial temperature of the brackish/saline water in the absorber around 70 °C, maintaining the water temperature at the boiling point during sunshine hours and enhancing the amount of distillate significantly. SDCs with the STS were more effective than the immobile and non-sun tracking SDCs in terms of obtaining higher operating absorber temperatures. Therefore, SDCs which are integrated with small-scale absorbers and sun-tracking systems are recommended as a cost-effective and reliable alternative of an impure water treatment system that can produce hygienic and pathogen-free fresh water, particularly during the SARS-CoV-2 pandemic, for the benefit of the communities in remote and rural areas—including those located in the Middle East, South-East Asia, and Africa—which are suffering from water scarcity and have abundant annual bright sunshine hours.

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References

1. Gleick, P.H. *Water in Crisis: A Guide to the World's Freshwater Resources*; Oxford University Press Pacific: Oxford, NY, USA, 1993.
2. Holdsworth, J. 18—Authorised EU health claims for water. In *Foods, Nutrients and Food Ingredients with Authorised Eu Health Claims*; Sadler, M., Ed.; Woodhead Publishing Series in Food Science, Technology and Nutrition; Woodhead Publishing: Sawston, UK, 2014; pp. 373–395.
3. Gutierrez, J.R.; Whitford, W.G. Chihuahuan desert annuals: Importance of water and nitrogen. *Ecology* **1987**, *68*, 2032–2045. [CrossRef] [PubMed]
4. Rastogi, S.C. *Essentials of Animal Physiology*, 4th ed.; New Age International Publishers: New Delhi, India, 2008; Available online: https://www.vet-ebooks.com/essentials-of-animal-physiology-4th-edition/ (accessed on 9 January 2022).
5. Science Learning Hub—Pokapū Akoranga Pūtaiao. Earth's Water Distribution. Available online: https://www.sciencelearn.org.nz/images/802-earth-s-water-distribution (accessed on 20 December 2021).
6. Cech, T.V. *Principles of Water Resources: History, Development, Management, and Policy*, 3rd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2010.
7. Kumar, K.V.; Bai, R.K. Performance study on solar still with enhanced condensation. *Desalination* **2008**, *230*, 51–61. [CrossRef]
8. Tiwari, G.N.; Singh, H.N.; Tripathi, R. Present status of solar distillation. *Sol. Energy* **2003**, *75*, 367–373. [CrossRef]
9. Vineis, P.; Chan, Q.; Khan, A. Climate change impacts on water salinity and health. *J. Epidemiol. Glob. Health.* **2011**, *1*, 5–10. [CrossRef] [PubMed]
10. Guardian News & Media Limited. The Guardian for 200 Years. Available online: https://www.theguardian.com/environment/2020/nov/26/more-than-3-billion-people-affected-by-water-shortages-data-shows (accessed on 26 November 2020).
11. Tabrizi, F.F.; Sharak, A.Z. Experimental study of an integrated basin solar still with a sandy heat reservoir. *Desalination* **2010**, *253*, 195–199. [CrossRef]
12. El-Ghonemy, A.M.K. Water desalination systems powered by renewable energy sources: Review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1537–1556. [CrossRef]
13. Sampathkumar, K.; Arjunan, T.V.; Pitchandi, P.; Senthilkumar, P. Active solar distillation—A detailed review. *Renew. Sustain. Energy Rev.* **2010**, *14*, 1503–1526. [CrossRef]
14. Arunkumar, T.; Raj, K.; Dsilva Winfred Rufuss, D.; Denkenberger, D.; Tingting, G.; Xuan, L.; Velraj, R. A review of efficient high productivity solar stills. *Renew. Sustain. Energy Rev.* **2019**, *101*, 197–220. [CrossRef]
15. United Nations. *WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply, Sanitation and Hygiene—Progress on Household Drinking Water, Sanitation and Hygiene 2000–2020*; IMI-SDG6 SDG 6 Progress Reports; United Nations: San Francisco, CA, USA; Available online: https://www.unwater.org/publications/who-unicef-joint-monitoring-program-for-water-supply-sanitation-and-hygiene-jmp-progress-on-household-drinking-water-sanitation-and-hygiene-2000-2020/ (accessed on 1 July 2021).

16. World Health Organization. *Global Costs and Benefits of Drinking-Water Supply and Sanitation Interventions to Reach the MDG Target and Universal Coverage*, 1st ed.; WHO Press: Geneva, Switzerland, 2012; pp. 1–67.
17. Jasrotia, S.; Kansal, A.; Kishore, V.V.N. Application of solar energy for water supply and sanitation in Arsenic affected rural areas: A study for Kaudikasa village, India. *J. Clean. Prod.* **2012**, *37*, 389–393. [CrossRef]
18. World Health Organization. *Guidelines for Drinking-Water Quality, Incorporating First Addendum Vol. 1. Recommendations*, 3rd ed.; WHO Press: Geneva, Switzerland, 2008.
19. Bhattacharya, P.; Welch, A.H.; Stollenwerk, K.G.; McLaughlin, M.J.; Bundschuh, J.; Panaullah, G. Arsenic in environment: Biology and chemistry. *Sci. Total Environ.* **2007**, *379*, 109–120. [CrossRef]
20. Mahendra, P.; Yodit, A.; Angesom, H.; Sumitra, P.; Vijay, J.J. Public Health Hazards Due to Unsafe Drinking Water. *Air Water Borne Dis.* **2018**, *7*, 1000138.
21. Adio, S.A.; Osowade, E.A.; Muritala, A.O.; Fadairo, A.A.; Oladepo, K.T.; Obayopo, S.O.; Fase, P.O. Solar distillation of impure water from four different water sources under the southwestern Nigerian climate. *Drink. Water Eng. Sci.* **2021**, *14*, 81–94. [CrossRef]
22. Pruss-Ustun, A.; Bos, R.; Gore, F.; Bartram, J. *Safer Water, Better Health: Costs, Benefits and Sustainability of Interventions to Protect and Pro Mote Health*; World Health Organization: Geneva, Switzerland, 2008.
23. Cengel, Y.A.; Boles, M.A. *Thermodynamics: An Engineering Approach*, 8th ed.; McGraw Hill: New York, NY, USA, 2015; p. 712.
24. Goosen, M.; Mahmoudi, H.; Ghaffour, N. Overview of renewable energy technologies for freshwater production. In *Renewable Energy Applications for Freshwater Production*; CRS Press: London, UK; IWA Publishing: London, UK, 2012; pp. 25–77.
25. Kalogirou, S.A. Concentrating solar power plants for electricity and desalinated water production. In Proceedings of the World Renewable Energy Congress, Linköping, Sweden, 8 May 2011. [CrossRef]
26. Kalogirou, S.A. *Solar Energy Engineering: Processes and Systems*; Academic Press: San Diego, CA, USA, 2014.
27. UAE. World Resources Institute's Aqueduct Water Risk Atlas August 2019 Report. Available online: https://www.thenationalnews.com/uae/environment/uae-water-resources-under-extreme-stress-new-report-finds-1.895660 (accessed on 14 January 2022).
28. Solar Power—Open Source Learning. Available online: https://mediawiki.middlebury.edu/wikis/OpenSourceLearning/images/5/53/Sunshine_Map.jpg (accessed on 14 January 2022).
29. Hanson, A.; Zachritz, W.; Stevens, K.; Mimbela, L.; Polka, R.; Cisneros, L. Disti late water quality of a single-basin solar still: Laboratory and field studies. *Sol. Energy* **2004**, *76*, 635–645. [CrossRef]
30. Riahi, A.; Yusof, K.W.; Isa, M.H.; Mahinder Singh, B.S.; Mustaffa, Z.; Ahsan, A.; Ul Mustafa, M.R.; Sapari, N.; Zahari, N.A.M. Potable water production using two solar stills having different cover materials and fabrication costs. *Environ. Prog. Sustain. Energy* **2018**, *37*, 584–596. [CrossRef]
31. Ahsan, A.; Imteaz, M.; Thomas, U.A.; Azmi, M.; Rahman, A.; Nik Daud, N.N. Parameters affecting the performance of a low cost solar still. *Appl. Energy* **2014**, *114*, 924–930. [CrossRef]
32. Malik, M.A.S.; Tiwari, G.N.; Kumar, A.; Sodha, M.S. *Solar Distillation*; Pergaman Press: Oxford, UK.; London, UK, 1982.
33. Tiwari, G.N.; Madhuri. Effect of water depth on daily yield of the still. *Desalination* **1987**, *61*, 67–75. [CrossRef]
34. Akash, B.A.; Mohsen, M.S.; Nayfeh, W. Experimental study of the basin type solar still under local climate conditions. *Energy Convers. Manag.* **2000**, *41*, 883–890. [CrossRef]
35. Toure, S.; Meukam, P. A numerical model and experimental investigation for a solar still in climatic conditions in Abidjan (Côte d'Ivoire). *Renew. Energy* **1997**, *11*, 319–330. [CrossRef]
36. Parsa, S.M. Reliability of thermal desalination (solar stills) for water/wastewater treatment in light of COVID-19 (novel coronavirus "SARS-CoV-2") pandemic: What should consider? *Desalination* **2021**, *512*, 115106. [CrossRef]
37. Muthu Manokar, A.; Prince Wiston, D.; Kabeel, A.E.; El-Agouz, S.A.; Sathyamurthy, R.; Arunkumar, T.; Madhu, B.; Ahsan, A. Integrated PV/T solar still-A mini-review. *Desalination* **2018**, *435*, 259–267. [CrossRef]
38. Dwivedi, V.K.; Tiwari, G.N. Experimental validation of thermal model of a double slope active solar still under natural circulation mode. *Desalination* **2010**, *250*, 49–55. [CrossRef]
39. Riahi, A.; Wan, Y.K.; Mahinder Singh, B.S.; Isa, M.H.; Olisa, E.; Zahari, N.A.M. Sustainable potable water production using a solar still with photovoltaic modules-AC heater. *Desalination Water Treat.* **2016**, *57*, 14929–14944. [CrossRef]
40. Riahi, A.; Zakaria, N.A.; Isa, M.H.; Yusof, K.W.; Mahinder Singh, B.S.; Mustaffa, Z.; Takaijudin, H. Performance investigation of a solar still having polythene film cover and black painted stainless steel basin integrated with a photovoltaic module–direct current heater. *Energy Environ.* **2019**, *30*, 1521–1535. [CrossRef]
41. Manchanda, H.; Kumar, M. Study of water desalination techniques and a review on active solar distillation methods. *Environ. Prog. Sustain. Energy* **2018**, *37*, 444–464. [CrossRef]
42. Kumar, B.P.; Winston, D.P.; Pounraj, P.; Manokar, A.M.; Sathyamurthy, R.; Kabeel, A.E. Experimental investigation on hybrid PV/T active solar still with effective heating and cover cooling method. *Desalination* **2018**, *435*, 140–151. [CrossRef]
43. Riahi, A.; Yusof, K.W.; Mahinder Singh, B.S.; Olisa, E.; Sapari, N.B.; Isa, M.H. The performance investigation of triangular solar stills having different heat storage materials. *Int. J. Energy Environ. Eng.* **2015**, *6*, 385–391. [CrossRef]
44. Al-Garni, A.Z. Productivity enhancement of solar still using water heater and cooling fan. *J. Sol. Energy Eng. Trans. ASME* **2012**, *134*, 031006. [CrossRef]

45. Phadatare, M.K.; Verma, S.K. Influence of water depth on internal heat and mass transfer in a plastic solar still. *Desalination* **2007**, *217*, 267–275. [CrossRef]
46. Velmurugan, V.; Deenadayalan, C.K.; Vinod, H.; Srithar, K. Desalination of effluent using fin type solar still. *Energy* **2008**, *33*, 1719–1727. [CrossRef]
47. Panchal, H.; Patel, P.; Patel, N.; Thakkar, H. Performance analysis of solar still with different energy-absorbing materials. *Int. J. Ambient. Energy* **2017**, *38*, 224–228. [CrossRef]
48. Panchal, H. Performance investigation on variations of glass cover thickness on solar still: Experimental and theoretical analysis. *Technol. Econ. Smart Grids Sustain. Energy* **2016**, *1*, 7. [CrossRef]
49. Ahsan, A.; Imteaz, M.; Rahman, A.; Yusuf, B.; Fukuhara, T. Design, fabrication and performance analysis of an improved solar still. *Desalination* **2012**, *292*, 105–112. [CrossRef]
50. Kabeel, A.E.; Khalil, A.; Omara, Z.M.; Younes, M.M. Theoretical and experimental parametric study of modified stepped solar still. *Desalination* **2012**, *289*, 12–20. [CrossRef]
51. Abdel-Rehim, Z.S.; Lasheen, A. Improving the performance of solar desalination systems. *Renew. Energy* **2005**, *30*, 1955–1971. [CrossRef]
52. Tarawneh, M.S.K. Effect of water depth on the performance evaluation of solar still. *Jordan J. Mech. Ind. Eng.* **2007**, *1*, 23–29.
53. Taamneh, Y.; Taamneh, M.M. Performance of pyramid-shaped solar still: Experimental study. *Desalination* **2012**, *291*, 65–68. [CrossRef]
54. Aybar, H.S.; Assefi, H. Simulation of a solar still to investigate water depth and glass angle. *Desalination Water Treat.* **2009**, *7*, 35–40. [CrossRef]
55. World Health Organization. *Guidelines for Drinking-Water Quality*, 3rd ed.; WHO Press: Geneva, Switzerland, 2008.
56. Balladin, D.A.; Headley, O.; Roach, A. Evaluation of a concrete cascade solar still. *Renew. Energy* **1999**, *17*, 191–206. [CrossRef]
57. KIkuchi, S.; Oyoda, H.T.; Akami, A.T.; Himada, S.S.; Oba, M.O.; Ekiyama, T.S. Simple solar still using solar energy and compost heat for family use. *J. Arid L. Stud.* **2012**, *21*, 207–210.
58. Ayoub, G.M.; Dahdah, L.; Alameddine, I.; Malaeb, L. Vapor-induced transfer of bacteria in the absence of mechanical disturbances. *J. Hazard. Mater.* **2014**, *280*, 279–287. [CrossRef]
59. Ayoub, G.M.; Dahdah, L.; Alameddine, I. Transfer of bacteria via vapor in solar desalination units. *Desalination Water Treat.* **2015**, *53*, 3199–3207. [CrossRef]
60. Malaeb, L.; Ayoub, G.M.; Al-Hindi, M.; Dahdah, L.; Baalbaki, A.; Ghauch, A. A biological, chemical and pharmaceutical analysis of distillate quality from solar stills. *Energy Procedia* **2017**, *119*, 723–732. [CrossRef]
61. Parsa, S.M.; Rahbar, A.; Javadi, Y.D.; Koleini, M.H.; Afrand, M.; Amidpour, M. Energy-matrices, exergy, economic, environmental, exergoeconomic, enviroeconomic, and heat transfer (6E/HT) analysis of two passive/active solar still water desalination nearly 4000 m: Altitude concept. *J. Clean. Prod.* **2020**, *261*, 121243. [CrossRef]
62. Kalbasi, R.; Esfahani, M.N. Multi-effect passive desalination system, an experimental approach. *World Appl. Sci. J.* **2010**, *10*, 1264–1271.
63. Pounraj, P.; Prince Winston, D.; Kabeel, A.E.; Praveen Kumar, B.; Manokar, A.M.; Sathyamurthy, R.; Christabel, S.C. Experimental investigation on Peltier based hybrid PV/T active solar still for enhancing the overall performance. *Energ. Conver. Manag.* **2018**, *168*, 371–381. [CrossRef]
64. Arunkumar, T.; Kabeel, A.E.; Raj, K.; Denkenberger, D.; Sathyamurthy, R.; Ragupathy, P.; Velraj, R. Productivity enhancement of solar still by using porous absorber with bubble-wrap insulation. *J. Clean. Prod.* **2018**, *195*, 1149–1161. [CrossRef]
65. Pal, P.; Yadav, P.; Dev, R.; Singh, D. Performance analysis of modified basin type double slope multi–wick solar still. *Desalination* **2017**, *422*, 68–82. [CrossRef]
66. Kumar, S.; Tiwari, A. Design, fabrication and performance evaluation of a hybrid photovoltaic/ thermal (PV/T) double slope active solar still. *Energy Convers. Manag.* **2010**, *51*, 1219–1229. [CrossRef]
67. Dev, R.; Abdul-Wahab, S.A.; Tiwari, G.N. Performance study of the inverted absorber solar still with water depth and total dissolved solid. *Appl. Energy* **2011**, *88*, 252–264. [CrossRef]
68. Joshi, P.; Tiwari, G.N. Energy matrices, exergo-economic and enviro-economic analysis of an active single slope solar still integrated with a heat exchanger: A comparative study. *Desalination* **2018**, *443*, 85–98. [CrossRef]
69. Sohani, A.; Hoseinzadeh, S.; Berenjkar, K. Experimental analysis of innovative designs for solar still desalination technologies; an in-depth technical and economic assessment. *J. Energy Storage.* **2021**, *33*, 101862. [CrossRef]
70. Tripath, R.; Tiwari, G.N. Effect of water depth on heat and mass transfer in a solar still: In summer climate condition. *Desalination* **2006**, *217*, 267–275.
71. Tripathi, R.; Tiwari, G.N. Thermal modelling of passive and active solar stills for different depths of water by using the concept of solar fraction. *Sol. Energy* **2006**, *80*, 956–967. [CrossRef]
72. Singh, G.; Kumar, S.; Tiwari, G.N. Design, fabrication and performance evaluation of a hybrid photovoltaic thermal (PVT) double slope active solar still. *Desalination* **2011**, *277*, 399–406. [CrossRef]
73. Balachandran, G.B.; David, P.W.; Mariappan, R.K.; Kabeel, A.E.; Athikesavan, M.M.; Sathyamurthy, R. Improvising the efficiency of single-sloped solar still using thermally conductive nano-ferric oxide. *Environ. Sci. Pollute. Res.* **2020**, *27*, 32191–32204. [CrossRef]

74. Chin, A.W.H.; Chu, J.T.S.; Perera, M.R.A.; Hui, K.P.Y.; Yen, H.L.; Chan, M.C.W.; Peiris, M.; Poon, L.L.M. Stability of SARS-CoV-2 in different environmental conditions. *Lancet Microbe* **2020**, *1*, 10. [CrossRef]
75. Chan, K.H.; Sridhar, S.; Zhang, R.R.; Chu, H.; Fung, A.Y.F.; Chan, G.; Chan, J.F.W.; To, K.K.W.; Hung, I.F.N.; Cheng, V.C.C.; et al. Factors affecting stability and infectivity of SARS-CoV-2. *J. Hosp. Infect.* **2020**, *106*, 226–231. [CrossRef]
76. Yu, L.; Peel, G.K.; Cheema, F.H.; Lawrence, W.S.; Bukreyeva, N.; Jinks, C.W.; Peel, J.E.; Peterson, J.W.; Paessler, S.; Hourani, M.; et al. Catching and killing of airborne SARS-CoV-2 to control spread of COVID-19 by a heated air disinfection system. *Mater. Today Phys.* **2020**, *15*, 100249. [CrossRef]
77. Wang, D.; Sun, B.C.; Wang, J.X.; Zhou, Y.Y.; Chen, Z.W.; Fang, Y.; Yue, W.H.; Liu, S.M.; Liu, K.Y.; Zeng, X.F.; et al. Can masks be reused after hot water decontamination during the COVID-19 pandemic? *Engineering* **2020**, *6*, 1115–1121. [CrossRef]
78. Ahmed, W.; Bertsch, P.M.; Bibby, K.; Haramoto, E.; Hewitt, J.; Huygens, F.; Gyawali, P.; Korajkic, A.; Riddell, S.; Sherchan, S.P.; et al. Decay of SARS-CoV-2 and surrogate murine hepatitis virus RNA in untreated wastewater to inform application in wastewater-based epidemiology. *Environ. Res.* **2020**, *191*, 110092. [CrossRef]
79. Chaouchi, B.; Zrelli, A.; Gabsi, S. Desalination of brackish water by means of a parabolic solar concentrator. *Desalination* **2007**, *217*, 118–126. [CrossRef]
80. Omara, Z.; Eltawil, M.A. Hybrid of solar dish concentrator, new boiler and simple solar collector for brackish water desalination. *Desalination* **2013**, *326*, 62–68. [CrossRef]
81. Gorjian, S.; Ghobadian, B.; Tavakkoli Hashjin, T.; Banakar, A. Experimental performance evaluation of a stand-alone point-focus parabolic solar still. *Desalination* **2014**, *352*, 1–17. [CrossRef]
82. Prado, G.O.; Vieira, L.G.M.; Damasceno, J.J.R. Solar dish concentrator for desalting water. *Sol. Energy* **2016**, *136*, 659–667. [CrossRef]
83. McGuigan, K.G.; Conroy, R.M.; Mosler, H.-J.; du Preez, M.; Ubomba-Jaswa, E.; Fernandez-Ibanez, P. Solar water disinfection (SODIS): A review from bench-top to roof-top. *J. Hazard. Mater.* **2012**, *235–236*, 29–46. [CrossRef]
84. Aljabair, S.; Habeeb, L.J.; Ali, A.M. Experimental analysis of parabolic solar dish with radiator heat exchanger receiver. *J. Eng. Sci. Technol.* **2020**, *15*, 437–454.
85. Li, L.; Kecskemethy, A.; Arif, A.F.M.; Dubowsky, S. A Novel Approach for Designing Parabolic Mirrors Using Optimized compliant Bands. In Proceedings of the International Design Engineering Technical Conference and Computers and Information in Engineering, IDETC, Washington, DC, USA, 28 August 2011.
86. Aliman, O.; Daut, I.; Isa, M.; Adzman, M.R. Simplification of sun tracking mode to gain high concentration solar energy. *Am. J. Appl. Sci.* **2007**, *4*, 171–175. [CrossRef]
87. Singh, S.K.; Bhatnagar, V.P.; Tiwari, G.N. Design parameters for concentrator assisted solar distillation system. *Energy Convers. Manag.* **1996**, *37*, 247–252. [CrossRef]
88. Riffat, S.; Mayere, A. Performance evaluation of v-trough solar concentrator for water desalination applications. *Appl. Therm. Eng.* **2013**, *50*, 234–244. [CrossRef]
89. Sinitsyn, S.; Panchenko, V.; Kharchenko, V.; Vasant, P. Oprimization of parquetting of the concentrator of photovoltaic thermal module. In *Intelligent Computing and Optimization. ICO 2019. Advances in Intelligent Systems and Computing*; Vasant, P., Zelinka, I., Weber, G.W., Eds.; Springer: Cham, Switzerland, 2020; Volume 1072.
90. Panchenko, V. Photovoltaic thermal module with paraboloid type solar concentrators. *Int. J. Energy Optim. Eng. (IJEOE)* **2021**, *10*, 23. [CrossRef]
91. Garg, H.P.; Prakash, J. *Solar Energy Fundamentals and Applications*, 1st ed.; McGraw Hill: Delphi, Greece, 2000.
92. Johnston, G.; Lovegrove, K.; Luzzi, A. Optical performance of spherical reflecting elements for use with paraboloidal dish concentrators. *Sol. Energy* **2003**, *74*, 133–140. [CrossRef]
93. Chaichan, M.T.; Kazem, H.A. Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM). *Case Stud. Therm. Eng.* **2015**, *5*, 151–159. [CrossRef]
94. Nuwayhid, R.Y.; Mrad, F.; Abu-Said, R. The realization of a simple solar tracking concentrator for university research applications. *Renew. Energy* **2001**, *24*, 207–222. [CrossRef]
95. Kaushika, N.D.; Reddy, K.S. Performance of a low cost solar paraboloidal steam generating system. *Energy Convers. Manag.* **2000**, *41*, 713–726. [CrossRef]
96. Born, M.; Wolf, E. *Principles of Optics*, 5th ed.; Pergamon Press: Oxford, NY, USA, 1975.
97. Bahrami, M.; Avargani, V.M.; Bonyadi, M. Comprehensive experimental and theoretical study of a novel still coupled to a solar dish concentrator. *Appl. Therm. Eng.* **2019**, *151*, 77–89. [CrossRef]
98. Arunkumar, T.; Denkenberger, D.; Velraj, R.; Sathyamurthy, R.; Tanaka, H.; Vinothkumar, K. Experimental study on a parabolic concentrator assisted solar desalting system. *Energy Convers. Manag.* **2015**, *105*, 665–674. [CrossRef]
99. Srithar, K.; Rajaseenivasan, T.; Karthik, N.; Periyannan, M.; Gowtham, M. Standalone triple basin solar desalination system with cover cooling and parabolic dish concentrator. *Renew. Energy* **2016**, *90*, 157–165. [CrossRef]
100. Badran, A.A.; Al-Hallaq, A.A.; Eyal Salman, I.A.; Odat, M.Z. A solar still augmented with a flat plate collector. *Desalination* **2005**, *172*, 227–234. [CrossRef]
101. Velmurugan, V.; Gopalakrishnan, M.; Raghu, R.; Srithar, K. Single basin solar still with fin for enhancing productivity. *Energy Convers. Manag.* **2008**, *49*, 2602–2608. [CrossRef]

102. Kumar, S.; Tiwari, G.N. Life cycle cost analysis of single slope hybrid (PV/T) active solar still. *Appl. Energy* **2009**, *86*, 1995–2004. [CrossRef]
103. Velmurugan, V.; Kumaran, S.S.; Prabhu, V.N.; Srithar, K. Productivity enhancement of stepped solar still performance analysis. *Therm. Sci.* **2008**, *12*, 153–163. [CrossRef]
104. Ali Samee, M.; Mirza, U.K.; Majeed, T.; Ahmad, N. Design and performance of a simple single basin solar still. *Renew. Sustain. Energ. Rev.* **2007**, *11*, 543–549. [CrossRef]
105. El-Sebaii, A.A.; Ramadan, M.R.I.; Aboul-Enein, S.; Salem, N. Thermal performance of a single-basin solar still integrated with a shallow solar pond. *Energy Convers. Manag.* **2008**, *49*, 2839–2848. [CrossRef]
106. Kabeel, A.E.; Dawood, M.M.K.; Ramzy, K.; Nabil, T.; Elnaghi, B.; Elkassar, A. Enhancemnet of single solar still integrated with solar dishes: An experimental approach. *Energy Convers. Manag.* **2019**, *196*, 165–174. [CrossRef]