Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25073

181 (2020) 47–63
March

Techniques for water disinfection, decontamination and desalinization: a review

J. Zuluaga-Gomez[a,b,c,*], P. Bonaveri[b], D. Zuluaga[b], C. Álvarez-Peña[a], N. Ramírez-Ortiz[a]

[a]*Universidad de Oviedo, Oviedo, Asturias, 26 Rue de l'Épitaphe, 25000 Besançon, Spain, Tel. +33 0609525453; emails: juan.zuluaga@eu4m.eu (J. Zuluaga-Gomez), tina@uniovi.es (C. Álvarez-Peña), nicolas.ramirez@eu4m.eu (N. Ramírez-Ortiz)*
[b]*Universidad Autónoma del Caribe, Barranquilla, Colombia, emails: PBonaveri@uac.edu.co (P. Bonaveri), danielazuluagag@outlook.com (D. Zuluaga)*
[c]*École nationale supérieure de mécanique et des microtechniques, 25000 Besançon, France*

Received 25 March 2019; Accepted 25 October 2019

A B S T R A C T

Freshwater is a critical component for social and economic sustainability, but also the water scarcity is a foremost threat nowadays. During the last century, many governments have been implementing public policies for reducing the water consumption, optimize the potabilization processes, and promote cleaner techniques for wastewater treatment such as desalinization, heterogeneous photocatalysis, oxidation processes, ozonation, and so on. The review begins with a short presentation of the first explored water purification techniques starting from the Bronze Age, then, it is presented the minimum quality parameters and comments that disinfection, decontamination, and desalinization of wastewater and seawater must achieve. It is also reviewed several water purification methods based on microbiological, chemical and physical techniques. This review conveys a fine reviewing of solar stills, solar collectors and heterogeneous photocatalysis, presenting characteristics and latest innovations from several researchers. Finally, the residual products from those techniques are also called "by-products", therefore, it is explained the main methodologies that current researchers are employing for reducing, but also for exploitation of by-products in two or three-stage (fish farming or crop irrigation) processes.

Keywords: Fresh water; Solar still; Solar collector; Photocatalysis; By-products.

1. Introduction

Water is the most precious resource of our times, it is essential for all social and economic activities [1]. The nature of water resources is alternated by periods of drought and intense prolonged rainfalls, making it more significant [2]. Despite the social, political, economic or environmental dynamism, non-access to drinking water is not directly related to water shortages, drought or rationing [3,4]. On the other hand, it is a difficult phenomenon to define either, because it's context-dependent, or because of its irregular behavior through the years [3]. Water scarcity covers aspects related to the availability of the resource. According to the European Union in 2007 [5], scarcity occurs when the minimum average amount of water needed for a given population is not covered [6]. Other studies mention that overuse created the phenomenon. The rapid population growth has been proven as an environmental cause that led to water contamination [7,8]. In other words, from the climatic point of view, it is a simple ratio between precipitation and the potential of evapotranspiration [9]. Contrary, in recent years the water efficiency has grown in interest [10] not only in the population but also in the industrial-commercial field and farmers (with optimization models for crop irrigation). In consequence, various guidelines and strategies in wastewater decontamination systems have been created, increasing the volume of water available [11].

* Corresponding author.

To understand the above, the problem of contamination and water scarcity must be traced back in time to see how in the past, its treatment has been perceived. In the Bronze Age (3200–1100 BC) in Crete, the Aegean Islands and the Indus Valley were the first civilizations to put in practice some technical treatment for water denomination. Then, in the Archaic (750–480 BC) and Classic age (480–336 BC), archaeological evidence shows [12] that ancient Greek civilizations developed an approach to solve this problem. Later and until a few decades ago, the problem of wastewater was solved by depositing it into rivers, seas, and lakes, while in other places, alternatively, it was poured into entire crops fields. This last method had an additional benefit, because the crops showed a superlative aspect during their growth, together with the advantage of maintaining the fertility of the soils. This is still practiced in some countries where the option of water treatment is not possible, or where public policies (on the possible impact of health) are inexistent when practicing this technique [13].

Throughout history, it has been seen that the discharging sewage in the streets, apart from causing bad odors, have been the triggers of great public health problems in large cities, such as bubonic plague and typhoid fever, thus decimating the population. Scientists have determined that there is a direct relationship between wastewater discharge and public health. In spite of everything, one of the most efficient (discovered in the 30s) technologies for wastewater decontamination is the mixing of activated sludge [14] and a source of oxygen; it makes use of anaerobic microorganisms to degrade organic matter in the wastewater, producing an effluent of optimum quality, however, needs qualified personnel. Other processes have been developed to obtain drinking water, such as bioreactors, water desalination plants (reverse osmosis), biological treatment, physical separation, and electrochemistry, even passive decontamination of water with the use of solar evaporators or "solar stills".

The reuse of wastewater has been recognized as a practical solution to the scarcity facing earth today [15]. Therefore, several research groups in China [16–21] have devoted themselves to analyzing the efficiency of the techniques mentioned above, either by data envelopment analysis, fuzzy logic, among others. Despite promising results, in most cases, only ideal scenarios have been considered, which may contain tendencies or "biased" results [1,13].

Nowadays countries from North Africa and South Asia, and China have water scarcity. The Food and Agriculture Organization of the United Nations, UNICEF and World Health Organization (WHO) highlighted that the majority of the countries of America, Oceania, Southern Europe, and Russia have abundant water resources, and drought problems are usually limited to specific areas [23,23]. An important issue to be addressed to minimize the human impact on water resources is to analyze the percentage of water use by sector. In Colombia, 50% of the water is used in irrigation, while 27% and 13% is dedicated to municipal and industrial areas, respectively, but a 6%, together with 4%, is used in livestock and cooling of thermal plants. However, a country like Algeria uses 59% of its water resources in agriculture, 36% and 5% in municipal and industrial areas, respectively [23]. In conclusion, the irrigation of crops is the index that consumes more water; then, it has become important to design, build and implement technological and public policies for the reduction of stress and water scarcity in many countries.

During the latest decades, many wastewater decontamination techniques have been recognized for their cheapness, low by-products generation and easy implementation, one of those is the solar stills. Solar stills have been used as an alternative water-purification method for more than 100 years [24]. In addition, solar stills are the simplest way to desalinate water. They are single-slope or double-slope (in the form of a pyramid), normally made with materials that have a low thermal transfer coefficient. The operating principle of a solar still can be seen in Fig. 1 (single-slope solar still). The brackish water is deposited in the bed (or lower part) and depending on diverse factors, the interior temperature increases creating a vapor free of contaminants and brine. Subsequently, the condensed drops in the upper plate (usually glass) go to a reservoir that collects the condensed and potable water free of contaminants, this process is aid by gravity.

The yield of the solar still depends on factors such as inclination angle, collector area, interior temperature, solar radiation, wind speed, interior, and exterior material, among others [25]. So far, two types of solar stills have been described, passive and active solar stills. While the first is similar to Fig. 1, the active one has the same principle but adding a solar collector, responsible for heating a working fluid that accelerates the evaporation of salty or contaminated water. Similarly, there are active solar stills with extra combinations, such as solar heaters, waste heat recovery, preheated water active solar still, regenerative solar still, and heat exchanger [26]. The solar stills are not limited to pyramidal or straight shapes, but also Dhiman [27] developed a spherical–shape solar still. The analysis is based on the heat and mass transfer relationships by Dunkle [28], which have been modified empirically to validate the experimental results of Menguy et al. [29], and in its results showed a 30% increase in efficiency compared with conventional models.

On the other hand, heterogeneous photocatalysis has been implemented as a solution for the decontamination of wastewater, which relies on chemical components and not in environmental and geometrical characteristics (such as solar stills and solar collectors). This technique uses TiO_2, ZnO, Fe_2O_3 or Al_2O_3 as semiconductors or photocatalytic

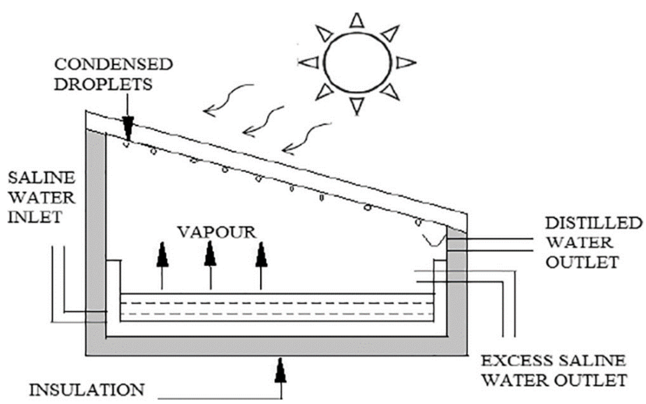

Fig. 1. Single slope solar still [26]. Copyright, reprinted with permission from Elsevier.

agents and through a source of ultraviolet light, the method can eliminate organic and inorganic components. The use of photocatalysis with TiO_2 generated special interest as a new alternative for water photocatalytic decontamination. The TiO_2 works as a semiconductor that absorbs ultraviolet light and during the whole process, it is generated hydroperoxide radicals (HO_2), and superoxide radicals (O_2^-), useful in the inactivation or degradation of bacteria and pollutants into water (H_2O) or carbon dioxide (CO_2) that exits in wastewater [30,31]. Several factors influence the final performance, such as catalyst mass, initial pollutants, impurities and contaminants concentration, temperature, pH, light intensity, wavelength, radiant flux, quantum yield, among others [32].

It is important to recall, that this review aims to summarize: (i) current state of water worldwide, (ii) main parameters for determining water quality, and (iii) the most used techniques for disinfection, decontamination, and desalination. On the other hand, it aims to review deeper: (i) solar stills and their main geometrical configurations, (ii) solar collectors and their operation together with solar stills, (iii) heterogeneous photocatalysis as a disinfection technique, and (iv) methodologies for by-products management. The second section explains the current worldwide state of water and their minimum requirements to be called "drinkable water". At the same time, the reader may review the global water problematic that many countries are facing today. The third section mentions the previous and present developments on solar stills and solar collectors and the benefits of mixing both techniques. In the fourth section, it is short reviewed the heterogeneous photocatalysis as a disinfection method. The section fifth targets the generation and management of the by-product, and how researchers and farmers have been using them as food and fertilizers.

2. Water resources, water quality and others

Water covers approximately three-quarters of Earth's surface. About 97% is salty seawater and 2% is frozen in glaciers and polar ice caps. Thus, the remaining 1% of the world's water supply is a precious commodity that is indispensable for human survival. Countries in North Africa, South Asia, and China lack freshwater, where the demand exceeds the country's supply, obtained either from renewable sources or by decontamination or disinfection. Fig. 2a notes that the population density of the countries of South Asia, together with China, has had a quite remarkable growth in recent years. On the other hand, Fig. 2b shows the total renewable water resources per inhabitant index (m^3/y). It can be seen the trend of absence of water resources and the increase in water's stress; consequently, there are more droughts than in other countries. Therefore, most of the studies done and public policies related to the conservation, reuse, and reduction of water consumption are concentrated on this sector of the planet [16–21].

To be able to determine the required water quality after a decontamination, disinfection or desalinization process, the following aspects must be assumed during and after each procedure:

2.1. Public health

The water either, desalinated, disinfected or decontaminated by solar stills, solar collectors or heterogeneous photocatalysis (1) may have an absence of important - and basic - minerals for human health and vegetation (if used for crops irrigation); therefore, the absence of calcium and magnesium in the water are related with public health problems. On the other hand, (2) the biostability of water over the distribution systems can affect public health as well. Normally, the water pipes must be able to avoid and/or minimize the re-growth of bacteria. Birnhack et al. [33] mentioned that these two aspects are significant to maintaining a high index (with respect to freshwater) of public health.

2.2. Interaction of water with distribution systems

For decades, it has been recognized that a decent water quality is directly related to the elimination of water interaction with distribution systems, whether based on concrete (dissolution) or metal (corrosion). First, corrosion problems have a straight relationship with the physical integrity, maintenance costs, and longevity of distribution systems [34–37]. However, Sarin et al. [34] mentioned that corrosion could expose users to metals' ions such as copper, zinc, iron, among others, consequently, affecting the health of consumers [34,37,38]. Nonetheless, research has shown that chemical water treatment may not be one of the best solutions, due to interaction with distribution systems, which in many cases are built with materials that may react. An example is

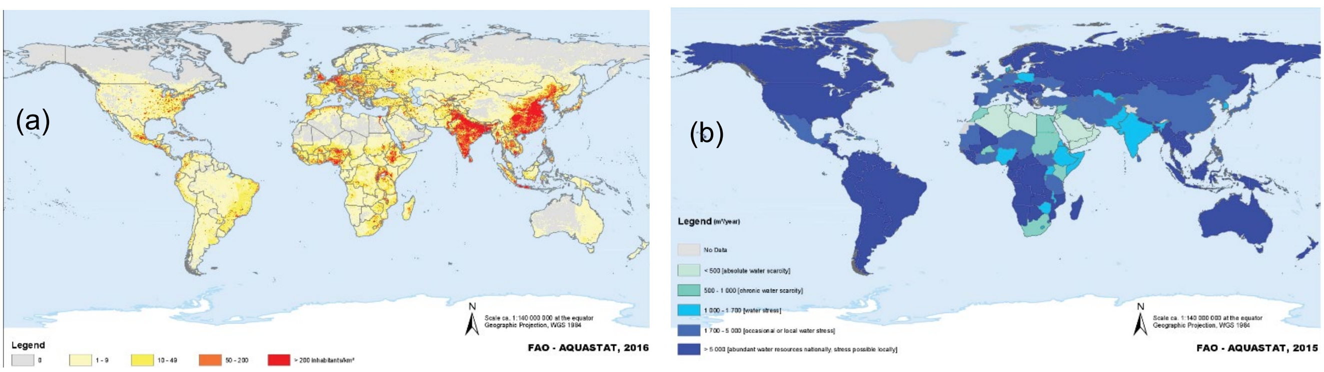

Fig. 2. (a) Population density and (b) total renewable water resources per inhabitant, according to FAO-AQUASTAT, 2016 [23].

called "red water event"; Birnhack et al. [33] describes it as a short-time corrosion leak into the distribution systems.

2.3. Quality of irrigation water

As mentioned in the previous section, most of the water used in developing countries is used for irrigating crops, so this water must follow minimum quality protocols. Certainly, the quality of the decontaminated water is proportional to the quality of the water treatment system, which, in some cases, it has built locally. The sodium adsorption ratio (SAR) must be regulated in this type of system. A recent Israeli regulation mentions that SAR should not exceed 5.0 points, likewise, this value will reduce the soil contamination to a permissible level. Lahav et al. [39] mention that it is advantageous to add Ca^{2+}, Mg^{2+}, SO_4^{2-} ions to the decontaminated water to increase the quality of irrigation water.

2.4. Main parameters for determining water quality

The water quality must comply with several characteristics to be labeled as "drinkable". Hence, a methodology or system that completely regulates from the beginning (input parameters) to the end (output parameters) has been gaining huge importance among many research teams. Features such as calcium ions [Ca^{2+}], alkalinity, pH, total dissolved solids and calcium carbonate precipitation potential (CCPP) (Ca^{2+}) should be regulated during the entire process [33]. Several countries have been struggling for standardizing the limitations of those elements, for example, Israel or Colombia [33,40,41]. The following parameters must be monitored for measure the quality of water to human consumption:

2.4.1. Calcium ions or (Ca^{2+})

According to several organizations, an adequate amount of calcium ions must be between 50 and 60 mg/L. Colombian legislation establishes a maximum acceptable value of 60 mg/L, however, other researchers have reported cases where it may be a little higher due to economic criteria. In those cases, establishing that the CCPP is positive and that the pH has an approximate value of 8 points, therefore 80–120 mg/L is allowed, similar to $CaCO_3$.

2.4.2. H_2CO_3 or alkalinity

In many cases, it is accepted to have a high alkalinity value, because it increases the buffering capacity of water [42]. Pai et al. [42] also called buffering capacity "pH-shift", and the water can resist changes and maintain a stable pH balance even if acids or other bases are added to it; it also prevents the release of metal ions into the water (e.g. red water events) [39,40]. Furthermore, if it is necessary to reduce ammonium and nitrate, high alkalinity could aid in the process. In agricultural processes, it is needed water with high buffer capacity, in other words, high alkalinity to maintain a stable pH when acid and/or basic fertilizers are applied.

2.4.3. Magnesium ions or (Mg^{2+})

In Israel [33,40] there is no threshold for (Mg^{2+}) but Colombian legislation advises that 36 mg/L is the maximum acceptable value for quality water. Magnesium is imperative for both, crops [43] and human health [33,37–39]. However, controversial studies are mentioning that a high magnesium index in the water has an inverse relationship with the mortality rate, meaning that higher magnesium concentration lower mortality rate [44], on the contrary, Morris et al. [45] mentions that a high magnesium concentration does not have a significant impact on cardiovascular and coronary problems. Despite the lack of unanimous agreement on this issue, the WHO has concluded that "There is a growing consensus among epidemiologists about the quantity of magnesium, because epidemiological evidence, along with clinical and nutritional evidence, is already strong enough to suggest that new guidance should be issued" [46]. The WHO's recommendations in its recent publications, advice countries to keep struggling to maintain a minimum Mg^{2+} concentration in all drinking waters [37,46].

2.4.4. $CaCO_3$ or precipitation index

This value has two points of view; Firstly, Birnhack et al. [33] mentioned a low index is required when the water is for human consumption or agriculture because the water needs to be kept reserved in one place for a long time. On the other hand, a high CCPP rate is related to a decreasing in the rate of corrosion (e.g. red water events). In Colombia, the regulations allow a maximum acceptable value of 200 mg/L. however, as mentioned above, it may be lower depending on the future uses.

2.4.5. pH - hydrogen potential

According to the WHO, a value between 6 and 8.5 in pH [37,46] is optimal for water consumption. Therefore, a higher buffer capacity is needed to protect the water from wide pH changes derived from some processes (either deliberate or not), and perhaps resulting in CCPP changes. Colombia establishes a limit of 6.5 to 9.0 in the pH of water for either, human consumption or irrigation.

2.4.6. Others

According to the Colombian normative, other important parameters must be analyzed and limited during the decontamination and disinfection processes. Some of these are conductivity, chlorides, aluminum, iron, manganese, molybdenum, sulfates, zinc, phosphates, biological such as *Escherichia coli* and total coliforms [41]. All this has an important role in achieving an acceptable water quality for both, drinking and irrigation purposes.

2.5. Types of reclamation treatments

In some situations, it is more feasible, profitable or cleaner to reuse the wastewater than take it directly from a source, whether river, sea or underground, so the whole process may become different, for example, chemical, physical and/or biological treatments. There are three states of the resulting water after its treatment, whatever its origin and purpose:

Table 1
Microbiological, chemical and physical wastewater treatments techniques

Type	Technique	Comments	Reference
Microbiological	Maturation lagoons	Maturation ponds of 10 d for settling, algae can grow.	Macdonald and Ernst [47]
	Coagulation–flocculation	Environmentally friendly but slow process.	Lin and Peng [48] Ciabatti et al. [52]
Chemical	Microbiological degradation	Color removal up to 80% using anaerobic reactor, but slow process.	Sandhya and Swaminathan [49]
	Bio-digester microflora co-culture	Color removal using a biosulphidogenic batch reactor, need for adequate nutrients, use of bio-digester sludge.	Togo et al. [50]
	Coagulants–flocculants	Economically feasible, but produce sludge.	Hao et al. [51]
		Use potassium ferrate, an environmentally-friendly chemical reagent containing iron in the + 6 oxidation state.	Ciabatti et al. [52]
Physical	Filtration	Sand filtration and ultrafiltration as pre-treatments processes, then reverse osmosis. High cost.	Marcucci et al. [53]
	Nanofiltration	Ultrafiltration pre-treatment for use in nanofiltration process. High cost.	Barredo-Damas et al. [54]
Combined systems	Coagulation, electrochemical oxidation and activated sludge	The slow process, treatment base on microbiological degradation but is environmentally friendly.	Lin and Peng [48]
	Two-steps: filtration + nanofiltration	*First step*: pre-treatment processes, sand filtration. *Second step*: nanofiltration and reverse osmosis.	Marcucci et al. [53] Barredo-Damas et al. [54]

- A treatment capable of providing quality water to be reused (i.e. industrial or chemical processes) but not suitable for human consumption,
- Two or more treatments together capable of providing water that can be used in irrigation,
- Processes coupled with post-treatments methodologies, resulting in water for human consumption, fulfilling the respective country regulations [33,40,41].

This review presents the last advances in two methodologies focused on produce drinkable water from sea, underground or wastewater. Nevertheless, it is also presented past and present active and passive techniques for decontamination, desalination, and disinfection of water. However, it should be noted that some treatments only prepare water for use in another treatment (i.e. disinfection) and thus obtain water either for reuse (industrial or irrigation purposes) [13] or human consumption (must have a process of re-mineralization and re-carbonation, if applicable).

Table 1 shows (non-exhaustive) some techniques used for the decontamination of wastewater [55], despite their benefits, most of them generate by-products that must be treated or deposited in specific places that might affect the surrounding environment (further information in section). Additionally, the methods in Table 1 are usually part of a general process to obtain drinkable water, which means that other techniques are between the front-end stages, such as disinfection (elimination of microorganisms), re-mineralization and re-carbonation [13,14,55]. Table 2 presents some techniques normally employed in the end-stage to obtain potable water.

The macro-processes selection to obtain drinkable water is based on many factors, such as location, type of water to be treated (industrial, river, sea, underground, seawater, etc.), amount of population that will use it, available budget, and many others. In other words, some techniques require more investment but other techniques are suitable just for small-scale solutions. For example, high-tech facilities are better for great cities, but a system that relies on natural (e.g. microbiological) technologies are feasible smaller cities. Countries located close to the Mediterranean Sea (Fig. 2) are prone to using reverse osmosis plants for water desalination, but South American countries near the equatorial line oftener use microbiological or chemical facilities. However, combining different processes suitable for each situation would create much better systems.

2.6. Post-treatment (PT) characteristics

The water resulting from the decontamination or desalination processes does not contain the chemical characteristics to be classified as drinkable water, thus, the resulting product needs post-treatment techniques (discussed above) for reducing or increase parameters such as pH, magnesium

Table 2
Disinfection technologies for wastewater decontamination/desalinization

Type	Technique	Comments	Reference
Chemical	Chloramination	The most used technology nowadays. Reacting with organic compounds generates by-products.	Salgot et al. [13] Park et al. [56]
	Peracetic acid	Low chlorinated (by-product) generation. Expensive, but the price is going down.	Shah et al. [57]
	Ozonation	Oxidation using gas with no alteration of the volume, but a high cost.	Salgot et al. [13] Gogate and Pandi [58]
		Not commonly used, and for small facilities.	Robinson et al. [59]
Physical	Gamma radiation	Have to be employed with other methods.	Verma et al. [55]
		Rarely employed in Europe and not used for a big scale (laboratory).	Robinson et al. [59] Sommer et al. [60]
	Ultraviolet radiation (UV-radiation)	Multiple lamp systems for water disinfection and not sludge production, but the formation of by-products.	Bonaveri et al. [32] Vogelpohl [61] Moody and Dally [62]
	Membrane-based technologies	Ultrafiltration, nanofiltration, and reverse osmosis: sand and suspended filtration is needed as pre-treatment process and high cost.	Salgot et al. [13] Marcucci et al. [53] Barredo-Damas et al. [54]
	Infiltration–percolation	Filtration pre-treatment is needed. Not commonly used.	Mottier et al. [63]

ions, calcium ions, CCPP and so forth. Ludwig and Hetschel [64] and Gabbrielli [65] propose a method for remineralization and potabilization for desalinated water, nevertheless, it is suitable for underground and wastewater [66]. The post-treatment processes refer directly to re-mineralization, re-carbonation, and in other words "potabilization of water". Re-mineralization can be defined as introducing minerals to water (mentioned in section 2.4); whose normally are eliminated thought the decontamination technique. On the other hand, the term "re-carbonation" is the increase of inorganic carbon concentration in the water, until it reaches at least the minimum parameters according to WHO [37,46] the Colombian regulation and diverse authors suggest a rate between 5 and 10 mg/L [41,67]. Therefore, the PT processes intend to perform both re-mineralization and re-carbonation.

3. Solar still and solar concentrators

The use of solar stills was recorded for the first time by Arab alchemists in 1551 and then, Della Porta in 1589, Lavoisier in 1862 and Mauchot in 1869 [68,69]. Fig. 1 shows the principle of operation. The solar stills' main characteristics are an (i) inclined glass cover, (ii) the basin is made of copper, aluminum or galvanized iron [69], (iii) the basin's interior is usually painted black for increase the solar radiation absorption, (iv) normally, the heat transfer between the interior and exterior needs to be as small as possible, and (v) the bottom must be sealed correctly to avoid steam leakage.

About 97.5% of the earth's water is not fit for human consumption without having one or more previous treatments, consequently, many cities cannot afford expensive facilities for water treatment. At the same time, different studies show that even the purest rainwater is not as clean as the one obtained from solar stills [69–71]. Thus, starting from the last assumptions, the solar stills stand as a reasonable solution. Studies show that a single basin single slope (SBSS) solar still is easy to build, simple to operate, has low maintenance and is cheap compared with similar techniques and under similar conditions [72,73]. Despite this, the water production over time keeps being very low, so other studies show that modifications can enhance the amount of distilled water, such as the use of phase change materials (PCM), solar concentrators mixed with solar stills, multi-stage systems and so forth. Throughout history, some researchers have tried to overcome the SBSS solar still barrier, producing a new variety of solar stills. Table 3 aims to give to the reader an overview and comments about several configurations of solar stills (it is not a table to evaluate the performance). It is important to recall that the solar stills could vary depending on their geometry, size, production time, construction parameters, basin quantity, type, and geometry.

Further information about solar stills could be found in Nayi and Modi research results [69], but also Selvaraj and Natarajan [26] have further reviewed. They present an exhaustive study of the latest developments related to the combination of solar stills with solar collectors. Table 3 summarizes several solar stills configurations for desalination and water decontamination, the methodologies vary from single-stage to multi-stage. There are some studies using side-techniques to accelerate or improve the distilled water yield, going from PCM materials, solar collectors, top cover modification and multi-stage solar stills. For instance, Feilizadeh et al. [93] developed and implemented an active multi-stage solar still, which included a solar collector and four stages for distilling water; as well, they study the solar collector's effect over the basin area (CBA) and efficiencies in summer and winter.

On the other hand, Velmurugan et al. [25] mention that the distilled water yield in a stepped solar still may vary

Table 3
Passive and active configuration of different solar stills

Type	Remarks	Comments and remarks	Reference
Single basin single slope (SBSS) solar still	Wick solar still, solar still with sponges, solar still with gins.	Productivity increased 29.6% - wick type, 15.3% - sponges type, 45.5% - fins type	Velmurugan et al. [73]
	Typical single basin solar still	Water depth and glass cover inclination were studied. Production of 5.3 kg/m^2. Less evaporation rate with more water depth.	Aybar and Assefi [74]
	Using absorbing materials (PCM materials)	The addition of potassium permanganate resulted in a 26% improvement in efficiency. Accordance between theoretical and experimental approaches.	Nijmeh et al. [75]
	Active SBSS solar still using PCM materials	The annual average of daily productivity with PCM materials is 23.8% higher than without PCM materials.	El-Sebaii et al. [76]
	SBSS solar still coupled with flat plate collector	Increase by 35% evaporation rate comparing with passive solar still.	Panchal et al. [77] Abujazar et al. [78]
Single basin double slope (SBDS) solar still	SBDS solar still with built-in sandy heat reservoir	Sandy heat reservoir to basin solar still enhances daily productivity.	Tabrizi and Sharak [78]
	Active SBDS solar still using PCM materials	Six different PCM materials tested, solar incidence angle and transmittance of the covers, considered.	Murugavel et al. [79]
	Passive SBDS and SBSS solar still comparison	Different environmental and operational parameters influencing the still productivity, 3.07 L/m^2/d production, with 0.01 m water depth.	Rajamanickam and Ragupathy [80]
Triple basin single slope (TBSS) solar still	Active TBSS solar still	Use of solar collectors together with solar cells.	Nishikawa et al. [81]
	Active TBSS solar still, corrugate shape in the bottom of each stage	Corrugated shape stacked trays decreases the condensation resistance, improves the amount of water produced.	Xiong et al. [82]
	Computational simulation of passive TBSS solar still	Computational approach, 12.635 kg/m^2/d of water distilled.	El-Sebaii [83]
Multi-stage solar still	Passive multi-stage solar still	Transient simulations of the evaporation and condensation processes inside the multi-stage still were made. Experimental and theoretical, in accordance, 9 kg of water distilled per day.	Shatat and Mahkamov [84]
Stepped solar still	Active stepped solar still with internal reflectors	Enhancing the multi-stage solar still, with internal and external reflectors Productivity with reflectors is increased by 103%.	Omara et al. [85] Eltawil and Omara [86]

(continued)

Table 3 Continued

Type	Remarks	Comments and remarks	Reference
Enhanced solar stills	Active SBSS solar still coupled with flat plat collector	Comparison between passive and active SBSS solar still. Active mode powered with photovoltaic system. Productivity enhanced by 56% and 82% with and without condenser.	Panchal et al. [77] Abujazar et al. [78] Eltawil and Omara [86]
	Solar still with tube collectors	Energy and exergy efficiencies as 33.8% and 2.6% respectively.	Kumar et al. [87]
	Spherical solar still	The mathematical model developed to predict the thermal performance of spherical solar still.	Dhiman [27]
Solar stills top cover modification	V-type-shape solar still	The internal and external heat transfer modes are studied. Four different approaches, (1) charcoal, (2) without charcoal, (3) boosting mirrors, and (4) charcoal and boosting mirrors.	Kumar et al. [88]
	Hemispherical-shape solar still	Approaches with and without top cover cooling effect, efficiencies in 34% and 42%, respectively. Solar radiation, water quality, and cost have been considered.	Arunkumar et al. [89]
	SBSS solar still with pyramid shape	Thermal and economical comparison between normal SBSS and pyramid solar still.	Fath et al. [90]
	Tubular-shape solar still	Tubular multi-wick shape is proposed. Comparison between multi-wick and tubular solar stills.	Kumar and Anand [91]
	Conical-shape solar still	Comparison between conventional and conical-shape (higher production of distilled water) solar still. Correlations for the heat and mass transfer coefficients have been obtained.	Gad et al. [92]
Others	Roof-type active multi-stage solar still	Production enhanced with a multi-stage approach.	Dunkle [28]
	Pyramid solar still review	Exhaustive review of pyramid solar still.	Nayi and Modi [69]
	Basin type multi-stage solar still	First approach of collector over basin area (CBA) effect in outdoor experiments, one collector: 11.56 L/d, two collectors: production increased 96%, third collector: production increased 23%.	Feilizadeh et al. [93]
	Review: seventeen different solar still configuration	Simplified model for cost analysis, better: single-slope and pyramid-shaped, highest production: 1,533 L/m^2 (annual), lowest production: 250 L/m^2 (annual).	Kabeel et al. [94]

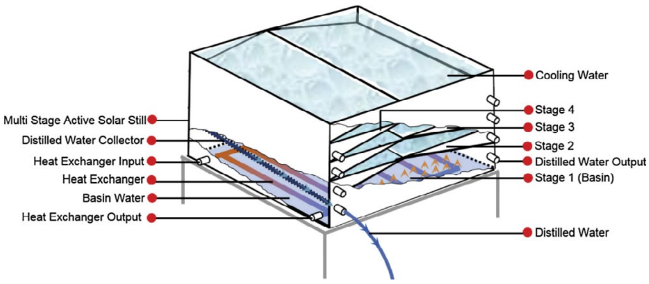

Fig. 3. A schematic view of a multi-stage (4) solar still basin chamber [95]. Copyright, reprinted with permission from Elsevier.

depending on many factors. Solar radiation intensity [97], basin water depth [98,99], glass cover plate inclination [98,100,101] and its thickness [97], temperature difference between the cover plate and water [100,101], wind velocity [76,102], feedwater flow rate, convective heat transfer from cover plate and sidewalls, solar tracking, using of PCM materials, coating and external enhancements [103]. To put it in context, Fig. 3 shows an SBSS solar still, where almost all the parameters are controllable, but those related to meteorology are hardly modifiable, such as wind velocity and radiation intensity.

The distilled water yielded per day is a key factor to analyze in solar stills, indeed, some studies have obtained improvements of more than 100% [86–88,104]. Arunkumar et al. [105] have studied the influence of PCM in the total distilled water per day on SBSS solar still, also, they measure the water, PCM material, air, inner and outer cover temperatures. They concluded that a 26% boost of productivity is possible when mixing solar collectors and PCM with solar stills; Fig. 4 shows a schematic representation of their approach.

3.1. Solar radiation

The productivity and efficiency of solar still improve with an increase in radiation intensity was concluded by Omar et al. [85] using SBSS solar still. In most cases, the highest solar intensity is present at the beginning of the afternoon with lower temperatures in the morning and later afternoon.

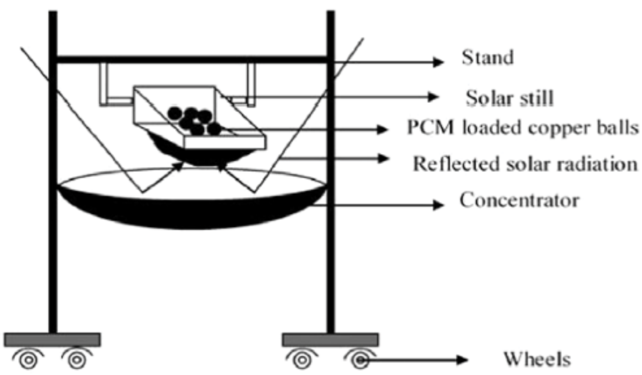

Fig. 4. The schematic diagram of solar still assisted with a hemispherical solar collector and PCM materials [105]. Copyright, reprinted with permission from Elsevier.

On the other hand, location also plays an important role, thus, different parts of the planet are suitable for solar stills rather than others, because they receive different solar radiation intensity. Arunkumar et al. [105], mentioned that during their experiments the solar radiation is transmitted through the solar still's glass cover and is absorbed by the PCM and basin, hence, higher solar radiation, higher the PCM working time.

3.2. Basin water depth

The basin water depth has a high rate of influence on the productivity of the system, several studies have concluded that it is inversely proportional to the final productivity [37,74,80,99]. Rajamanickam and Ragupathy [80] performed several tests at different water depths (1, 2.5, 5, and 7 cm), finally concluding that the largest amount of distilled water was with 1 cm water depth, obtaining 3 L/m^2, rather than the other depths.

Tripathi and Tiwari [97], concluded that the solar fraction plays a very important role at lower values of solar altitude angle, as well the internal convective heat transfer coefficient decreases with the increase of water depth in the basin due to decrease in water temperature, they tested 0.05, 0.1, and 0.15 m basin water depths.

3.3. Glass cover plate inclination

Solar stills are usually coated with high transmissive materials; the cover is made of glass because it is the place where condensation takes place. Akash et al. [104] concluded that the solar still optimum inclination angle of the top cover is 35°. The experiments were conducted in Jordan (Arab country in Western Asia) using a solar still with various cover tilt angles of 15°, 25°, 35°, 45°, and 55°. Tiwari et al. [98] discovered that the distilled water yield increases when the glass inclination also is increased. Nevertheless, that is directly proportional in winter and inverse proportional in summer; therefore, there is a significant reduction in evaporative co-efficient heat transfer when increasing the inclination in summer and winter. Aybar and Assefi [74] found that the best glass cover inclination should be 35° for solar stills.

On the other hand, many researchers concluded that depending on the latitude angle of the place (city), the glass cover inclination was also selected [96,99–101]. Fath et al. [90] suggest that places with latitude greater than 20° are suitable for SBSS, rather than pyramid-shaped solar stills. Panchal and Shah [105], present a study where the solar still is inclined at an angle of 30° and the latitude is 23.6°.

3.4. Temperature difference between the cover plate and water

It is known that the higher the temperature between the cover plate and the water will influence directly the rate of distillation; many authors have enhanced the yielding, changing the coating materials, water depth, and glass-cover inclination. Murugavela et al. [106] found that the production rate increases when the water and glass temperature increase. Nevertheless, they found that in a single basin double slope (SBDS) solar still the higher temperature difference between the water and glass the lower production rate (in the same conditions). On the other hand, Al-Garni [107] performed experiments that showed productivity increased by 370% when two water heaters of 500 W are used. When an external cooling fan was used, productivity was found to decrease by four times. Therefore, it can be said that the delta temperature between the cover plate and the water, is very important for the performance of the solar still. It is possible to conclude from Section 3.2 that the water depth also could modify the temperature between the cover plate and the water.

3.5. Wind velocity

An increase in wind velocity increases the convective heat transfer between glass and ambient and thus results in improved condensation of distillate [24]. Al-Garni [107] as well performed experiments with changing the wind speed using an external cooling fan and the productivity was found to decrease by 4% and 8% for wind speeds of 7 and 9 m/s respectively. El-Sebaii [100] concluded that the daily productivity of the vertical solar still increases with an increase in length, width, and wind speed up to a typical value. The wind speed may modify the heat flux between the solar still and the surrounding environment therefore the yields may vary during the day. It is important to recall that some authors have obtained better results when there is no wind at all. Contrary, some authors suggest that wind may enhance the process of water evaporation inside the basin; thus, further studies are required in this parameter.

3.6. Energy storing materials, PCM

The PCM are resources capable of melting and solidifying at a certain temperature, and when is needed, storing and releasing a large amount of thermal energy. Thermal energy storage as latent heat is an effective way to store thermal energy for heating water (stored before from received sun energy). The main drawback of solar stills systems is the solar radiation absence in the afternoon and night shifts, nevertheless, the PCM materials stand as a solution that releases stored thermal energy in these hours, improving the performance of solar stills system even at non-light or non-radiant hours, thence, the output yield is increased over a greater period. Arunkumar et al. [105] indicate that the effect of thermal storage in the concentrator-coupled hemispherical SBSS solar still increases productivity by 26%. In addition, they concluded that productivity was increased due to the integration of PCM balls inside the basin.

It is found that daylight productivity (in kg/m^2) decreases as the PCM mass increases, but the productivity through the night and daily increases significantly with an increase of PCM mass due to the increased amount of the heat stored within the PCM. During the PCM's discharging phase, the convective heat transfer coefficient from the basin liner to basin water is doubled; thus, the evaporative heat transfer coefficient is increased by 27% when using 3.3 cm of stearic acid (PCM material) beneath the basin liner, concluded by El-Sebaii et al. [108].

Tian and Zhao [109] present a review of the benefits and drawbacks of PCM materials as thermal energy storage for solar collectors. In addition, there are many types of PCM materials that can be used together with solar stills to improve the daily production of distilled water. Fig. 4 shows a basic scheme of PCM performance over the day yield production. Fig. 5 contrasts the advantage between using and not using PCM materials, Arunkumar et al. [105] explain that an improvement of 26% is obtained, as well as distilling water during off-shine hours between 15:00 and 17:30.

In the literature, there are many other types of PCM materials, based on organic and inorganic materials, with different latent heat, but in most cases ball-shaped [105] or rocks. Examples of PCM materials are stearic acid, sand-rock minerals, cast iron and steel, NaCl, silica and magnesia firebricks [111]. The main characteristics depend on working temperature, density, thermal conductivity, specific heat and cost per kilogram.

The total distilled yield is proportional to the number of stages and improvements in the distillation process, such as PCM materials, solar collectors and/or multi-stage solar stills. The active multi-stage solar still presented by Feilizadeh et al. [93] shows that increasing the CBA index, a greater amount of distilled water could be obtained. They tested CBA rates of 3.45, 6.9 and 10.35, thus, the distillate production was, 11.56, 22.67 and 27.38 L/m^2/d in winter and 17.36, 25.64 and 31.60 L/m^2/d in the summer, respectively. Therefore, this solar still showed the greatest efficiency among the ones reviewed in the bibliography (Table 3) and its set-up can be seen in Fig. 6.

Likewise, other authors have proposed a solar concentrator coupled to an SBDS solar still [112], an SBSS solar still with an evacuated tube collector [113], a stepped solar still with air heater [114], wind-turbine inclined solar still collector integrated with an SBSS solar still [115]. Finally, Arunkumar et al. [116,117], proposed two SBSS solars still, firstly, one integrated with concentric tubular solar still; secondly, a pyramidal solar still integrates to concentric tubular solar.

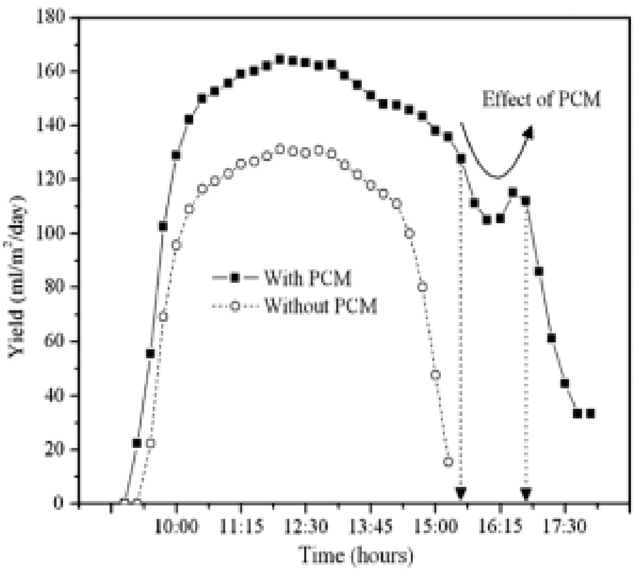

Fig. 5. Hourly variation of distillate water yield with respect to time, when using PCM materials [105]. Copyright, reprinted with permission from Elsevier.

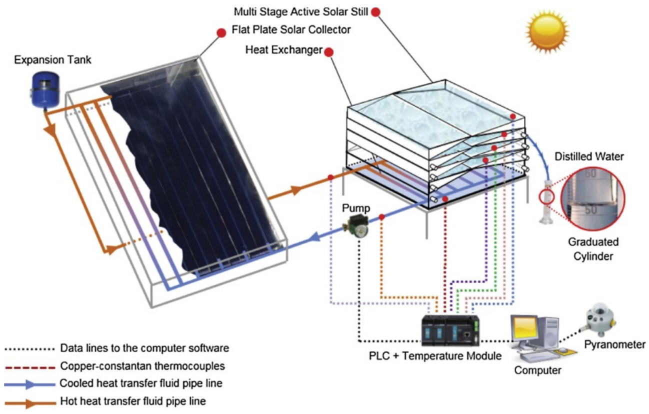

Fig. 6. Schematic experimental set-up of an active multi-stage solar still [95]. Copyright, reprinted with permission from Elsevier.

4. Advances in photocatalysis for wastewater decontamination and disinfection

Heterogeneous photocatalysis has been recognized in the last decades as a formidable technique for decontamination and disinfection of wastewater. It uses semiconductors like TiO_2, ZnO, Fe_2O_3, Al_2O_3 as photocatalytic materials; in general, titanium dioxide (TiO_2) has shown a higher performance in the Anatase phase due to its stability (rutile and brookite) and capacity of absorbing a bigger wavelength. The semiconductor is blasted with photons from an ultraviolet light (from an artificial source or sunlight) source, then, during this process, some components and elements are generated, specifically, superoxide (O_2^-) radicals and hydroperoxide radicals (HO_2) that will become in reactive oxygen species used for degradation of pollutants into the water.

The advanced oxidation processes (AOP) are one of the most used techniques for wastewater disinfection and decontamination nowadays. They converge in a mechanism of formation of highly oxidizing hydroxyl (OH^-) radicals, which contribute to the total mineralization of the contaminating compounds present in the water. Alternatively, it acts in the inactivation of bacteria such as *Pseudomonas aeruginosa*, *Escherichia coli*, *Salmonella typhi*, *Cholera gravis*, etc. It has been found that those radicals generate the greatest incidence in the disinfection of bacterial populations [32].

Heterogeneous photocatalysis joins other initiatives that in recent years have been born to reduce the impact of humanity in water pollution, also in methodologies to achieve the state of potable water for human consumption [118–120]. Specifically, the TiO_2 as photocatalytic agent has gained particular interest because of its heterogeneous nature, offering the possibility of reusing, wide pH range, abundantly availability (becoming economic), highly stable, biocompatible, and environmental-friendly metal oxide, on the other hand, it can degrade inorganic [121–123] and organic [124–126] components.

To develop efficient photocatalytic processes, it is necessary to immobilize the photocatalytic agent in supports (e.g. rods, metallic nets) avoiding mixing with other materials and giving the possibility to reuse the semiconductor. Normally, the heterogeneous photocatalysis with TiO_2 is based on an ultraviolet (UV) light source; however, some research has focused their researches on using the UV waves from solar radiation [122–128] instead of a specific source. The ability of TiO_2 as a catalytic agent was discovered more than 90 years ago [128,129], but its conjunctural point was after the exhaustive review of Fujishima and Honda [127].

$$TiO_2\left(\text{or semiconductor}\right) + h\nu \rightarrow TiO_2\left(e^-_{CB} + h^+_{VB}\right) \quad (1)$$

$$TiO_2\left(h^+_{VB}\right) + H_2O \rightarrow TiO_2 + OH^- + H^+ \quad (2)$$

$$O_2 + e^-_{CB} \rightarrow TiO_2 + O_2^{\bullet-} \quad (3)$$

$$O_2^{\bullet-} + H^+ \rightarrow HO_2^{\bullet} \quad (4)$$

$$O_2^{\bullet-} + HO_2^{\bullet} \rightarrow O_2 + H_2O_2 \quad (5)$$

$$TiO_2\left(e\right) + H_2O_2 \rightarrow TiO_2 + OH^- + OH^{\bullet} \quad (6)$$

The photoexcitation process begins when there is sufficient energy in the form of light; in this case, the energy of the excitation source is greater than the band-gap energy of the material, bringing as a consequence the liberation of an electron (e^-_{CB}) to the conduction band (CB) and generating a positive electron-hole (h^+_{BV}) in the valence band (VB), as shown in Eq. (1). Then, this electron-hole pair reduces and oxidizes (Eq. (2)) producing hydrogen ions (H^+) and hydroxyl radicals (OH^-). In Eq. (3), the excited electrons or photoexcited electron (e^-_{CB}) may react with oxygen (O_2) producing superoxide (O_2^-) radicals. Consequently, an oxidized electron donor and electron acceptor is formed by reducing the process that occurs on the surface of the catalyst without leading to a change in the structure of the material. Additionally, the photoexcited electrons may react with the previous hydrogen ions (H^+), therefore producing hydroperoxide radicals (HO_2) (Eq. (4)). Banerjee et al. [128] concluded that eventually, the hydroxyl groups gradually desorb from the surface in the form of H_2O_2 or H_2O + O_2 and the surface reverts to the original less hydrophilic state as demonstrated in Eqs. (5) and (6) [32,129,130]. Fig. 7 summarizes the whole post-photoexcitation process.

The anatase phase of titanium dioxide despite having so many catalytic benefits has the problem that it requires UV light at a wave of <390 nm as the main input. In the case of systems whose main energy source is solar radiation, the sunlight beam contains only 4% UV light [127]. However, there are several ways to improve the photocatalytic effect, either directly with a UV light source or sunlight.

A proposed solution to the problem of the slight activity with sunlight is the use of titanium dioxide's heterojunction photocatalyst process. This uses TiO_2 in the anatase phase, combined with the brookite or rutile phase; in fact, some authors have shown considerable improvement during sunlight processes [131–133] when the heterojunction has been used. On the other hand, there is the method of adding dopants [128,134], additives and chemical modifiers to increase

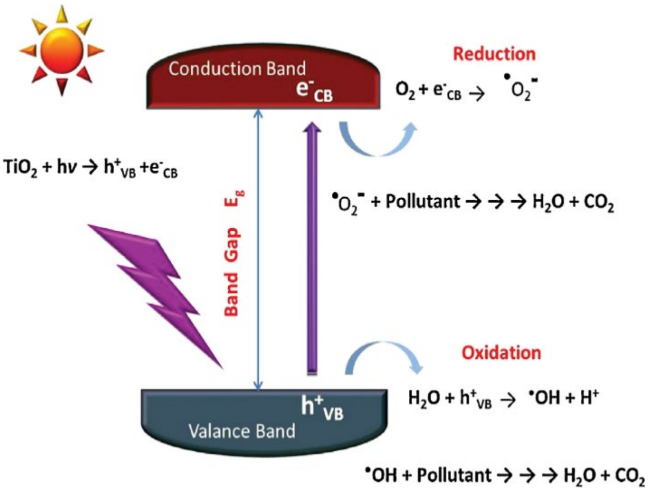

Fig. 7. Schematic illustration of various processes occurring after photoexcitation of pure TiO_2 with UV light [130]. Copyright, reprinted with permission from Elsevier.

the photocatalytic activity. Dopants can be non-metals compounds, such as carbon [135], nitrogen [136–137], fluorine [138] and sulphur [139]. On the other hand, the metal dopants are based on iron [139], silver [140], chromium [141] and manganese [142]. When a doping agent is used in the process of heterogeneous photocatalysis, it can change the chemical and physical properties (molecular structure) of the sample, leading to an increase or decrease in photocatalytic activity, therefore, precautions must be taken to avoid the opposite effect. The purpose of adding a doping agent can be seen in Fig. 8, where the bandgap between the VB and CB [143] is narrowed when new "states" born, thus, increasing the photocatalytic activity. Finally, a more extensive and exhaustive information about photocatalysis processes for wastewater decontamination and disinfection can be found in Byrne et al. [125], Blake [132], Fujishima and Zhang [135], Etacheri et al. [141] works.

5. Management of wastewater treatments by-products

The increase in water stress due to the increase in the world population leads to the need to produce more food as explained in section 2; therefore, agriculture consumes a greater amount of water resources. In recent years, new wastewater, desalination, and disinfection treatments have arisen in order to decrease the water scarcity seen worldwide. However, all the methodologies during the chemical or physical phase produce a series of by-products, most of which are toxic and need special treatment. In Acher et al. [142] mentioned that the toxicity of the by-products found in water disinfection and decontamination by chlorination [13,57], the hazards in handling these disinfectant agents, and environmental toxicity of the ozone escaping into the atmosphere during ozonation [13,59,60] have prompted environmental and public health agencies to insist on replacing these chemical methods with more eco-friendly methods [144,145]. On the other hand, some authors have studied the performance of peracetic acid as a chlorine [13,57] alternative for wastewater disinfection. Dell'Erba et al. [144] mention that

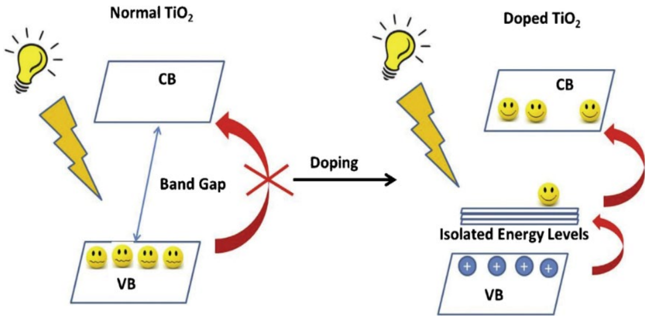

Fig. 8. Bandgap narrowing with a dopant [143]. Copyright, reprinted with permission from Elsevier

even the technical and economic effectiveness of this method, the possible formation of unhealthy disinfection by-products still needs to be fully studied.

The implementation of solar stills and solar concentrators has been shown as a solution to the excessive generation of by-products in wastewater treatment processes because only solar radiation is necessary for its operation. Nevertheless, it is imperative to mention that depending on the water origin (e.g. seawater, underground or wastewater) different by-products could be generated.

The phenomenon of by-products formation has been studied in its majority around the brine from desalinization plants. Normally, there are two types of reject brine, by either concentration or retention. There are some cases, where desalinization plants usually pour the by-products directly into the sea or nearby water sources that flow into the sea [147–148]. Although the desalinization process provides freshwater for human consumption, either by methodologies presented in Tables 1 and 2 or by using solar still or solar concentrators, it has a great impact on nature if it is not managed correctly [146,149,150].

The rejected brine management is focused on three different topics, (i) direct disposal, (ii) brine minimization or (iii) direct reuse. Firstly, direct disposal strategies involve offshore and inland disposal methods [149–152], but it has greater environmental repercussions. Secondly, brine minimization struggles in reducing brine production with either membrane-based or alternative methods such as thermal or another emerging technology [152–155]. For example, Martinetti et al. [152], have determined that forward osmosis achieved water recoveries up to 90% from the brines and vacuum-enhanced direct contact membrane distillation achieved water recoveries up to 81% from the brines. Subramani and Jacangelo [153] have found that the total water recovery, by either membrane-based, thermal-based, or emerging technologies are capable of reducing the concentrate volume (reject brine) using two or three-stage processes, achieving zero liquid discharge.

Membrane-based technologies are less energy-intensive when compared to thermal-based technologies. Nevertheless, if the stored water quality is complex, like having industrial effluents, the use of membrane-based technologies is restricted. On the other hand, the thermal-based processes require a lot of energy and do not allow high water flows, therefore, more studies and research is needed to achieve better performance. Other authors, presented technologies such as forward osmosis and membrane distillation [155] to reduce the brine generation. Likewise, new technologies where reject brine is combined with microorganisms obtaining a compound for use in for halophyte forage shrub [156].

Finally, Rodríguez-DeLaNuez et al. [150] further review techniques for direct and indirect by-products reuse such as hydrotherapy, wetlands regeneration, nanofiltration, membrane distillation, halophilic species, osmotic power, freezing-melting, evaporation ponds, electrodialysis, rapid spray evaporation, zero discharge, among others. Nanofiltration, electrodialysis and wetlands regeneration stand as the commonest techniques due to economic and technical factors. However, the most efficient methods are hydrotherapy, halophilic species, osmotic power, and evaporation ponds. On the other hand, evaporation ponds, zero discharge, and osmotic power are better prepared for brine management [152]. Fig. 9 summarizes the process that was employed in a Semi-Arid Region of Brazil, for both, in the integrated production scheme of fish and halophyte forage shrub and the irrigation of a range of crops.

In addition, due to its high characteristics and good performance in arid regions and saline waters, the cultivation of the spirulina cyanobacteria is proposed as an alternative worthy method for fish farming boosting. Sánchez et al. [145] propose a full three-stage strategy for reuse the reject brine. The first stage cultivates spirulina cyanobacteria for fish farming (Fig. 9) using the rejected brine. Right after this stage, the brine enters a mixture pond where it is enriched with organic matter from local agricultural waste. This brine is finally used to irrigate the Atriplex field, whose harvest will help to feed livestock, this was proposed by Sanchez et al. [145] and reviewed in Gabelich et al. [149] article.

Fig. 10 depicts one facility of the fourteen created by the Brazilian Environmental Agency. Each facility consists of 2 hectares and has four stages; nevertheless, these must be located close to the reverse osmosis plant (stage 1). The brine rejected is stored in an elevated storage tank (tanks around stage 1). Stage 2 is composed of two pounds of fish farms (in this case tilapia's farms) followed by another tank where the brine is enriched with organic matter (between stages 2 and 3). Then, a plantation of Atriplex shrubs with a size of 1 hectare is enriched with the brine and organic matter. The last stage (fourth stage) has a small area needed for haymaking and auxiliary services Despite the potabilization treatments advantages, it is mandatory to minimize the generation of by-products that may contaminate the surrounding environment; therefore, some researchers and governments are working towards policies and facilities for the treatment of these by-products. A clear example is desalination plants, where the rejected brine is at high temperature and contain chemicals that are hazardous to marine life. If there is no equity between the quality of the water in the coasts and the sea, this produces serious consequences, such as alterations to the natural dissolved oxygen, alkalinity, pH variations, and so on. Finally, there must be a responsible use of water, consequently, the governments must start to educate in water consumption and the creation of public policies to shorten the problem of water shortages.

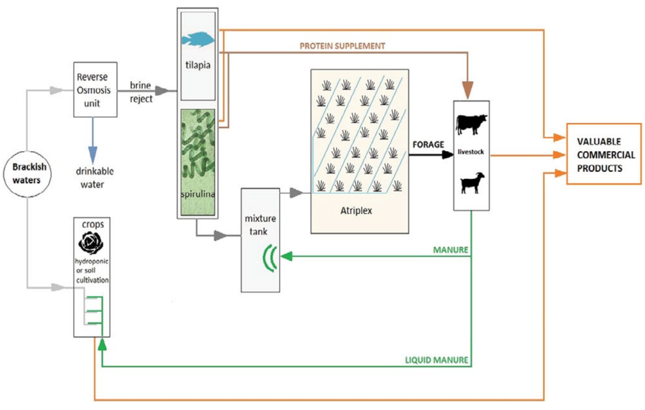

Fig. 9. A schematic integrated production of the use of inland desalination brine reject [147–148]. Copyright, reprinted with permission from Elsevier.

6. Conclusions

This review gave to the reader a general overview of the worldwide state of water but also suggested some techniques and methodologies that researchers, general community and governments could implement to reduce water scarcity. Firstly, many countries have established laws regarding the basic water's minerals for human health and vegetation, for example, the absence of calcium and magnesium may affect public health. It is important to recall also that each country possesses its own regulation and requirements towards suitable water for human consumption, nonetheless, parameters such as calcium, magnesium, precipitation index, alkalinity, and pH are around similar rates.

Secondly, the review wanted to explain the last advances in solar stills, but also, how recent studies have used enhancements to increase the yield of distilled water, such as solar collectors and PCM materials. We explained the main solar still's architectures, geometrics, and performance. It is important to mention that the aim was not to compare one by one, but we reviewed their main advantages in the quantity of water produced. The yield of a solar still may vary depending on two groups of variables. Firstly, variables such as solar radiation, location, and wind velocity; secondly, geometrical and structural characteristics may influence as well the performance of these solar stills, such as CBA rate, coating material, type of solar still, use of PCM materials and

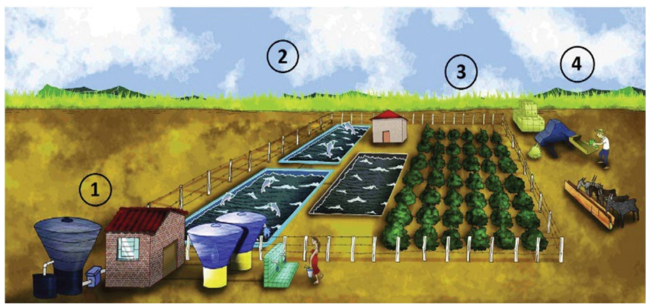

Fig. 10. Integrated production scheme for the use of inland desalination brine [147,151]. Copyright, reprinted with permission from Elsevier.

solar collectors, among others. The solar collectors and solar stills are similar systems, where in the first one the sunlight is reflected in one point using mirrors, then a fluid is heated for a specific purpose. A system composed of solar stills together with a solar collector has shown much better results than each one working individually, even in many experiments are used PCM materials to store energy through the day and releasing in non-daylight hours. For example, one outdoor experiment with a Basin type multi-stage solar still with solar collector, presented a yield of 11.56 L/d with a single basin, a 96% increase using two basins, then a 25% plus with three basins. A still-standing problem with the majority of wastewater techniques is the generation of toxic by-products, either chemical or biological.

Nevertheless, the AOP, like photocatalysis belongs to clean technologies, where the water pollutants are degraded into CO_2 and H_2O. Therefore, the AOP has become a worthy eco-friendly technique to obtain freshwater, where the by-products are highly minimized due to the reusability of the semiconductors, but, the initial costs and the problem of UV light source, still being a problem. In conclusion, even if high-quality water is produced from whatever technique, it is imperative to keep the by-product's environmental impact as low as possible to obtain a feasible system for both, the governments and the environment.

Acknowledgments

The authors are grateful to the Administrative Department of Science, Technology, and Innovation – Colciencias and Universidad Autónoma del Caribe, for providing the framework and support under the program "Jovenes Investigadores" (Young researcher's program) [Grant OJ-092-2017].

References

[1] M. Pedro-Monzonís, A. Solera, J. Ferrer, T. Estrela, J. Paredes-Arquiola, A review of water scarcity and drought indexes in water resources planning and management, J. Hydrol., 527 (2015) 482–493.
[2] N. Hanasaki, S. Fujimori, T. Yamamoto, S. Yoshikawa, Y. Masaki, Y. Hijioka, M. Kainuma, Y. Kanamori, T. Masui, K. Takahashi, S. Kanae, A global water scarcity assessment under shared socio-economic pathways - Part 2: water availability and scarcity, Hydrol. Earth Syst. Sci. Discuss., 17 (2013) 2393–2413.
[3] S.M. Quiring, Developing objective operational definitions for monitoring drought, J. Appl. Meteorol. Climatol., 48 (2009) 1217–1229.
[4] EU, Report on the Review of the European Water Scarcity and Drought Policy, European Commission and European Environment Agency, 2012. Available at: https://ec.europa.eu/environment/water/quantity/pdf/COM-2012-672final-EN.pdf
[5] EU, Addressing the Challenge of Water Scarcity and Droughts in the European Union, Communication from the Commission to the Council and the European Parliament, Addressing the Challenge of Water Scarcity and Droughts in the European Union, European Commission, Brussels, 2007.
[6] A.F.V. Loon, H.A.J.V. Lanen, Making the distinction between water scarcity and drought using an observation-modeling framework, Water Resour. Res., 49 (2013) 1483–1502.
[7] D. Han, M.J. Currell, G. Cao, Deep challenges for China's war on water pollution, Environ. Pollut., 218 (2016) 1222–1233.
[8] M. Kummu, P.J. Ward, H. de Moel, O. Varis, Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia, Environ. Res. Lett., 5 (2010) 034006.
[9] G. Tsakiris, H. Vangelis, Establishing a drought index incorporating evapotranspiration, Eur. Water, 9 (2005) 3–11.
[10] C.-W. Chen, C.-C. Wei, H.-J. Liu, N.-S. Hsu, Application of neural networks and optimization model in conjunctive use of surface water and groundwater, Water Resour. Manage., 28 (2014) 2813–2832.
[11] A. Singh, Optimal allocation of resources for increasing farm revenue under hydrological uncertainty, Water Resour. Manage., 30 (2016) 2569–2580.
[12] A.N. Angelakis, X.Y. Zheng, Evolution of water supply, sanitation, wastewater, and storm water technologies globally, Water, 7 (2015) 455–463.
[13] M. Salgot, M. Folch, Wastewater treatment and water reuse, Curr. Opin. Environ. Sci. Health, 2 (2018) 64–74.
[14] Z. Hu, S. Yan, L. Yao, M. Moudi, Efficiency evaluation with feedback for regional water use and wastewater treatment, J. Hydrol., 562 (2018) 703–711.
[15] X. Garcia, D. Pargament, Reusing wastewater to cope with water scarcity: economic, social and environmental considerations for decision-making, Resour. Conserv. Recycl., 101 (2015) 154–166.
[16] L. Yang, H. Ouyang, K. Fang, L. Ye, J. Zhang, Evaluation of regional environmental efficiencies in China based on super-efficiency-DEA, Ecol. Indic., 51 (2015) 13–19.
[17] G. Wu, Z. Miao, S. Shao, K. Jiang, Y. Geng, D. Li, H. Liu, Evaluating the construction efficiencies of urban wastewater transportation and treatment capacity: evidence from 70 megacities in China, Resour. Conserv. Recycl., 128 (2018) 373–381.
[18] G. Deng, L. Li, Y. Song, Provincial water use efficiency measurement and factor analysis in China: Based on SBM-DEA model, Ecol. Indic., 69 (2016) 12–18.
[19] X. Zhou, Z. Xu, L. Yao, Y. Tu, B. Lev, W. Pedrycz, A novel data envelopment analysis model for evaluating industrial production and environmental management system, J. Cleaner Prod., 170 (2018) 773–788.
[20] M. Shafiee, F.H. Lotfi, H. Saleh, M. Ghaderi, A mixed integer bi-level DEA model for bank branch performance evaluation by Stackelberg approach, J. Ind. Eng. Int., 12 (2016) 81–91.
[21] Y. Bian, S. Yan, H. Xu, Efficiency evaluation for regional urban water use and wastewater decontamination systems in China: a DEA approach, Resour. Conserv. Recycl., 83 (2014) 15–23.
[22] UNICEF and World Health Organization, Progress on Sanitation and Drinking Water – 2015 Update and MDG Assessment, (https://www.unicef.org/publications/index_82419.html) (accessed 20 September 2018), UNICEF, 2015. Available at: https://www.unicef.org/publications/index_82419.html.
[23] UN, Food and Agriculture Organization of the United Nations, Food and Agriculture Organization (FAO), 2018. Available at: http://www.fao.org/family-farming/detail/en/c/1189078/
[24] M. Telkes, Fresh water from seawater by solar distillation, Ind. Eng. Chem., 45 (1953) 1108–1114.
[25] V. Velmurugan, S.S. Kumaran, V.N. Prabhu, K. Srithar, Productivity enhancement of stepped solar still: performance analysis, Therm. Sci., 12 (2008) 153–163.
[26] K. Selvaraj, A. Natarajan, Factors influencing the performance and productivity of solar stills - a review, Desalination, 435 (2018) 181–187.
[27] N.K. Dhiman, Transient analysis of a spherical solar still, Desalination, 69 (1988) 47–55.
[28] R.V. Dunkle, Solar Water Distillation: The Roof Type Still and a Multiple Effect Diffusion Still, International Heat Transfer Conference, University of Colorado, USA, 1961, p. 895.
[29] G. Menguy, M. Benoit, R. Louat, A. Makki, M. Schwartz, New Solar Still Design and Experimentation (The Wiping Spherical Still), Private Communication, Group D {} Etudes Thermiques et Solaires, Universit Claude Bernard, 1980.
[30] A.L. Moreno, C.A. Castro, A. Centeno, S.A. Giraldo, Cinética de la Desinfección Fotocatalítica de Agua contaminada con *E. coli*: Efecto de la Concentración del Foto- catalizador y la Potencia de Irradiación, Informacion tecnologica, 22 (2011) 69–78.
[31] N. Daneshvar, A. Niaei, S. Akbari, S. Aber, N. Kazemian, Photocatalytic disinfection of water polluted by *Pseudomonas aeruginosa*, Global Nest J, 9 (2007) 1–5.

[32] P. Bonaveri, M. Sánchez, Luis, Aplicaciones de Energía Solar. De la limitante de los re-cursos fósiles y la sostenibilidad, hacia la implementación de soluciones limpias, Editorial Uniautonoma, Universidad Autonoma del Caribe, 2017 Available at: https://www.librosyeditores.com/ingenieria/9781-aplicaciones-de-energia-solar-de-la-limitante-de-os-recursos-fosiles-y-la-sostenibilidad-haca-la-implementacion-de-soluciones-9789585431010.html.

[33] L. Birnhack, N. Voutchkov, O. Lahav, Fundamental chemistry and engineering aspects of post-treatment processes for desalinated water—a review, Desalination, 273 (2011) 6–22.

[34] P. Sarin, V.L. Snoeyink, J. Bebee, W.M. Kriven, J.A. Clement, Physicochemical characteristics of corrosion scales in old iron pipes, Water Res., 35 (2001) 2961– 2969.

[35] M. Edwards, Controlling corrosion in drinking water distribution systems: a grand challenge for the 21st century, Water Sci. Technol., 49 (2004) 1–8.

[36] T.F. Seacord, J.E. Singley, G. Juby, N. Voutchkov, Post-Treatment Concepts for Seawater and Brackish Water Desalting, AMTA/SEDA Technology Transfer Workshop, Isle of Palms, SC, 2003.

[37] WHO and FAO, Safety Evaluation of Certain Food Additives and Contaminants, Seventy-third Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), Geneva, 2008.

[38] A. Plottu-Pecheux, C. Democrate, B. Houssais, D. Gatel, J. Cavard, Controlling the corrosiveness of blended waters, Desalination, 138 (2001) 237–249.

[39] O. Lahav, M. Kochva, J. Tarchitzky, Potential drawbacks associated with agricultural irrigation with treated wastewaters from desalinated water origin and possible remedies, Water Sci. Technol., 61 (2010) 2451–2460.

[40] O. Lahav, L. Birnhack, Quality criteria for desalinated water following post-treatment, Desalination, 207 (2007) 286–303.

[41] C. Sánchez, M.C. López, L.A. Galeano, Y. Qvarnstrom, K. Houghton, J.D. Ramírez, Molecular detection and genotyping of pathogenic protozoan parasites in raw and treated water samples from southwest Colombia, Parasites Vectors, 11 (2018) 563.

[42] S.-C. Pai, Y.-J. Tsau, T.-I. Yang, pH and buffering capacity problems involved in the determination of ammonia in saline water using the indophenol blue spectrophotometric method, Anal. Chim. Acta, 434 (2001) 209–216.

[43] D. Pimentel, J. Houser, E. Preiss, O. White, H. Fang, L. Mesnick, T. Barsky, S. Tariche, J. Schreck, S. Alpert, Water resources: agriculture, the environment, and society, Bioscience, 47 (1997) 97–106.

[44] A. Catling, I. Abubakar, I.R. Lake, L. Swift, P.R. Hunter, A systematic review of analytical observational studies investigating the association between cardiovascular disease and drinking water hardness, J. Water Health, 6 (2008) 433–442.

[45] R.W. Morris, M. Walker, L.T. Lennon, A.G. Shaper, P.H. Whincup, Hard drinking water does not protect against cardiovascular disease: new evidence from the British Regional Heart Study, Eur. J. Cardiovasc. Prevent. Rehabil., 15 (2008) 185–189.

[46] WHO, Dengue Guidelines for Diagnosis, Treatment, Prevention and Control, World Health Organization, 2009. Available at: https://www.who.int/tdr/publications/documents/dengue-diagnosis.pdf and https://www.who.int/csr/resources/publications/dengue_9789241547871/en/

[47] R.J. Macdonald, A. Ernst, Disinfection efficiency and problems associated with maturation ponds, Water Sci. Technol., 19 (1987) 557–567.

[48] S.H. Lin, C.F. Peng, Continuous treatment of textile wastewater by combined coagulation, electrochemical oxidation and activated sludge, Water Res., 30 (1996) 587–592.

[49] S. Sandhya, K. Swaminathan, Kinetic analysis of treatment of textile wastewater in hybrid column upflow anaerobic fixed bed reactor, Chem. Eng. J., 122 (2006) 87–92.

[50] C.A. Togo, C.C.Z. Mutambanengwe, C.G. Whiteley, Decolourisation and degradation of textile dyes using a sulphate reducing bacteria (SRB)-biodigester microflora co-culture, Afr. J. Biotechnol., 7 (2008) 114–121.

[51] O.J. Hao, H. Kim, P.-C. Chiang, Decolorization of wastewater, Crit. Rev. Env. Sci. Technol., 30 (2000) 449–505.

[52] I. Ciabatti, F. Tognotti, L. Lombardi, Treatment and reuse of dyeing effluents by potassium ferrate, Desalination, 250 (2010) 222–228.

[53] M. Marcucci, G. Nosenzo, G. Capannelli, I. Ciabatti, D. Corrieri, G. Ciardelli, Treatment and reuse of textile effluents based on new ultrafiltration and other membrane technologies, Desalination, 138 (2001) 75–82.

[54] S. Barredo-Damas, M.I. Alcaina-Miranda, M.I. Iborra-Clar, A. Bes-Pia, J.A. Mendoza-Roca, A. Iborra-Clar, Study of the UF process as pretreatment of NF membranes for textile wastewater reuse, Desalination, 200 (2006) 745–747.

[55] A.K. Verma, R.R. Dash, P. Bhunia, A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters, J. Environ. Manage., 93 (2012) 154–168.

[56] S.H. Park, L.P. Padhye, P. Wang, M. Cho, J.-H. Kim, C.-H. Huang, N-nitrosodimethylamine (NDMA) formation potential of amine-based water treatment polymers: effects of in situ chloramination, breakpoint chlorination, and pre-oxidation, J. Hazard. Mater., 282 (2015) 133–140.

[57] A.D. Shah, Z.-Q. Liu, E. Salhi, T. Höfer, U. von Gunten, Peracetic acid oxidation of saline waters in the absence and presence of H_2O_2: secondary oxidant and disinfection byproduct formation, Environ. Sci. Technol., 49 (2015) 1698–1705.

[58] P.R. Gogate, A.B. Pandit, A review of imperative technologies for wastewater treatment I: oxidation technologies at ambient conditions, Adv. Environ. Res., 8 (2004) 501–551.

[59] T. Robinson, G. McMullan, R. Marchant, P. Nigam, Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative, Bioresour. Technol., 77 (2001) 247–255.

[60] R. Sommer, W. Pribil, S. Appelt, P. Gehringer, H. Eschweiler, H. Leth, A. Cabaj, T. Haider, Inactivation of bacteriophages in water by means of non-ionizing (UV-253.7 nm) and ionizing (gamma) radiation: a comparative approach, Water Res., 35 (2001) 3109–3116.

[61] A. Vogelpohl, Applications of AOPs in wastewater treatment, Water Sci. Technol., 55 (2007) 207–211.

[62] K.W. Moody, J.L. Dally, Apparatus and Method for UV Wastewater Purification in Septic Tank Systems, U.S. Provisional Patent Application, 2001.

[63] V. Mottier, F. Brissaud, P. Nieto, Z. Alamy, Wastewater treatment by infiltration percolation: a case study, Water Sci. Technol., 41 (2000) 77–84.

[64] H. Ludwig, M. Hetschel, Treatment of distillates and permeates from seawater desalination plants, Desalination, 58 (1986) 135–154.

[65] E. Gabbrielli, A tailored process for remineralization and potabilization of desalinated water, Desalination, 39 (1981) 503–520.

[66] P. Leroy, Corrosion control of feeders carrying potable water from desalination of sea water case of the Yanbu Medina water supply system (Saudi Arabia), Desalination, 44 (1983) 317–324.

[67] B.R. Lewandowski, K.L. Lusker, Z. LeJeune, D. Lytle, P. Zhou, P. Sprunger, J. Garno, Impact of pH, dissolved inorganic carbon, and polyphosphates for the initial stages of water corrosion of copper surfaces investigated by AFM and NEXAFS, Corros. Sci., 1 (2011) 16–26.

[68] I. Al-Hayeka, O.O. Badran, The effect of using different designs of solar stills on water distillation, Desalination, 169 (2004) 121–127.

[69] K.H. Nayi, K.V. Modi, Pyramid solar still: a comprehensive review, Renewable Sustainable Energy Rev., 81 (2018) 136–148.

[70] T. Arunkumar, D. Denkenberger, R. Velraj, R. Sathyamurthy, H. Tanaka, K. Vinothkumar, Experimental study on a parabolic concentrator assisted solar desalting system, Energy Convers. Manage., 105 (2015) 665–674.

[71] A.F. Mashaly, A.A. Alazba, Experimental and modeling study to estimate the productivity of inclined passive solar still using ANN methodology in arid conditions, J. Water Supply Res. Technol. AQUA, 67 (2018) 332–346.

[72] N. Rahbar, J.A. Esfahani, Experimental study of a novel portable solar still by utilizing the heatpipe and thermoelectric module, Desalination, 284 (2012) 55–61.

[73] V. Velmurugan, M. Gopalakrishnan, R. Raghu, K. Srithar, Single basin solar still with fin for enhancing productivity, Energy Convers. Manage., 49 (2008) 2602–2608.
[74] H. Aybar, H. Assefi, Simulation of a solar still to investigate water depth and glass angle, Desal. Wat. Treat., 7 (2009) 35–40.
[75] S. Nijmeh, S. Odeh, B. Akash, Experimental and theoretical study of a single-basin solar sill in Jordan, Int. Commun. Heat Mass Transfer, 32 (2005) 565–572.
[76] A.A. El-Sebaii, S.J. Yaghmour, F.S. Al-Hazmi, A.S. Faidah, F.M. Al-Marzouki, A.A. Al-Ghamdi, Active single basin solar still with a sensible storage medium, Desalination, 249 (2009) 699–706.
[77] H. Panchal, M.I. Patel, B. Patel, R. Goswami, M. Doshi, A comparative analysis of single slope solar still coupled with flat plate collector and passive solar still, Int. J. Res. Rev. Appl. Sci., 7 (2011) 111–116.
[78] F.F. Tabrizi, A.Z. Sharak, Experimental study of an integrated basin solar still with a sandy heat reservoir, Desalination, 253 (2010) 195–199.
[79] K.K. Murugavel, S. Sivakumar, J.R. Ahamed, K.K. Chockalingam, K. Srithar, Single basin double slope solar still with minimum basin depth and energy storing materials, Appl. Energy, 87 (2010) 514–523.
[80] M.R. Rajamanickam, A. Ragupathy, Influence of water depth on internal heat and mass transfer in a double slope solar still, Energy Procedia, 14 (2012) 1701–1708.
[81] H. Nishikawa, T. Tsuchiya, Y. Narasaki, I. Kamiya, H. Sato, Triple effect evacuated solar still system for getting fresh water from seawater, Appl. Therm. Eng., 18 (1998) 1067–1075.
[82] J. Xiong, G. Xie, H. Zheng, Experimental and numerical study on a new multi-effect solar still with enhanced condensation surface, Energy Convers. Manage., 73 (2013) 176–185.
[83] A.A. El-Sebaii, Thermal performance of a triple-basin solar still, Desalination, 174 (2005) 23–37.
[84] M.I. Shatat, K. Mahkamov, Determination of rational design parameters of a multi-stage solar water desalination still using transient mathematical modelling, Renewable Energy, 35 (2010) 52–61.
[85] Z.M. Omara, A.E. Kabeel, M.M. Younes, Enhancing the stepped solar still performance using internal and external reflectors, Energy Convers. Manage., 78 (2014) 876–881.
[86] M.A. Eltawil, Z.M. Omara, Enhancing the solar still performance using solar photovoltaic, flat plate collector and hot air, Desalination, 349 (2014) 1–9.
[87] S. Kumar, A. Dubey, G.N. Tiwari, A solar still augmented with an evacuated tube collector in forced mode, Desalination, 347 (2014) 15–24.
[88] B.S. Kumar, S. Kumar, R. Jayaprakash, Performance analysis of a "V" type solar still using a charcoal absorber and a boosting mirror, Desalination, 229 (2008) 217–230.
[89] T. Arunkumar, R. Jayaprakash, D. Denkenberger, A. Ahsan, M.S. Okundamiya, S. Kumar, H. Tanaka, H.Ş. Aybar, An experimental study on a hemispherical solar still, Desalination, 286 (2012) 342–348.
[90] H.E. Fath, M. El-Samanoudy, K. Fahmy, A. Hassabou, Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations, Desalination, 159 (2003) 69–79.
[91] A. Kumar, J.D. Anand, Modelling and performance of a tubular multiwick solar still, Energy, 17 (1992) 1067–1071.
[92] H.E. Gad, S.S. El-Din, A.A. Hussien, K. Ramzy, Thermal analysis of a conical solar still performance: an experimental study, Sol. Energy, 122 (2015) 900–909.
[93] M. Feilizadeh, M.K. Estahbanati, K. Jafarpur, R. Roostaazad, M. Feilizadeh, H. Taghvaei, Year-round outdoor experiments on a multi-stage active solar still with different numbers of solar collectors, Appl. Energy, 152 (2015) 39–46.
[94] A.E. Kabeel, A.M. Hamed, S.A. El-Agouz, Cost analysis of different solar still configurations, Energy, 35 (2010) 2901–2908.
[95] A. Ghoneyem, A. Ileri, Software to analyze solar stills and an experimental study on the effects of the cover, Desalination, 114 (1997) 37–44.
[96] A.K. Singh, G.N. Tiwari, P.B. Sharma, E. Khan, Optimization of orientation for higher yield of solar still for a given location, Energy Convers. Manage., 36 (1995) 175–181.
[97] R. Tripathi, G.N. Tiwari, Thermal modeling of passive and active solar stills for different depths of water by using the concept of solar fraction, Sol. Energy, 80 (2006) 956–967.
[98] G.N. Tiwari, J.M. Thomas, E. Khan, Optimisation of glass cover inclination for maximum yield in a solar still, Heat Recovery Syst. CHP, 14 (1994) 447–455.
[99] G.N. Tiwari, M.H.P. Garg, Effect of water flow over the glass cover of a single basin solar still with an intermittent flow of waste hot water in the basin, Energy Convers. Manage., 25 (1985) 315–322.
[100] A.A. El-Sebaii, Effect of wind speed on some designs of solar stills, Energy Convers. Manage., 41 (2000) 523–538.
[101] R. Sathyamurthy, S.A. El-Agouz, P.K. Nagarajan, J. Subramani, T. Arunkumar, D. Mageshbabu, B. Madhu, R. Bharathwaaj, N. Prakash, A review of integrating solar collectors to solar still, Renewable Sustainable Energy Rev., 77 (2017) 1069–1097.
[102] O.O. Badran, M.M. Abu-Khader, Evaluating thermal performance of a single slope solar still, Heat Mass Transfer, 43 (2007) 985–995.
[103] T. Arunkumar, D. Denkenberger, A. Ahsan, R. Jayaprakash, The augmentation of distillate yield by using concentrator coupled solar still with phase change material, Desalination, 314 (2013) 189–192.
[104] B.A. Akash, M.S. Mohsen, W. Nayfeh, Experimental study of the basin type solar still under local climate conditions, Energy Convers. Manage., 41 (2000) 883–890.
[105] H. Panchal, P.K. Shah, Investigation on solar stills having floating plates, Int. J. Energy Environ. Eng., 3 (2012) 8.
[106] K.K. Murugavela, K.K. Chockalingama, K. Srithar, Modeling and verification of double slope single basin solar still using laboratory and actual solar conditions, Jordan Mech. Ind. Eng., 3 (2009) 228–235.
[107] A.Z. Al-Garni, Enhancing the solar still using immersion type water heater productivity and the effect of external cooling fan in winter, Appl. Solar Energy, 48 (2012) 193–200.
[108] A.A. El-Sebaii, A.A. Al-Ghamdi, F.S. Al-Hazmi, A.S. Faidah, Thermal performance of a single basin solar still with PCM as a storage medium, Appl. Energy, 86 (2009) 1187–1195.
[109] Y. Tian, C.-Y. Zhao, A review of solar collectors and thermal energy storage in solar thermal applications, Appl. Energy, 104 (2013) 538–553.
[110] S.K. Singh, V.P. Bhatnagar, G.N. Tiwari, Design parameters for concentrator assisted solar distillation system, Energy Convers. Manage., 37 (1996) 247–252.
[111] K. Sampathkumar, P. Senthilkumar, Utilization of solar water heater in a single basin solar still—an experimental study, Desalination, 297 (2012) 8–19.
[112] A.S. Abdullah, Improving the performance of stepped solar still, Desalination, 319 (2013) 60–65.
[113] M.A. Eltawil, Z. Zhengming, Wind turbine-inclined still collector integration with solar still for brackish water desalination, Desalination, 249 (2009) 490–497.
[114] T. Arunkumar, R. Velraj, D. Denkenberger, R. Sathyamurthy, K. Vinothkumar, K. Porkumaran, A. Ahsan, Effect of heat removal on tubular solar desalting system, Desalination, 379 (2016) 24–33.
[115] T. Arunkumar, R. Velraj, D.C. Denkenberger, R. Sathyamurthy, K.V. Kumar, A. Ahsan, Productivity enhancements of compound parabolic concentrator tubular solar stills, Renewable Energy, 88 (2016) 391–400.
[116] L.E.M. Sánchez, P.D. Bonaveri, Presentación didáctica comparativa del beneficio ecológico-económico del uso de las energías alternativas en hogares comunitarios e infan- tiles en Barranquilla, en el marco del contexto de sostenibilidad energética, 2012.
[117] L.E.M. Sánchez, B. Arangoa, P. Daniel, Construction alternatives using low-cost materials for the thermal test of box-type solar cookers, Revista ION, 25 (2012) 17–23.
[118] P.D. Bonaveri, Ciencia, tecnología, sociedad global y medio ambiente, 2010.

[119] M.N. Chong, B. Jin, C.W. Chow, C. Saint, Recent developments in photocatalytic water treatment technology: a review, Water Res., 44 (2010) 2997–3027.
[120] R. George, N. Bahadur, N. Singh, R. Singh, A. Verma, A.K. Shukla, Environmentally benign TiO_2 nanomaterials for removal of heavy metal ions with interfering ions present in tap water, Mater. Today:. Proc., 3 (2016) 162–166.
[121] M.I. Litter, Last advances on TiO_2-photocatalytic removal of chromium, uranium and arsenic, Curr. Opin. Green Sustainable Chem., 6 (2017) 150–158.
[122] R. Molinari, C. Lavorato, P. Argurio, Recent progress of photocatalytic membrane re- actors in water treatment and in synthesis of organic compounds. A review, Catal. Today, 281 (2017) 144–164.
[123] M. Gmurek, M. Olak-Kucharczyk, S. Ledakowicz, Photochemical decomposition of endocrine disrupting compounds-a review, Chem. Eng. J., 310 (2017) 437–456.
[124] N.F.F. Moreira, J.M. Sousa, G. Macedo, A.R. Ribeiro, L. Barreiros, M. Pedrosa, J.L. Faria, M.F.R. Pereira, S. Castro-Silva, M.A. Segundo, C.M. Manaia, O.C. Nunes, A.M.T. Silva, Photocatalytic ozonation of urban wastewater and surface water using immobilized TiO_2 with LEDs: micropollutants, antibiotic resistance genes and estrogenic activity, Water Res., 94 (2016) 10–22.
[125] C. Byrne, G. Subramanian, S.C. Pillai, Recent advances in photocatalysis for environmental applications, J. Environ. Chem. Eng., 6 (2018) 3531–3555.
[126] N. Shaham-Waldmann, Y. Paz, Away from TiO_2: a critical mini review on the developing of new photocatalysts for degradation of contaminants in water, 42 (2016) 72–80.
[127] A. Fujishima, K. Honda, Photolysis-decomposition of water at the surface of an irradiated semiconductor, Nature, 238 (1972) 37–38.
[128] S. Banerjee, D.D. Dionysiou, S.C. Pillai, Self-cleaning applications of TiO_2 by photoinduced hydrophilicity and photocatalysis, Appl. Catal., B, 176 (2015) 396–428.
[129] D.S. Muggli, L. Ding, Photocatalytic performance of sulphated TiO_2 and Degussa P-25 TiO_2 during oxidation of organics, Appl. Catal., B, 32 (2001) 181–194.
[130] Z. Zhang, C.-C. Wang, R. Zakaria, J.Y. Ying, Role of particle size in nanocrystalline TiO_2-based photocatalysts, J. Phys. Chem. B, 102 (1998) 10871–10878.
[131] R.I. Bickley, T. Gonzalez-Carreno, J.S. Lees, L. Palmisano, R.J. Tilley, A structural investigation of titanium dioxide photocatalysts, J. Solid State Chem., 92 (1991) 178–190.
[132] D. Blake, Bibliography of Work on the Heterogeneous Photocatalytic Removal of Hazardous Compounds from Water and Air-Update Number 4 to October 2001, 2001.
[133] S. Sakthivel, H. Kisch, Daylight photocatalysis by carbon-modified titanium dioxide, Angew. Chem. Int. Ed., 42 (2003) 4908–4911.
[134] C. Byrne, R. Fagan, S. Hinder, D.E. McCormack, S.C. Pillai, New approach of modifying the anatase to rutile transition temperature in TiO_2 photocatalysts, RSC Adv., 6 (2016) 95232–95238.
[135] A. Fujishima, X. Zhang, Titanium dioxide photocatalysis: present situation and future approaches, C.R. Chim., 9 (2006) 750–760.
[136] D. Li, H. Haneda, N.K. Labhsetwar, S. Hishita, N. Ohashi, Visible-light-driven photo-catalysis on fluorine-doped TiO_2 powders by the creation of surface oxygen vacancies, Chem. Phys. Lett., 401 (2005) 579–584.
[137] H.M. Yadav, S.V. Otari, V.B. Koli, S.S. Mali, C.K. Hong, S.H. Pawar, S.D. Delekar, Preparation and characterization of copper-doped anatase TiO_2 nanoparticles with visible light photocatalytic antibacterial activity, J. Photochem. Photobiol., A, 280 (2014) 32–38.
[138] L. Kösi, S. Papp, J. Ménesi, E. Illés, V. Zöllmer, A. Richardt, I. Dékány, Photocatalytic activity of silver-modified titanium dioxide at solid-liquid and solid-gas interfaces, Colloids Surf., A, 319 (2008) 136–142.
[139] S. Karvinen, The effects of trace elements on the crystal properties of TiO_2, Solid State Sci., 5 (2003) 811–819.
[140] K.C. Heo, C.I. Ok, J.W. Kim, B.K. Moon, The effects of manganese ions and their magnetic properties on the anatase-rutile phase transition of nanocrystalline TiO_2: Mn prepared by using the solvothermal method, J. Korean Phys. Soc., 47 (2005) 861–865.
[141] V. Etacheri, C.D. Valentin, J. Schneider, D. Bahnemann, S.C. Pillai, Visible-light activation of TiO_2 photocatalysts: advances in theory and experiments, J. Photochem. Photobiol., C, 25 (2015) 1–29.
[142] A. Acher, E. Fischer, R. Turnheim, Y. Manor, Ecologically friendly wastewater disinfection techniques, Water Res., 31 (1997) 1398–1404.
[143] V. Lazarova, P. Savoye, M.L. Janex, E.R.B. Iii, M. Pommepuy, Advanced wastewater disinfection technologies: state of the art and perspectives, Water Sci. Technol., 40 (1999) 203–213.
[144] A. Dell'Erba, D. Falsanisi, L. Liberti, M. Notarnicola, D. Santoro, Disinfection by-products formation during wastewater disinfection with peracetic acid, Desalination, 215 (2007) 177–186.
[145] A.S. Sánchez, I.B.R. Nogueira, R.A. Kalid, Uses of the reject brine from inland desalination for fish farming, *Spirulina* cultivation, and irrigation of forage shrub and crops, Desalination, 364 (2015) 96–107.
[146] A. Giwa, V. Dufour, F.A. Marzooqi, M.A. Kaabi, S.W. Hasan, Brine management methods: Recent innovations and current status, Desalination, 407 (2017) 1–23.
[147] G.A. Bazedi, R.S. Ettouney, S.R. Tewfik, M.H. Sorour, M.A. El-Rifai, Salt recovery from brine generated by large-scale seawater desalination plants, Desal. Wat. Treat., 52 (2014) 4689–4697.
[148] N. Afrasiabi, E. Shahbazali, RO brine treatment and disposal methods, Desal. Wat. Treat., 35 (2011) 39–53.
[149] C.J. Gabelich, P. Xu, Y. Cohen, Concentrate treatment for inland desalting, Sustainable Sci. Eng., 2 (2010) 295–326.
[150] F. Rodríguez-DeLaNuez, N. Franquiz-Suárez, D.E. Santiago, J.M. Veza, J.J. Sadhwani, Reuse and minimization of desalination brines: a review of alternatives, Desal. Wat. Treat., 39 (2012) 137–148.
[151] C. Kazner, S. Jamil, S. Phuntsho, H.K. Shon, T. Wintgens, S. Vigneswaran, Forward osmosis for the treatment of reverse osmosis concentrate from water reclamation: process performance and fouling control, Water Sci. Technol., 69 (2014) 2431–2437.
[152] C.R. Martinetti, A.E. Childress, T.Y. Cath, High recovery of concentrated RO brines using forward osmosis and membrane distillation, J. Membr. Sci., 331 (2009) 31–39.
[153] A. Subramani, J.G. Jacangelo, Treatment technologies for reverse osmosis concentrate volume minimization: a review, Sep. Purif. Technol., 122 (2014) 472–489.
[154] R. Raja, S. Hemaiswarya, R. Rengasamy, Exploitation of Dunaliella for β-carotene production, Appl. Microbiol. Biotechnol., 74 (2007) 517–523.
[155] R.E. Sergany, M.E. Fadly, A.E. Nadi, Brine desalination by using algae ponds under nature conditions, Am. J. Environ. Eng., 4 (2014) 75–79.