A detailed Review of Solar Desalination Systems with Different Enhancement Methods

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Abstract: The fresh water resources in the world, are not enough to face the human growth, the increasing of needs and the drought of the climate are increasingly insufficient and moreover threatened by all kinds of pollution. The drinking water crisis is strongly reviving the interest in developing desalination techniques that are less expensive, simpler, robuster, reliabler, if possible, less energy consuming and respectful of the environment. It is in this logic that water desalination stations are part of the process, since they make it possible to produce drinking water from sea water or brackish water using special techniques. Solar distillation is a less energy-consuming desalination method because it uses a free source of renewable energy. Work on conventional solar stills where evaporation and condensation take place in the same enclosure showed that the efficiency is low. The work is then oriented towards the separation of the two phenomena where the efficiency of this type of still is higher. These stills are named as humidification-dehumidification solar stills. These types of stills have been the subject of numerous studies to improve efficiency such that the solar collectors used are flat collectors. In this review paper, different methods and techniques of desalination systems will be present and evaluated with other enhancement methods. Many desalination systems have been developed to overcome the water shortage problem, but most of these techniques require intensive energy. Therefore, utilizing renewable energy for desalination is considered as the most important and economical method for producing potable water with low cost. The conclusions from this review paper is showed the different methods, techniques and enhancement methods for obtaining fresh potable water.

1 Introduction

Seawater desalination appears to be the best solution for supplying water to all of the world's people who will face water scarcity in 2040. The desalination market is expanding rapidly, at a rate of 10 to 15% per year. Every year, 18,000 desalination plants produce 21 billion m^3 of drinking water [1]. The capacity of half of these installations is less than 1,000 m^3 per day. However, current techniques, such as thermal processes that are powered by petroleum energy and have a high energy impact, are not sustainable. For every $1m^3$ of water produced, 1 to 2 liters of diesel must be burned, resulting in 2 to 3 kg of CO_2 emissions. Thus, worldwide, desalination emits 80 million tons of CO_2 per year and, if nothing is done, several hundred million tons by 2040. When confronted with this issue, we face a dual challenge: supplying drinking water to populations living in isolated coastal areas or with brackish water resources on the one hand, and with the local means available on the other. The world's total water is used as 70% for agricultural, 20% for industry, and only 10% for household requirements [2]. It should be highlighted that water conservation methods should be addressed before any desalination process is implemented. Governments significantly subsidies irrigation water in most parts of the world, so farmers don't have any incentive to take part in drip irrigation or different water-saving techniques. It's worth noting that this research looked at many ways for solar desalination systems with various improvement methods. The Humidification–Dehumidification (HDD) procedures and the performance of solar stills are focus on these technologies.

2. Desalination Techniques

Desalination can be done in two different ways to get fresh water. The first approach is based on a phase

change process, whereas the second is a membrane process. The phase change process converts water to a vapor from a liquid, which is then converted back to a liquid by the condensation process [3]. In nature, phase change solar desalination is utilized to create rain, which is our planet's primary source of fresh water. The driving force, which includes pressure, concentration, and temperature gradient, impact the membrane process. Solar energy can also be utilized to desalinate saltwater by providing electricity, which is used to power the membrane processes. The foremost imperative innovations utilized in different desalination forms are scheduled in Table 1 [4].

Table (1): Different desalination processes.

Phase-change processes	Membrane processes
1- Multi stage flash	1- Reverse osmosis
2- Multiple effect boiling	
3- Vapor compression	
• Mechanical vapor compression	
• Thermal vapor compression	
4- Freezing	
5- Solar stills	2- Electro-dialysis
• Passive solar stills	
• Active solar stills	

3. Humidification–Dehumidification Desalination (HDD) Techniques

A review of several studies on Humidification–Dehumidification desalination (HDD) techniques will be presented in this section. A unique solar supported with a heat pump desalination machine had been presented by Hawaladar et al. [5]. A condenser, compressor, evaporator, desalination chamber, solar evaporator-collector, feed tank, collecting unit, and vacuum pump make up their system. In the device, they employed a spray nozzle to create droplets of feed water. Their experiment was carried out in Singapore under a variety of operating and environmental conditions. The acquired performance ratio from the desalination unit ranged from 0.77 to 1.15, according to their findings. In addition, the desalination system's performance coefficient was modified between 5.0 and 7.0. Figure 1 depicts a unique solar-assisted heat pump desalination plant. Nafey et al. [6] conducted experiments using solar energy to

examine a desalination system about the humidification–dehumidification desalination (HDD) technology. They discovered that dehumidifier cooling water flow rate, the temperature of the salt water at humidifier inlet, sun intensity, and flow of air all affect system productivity. In addition, atmospheric air temperature and wind speed variations had been found to have only a minor impact on system production.
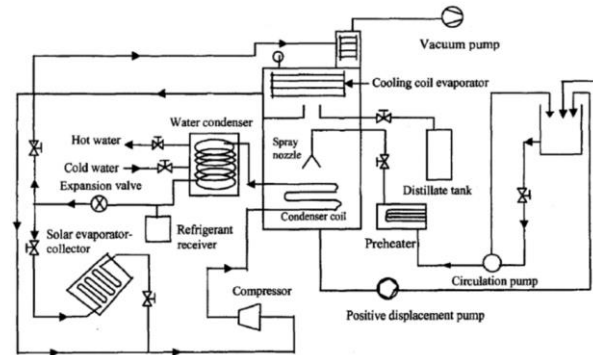

Fig. (1) Diagram of the experimental system [5].

Lalzad et al. [7] researched revolutionary solar energy distillation plant in a novel procedure, which involves merely lowering the pressure owing to the evaporator's height. They created a mathematical model and a prototype plant, which they put to the test by varying the evaporator pressure, heat input, and feed water flowrate at various temperatures. The results of their experiments corroborated the theoretical findings. At constant state temperatures, the system productivity was at 1.4 kg/kWh, which is around 90% of the maximum achievable output.

Gao et al. [8] evaluated the performance of new heat pump desalination setup with humidification and dehumidification. A mechanical vapor compression pump had been built. A mathematical model had been built for the humidifier. The results revealed that the theoretical and experimental results are in arrangement. For 500W of electricity, the desalination system produced 60 kg of freshwater every day.

Zamen et al. [9] examined the overall performance of the humidification–dehumidification (HD) desalination process. The results showed that the independent function has a cost of 7–28% less than other objective functions.

Chaiwongsa and Duangthongsuk [10] presented an analysis for the probable of hot water by traditional air-water heat pump usage as shown in Fig. (2). A 1TR air conditioner system with cooling capacity had been

used. The results presented that the improved system produces 200 liter of hot water and saves 3.5 kW - 4.5 kW of electricity. Also the hybrid heat pump coupled with HDH desalination produced 2.79 kg/h of potable water at cost of 0.0114 $/ liter.
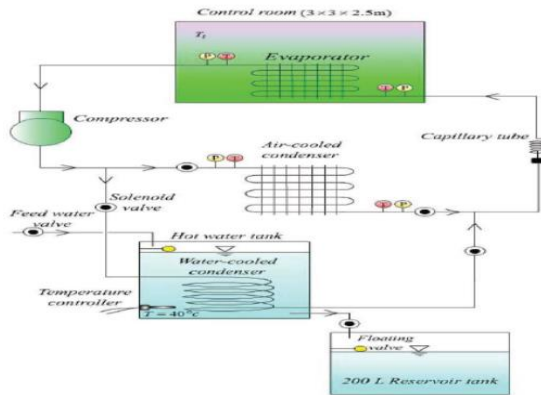

Fig. (2) Diagram of the experimental desalination unit [10].

Kabeel and El-Said [11] studied dissimilar several arrangements of hybrid air humidification and dehumidification–single stage flashing (HDH–SSF) desalination systems powered by solar energy. Their system performance had been evaluated based on the main parameters such as, production of water, cost of water, impact of environment and the thermal behavior of the system. The results indicated that, the solar air heater integrated with hybrid system has the greatest economical pattern with production of water up to 96l in a day in August with a production cost of 12.53$/m³.

Kabeel et al. [12] conducted experimental studies about solar humidification-dehumidification technique using forced and natural circulation of air. The results revealed that the redesigned condenser design boosted the condenser effectiveness to 0.71, compared to 0.49 for the standard version proposed design.
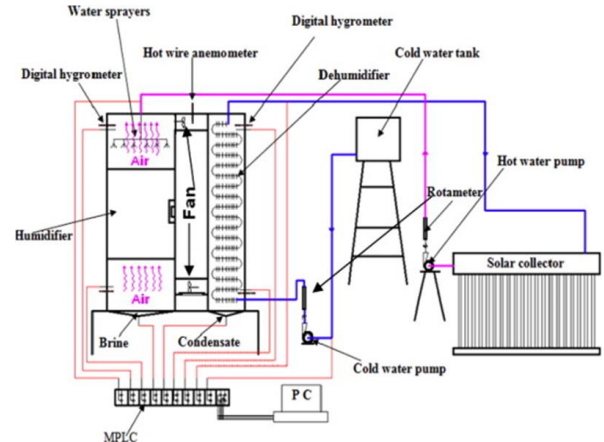

Fig. (3) Diagram of the system used in the study [12].

Li et al. [13] carried out experiments on the HDH desalination system using evacuated tubes solar air heaters, as presented in Fig (4). The humidifier and dehumidifier were created using mathematical design methodologies. According to the testing results, dissimilar inlet water temperatures sprayed in the pad humidifier from 9 °C to 27 °C improved relative humidity of outlet moisture from 89% to 97% and air temperature from 35 °C to 42 °C at outlet. The findings were also useful in determining the best proposal to produce 1000 l/day solar HDH desalinating system employing a novel type of solar air heater.
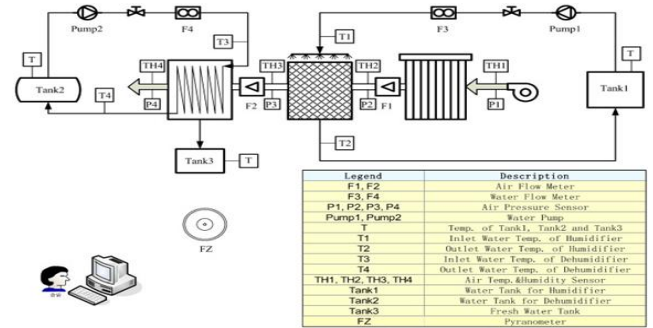

Fig. (4) Schematic diagram of the system using evacuated tubes solar air heater [13].

Zamen et al. [14] tested two-stage methods in order to increase fresh water production by the humidification–dehumidification process as shown in Fig. (5). A 80 m2 solar collecting surface pilot plant in waterless area with had been built. The system had been verified at cold days as well as at hot days. The findings cleared that the two-stage HD desalination unit improved heat recovery in condensers and the

consumption of thermal energy had been reduced. Also, the yield amplified by 20% when compared to the single-stage system unit.
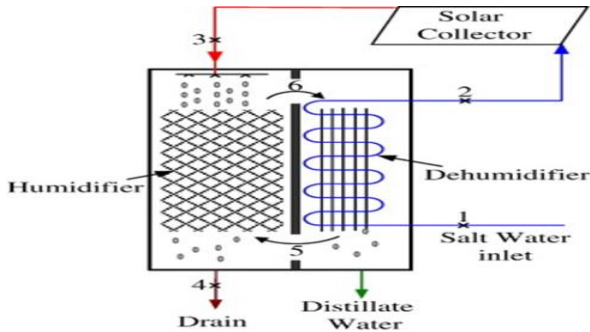

Fig. (5) Schematic diagram of the plant with two-stage technique [14].

Experiments had been conducted by Kabeel and El-Said [15] on a humidification dehumidification solar desalination system integrated with single stage flashing evaporation component. Theoretical models of heat, mass transfer, and flow field were also created. The investigation of the system yielded major operational compatibility among the air humidification dehumidification technique and flash evaporation desalination. Sharqawy et al. [16] examined humidification–dehumidification design coupled with desalination systems by using low temperature source as shown in Fig. (6). Their design details with the humidifier and dehumidifier were used to create the sizes of the humidifier and dehumidifier under several design states. The results showed that the optimal ratios of flow rate of mass for every cycle that maximizes the output ratio. Also, it has been proved that by enhancing the effectiveness of large-size humidifiers and dehumidifiers, a greater gained-output ratio may be achieved.
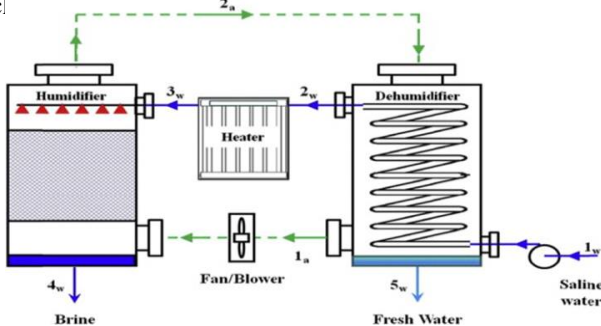

Fig. (6) Diagram of the desalination systems using a low-temperature source [16].

Amin et al. [17] analyzed the performance of a pilot solar desalination system with a heat pump. A direct expansion solar aided heat pump and a single-effect evaporator unit make up that system. The system's performance had been measured and analyzed based on solar irradiation and compressor speed. The ratio of performance achieved from 0.43 to 0.88 ranges, and the average coefficient of performance was around 8, with a maximum productivity of 1.38 kg/h.

Attia [18] suggested a study for heat pump seawater distillation system by passive vacuum generation system usage. The proposed system was prepared by decreasing the saturation temperature of the seawater in order to match the operating ranges of temperature of these refrigerants. The experimental results presented that the coefficient of performance reached to 8, 9, and 7.5 at the optimal saturation temperature of 5 °C.

Fouda et al. [19] conducted a theoretical study for the performance of an integrated solar system for air conditioning, humidification, dehumidification, and water desalination in hot and humid climates. All different operating parameters characteristics had been calculated. The results analysis showed that, the system was further economic and efficient in hot and humid climates.
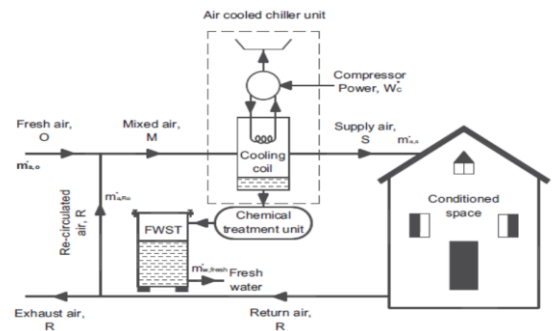

Fig. (7) Diagram of the experimental set-up [19].

Siddiqui et al. [20] built solar humidification-dehumidification desalination system, which integrated with centrifugal air blower. The system had been added to a humidification chamber with two electric water heaters and a condenser as illustrated in Fig. (8). The results revealed that the daily productivity and gained production ratio rose by up to 57 percent.
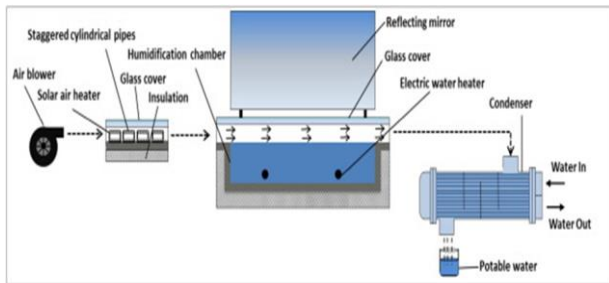
Fig. (8) Diagram of the solar humidification-dehumidification system [20].

Fig. (9) Diagram of the experimental set-up [22].

Gang et al. [21] experimentally studied a new multi-effect solar desalination system based on humidification–and dehumidification (HDH) process. In order to improve the evaporation manner, warm saline water had been drenched on the absorbent ball humidifiers. The results indicated that the maximum ratio of performance of system at the temperature of 85 °C reached to 2.65. Also, increasing the heating temperature from 60 to 90 °C with water flow rate of 2t/h increased the water productivity from 59.41 to 182.47 kg/h.

Moumouh et al. [22] examined theoretically solar humidification–dehumidification desalination unit. A numerical model for the unit design based on energy and mass balances as well as condenser and cooling tower thermodynamic calculations were created. The acquired results from the theoretical model suggested that. The model provides extremely good agreement with the experimental results showed in Fig. (9).
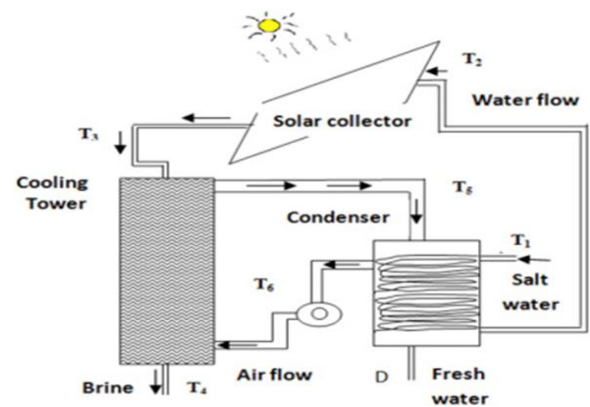
El-Ghetany and Khattab [23] presented numerically the calculating of the performance of a Humidification – Dehumidification solar water desalination system. According to their findings, the daily output of condensed (fresh) water is affected by saline flow rate of water, temperature and mass of air flow rate. The best production was likewise attained between 3 and 4 p.m. Finally, the system's maximum productivity was 64.3 liter per day, and every kWh/m/day that fell on the collector surface created 7.9 liter per day.

Zubair et al. [24] examined the performance and the cost of sun-powered humidification, dehumidification desalination system using solar evacuated tubes as shown in Fig. (10). The system was adjusted for different locations during the day. The results showed that Sharurah has the highest water output, while Dhahran has the lowest, with 19,445 and 16,430 liters per capita, respectively.
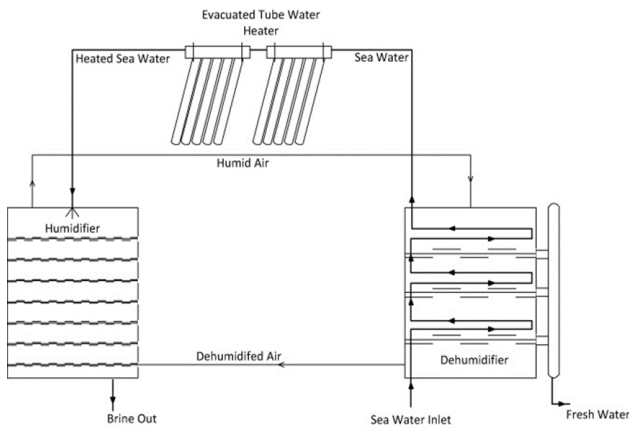
Fig. (10) Diagram of the experimental system [24].

An investigation for unique solar heat pump desalination unit for drinkable water was presented by Xu et al. [25]. Condenser, packing humidifier, compressor, evaporator, precooled, centrifugal fan, and tank make up their system. Based on the process air, cooling seawater, and mixture ratio, they researched and evaluated the unit's performance. The greatest yield was about 12.38 kg/kWh at the flow rate of the cooling seawater and process flow rate of air were 0.3 m3/h and 450 m3/h, respectively.

Lawal et al. [26] studied theoretically a humidification-dehumidification system with heat pump assistance as presented in Fig. (11). The heat of system condenser was utilized to rise the temperature of the seawater before inflowing the humidifier and the evaporator absorbed the heat from water provided to the dehumidifier. The results cleared that, the maximum achievable GOR was around 8.88 and 7.63 at 80% components effectiveness and mass flow rate ratios of 0.63 and 1.3, respectively.
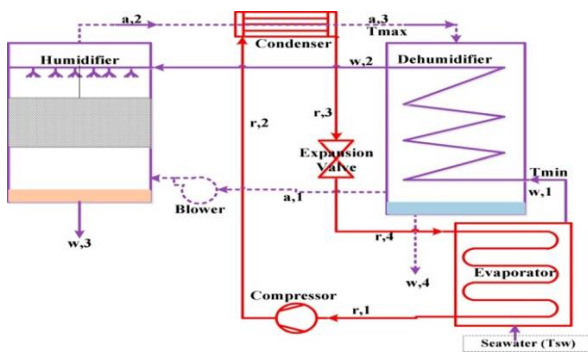

Fig. (11) Diagram of the system assisted by heat pump [26].

El-Maghlany et al. [27] investigated a two-stage dehumidification water desalination system that used a humidification-dehumidification process, as shown in Fig. (12). A heat pump condenser was used in the HD desalination system in order to enhance the moisture absorbing capacity of air. Water was sprayed at a constant flow rate of 2.2 LPM using cross, counter, and parallel flow spraying systems. The results showed that the parallel flow spraying system had the highest output in both single and two stage dehumidification, with productivity of 2.34 and 4.44 liters per hour.

He et al. [28] investigated humidification dehumidification desalination system in combination with a mechanical compression heat pump. A numerical model had been investigated for the desalination unit. The results concluded that the simulation results presented the optimum performance of the system, acting as $82.12 \, kgh^{-1}$ for the water productivity and 5.14 for the gain productivity ratio, was attained at the balance condition of the dehumidifier.
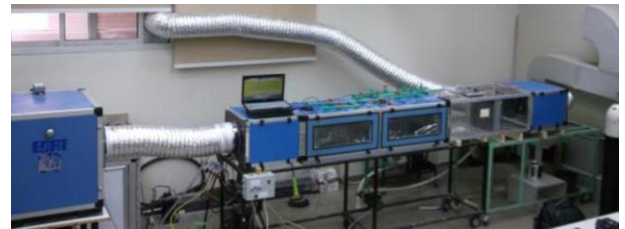

Fig. (12) Photograph of the desalination system [27].
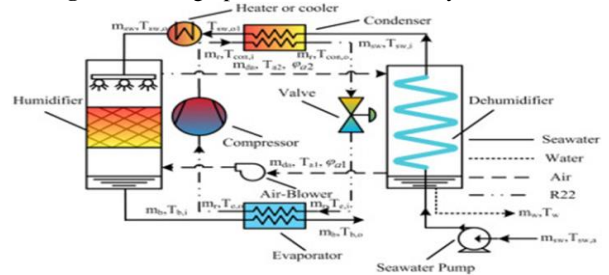
Fig. (13) Diagram of the system coupled with mechanical heat pump [28].

Tariq et al. [29] developed air saturator for desalination humidification-dehumidification applications. The air saturation in the wet channel process was adjusted by means of integrating an infiltration flow from the dry passes to the wet passes of the air saturator as shown in Fig. (14). The suggested system provided 30 percent higher fresh water productivity, 46% higher recovery ratio, and 11% higher gain-output-ratio.

Fig. (14) Schematic diagram of the system [29].
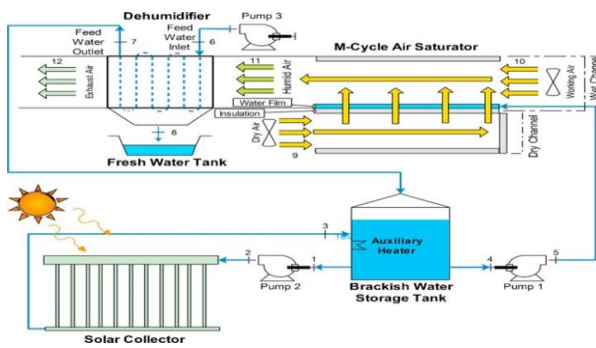
Dehghani et al. [30] studied the performance of a humidification-dehumidification desalination system powered by a heat pump as illustrated in Fig. (15). The heat pump was presented to run the HDH cycle's cooling and heating needs at the identical time. The system was able to establish by alternating the mass flow rate ratio of seawater to freshwater or seawater to dry air.
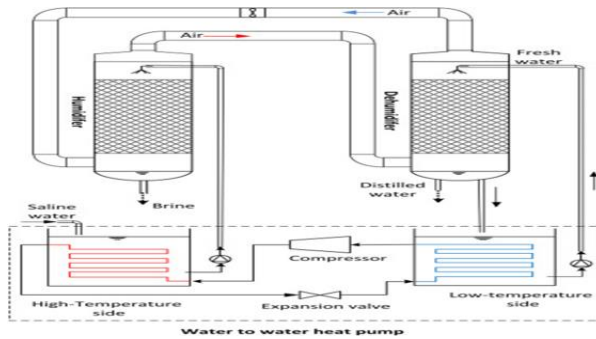

Fig. (15) Diagram of the desalination system [30].

Lawal et al. [31] conducted theoretical study on humidification-dehumidification desalination system integrated with a heat pump. The model is built on the first law of thermodynamics basics. The results concluded that the optimal ratio of gain output was about 8.88 and 7.63 at 80% components effectiveness and mass flow rate ratio of 0.63 and 1.3 for modified air heated and water heated cycle, respectively.

Santosh et al. [32] studied the hybrid humidification-dehumidification desalination system powered by the vapor compression refrigeration unit's waste heat performance. TRNSYS software was used to establish heat and mass transfer mechanisms in the various components of the system. The average condensate generation rate dropped as the space conditioning temperature increased, according to their findings. Furthermore, the cost of the produced freshwater from the system was around 0.1658 $/kg. Finally, the results showed that the proposed model may

be utilized to design and forecast the behavior of the desalination unit under a variety of meteorological situations.

Lawal et al. [33] performed a critical review for the humidification-dehumidification desalination systems driven by thermal-based renewable and low-grade energy sources. The findings concluded that low-grade energy was obtained from the refrigeration systems, PV/T, and power plants. Coupling the HDH systems with power plants or geothermal energy was efficient in performance and evaluation. Solar collectors and PV/T could drive HDH systems efficiently in off-grid regions.

Lawal et al. [34] studied experimentally a humidification-dehumidification desalination system for water desalination and space conditioning driven by heat pump. The system had been evaluated based on many parameters such as, the temperature and flow rate of feed water, also the flow rate of the chilled water. The results concluded that the integrated system was able to reach the max gain output ratio of 4.07, coefficient of performance of 4.85, recovery ratio of 4.86%, and water productivity of 287.8 liter per day and energy utilization factor of 3.04. Also, the minimum specific electrical energy consumption of the system was about 160.16 kW.hr per m3 water.

Anand and Murugavelh [35] studied the performance of augmented desalination and cooling system. A new design had been used with the modified vapor compression refrigeration coupled with humidification-dehumidification desalination component as presented in Fig. (16). The results concluded that the maximum obtained productivity and cooling output are 7.35 LPH and 1.89 kW respectively. Also, the coefficient of performance, gained output ratio and energy utilization factor were about 2.16, 6.11 and 8.27 respectively. In addition the annual average desalination was about 25.884 m3 per year and the unit cost of desalination was 0.0096 $/L.
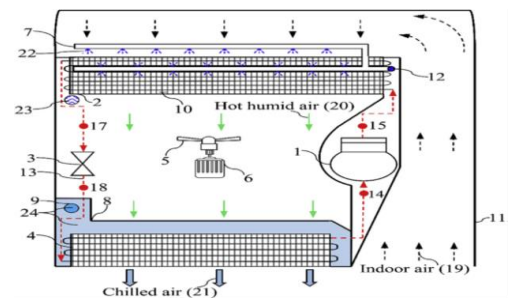

Fig. (16) Flow diagram of the desalination system [35].

Abbady et al. [36] presented a study that using three modified cycles in order to enhance the performance of humidification–dehumidification seawater desalination as shown in Fig. (17). Many factors like gain output ratio, productivity, exergetic efficiency, and recovery ratio had been investigated. Raising the ratio of mass flow rate, water temperature, and the flow rate of cooling water enhanced the productivity significantly. The fins cycle boosts productivity, gain output ratio, recovery ratio, and exergetic efficiency by 18%, 12.33%, 13.73%, and 15.9%, respectively.
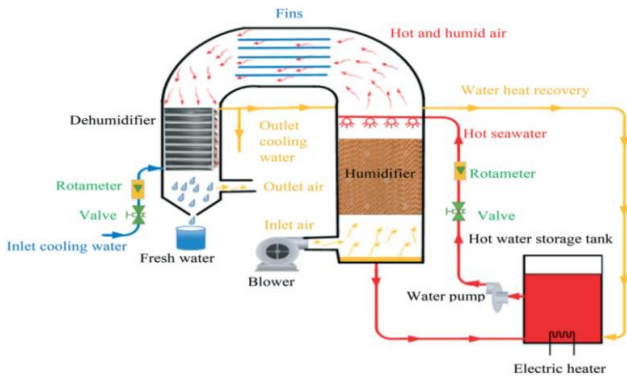

Fig. (17) Diagram of the desalination system [36].

Tlili et al. [37] investigated a humidification–dehumidification desalination unit to research the impact of pertinent parameters on the overall performance of the process with respect to the irreversibility's and energy losses. The obtained results showed that the inlet water temperature and flow rate have a great effect on the system performance. Also, increasing the water temperature in the dehumidifier outlet lets to reduce the exergy losses in the dehumidifier.

Sachdeva et al. [38] demonstrated a solar desalination plant based on the humidification and dehumidification principle and waste hot air from an air conditioner to produce water throughout the day and night as shown in Fig. (18). MATLAB code had been used to simulate a numerical model and compare the results to those of the conventional system. According to the findings, usage of hot air from an air conditioner's condenser enhanced productivity by 21% to 31% every day. The air mass flow rate of 0.032– 0.035 kg/s in the air heater was appropriate and resulted in a maximum production of 6 kg per day, while the cooling water mass flow rate of 0.038 kg/s was appropriate and resulted in a maximum
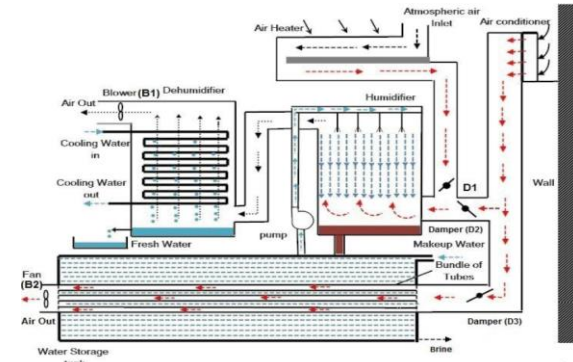
productivity of 7 kg per day.

Fig. (18) Diagram of the desalination plant [38].

Shalaby et al. [39] conducted experiments on a hybrid solar humidification dehumidification system for desalination of very saline water. using of a solar reflector with this desalination machine reduced 16.5% of daily electrical energy consumption.

El-Said et al. [40] presented an experimental research for a solar desalination unit paired with a unique humidifier as illustrated in Fig. (19). High-frequency ultrasonic atomizer and the variation of water height had been examined on productivity with a hot air stream flow rate. The findings revealed that increasing the number of atomizers and decreasing the water height boosts daily productivity. Also, while utilizing six atomizers, the highest daily production increased by 38.6% and 115%, respectively, when compared to atomizers four and two. When compared to 2 cm and 3 cm, a water height of 1 cm was the most efficient, with an increase of 16% and 28.6%, respectively.
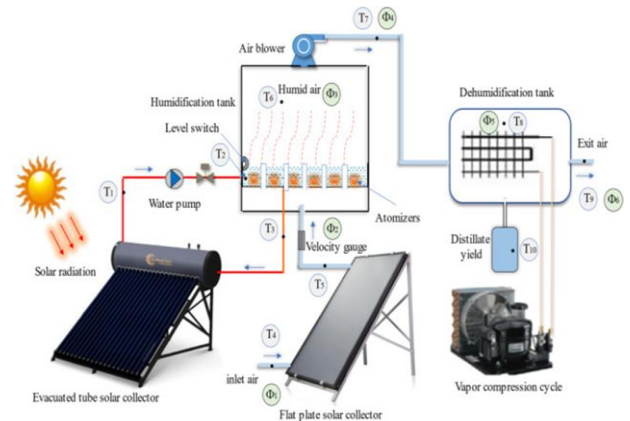

Fig. (19) Diagram for solar desalination unit [40].

Mohamed et al. [41] used a closed-air cycle to

improve a solar humidification dehumidification water desalination system as presented in Fig. (20). For the solar humidification-dehumidification unit, a theoretical and experimental analysis had been conducted. The obtained results revealed that at water temperatures of 40 °C, 50 °C, 60 °C, and 70 °C, respectively, the gain output ratio and productivity improved with an average value of 0.71, 0.74, 0.78, and 0.81, and the productivity reached 1.46 kg/h, 2.59 kg/h, 4.40 kg/h, and 6.99 kg/h. Finally, a good settlement had been noticed among the theoretical results and experimental ones with a maximum recorded gain output ratio of 0.86 at water to
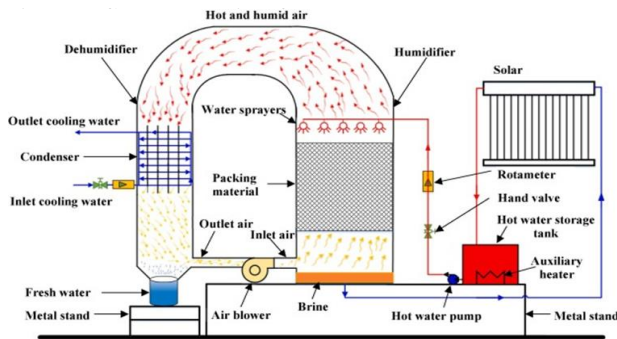

Fig. (20) Schematic diagram of the water desalination unit [41].

Abdelaziz et al. [42] experimentally examined a solar desalination system as illustrated in Fig. (21). A high-frequency ultrasonic atomizer had been used as a humidifier in order to achieve 100% relative humidity. The impact of several characteristics such as water height, ultrasonic atomizer condition, and the flow rate of hot air stream on system production had been verified. The experiments results showed that increasing the number of atomizers and decreasing the water height boosts daily water productivity. As well as, the maximum daily water productivity was achieved at atomizer number 6, which increased by 38.6% and 115%, respectively, when compared to 4 and 2. In addition, the water height of 1 cm is the most efficient with 16% and 28.6% increment compared with 2 cm and 3 cm, respectively.
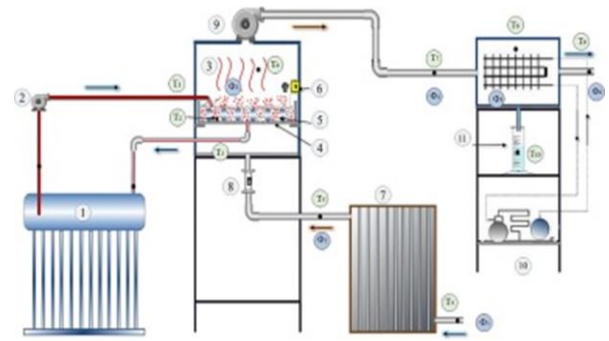

Fig. (21) Diagram of the solar desalination system [42].

Rafiei et al. [43] investigated a hybrid energy conversion system with evaluation of exergy, energy, and environmental criteria for producing power and freshwater. Many working fluids such as Al2O3, Cu, CuO, TiO2, and MWCNT nanoparticles in oil as the base fluid had been used. The obtained results lead to that the freshwater productivity varied between 15.28 kg/h to 15.46 kg/h with the application of nanofluid. In addition, the suggested desalination system with solar organic Rankine cycle system, significantly reduced amounts of CO2 emissions in the environment.

Chen et al. [44] investigated a solar-driven spray flash evaporation desalination unit improved by using microencapsulated phase change material. NaCl aqueous solution contained micro capsulated phase transition material as the working fluid was used for thermal energy storage and the spray flash evaporation process as presented in Fig. (22). The results cleared that utilizing the micro capsulated phase change material improved the water output ratio by 23.1% while lowering system energy consumption by 18.3%. A solar-driven spray flash evaporation desalination device using microencapsulated phase change material.
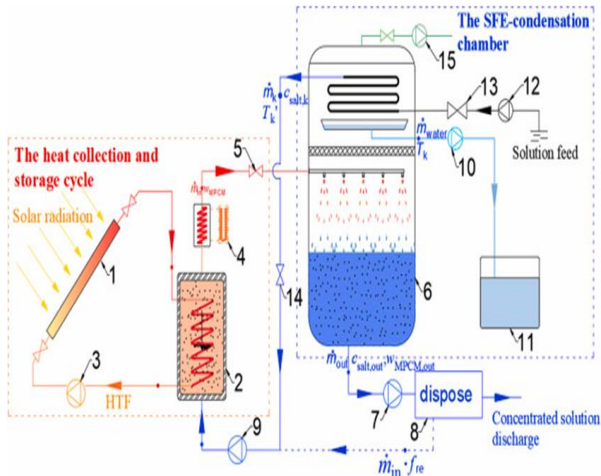
Fig. (22) Schematic diagram of the solar desalination system [44].

Fig. (23) Diagram of the experimental setup [47].

Wang et al. [45] fabricated an ordinary vacuum desalination system coupled with inner condenser and driven by solar energy source. The system performance had been evaluated under the actual weather by 18 m2 total area of a flat-plate solar collector usage. The experimental results showed that the daily productivity was about 154.14 kg and performance ratio is 1.36 at an average solar radiation of 672 W/m2.

A fog desalination system powered by an evacuated tube solar water heater had been studied experimentally and theoretically by Abu El-Maaty et al. [46]. The theoretical calculations revealed that increasing the water mass in the storage tank improved the efficiency of the evacuated tube solar water heater. Also, the experimental results showed that the recommended operating inlet water temperature for the desalination system greater than 55 °C based on the salinity testing.

4. Solar Stills Performance

Hansen and Murugavel [47] presented an experimental approach to improve the solar still act by utilizing dissimilar new absorber patterns as shown in Fig. (23). The experimental results showed that the overall efficiency of the set up with hot water thermal storage was about 46.9%. Also, the conventional inclined still productivity increased by 25.75%, when it was attached with fin shaped absorber and 74.5% output improved, when it is combined with basin still.
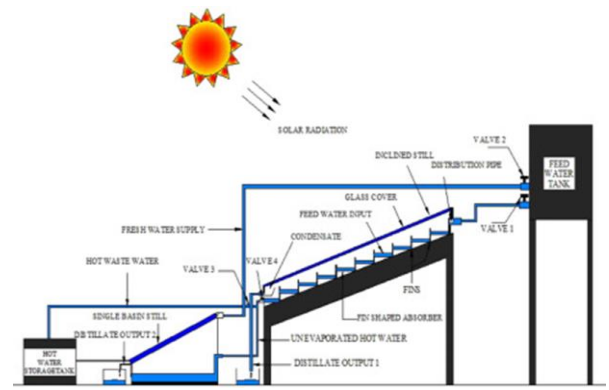
Fathy et al. [48] evaluated the performance of a parabolic trough collector (PTC) coupled to a double–slope solar still. Three desalinate systems were tested during the summer and winter months, one of them was traditional solar still, the second was solar still with fixed PTC, while the last one was solar still with tracked PTC, as well as two saline water depths in the basin of 20 and 30 mm had been examined. The results showed that, the daily output of a conventional solar still and a solar still with monitored PTC was approximately 10.93 kg/m2 and 4.51 kg/m2, respectively. The results showed also that in summer and at saline water deepness of 20 mm, the daily efficiency of the conventional solar still, solar still with fixed PTC and solar still with tracked PTC were 36.87, 23.26 and 29.81% respectively.

Dumk et al. [49] tested the performance of a modified sun still, consisted of single slope solar still with sand-filled cotton bags in order to increase the sensible energy storage capacity and water surface area as shown in Fig. (24). The experiments had been tested by 30 kg and 40 kg basin water usage. The results indicated that the collected output enhanced by 28.56 and 30.99% in for 30 and 40 kg basin water respectively.
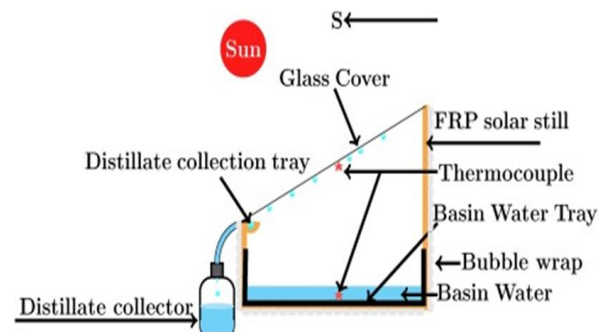

Fig. (24) Schematic diagram of the test rig [49].

Abdullah et al. [50] used reflectors and phase change material with nanoparticles to improve the solar still performance of the trays. The effect of interior reflectors and Nano-coating on the performance of the tray's distiller was examined as shown in Fig. (25). The results showed that, the largest distillate enhancement for trays still over conventional ones was 108 percent, and the trays' maximum efficiency was 51.5 %, compared to 35 percent for conventional trays. Kabeel et al. [51] carried out experimental study on the improving of the performance of pyramid-shaped solar stills by hollow circular fins and phase change materials usage as shown in Fig. (26). The results concluded that the hollow fins usage at the absorber improved the daily yield by 43 %. Adding the PCM to the fins enhanced the daily output by 101.5 %.

Sharshir et al. [52] studied the performance of solar still using floating coal, cotton fabric, and carbon black nanoparticles as shown in Fig. (27). The modified solar still had been tested, analyzed and compared with a conventional solar still. Three cases had been studied, the first case was modified solar still-A (coal only), the second was modified solar still-B (coal covered with cotton fabrics), and the third had been modified solar still-C (carbon black nanoparticles dispersed atop coal/cotton combination). The results cleared that for the third case, the highest enhancements in gathered output, average energy efficiency, and average exergy efficiency by 59.33, 75.12, and 142.7%, compared to the traditional one, respectively.
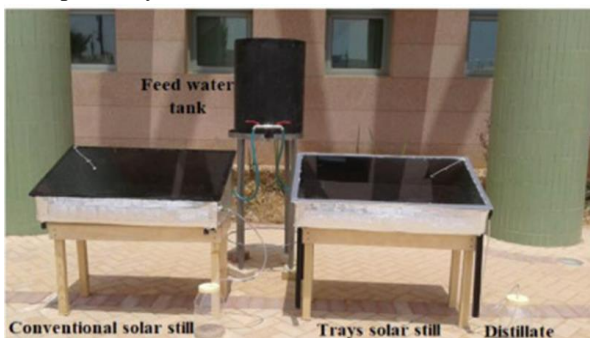

Fig. (25) Photograph of solar test rig [50].
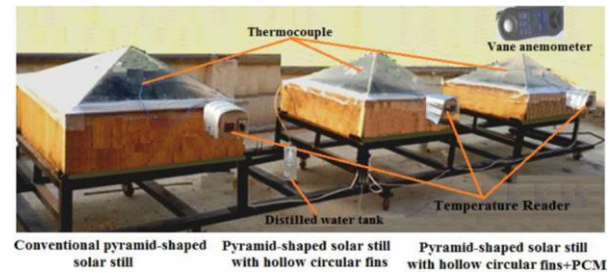
Fig. (26) Photograph of the experimental setup [51].
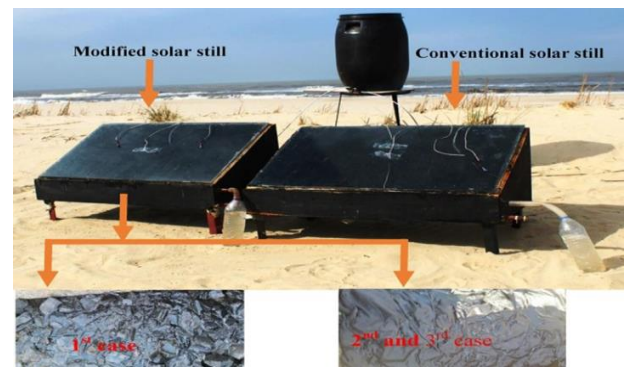
Fig. (27) Photograph of conventional and modified solar [52].

Shoeibi et al. [53] improved experimentally the solar still performed by nanofluids usage. Characteristic equation of the thermoelectric heating and cooling of solar still had been carried out for the system. A good agreement with proposed model and experiments results had been observed. The results showed that, the freshwater yield with the Al2O3, TiO2, CuO and MWCNT Nano fluids were improved by 11.57, 7.16, 6.32, and 4.66%, respectively.

The behavior of a tubular solar still that included a Nano-enhanced energy storage material, a v-corrugated aluminum basin, wick, and nanofluid had been examined by Abdelaziz et al. [54] as illustrated in Fig. (28). A nano-enhanced PCM in conjunction with a v-corrugated aluminum basin, wick, and Nano fluid was used. The experimental findings revealed that the modified system increased the daily water output and the thermal energy efficiency by 88.84 % and 82.16 % respectively.

Fig. (28): Schematic diagram of experimental test rig [54].

Peng et al. [55] developed the flat solar still, a compact flat solar still with high performance that functions similarly to a solar cell. Instead of relying on gravity, a capillary grid attached beneath the ultra-hydrophilic glass cover collected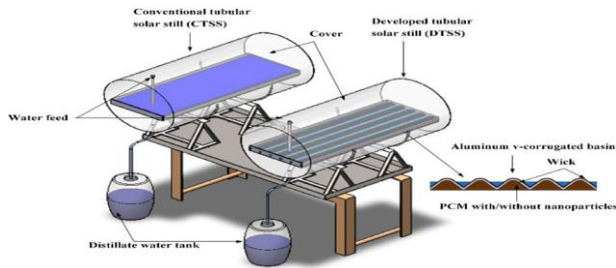 the water productivity in the flat solar still. Despite receiving less than 6.7 kWh/m2 of solar insolation, the energy efficiency and daily productivity of a double-stage flat solar system can reach 72% and 7 kg/m2, respectively. Furthermore, the theoretical study revealed that the improved mass transfer in flat solar due to the compact structure is still a significant parameter for achieving high performance.

Shoeibi et al. [56] developed a solar desalination system consisted of an evacuated tube heat pipe solar collector and a novel external condenser. The water vapor was sent to the external condenser, where it was distilled by striking the perforated copper plate before being linked to the water cooling system. The results revealed that the freshwater productivity of the system was 2.13 times higher than the conventional system. The external condenser's yield portion was around 18.62% of total water productivity. Also the solar desalination system saved over 29.19 tons of carbon dioxide.

Shoeibi et al. [57] estimated a solar desalination plant for district heating and potable water for home determinations. In order to collect the thermal energy and increase the system performance, a nano-enhanced phase transition material had been used. The results of proposed system showed that the productivity was 41.94 % higher than that of conventional solar desalination. Furthermore, CO2 removal was boosted by 41.7 percent and 18.4 percent, respectively.

5. Conclusion

Desalinating of brackish and seawater could be a solid source of new water generation that is helping to title the world's water shortage issues. This research provided a review of the literature on humidification-dehumidification (HDH) and solar still water desalinate systems. The study listed the recent and important researches that concerned with the different desalination techniques using renewable energy sources in recent years. This paper illustrated that utilizing renewable vitality sources for desalination may be a sensible and in fact develop elective to the rising and focusing vitality circumstance, as well as a maintainable arrangement to water shortage. Because of the harmful effects of burning fossil fuels, such as climate change and environmental pollution, using desalination systems with clean renewable energy resources is a pressing issue.

From the literature review it can be noticed that the humidification-dehumidification (HDH) system productivity depend on dehumidifier cooling water flow rate, saline water temperature at the inlet to the humidifier, solar intensity and the air flow rate. Coupling the HDH systems with power plants or geothermal energy was efficient in performance and evaluation. Solar collectors and PV/T could drive HDH systems efficiently in off-grid regions. The use of hot air from the condenser of air conditioner increased the productivity from 21% to 31% per day. Furthermore, increasing the temperature of the water in the dehumidifier outlet allows minimizing exergy losses in the dehumidifier and using the high frequency ultrasound atomizer and the water height with hot air stream flow rate on productivity and decreasing water height leads to an increase in daily productive. All developed mathematical model for the unit design, energy and mass balances as well as thermodynamic analysis of condenser and cooling tower showed a very good agreement results with the experimental results.

For the solar sills performance it can be concluded that the integrated solar still with fin shaped absorber configuration was more productive and the overall efficiency of their system with hot water thermal storage was about 46.9%. The maximum efficiency of trays still was 51.5% compared to 35% for conventional one. Using the hollow fins utilization at the absorber enhanced the productivity and using Nano fluids improved the system performance. Finally using micro capsulated phase change material increased the water production ratio by 23.1 %, and the system energy consumption reduced by 18.3 %. Theoretical results

revealed that increasing the amount of water in the storage tank increases the efficiency of the evacuated tube solar water heater while decreasing the temperature of the water.

Abbreviations

GOR	Gain of ratio
HD	Humidification–dehumidification
HDD	Humidification–dehumidification desalination
LPM	Liter per minute
LPH	Liter per hour
PCM	Phase change materials
PTC	Parabolic trough collector
SSF	Single stage flashing
TR	Ton refrigerant

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