Techniques for extracting pure water by solar still with Fresnel lens and phase change materials

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***Abstract*: The effect of adding Fresnel lens and phase change materials on water yield in Solar Desalination was studied. because of the massive demand for clean water and its limited supply in comparison to the amount of water on the Earth's surface, providing safe drinking water is one of the most important concerns facing the world. It was also confirmed that the system was affected by Fresnel lens and phase change materials Led to increased evaporation rates, the amount of water increased. The innovative design of the solar still cascade, which includes a slanted absorber plate and baffles, allows for a shallower water depth and improved solar radiation direction, resulting in increased production.**

***Keywords*: Fresnel lens, Phase Change Material, Solar Desalination.**

I. INTRODUCTION

Aside from population expansion, progress in all aspects of life has resulted in an increase in clean water use, which accounts for just 2.5 percent of the water on the planet's surface [1]. Finding practical technologies for desalinating salty water has become vital. People utilize energy for all types of water desalination, whether electrical or thermal, and this energy may be expensive and harmful to the environment. Figure 1 depicts energy usage from 1985 to 2020, leading researchers to look for plentiful and sustainable energy [2]. Solar energy is the most important source of renewable energy because of its abundance. Because it has been used to desalinate water in solar distillation systems, it has no negative environmental impact [2] [3].

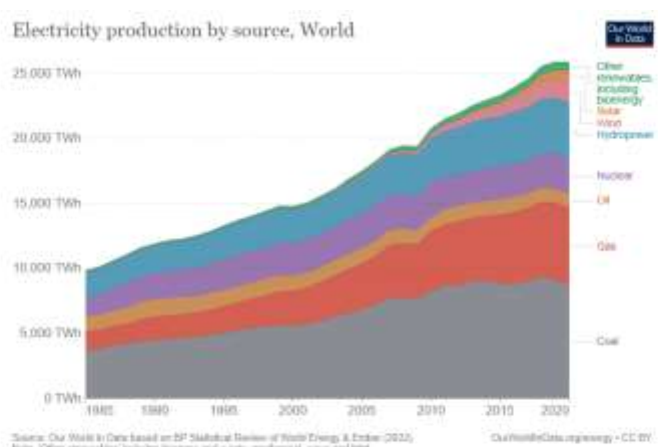

Figure 1. World energy consumption

II. DESALINATION TECHNOLOGY

Desalination methods are a set of operations for removing salts and other pollutants from unfit water and generating clean water [2]. The two primary aspects of the water desalination procedures (as depicted in figure 2) are membrane processes and filtration processes (in which the salty water passes through porous membranes to separate unwanted materials and branches from them). Furthermore, they have various subtypes, the most significant of which is reverse osmosis [2]. The thermal processes are covered in the second part (in which the water is heated to the temperature of evaporation to separate the salts and impurities, and then the steam is condensed to produce freshwater). After then, these procedures are classified as vapor compression, multi-stage, multi-effect boiling, and solar still [2]. Another method is electrolysis, which works on the concept of electrical potential difference between two attached films. [3].

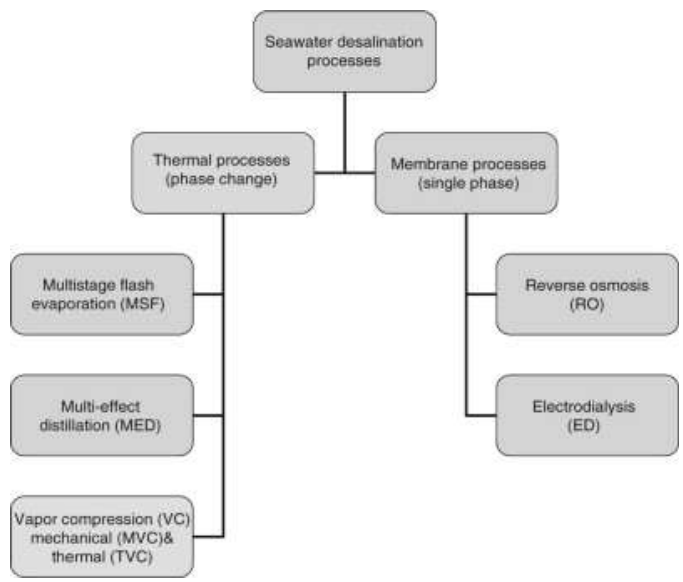

Figure2. Classification of Desalination processes

2.1 Solar Distillation Unit (SDU).

Solar stills are divided into two categories: Active Sun distillation systems rely only on solar radiation as a heat source. There are no other components that use or generate power. Different geometry modifications or sophisticated designs provide additional heat to the active distillation system. Additional elements that use or produce power distribution that is helpful to the system may also be available. Traditional design and effective design are the two types of passive SDUs available. Simple stills with merely reflecting surfaces or condensers are common in traditional designs. Stepped basins, cylinder covers, concave, spherical, conical, and triangular basins, as well as various forms of still structures, are all efficient designs. These structures have a limited yield output and operate passively, making them only suitable for a small population [4-5]. Many gadgets may be utilized to increase the solar distillation system's performance. These technologies (vacuum tubes, heat pipes, photovoltaic systems, and solar ponds, among others) are used to increase the efficacy of the solar still. Other types, including flat plate collectors, boost mirrors, fans, and pumps, are also utilized [4].

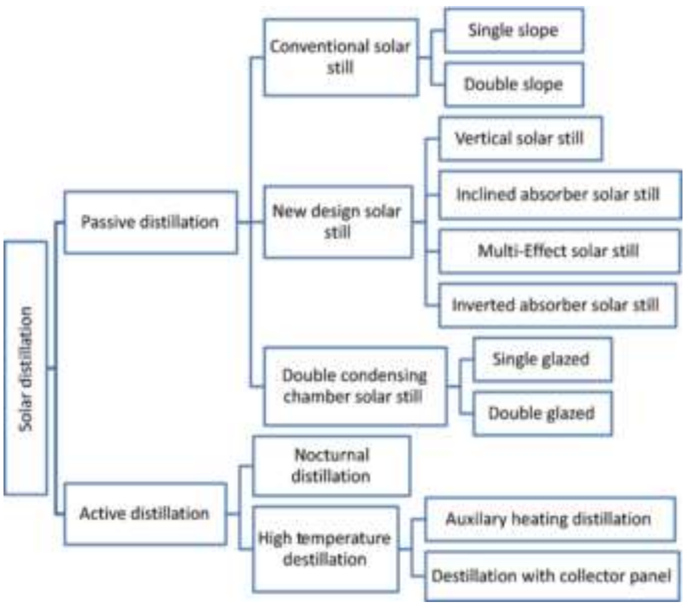

Figure 3 Classification of Solar Still [4].

2.1.1 Solar Distillation Mechanism

The solar water purification system operates in the same way as rain does, with water-absorbing heat, evaporating, and then condensing. Solar water distillation processes provide a closed-loop system that is more efficient due to the system's total administration, which allows it to be adjusted according to the conditions. The solar still unit, as illustrated in Figure 1, has a glass cover, a water-resistant basin, and a black liner to maximize solar energy absorption. The basin is filled with salt or somewhat saline water and let to heat up naturally under the sun. The steam then rises and falls on the glass cover, which is slanted at an angle and accumulates in a bowl. The residual salty water and suspended materials are left in the basin and will be removed later [5]. As indicated in Figure4, there are various classic distillates, including (single slope, Double slope glazing cover, V-shape and Spherical solar still).

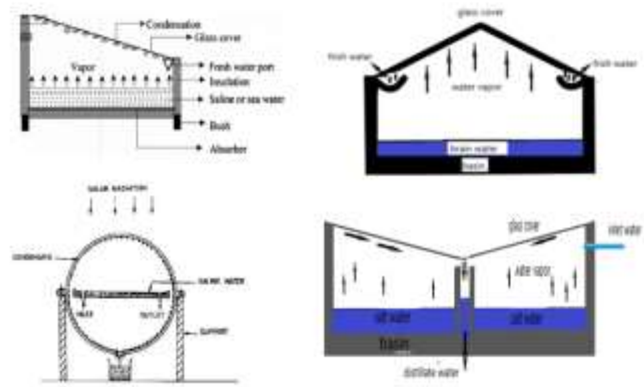

Figure 4. (Single slop, double slop, spherical and v type solar still).

Hashim [6] devised a single slop distillate with a double basin (SSDBS) and performed a daily experiment to compare the new distillate to the standard distillate. The performance of a new solar distiller with a glass cover with four faces was experimentally studied by Shareef and others [7], and the experiment was conducted in the city of Karbala, Iraq. The results of the investigation showed that the daily work efficiency of the distillate was 48 percent at a temperature of 24.9 Cand and the daily production amount was 6 liters/day.

III. PHASE CHANGE MATERIALS OF SOLAR STILL.

In systems that capture heat from solar radiation, there are several heat storage techniques. The thermal and chemical systems are the most visible of these systems. The categorization of heat storage's thermal and chemical systems is illustrated in further detail in Figure 5 [8].

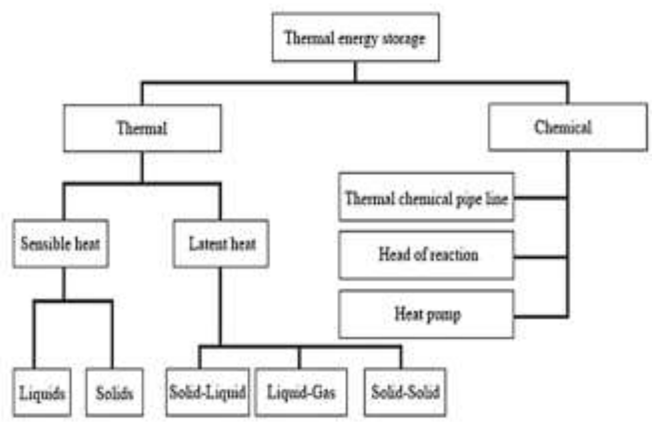

Figure 5. Solar energy storage systems [8].

It is advisable to employ thermal storage systems when estimating costs. By altering the temperature of the material, the stored energy becomes latent or palpable. To store heat, several researchers employed various materials such as basalt stones and steel wool fibers. PCM materials go through a phase shift, absorbing and releasing heat 14 times faster than other materials and retaining heat 14 times longer, making them ideal for solar thermal storage systems. To attain a lower operating temperature, phase change materials can be employed at a lower melting temperature. Phase-change materials, on the other hand, have a high melting temperature and a prolonged heat time [9].

3.1 Classification of PCM

Hydrocarbons, paraffin, and wax are examples of organic phase change materials, while molten salts and minerals are examples of inorganic phase change materials. Organic compounds have a melting point of roughly 60°C, allowing them to be used in temperatures as low as around 100°C. Inorganic compounds have a high melting point and can withstand temperatures of up to 1250 degrees Celsius, making them ideal for high-temperature applications.

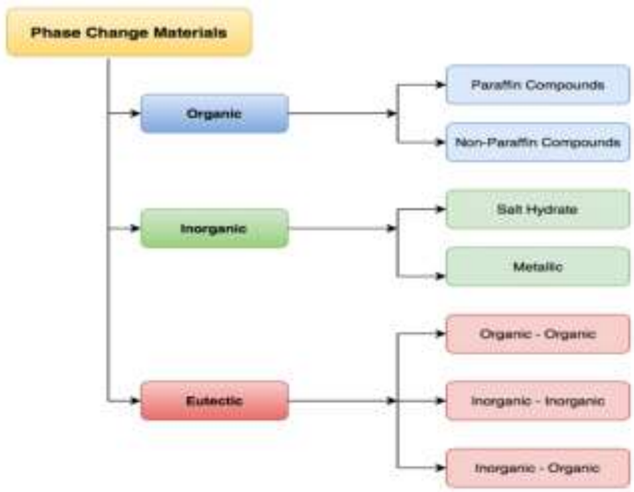

Figure 6. the classification of phase-change materials [9].

3.1.1 Organic Phase Change Materials

Organic materials, which comprise types of paraffin and non-paraffin, are compounds that enter the element of carbon in their atomic composition. These materials are distinguished by their capacity to melt and freeze repeatedly without losing any of their qualities in the process. Congruent melting and the concomitant heat change potential for fusibility is what it's called. These materials are usually corrosion resistant and crystalline without or with little cooling; this means that self-nucleation occurs [10].

3.1.2 Inorganic Phase Change Materials

Salts, metals, and salt hydrates phase transition materials are all examples of inorganic substances. It is distinguished by its high density, which causes growing enthalpy per volume and allows the phase shift to cover a wide temperature range. They exhibit the disadvantages of lack of thermal stability, corrosion, phase separation and separation, and sub-cooling [11].

3.1.3 Eutectics

A eutectic is a compound made up of two or more chemicals that can be classified as organic, inorganic, or organic-inorganic. It is notable for having a low melting point, known as the eutectic point. Each component melts and freezes in the same way, resulting in a combination of crystals [10].

3.2 Properties of PCM.

Ideal phase transition materials should have the following thermophysical, chemical, kinetic, and economic properties. [12]:

- Thermal properties include a melting point temperature within the acceptable range, a lot of latent heat, a lot of specific heat, and a lot of thermal conductivity in both solid and liquid phases.
- Physical characteristics include a low level of vapor pressure, good phase equilibrium, and a high-density during phase transition.
- Kinetic properties include no or minimum supercoiling, a high nucleation rate, and an appropriate crystallization rate.
- Chemical properties include long-term chemical stability and reversible phase transitions.
- Economical characteristics: readily available, low-cost, and recyclable.

The quantity of heat stored in the phase transition materials determines the distillation system's productivity. Because organic compounds have a low thermal conductivity coefficient ranging from (0.1 to 0.7) W/m. K and take longer to melt and re-freeze, enhancing the thermal conductivity of phase-changing materials is critical for improving the system's performance [13].

3.3 Application Phase Change Materials

Phase transition materials are used in a variety of applications [14]:

1. Buildings and Construction.
2. Application of Waste Heat Recovery
3-Mobilized Thermal Energy Storage
4. Applications in medicine.

IV. FRESNEL LENS

Augustine-jean Fresnel (1788–1827), a French scientist, invented a sort of composite compact lens for use in lighthouses [15][16].

The design allows the construction of lenses of large aperture and short focal length without the mass and volume of material that would be required by a lens of conventional design. A Fresnel lens can be made much thinner than a comparable conventional lens, in some cases taking the form of a flat sheet. The simpler dioptric (purely refractive) form of the lens was first proposed by Count Buffon,[8] and independently reinvented by Fresnel. The Fresnel lens reduces the amount of material required compared to a conventional lens by dividing the lens into a set of concentric annular sections. Fresnel lenses are often used to concentrate sunlight for heating and solar power applications. By using Fresnel lenses to concentrate sunlight onto a photovoltaic cell, the surface of the cell can be reduced by several hundred times, resulting in significant cost savings.

Figure 7. Fresnel lens[18]

4.1 classification of Fresnel lens

4.1.1 Linear Fresnel lens

Advantages of Linear Fresnel lens

1-A pipe can be used to disperse a long beam.
2-powers a steam engine, which is slower but safer.
3-If the liquid evaporates, there is a lower chance of harming the equipment.

Disadvantages of Linear Fresnel lens.

1-Unlike a trough, the beam is not continuous and linear.
2-it is not suitable for melting metals.
3-Due to its physical nature, it is more opaque, allowing less light to pass through to the project.

Figure 8. Linear Fresnel lens[16]

4.1.2 spot Fresnel lens

Advantages of spot Fresnel lens

1-melts copper and a variety of other metals.
2-heat transfer with a lot of power.
3-can be adjusted to a shorter focal length.
4-provides steam and sterling engine power.

Disadvantages of spot Fresnel lens

1-Equipment damage.
2-There is an immediate flame and a work danger.
3-It does not equally distribute throughout the pipe surface.

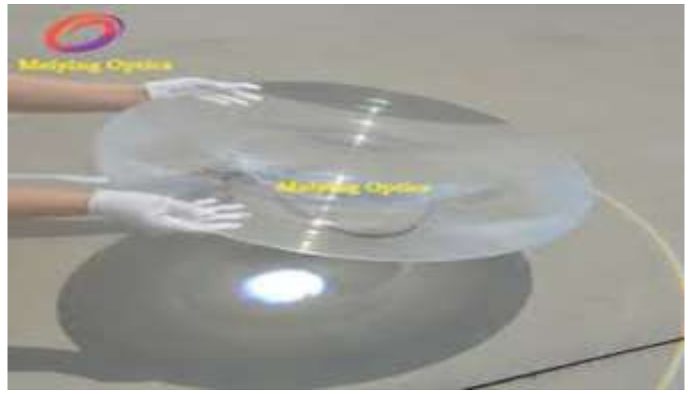

Figure 9.spot Fresnel lens [16]

V. NEW SOLAR STILL

The stepped absorber plate has the same construction as the traditional ones, but it is produced by a series of steps. Bouzaid et al. [19] created a new design for cascade solar still. To reduce the velocity of saltwater, the glass cover was inclined at a 30° angle, the absorber plate was produced in a series of stages, baffles were attached to horizontal and 35° sloping surfaces and weirs were installed. Due to the addition of a Fresnel lens and phase change materials, as well as the new absorber plate construction, which allows for a minimum depth of water and better orientation relative to the sun, the new design raises the temperatures of the absorber plate and the water.

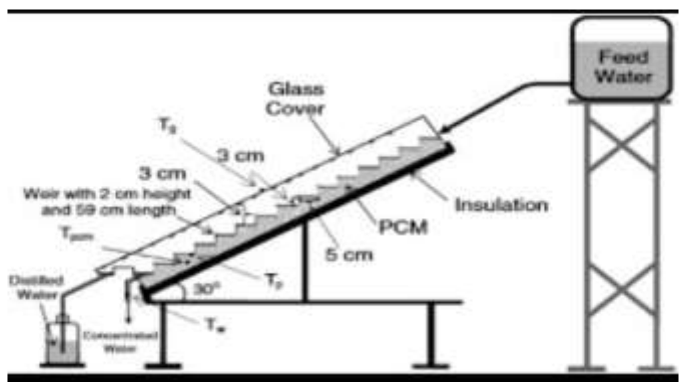

Figure 10. New design of cascade solar still (with slope surface and baffles)[17].

The efficiency of the active SS [18], $\eta = \frac{(\dot{m}_{ew})L}{\dot{q}_u + I_s(t)A_g}$ (1)

Where ($\dot{m}_{ew}$) denotes the hourly yield through solar still (kg/h), (L) designates the latent heat of distillation measured in J/kg,(Is (t)) solar radiation on SS (W/m2), (Ag) denotes area of the glass cover (m2),(qu) heat gain from the ETC tank through flowing water (W).

The hourly yield is given by [19]

$$m_{ew} = \frac{h_{ew}[T_w - T_g]}{L}(A_s)(3600) \quad (2)$$

(As) the basin liner still area, (L) is latent heat, (hew) heat loss coefficient by evaporation fromwater surface (W /m2°C), (Tw) water temperature (°C), (Tg) glass cover temperature (°C).Useful thermal energy supplied to the still through evacuated tubes.

VI. LITERATURE REVIEW

.**Reddy Sharon (2015) [20]** A hybrid solar still has been developed that can create both potable and hot water, and its performance has been predicted using transient mathematical modeling. The plan called for the use of both a traditional basin and an inclined still. Solar distillates rose by 107 percent in the hybrid still system compared to the traditional method. The temperature's average rate During the winter and summer, the solar distillation production for hot water was 45.09 ° C and 56.28 ° C, respectively. The water depth in the basin is 0.01 m, and the optimal fluid film thickness is 0.001 m. 0.10 m is the ideal distance between condensing and evaporating surfaces.

Chaichan and Kazem (2015) [21] To store thermal energy, paraffin wax was utilized as a phase transition material. Increasing the system's concentration efficiency to around 41.63 percent. With tracking the sun in the concentration dish, it was discovered that the water temperature in the solar distillation is around 50.47 percent. They discovered a 180 percent boost in the system's productivity. Increase the effectiveness of the heating system by about 37.33 percent. When phase change materials are introduced, the system's operating time increases to around 3 hours. Increasing the efficiency of the concentration system to around 21.64 percent raises the system's output by roughly 53.21 percent. They are enhancing the heating system's efficiency by 36.33 percent. Extend the system's operational time by around 5 hours.

Agrawal (2015) [22] He examined the output of daily distillers and researched water distillation in the presence and absence of phase transition materials. by creating two single-stepped solar still slopes, one with phase transition materials and the other without. The phase change materials boosted the distiller's efficiency by 30-35 percent during the day and by 127 percent at night, compared to those who did not utilize phase change materials. This is due to the large mass of phase change materials in the basin reducing the mass of water in the basin, resulting in an apparent improvement in the efficiency and output of daily distillate.

Ravishankar et al. (2016) [23] The temperature of the feeding water, the flow rate, and the temperature of the absorption plate in the inclined solar still basin, as well as the heat transfer coefficient, were all elements that affected drinking water production in a theoretical investigation. The yield increased by 57.14 percent at the lowest rate of mass flow, according to the findings. The influence of water temperature nourishing the entry was discovered, with an input temperature of 60 ° C, and the yield was improved by 65 percent.

Gugulothu et al. (2015) [24] used numerous types of phase change materials to conduct a practical evaluation of the performance of the solar distillation system. The stainless steel basin solar distillation has an active area of 1 m2. At a tilt of 32 degrees, the top cover of the solar distillation had transparent glass painted black for absorption, allowing the most significant quantity of solar energy to pass. Magnesium Sulfate Heptahydrate (MgSO4 7H2O), potassium dichromate (K2Cr2O7), and sodium acetate are the outcomes of experiments using various phase change materials (CH3COONa). The results revealed that employing Magnesium Sulfate Heptahydrate provided the optimum clean water production (MgSO4 7H2O).

Patil and Dambal (2016) [25] A single basin with a double slope was still employed for solar. The sensible heat was stored in black pebbles, and phase transition materials were paraffin wax. Experiments were carried out in the open air, and the solar distillation basin, which measured 0.7 m2, was made out of aluminum sheets. The productivity of solar distillation while using paraffin wax was 1100 ml, productivity, when the distillation basin was painted black, was 795 ml, and productivity when using black gravel was 954 ml, according to the data. Experiments revealed that mixing black gravel with paraffin wax resulted in the lowest solar distillation yield of 13%. While the best productivity is 30 percent when using paraffin wax to coat the distillation basin, and 18 percent when using black gravel to coat the distillation basin.

Kuhe and Edeoja (2016) [26] Experimental study of a single-slope basin and the use of phase-changing materials such as beeswax at a percentage of 14 kg, and then paint the basin black to increase absorption. The obtained results showed increasing the productivity of the solar still associated with the solar parabolic concentrator by 62%, with the effect of using thermal storage materials.

Aed Ibrahim Owaid et al. (2017) [27] A biaxial tracking Fresnel lens was used in an experimental study to improve the desalination system and increase productivity. Mathematical computations were carried out in a conventional manner. The quantity of distilled water without a concentrator was (4.7 liters per day), and the amount of distilled water with a concentrator was (7.14 liters per day), in addition to the amount of hot water wash (52.98 liters per day) at 42.52 degrees Celsius.

Lei Mu et al. (2019) [28] To supplement the clean water output of a typical solar still, a refraction-based mechanism for focusing sunlight is presented. The Fresnel lens was used in conjunction with a solar basin to refract light onto a focal point at the basin's bottom. Two significant findings were made: the first was a high rate of freshwater production, and the second was the existence of the nucleus boiling phenomena. When compared to a conventional system without FRL, the use of FRL resulted in a large increase in pure water output (L/m2/day) of about 467 percent and a considerable daily efficiency (h) improvement of about 84.7 percent.

Abdelsalam and Bahy Abdel-Mesih (2014) [29] When compared to a typical non-concentrating solar still, the findings of the experimental investigation indicated that the integration of linear Fresnel lenses nearly quadrupled the productivity of distilled water and enhanced the efficiency of a solar still by around 68.76 percent.

El-Agouz (2014) [30] presented practical and theoretical research to improve solar distillation performance utilizing a stepped still basin with the option of circulating water under the same circumstances. Before desalination, two types of water were used: seawater with a total dissolved solids (TDS) of 57100 mg/l and salty water with a TDS of 2370 mg/L. With the stepped still basin, the impact of utilizing each black and cotton was investigated. The results revealed that combining saltwater and seawater with black absorption boosted water production by roughly 48 percent and 43 percent, respectively, when compared to traditional methods. When utilizing saltwater and seawater with cotton, the generation of water was 47 percent and 53 percent, respectively, with a 20 percent increase in efficiency over a traditional still.

Samuel et al. (2016) [31] He investigated the use of salt balls and sponges to store energy in a single slope solar still, both theoretically and experimentally. In contrast to the presence or absence of the sponge, the results indicated that the usage of salt balls produces the greatest product, with water production of 3.7 L/m2, 2.7 L/m2, and 2.2 L/m2 correspondingly. Finally, solar distillation produces water at a lower cost due to the utilization of materials and low cost.

Obaid Younasa et al. (2015) [32] A theoretical and practical investigation was undertaken for a multi-stage solar distillation apparatus with the addition of a linear Fresnel lens to it. He put the system to the test in the field and created a mathematical model. When compared to the experimental data, modeling revealed a 5% variance in the results. The model was used to determine the seasonal behavior of an MSS based on average hourly direct beam radiation data for a whole year. According to the parametric optimization research, the system may provide maximum daily productivity of roughly 5 kg/m2 d or 11.4 kg/m2 d (depending on solar collector area).

Nidal Mouhsin et al. (2020) [33] A simulation was used in this work to validate the experimental results of the novel cascade solar still design. ANSYS FLUENT was used to create the revised design for the cascade solar still, and FLUENT software was used to model it. The retrieved data from the simulation results has been found to be in good agreement with the experimental data. It was also discovered that the cascade Solar's productivity was higher from 12:00 to 15:00 h. The cascade Solar's innovative design nevertheless provides better production than a single basin. The results reveal that the absorber plate temperature and productivity may reach more than 60 °C and 1.6 kg/m2h, respectively, based on experimental results of the novel design of the cascade solar still. The plate temperature reaches more than 50 °C, and the productivity is 0.6 kg/m2h, compared to the single basin.

Nidal Mouhsin et al. (2021) [34] In order to develop the simplest and cheapest kind of desalination, a novel design of inclined solar still with steppe absorber plate, slope surfaces, and baffles was developed, constructed, tested, and modeled using ANSYS FLUENT software. The simulation findings were found to be in good agreement with the experimental data. The productivity of the cascade Solar Still was also tested, and it was shown that it was greater from 12:00 to 15:00 hrs. According to the findings, the new design promises increased productivity.

Table (1) Publishing different methods to get pure water from saltwater

no	Author	Technique used	product water	Efficiency
1	.Reddy Sharon (2015) [20]	an inclined basin	----	107%
2	Chaichan and Kazem (2015) [21]	paraffin wax	----	180%
3	Agrawal (2015) [22]	pcm	-----	30-127%
4	Ravishankar et al. (2016) [23]	The influence of water temperature nourishing the entry was discovered	-----	65%
5	Gugulothu et al. (2015) [24]	(MgSO4 7H2O)+ (CH3COONa)	----	increase
6	Patil and Dambal (2016) [25]	paraffin wax		30%
7	Kuhe and Edeoja (2016) [26]	beeswax at a percentage of 14 kg		62%
8	AED IBRAHIM OWAID et al. (2017) [27]	Fresnel lens	7.14 liters per day	
9	Lei Mu et al. (2019) [28]	Fresnel lens	increase L/m2/day	84.7%
10	Abdelsalam and Bahy Abdel-Mesih (2014) [29]	Fresnel lens	nearly quadrupled the productivity of distilled water	68.67%
11	El-Agouz (2014) [30]	performance utilizing a stepped still basin		Increase 20%

12	Samuel et al. (2016) [31]	salt balls and sponges	3.7 L/m2	-----
13	Obaid Younasa et al. (2015) [32]	Fresnel lens	11.4 kg/m2	
14	Nidal Mouhsin et al. (2020) [33]	cascade Solar's	1.6 kg/m2h	
15	Nidal Mouhsin et al. (2021) [34]	a novel design inclined	-----	------

VII. CONCLUSION

1-Because it can be found in some of the world's most environmentally friendly regions, solar energy is one of the most effective renewable energy sources.

2-Because phase change materials store considerable quantities of thermal energy, they improve the distillate's production by allowing water evaporation to continue after nighttime.

3-The addition of a Fresnel lens to the distillation system improves the system's efficiency. It enhances the quantity of evaporation and the productivity of clean water by increasing the temperature, the amount of evaporated water increases, thus increasing the efficiency of the system.

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