A Review of New Solar Still Design Comprising a Five-Sided Glass Cover and Equipped with an External Tank for PCM

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Abstract: Various human activities have led to the consumption of large quantities of pure water, which has led researchers to find efficient and economical methods for desalinating seawater and water containing impurities. In this review paper, solar energy where it is permanent, abundant and environmentally friendly, to produce pure water was discussed using a new solar distillation device, representing the paper's novelty. The distillation was designed and used in the way led to increase efficiency and improve productivity by adding a solar collector to the system and equipped with a tank containing phase change material (PCM). It has a low melting point and can change the phase by absorbing the system's latent heat to maintain the system's temperature. Which contributes to increasing the distillation period even after sunset, thus increasing the daily productivity of freshwater. Using phase change materials will increase distillation hours from (3-4) hours after sunset, increasing the amount of production between (75 - 90) %.

Keywords: Desalination technology, Solar still, Phase change material, evacuated tube collectors

1. Introduction

The development in all areas of life, besides the quantity of population growth, has led to an increase in pure water utilization, which makes up only 2.5% of the water on the earth surface [1]. It has become necessary to find effective methods for desalination of salty water. All manners of water desalination that people use that consume energy, whether electrical or thermal, and this energy may be expensive and damage the environment, figure 1 shows the energy consumption for the period from 1992 to 2016, prompting researchers to find abundant and sustainable energy [2]. The most crucial type of renewable energy is solar energy for its abundance. It has no negative impact on the environment as it has been used to desalinate water in solar distillation systems [2] [3].

![Figure 1. World energy consumption](image-url)
2. Desalination technology

Desalination techniques are a series of procedures that remove salts and other impurities from unsuitable water and produce clean water [2]. The water desalination processes are divided into two main parts (as shown in figure 2.): membrane processes (in which the salty water passes through porous membranes to separate unwanted materials and branches from them). Moreover, several types are branched out from them, the most important of which is reverse osmosis [2]. The second section is the thermal processes (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). Then these processes are divided into several types (vapor compression, multi-stage, multi-effect boiling and solar still) [2]. There is another way called electrolysis that relies on the electrical potential difference principle between two joined films [3].

![Figure 2. Classification of Desalination processes](image)

2.1. Solar energy desalination:

The work of the solar distillation principle depends on the utilization of solar radiation to heat the saltwater to the point of evaporation to separate unwanted materials and then condense the vapour on a glass or plastic surface [3] [4]. According to the thermal power source, the solar distillates are classified to Passive stills and Active stills, where each class has several types, as shown in figure 3.
2.1.1. Solar still

The conventional solar distillation consists of a saltwater basin with a glass or transparent plastic cover above it that allows solar rays to enter the basin, and tubes for the entry of water and a stream inside the distiller to collect pure water [3]. There are several traditional distillates as shown in figure 4, including (single slope, Double slope glazing cover, V-shape and Spherical solar still).

There are other types of solar distillates, Hashim [4] designed a single slope distillate with a double basin (SSDBS) and conducted an experimental study to compare the new distillate and the traditional distillate daily. Shareef and others [6], studied the performance of a new solar distiller with a glass cover with four faces experimentally, and the experiment was in the city of Karbala, Iraq, the outcomes of the
investigation, presented that the daily work efficiency of the distillate was 48% at a temperature of 24.9 C° and the daily production amount was 6 liters/day.

2.1.2. Factors affecting solar stills productivity:

1. Glass– water temperature difference.
2. Free surface area and deepness of water.
3. Inlet water temperature.
4. Environmental air temperature.
5. Angle, thickness and material for glass cover.
6. Wind velocity.
7. Insulation solar still.

3. Solar collector

Solar collectors of various kinds are used to absorb solar rays and convert them into heat [8][9] that can be used in several applications such as water heating, building heating, electrical energy production, water desalination, and others [10]. There are many shapes and types of solar collectors, as shown in figure 5.

![Classification of solar collectors](https://example.com/solar-collectors.png)

**Figure 5.** Classification of solar collectors [11]

3.1. Concentrating collectors

To get the maximum amount of solar radiation, it is necessary to track the sun's position, and there are several types of these complexes such as (Parabolic trough collectors, Linear Fresnel reflectors, Central tower receivers, parabolic dish reflectors) [12].
3.2. Stationary collectors

These solar collectors remain stationary and directed to the sun at a specific inclination angle, having different types such as (Flat plate collectors, compound parabolic collector, and Evacuated tube collectors) [12] as shown in figure 6.

![Stationary collectors diagram](image)

Figure 6. Stationary collectors (Flat plate, Compound parabolic, and Evacuated tube collectors)

3.3. Solar still with solar collector

Providing pure water using solar distillers is one of the best methods used to desalinate water, especially in the absence of equipment for other means. To improve distillation productivity, solar collectors are a couple to the system to increase solar radiation absorbed to heat the water entering the distillate [23]. Al-Masha and others [14] experimentally investigate a traditional solar distiller’s performance by adding an evacuated tube collector to it. They found it through experience that the distillate's productivity increased by 102%, and the distillate's efficiency increased from 36% to 71%. The ocean's temperature and the intensity of solar radiation are the most important climatic factors affecting the production of the distillery. Pramod B V and others [15] studied the performance of a pyramidal solar distiller with a vacuum tube and a black stone placed at the base of the basin to increase the absorption of solar radiation. They concluded from this work that the solar collector's addition contributed to an increase of productivity 40% over the traditional distillate. S. Mamouri and others [16] introduced a solar-powered desalination system consisting of distillate and connected with a vacuum tube. The results showed an increase in the system’s production when using the solar collector and increased the distiller's efficiency’s work. The production rate reached 1.02 kg / m² per hour, and the efficiency was 22.9%.

4. Phase change material

Phase change material can absorb and release an enormous amount of heat. When enough heat applies to these materials, their phase changes from solid to liquid, and they keep heat in the form of latent heat
and when the ambient temperature decreases, the previous process reverses and turns from liquid to solid, in which heat is lost to the surrounding[19].

4.1. Classification of phase change materials

There are three main types of phase change materials, and several classes are branched out of them, as shown in figure 7. [3].

![Figure 7. Classification of phase change material](image)

4.1.1. Organic PCM

They are materials that contain carbon in their composition, such as paraffin wax and others. These materials are characterized by the ability to melt and solidify several times without affecting their properties during this process, as well as resistance to corrosive conditions [20].

4.1.2. Inorganic PCM:

This type comprises salts, minerals, and salt hydrates, which have a high density, which leads to large enthalpy and covers a wide range of temperatures. This type's disadvantage is thermal instability and can be subject to phase separation or corrosion conditions [20].

4.1.3. Eutectics

A eutectic is defined as a combination that includes two or more substances divided into organic, inorganic, and organic-inorganic, for a low melting point called a melting point. Each component melts and solidifies at the same time to form a homogeneous mixture of dissolved crystals [3].

4.2 Properties of Phase Change Materials

There are many properties that must be considered for choosing the appropriate PCM type, the most important of which are explained below [21].
Table 1. Properties of phase change materials

| Thermal properties | Physical properties | Chemical properties | Economics properties | Kinetic properties |
|--------------------|---------------------|---------------------|----------------------|-------------------|
| suitable phase change temperature | high density | long-term chemical stability | Cheap | no supercoiling |
| high latent heat of transition | small volume change | compatibility with materials of construction | available | sufficient crystallization rate |
| suitable thermal conductivity | low vapor pressure | no toxicity | | no fire hazard |

4.3. Application Phase Change Materials

Many applications use phase change materials [21]:

1. Buildings Applications.
2. Waste Heat Recovery Application.
3. Mobilized Thermal Energy Storage.
4. Medical applications.

Phase change materials have been used in solar distillation applications as they store heat to take advantage of it to continuity the distillation process in the absence of solar radiation. Shafii [22] designed a new desalination system consisting of four main parts: a solar collector, an evaporator, a basin with variable phase materials and an air condenser. The experiment showed that varying phase materials contributed to increasing the daily output by 30%. The presence of an air condenser is essential because the radiative cooling when using variable phase materials alone. Wen-Long Cheng, Yan-Kai Huo, Yong-Le Nian [23] Studied experimentally a new (shape-stabilized phase change material (SSPCM) used in solar water desalination system with simulation model design. The conclusions got from the study: SSPCM stability has avoided leakage and packaging problems within the solar distillation basin. The simulation model showed that increasing the thermal conductivity from (0.2 to 4) kg / m .k and increasing the melting temperature from 34 to 50 degrees Celsius contributed to increasing the daily productivity from 21% to 57%. Shareef and others [3] Studied developing the solar distillation system and enhancing the productivity of freshwater by adding phase change materials to the system. Notice in this paper that the use of these materials led to increasing the distillation period to several hours at night, which leads to an increase in the daily productivity and the efficiency of the system’s work. The cost per litre of the system uses phase change materials compared to the conventional distillation. Rashid and others [24] studied experimentally to improve the four-sided solar distiller’s performance by adding a tank containing phase change materials to the system. New phase change materials were tested (Polyvinyl pyrrolidine (PVP K-30), polyethylene glycol (PEG 6000) and carboxymethylcellulose sodium salt. (CMC), they found through experience that the system's operating time increased between 3 to 5 hours, and the amount of production increased between 20 to 110% compared to the distillate that does not contain the reservoir of phase change materials. Shafii [25] designed a new distillation system comprising a conventional distillation with connecting evacuated tubes and an external condensation tank that contains phase change materials used to store thermal energy in the form of latent heat and
also used to condense the steam produced in the distillate. They concluded from the experiment that the
daily production rate increased by 86%, reaching 6.555 kg/m² day, with work efficiency reaching 50%.

5. New solar still

The new system consists of three main parts: a solar distiller, a phase change material tank and a solar collector. The solar distillery is a metal basin with dimensions (75 * 75 * 10) cm and a five-sided glass cover (which contributes to increasing the area of condensation and allowing the entry of solar rays from all directions and for the longest possible period into the distillery). The system is supplied with water through copper tubes that pass inside the collection from the air’s evacuated tubes (number 7). These solar radiators increase the water temperature by absorbing solar rays and converting them into thermal energy that heats the water inside. Part of the steam formed inside the distillate is directed through copper tubes to an insulated external tank (75*75*25) cm containing phase change materials that act as a condenser for the steam passing through it, as well as storing the heat energy absorbed from the steam in the form of latent heat that is used to continue heating the water inside the distillate after the sun passes away. The heat is transferred from the phase change material to the distillate bed by a set of heat pipes immersed inside the phase change material and connected from the top to the distiller base. The table below shows the dimensions and materials used in the manufacture of the novel system.

Table 2. Dimensions and materials of new solar still

| Component       | Dimensions                      | Remarks                      |
|-----------------|---------------------------------|------------------------------|
| Basin           | (75*75*10)cm                   | Material: Plate stainless steel |
| Glass cover     | Thick 4mm                       | Material: Widow glass        |
|                 | (75*30*40*44) cm Left and right side |                              |
|                 | (75 * 40*40*46) cm back side   |                              |
|                 | (75 * 30*30*37) cm Front side  |                              |
|                 | (44 * 44 * 46*37) cm top side  |                              |
| PCM tank        | (75*75*25)cm                   | Material: Plate stainless steel |
| Heat pipe       | Numbers (70) 33cm length 1 cm in diameter | Material: copper pipe (Acetone) working fluid |
| ETC             | Numbers (7) 180 cm length 5.8 cm Do, 4.6 cm Di | Material: Evacuated glass tubes |
| Insulation      | 5cm thick                       | Material: glass wool         |

Figure 8. Five-sided glass cover solar still
The efficiency of the active SS [26]

\[ \eta = \frac{(m_{new})L}{q_u + I_s(t)A_g} \]  

(1)

Where \(m_{new}\) denotes the hourly yield through solar still (kg/h), \((L)\) designates the latent heat of distillation measured in J/kg, \((I_s(t))\) solar radiation on SS (W/m²), \((A_g)\) denotes area of the glass cover (m²), \(q_u\) heat gain from the ETC tank through flowing water (W).

The hourly yield is given by [27]:

\[ \dot{m}_{ew} = \frac{h_{ew}[T_w - T_g]}{L} (A_g) (3600) \]  

(2)

\((A_s)\) the basin liner still area, \((L)\) is latent heat, \((h_{ew})\) heat loss coefficient by evaporation from water surface (W/m²°C), \((T_w)\) water temperature (°C), \((T_g)\) glass cover temperature (°C).

Useful thermal energy supplied to the still through evacuated tubes [27]

\[ Q_0 = A_{ET} F_R ((\alpha \tau) e - U_{LE} \frac{A_L}{A_{ET}}) (T_w - T_a) \]  

(3)

\((A_{ET})\) is a diameter of absorber glass tube × total length of the tubes, \((A_L) = \pi A_{ET}\), \((F_R)\) heat removal factor, \((\alpha \tau)\) effective absorptance – transmittance product, \((U_{LE})\) overall heat transfer coefficient, \((I)_{eff}\) Intensity of solar radiation, \((T_w)\) Water temperature, \((T_a)\) Ambient temperature

6. Conclusion

Solar collectors have a significant role in raising the water's temperature entering the distillate, which helps increase the evaporation process and thus increase daily production. To increase the distillation hours until after sunset, phase change materials are used to keep thermal energy in the form of latent heat. Through the research, the following conclusions were obtained:

1. Desalination processes are varied, but the best method is solar distillation, as solar energy is available, renewable, and environmentally friendly.
2. Distillation productivity is affected by several factors such as wind speed, incoming water temperature, insulation of the distillation basin, and the glass cover angle. Still, the most important influencing factors are the intensity of solar radiation and the ambient temperature.
3. The new design of the distillation cover helped to increase the surface area to condense the vapor formed inside the distillation device, and because of its five-sided shape that makes it face solar radiation throughout the daylight hours, allowing the largest amount of solar energy to enter the distillation basin, thus increasing the amount of steam produced.
4. The efficiency of the distillation process increased when solar collectors used.
5. Used phase change materials contribute to increasing the distiller's daily productivity between (75 - 90) %, because it increases the hours of daily distillation from (3-4) hours.
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