A Review of Using Phase Change Materials to Improve the Productivity of a Solar Still

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Abstract: **To desalinate saline water and produce pure water, it is possible to use solar still technology (which is based on solar energy). This energy is abundant, free, renewable, and does not harm the environment. Because solar stills depend on solar radiation, their working time is only during daylight hours. Phase transition materials are used to maintain the freshwater production process's continuity while also increasing the solar still's productivity and efficiency. These materials are characterized by their ability to store and release large amounts of heat (latent heat) during the phase change. The daily production of solar stills can increase (50-125%) work (PVP K30: polyvinyl pyrrolidine, and PAA: polyacrylic acid) contribute to increasing the working hours of the distiller between (3-4) hours after sunset. Thus, the daily production quantity amount can increase by (50-75) %.**

Keywords: **solar energy, Solar still, Phase change material.**

I. INTRODUCTION

Water shortage is the most important problem facing the world [1]. As it is one factor affecting the economic development of every country. Some studies have showed that a third of the world's population will suffer from severe water shortage by 2025. 97 percent of the water on the planet's surface is salt water. (fig 1. Show world water distribution) and is unfit for human consumption [2]. There is another problem of great importance as well, which is energy. The disadvantage of existing fossil fuel energy is its high cost, consumptiveness and environmental pollution [3] [4].

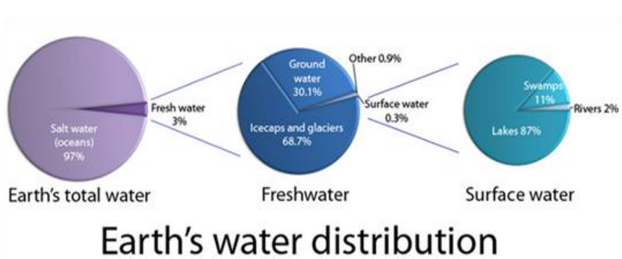

figure (1) world water distribution [5].

To solve energy problems, researchers turned to the study and exploitation of solar energy because its free, renewable and environmentally friendly. Solar energy is used in (Building conditioning, electric power production, water heating and water desalination) [6].

II. SOLAR DISTILLATION

There are two major forms of solar distillation, based on the type of manufacturing setup. First kind is the passive type. Solar radiation is received by the basin, heating and evaporating the basin water. The solar collector is separated **when using phase change materials. The new materials in current**

from the solar still in the second kind, which is referred to as this type active solar still [7].

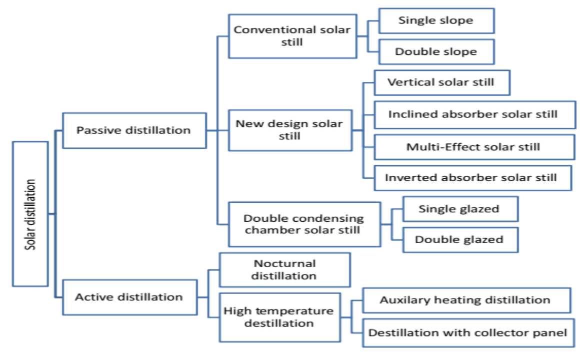

figure (2) solar distillation [7]

2.1 passive solar still

The passive desalination method is based on self-operating systems that eliminate the need for mechanical moving components. Passive methods, while often less energy efficient than active technologies, offer the potential to enhance the economic viability and dependability of small plants. Due to lower capital and operational costs, particularly in remote and disadvantaged areas. Solar stills, in particular, have been used for thousands of years and have a significant benefit in that they work just on Solar energy [8].

There are many types of passive solar distillates shown in the figure (3) below, such as (single slope(a), double slope(b), spherical (c), concave wick (d), Weir solar still cascade (e), tubular solar still(f),) [9].

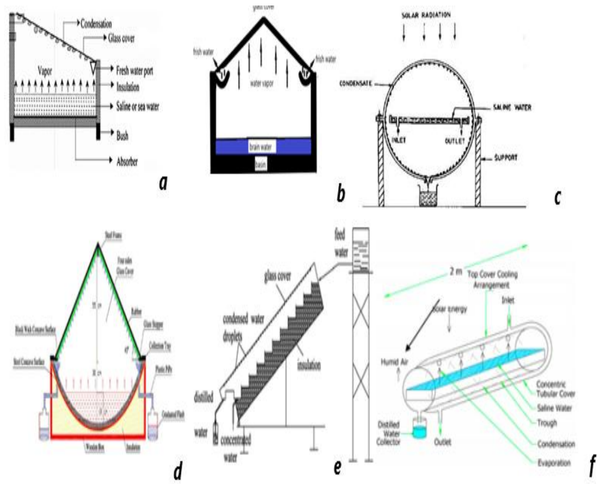

figure (3) types of passive solar distillates [9].

Only 35% of the solar energy is used to heat and evaporate the water in the solar still. And the rest is considered losses, as shown in Sankey diagram figure (4)[2].

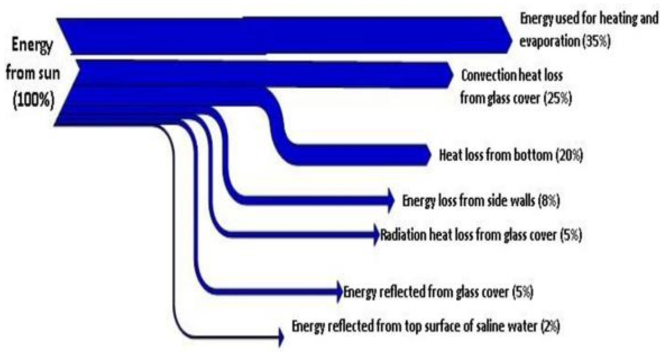

figure (4) Sankey solar still diagram [2].

2.2 Active solar still

When a heating source is added to the solar distillation system, it is called active solar still [9]. Many ways that may enhance the output of solar stills. Nanoparticles, wick materials, thermoelectric coolers, and integrated water heaters are examples of components that can be employed. Solar collectors with solar stills, glass cover cooling, fins, and energy storage features can be used [11].

Solar stills depend on thermal energy absorbed from solar radiation, so their work is limited to the daytime [12,13,14]. To increase the amount of productivity and raise the efficiency of the work of the distillers, phase change materials are used. These materials are characterized by their ability to preserve large amounts of latent heat to be used after sunset.

Abbas Sahi Shareef et al. [15] have improved the yield of the distillate. By using new phase change materials

comprising (Polyvinyl pyrrolidine (PVP K-30), polyethylene glycol PEG 6000 and carboxymethyl cellulose sodium salt (CMC)) mixed with water in different proportions. Practical results showed that the use of these materials reduced heat losses. The working hours were also increased (3-5) hours more than the distillers without using phase change materials. The daily production rate increased (40-120) % over the traditional distiller.

A.E. Kabeel et al. [16] studied improving the performance of a pyramidal solar still by adding phase change materials and circular fins to the system. Experimental results showed the highest productivity of the traditional pyramidal distiller 4.02 litters/m²/day. While the addition of circular fins contributed to raising the production quantity to 5.75 litters/m²/day, an increase of 43%. After adding phase change materials, the daily productivity increased to 8.1 litters/m²/day, with an increase rate of 101.5%.

Y.A.F. El-Samadony et al. [17] compared theoretically the use of different phase change materials to improve the yield of a conventional solar still. The economic aspects were studied besides the physical properties. Theoretical results showed that (Caprice palmitic $CaCl2 \cdot 6H2O$ (A48)) has the best productivity and the lowest cost. The researchers recommend the use of (A48) as it is less harmful to the environment and contributed to raising the daily production by 92%.

The effect of nanoparticle on enhanced phase change material (NPCM) on solar still performance is investigated by **D. Dsilva Winfred Rufuss et al. [18]**. titanium dioxide impregnated in paraffin (NPCM1), copper oxide impregnated in paraffin (NPCM2), and graphene oxide impregnated in paraffin (NPCM3) were formed by impregnating three kinds of nanoparticles (TiO2, CuO, and GO) in paraffin at 0.3 wt.% each. When NPCM was compared to PCM, thermal conductivity increased while temperatures of melting and solidification decreased. SSPCM, SSNPCM (1), SSNPCM (2) and SSNPCM (3) produced 3.9,4.9, 5.3 and 3.6 l/m2/day, respectively. SSNPCM-1 and 2 have productivity improvements of 26 and 35% above traditional distiller, respectively.

Ravi Shankar Sathyamurthy et al. [19] investigated the development of performing the tubular solar still by adding phase change materials and nanomaterials. The results of the experimental work showed that the addition of nanomaterials to the phase change materials increased (thermal conductivity) by 52%. This increase contributed to an increase in the water temperature of 7 °C and thus increased The evaporation process increased by 41.3%. The daily productivity of tube distillers, tube distillers with phase change materials and distillates with phase change materials and nanomaterials reached (2.95, 3.35 and 5.02) kg/m². The efficiency was (23.48, 30.31 and 50.85) % for each of the tube distillate, tube distillate with phase change materials and distillate with phase change materials and nanomaterials, respectively.

P. Manoj Kumar and others [20] studied raising the efficiency of the work of the single-slope solar still by adding phase change materials and nanomaterials to the system. The results were compared for three experiments. The experimental results showed that adding phase change materials (paraffin) increased the productivity by 51.22%. When adding nanomaterials to paraffin, the production rate increased by 67.07% compared to the traditional.

Ravi Gugulothu and others [21] They discussed an experimental study using three types of phase change materials to improve the productivity of solar stills. The materials used were (Sodium Acetate (CH3COONa), potassium Dichromate (K2Cr2O7), Sodium sulphate (Na2SO410H2O)) with a single tilt solar still. Through experimental work, it was found that sodium sulphate (Na2SO410H2O) with water was the best product. this because of the melting point temperature.

Hairong Li et al. [22] prepared phase change materials using polymers. These materials comprise polyethylene glycol (PEG)/sulfonated graphene (SG) with the solution treated in an aqueous medium. This mixture contributed to a fourfold increase in thermal conductivity when adding 4% by weight of (PEG/SG) materials. The researchers also showed that the aqueous preparation of these compounds is an effective technique to enhance the thermal performance of phase change materials. The polymeric materials used are characterized by their ability to store large amounts of latent heat. It is also considered an environmentally friendly material.

Guo-Qiang Qiet al. [23] studied improving the thermal storage efficiency of phase change materials by mixing a new compound. This compound comprises polyethylene glycol (PEG) as a phase change material with the addition of graphene oxide (GO) sheets with different mixing ratios ranging from (0.5-0.8%). The results showed that the new compound can maintain the thermal properties unchanged even after 200 melting and freezing cycles. The thermal storage capacity was 142.8 J g^{-1}.

An experimental study was conducted by **Bin Li et al. [24]** on a thermal energy storage system in a solar collector. The system comprises erythritol supplemented with 3% expanded graphene (EG) to form a composite phase change material. The compound was verified experimentally and numerically through a simulation program. Results showed that the compound of phase change materials has a high storage efficiency of 39.98%.

III. PHASE CHANGE MATERIAL (PCMS)

PCMs are mostly used in thermal management systems for cooling or reducing heat loss. Because this is an almost temperature controlled process [25]. Phase change materials can store large amounts of heat. When a heat source is shed on these materials, they absorb heat energy and store it as latent heat. During that, it changes phase. After the removal of the heat source, these materials release the stored energy to their surroundings to return to the first phase [26] [27].

3.1 Classification of PCMs

Phase transition materials are divided into three categories (organic, inorganics, and eutectic). This category includes a wide range of temperature requirements. Depending on the latent heat and melting point of the fusion [28].

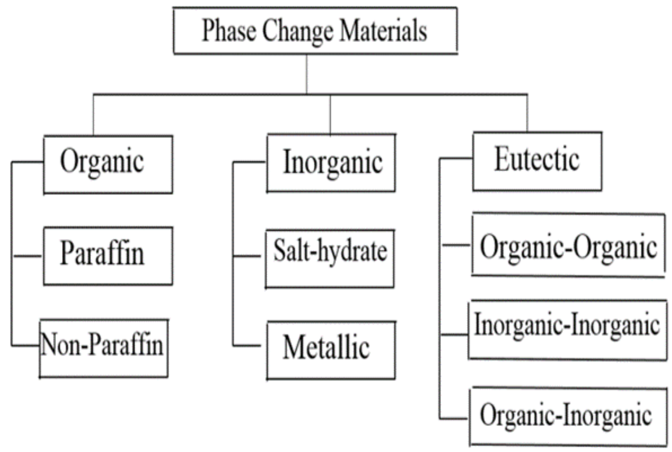

figure (5) Classification of PCMs [31].

• *Organic*

Organic materials, which comprise types of paraffin and non-paraffin, are compounds that include the element of carbon in their atomic structure. These materials are distinguished by their capacity to melt and freeze repeatedly, losing none of their characteristics. Congruent melting and the associated heat changes potential for fusibility is what it's termed. These materials are corrosion resistant and crystallization without or with little cooling, which is referred to as self-nucleation [29].

• *Inorganics*

Salts, metals, and salt hydrates phase transition materials are all examples of inorganic substances. It is distinguished with its high density, which causes growing enthalpy per volume and allows the phase transition to cover a wide temperature range. They also have the disadvantages of lack of thermal stabilization, corrosion, phase segregation, sub-cooling and separation [30].

• *Eutectic*

A eutectic is a compound made up of two or more components that can be classified as organic, inorganic, or organic-inorganic. It is notable for having a low melting point, known as the eutectic point. To build up the combination of the crystals of materials, each element melts and freezes in the same way [31].

Table (1) Comparison of Different Categories of PCMs [32]

Classification	Advantages	Disadvantages
Organic PCMs	Wide temperature range availability	Thermal conductivity is low.
	High heat of fusion No super-cooling	Flammability with a

	Noncorrosive	substantial volume change
	Chemically stable and recyclable	
	Compatibility with other materials is excellent.	
Inorganic PCMs	High heat of fusion High thermal conductivity	Super-cooling
	Volume change is low	Corrosion
	Low cost	
Eutectics	Sharp melting temperature	Lack of currently available
	High volumetric thermal storage density	Test data of thermo-physical properties

3.2 Thermophysical properties of PCMs

Table (1.1) lists the major features of phase transition materials that have been discovered via study [33].

Table (2) Thermophysical properties of PCMs

Thermal properties	Physical properties	Chemical properties	Economic properties
Phase change temperature suitability to application	Little density difference	stabilisation	Available and cheap
A significant variation of enthalpy near the temperature of utilized	maximum density	No phase separation Compatibility with container materials	
High thermal conductivity in together solid and liquid phases (although not always)	minimum or no undercooling	Non-toxic, non-flammable, non-polluting	

3.3 Stability of PCMs

Because of the long-term stability of these qualities, the physicochemical characteristics of PCM have been examined by many researchers in recent years. To enhance the system of thermal energy efficiency and storage, and heat transport mechanisms. Besides their other thermal characteristics, and over 150 materials have been identified as phase transition materials. These materials have been extensively researched for their physical and thermal properties in both solid and liquid forms. The results of the investigations on the latent heat and melting temperature of phase transition materials differed [34].

3.4 applications of Phase Change Materials

Phase change materials have uses other than solar heating and cooling, including [34]:

- Used for conditioning buildings
- Cooling of electronic devices
- Save thermal energy for use when needed

3.5 New phase change materials

(PVP K30: polyvinyl pyrrolidine, and PAA: polyacrylic acid) was used by mixing it in certain proportions and adding it to the water as a bass fluid to form a solution of phase change materials used to store heat and utilize it in the period after sunset. These materials were chosen to be mixed with water as a base fluid for several reasons. The most important of them are its abundance, stability, non-corrosion, and its ability to dissolve in water. It also does not interact with the tank material that contains it and does not pollute the environment.

To prepare the phase change materials, two steps are followed. The first is to mix the powder materials in specific proportions, and the required quantity is weighed with a sensitive electronic scale. The second step is to add the mixture to the water and mix it with a magnetic stirrer.

According to the amount of water, 10% polymeric components are added [35]. Following is a list of concentrations:

- PVP (30 gm) per 3 litres of water.
- PVP (25 gm) +PAA (5 gm) per 3 litres of water.
- PVP (20 gm) +PAA (10 gm) per 3 litres of water.

IV. CONCLUSION

- Relying on solar energy in the solar still has several advantages, including the preservation of the environment. This energy is free, abundant, and renewable.
- Phase change materials can store large amounts of heat as latent heat. It is possible to take advantage of this heat to continue producing pure water in the solar still during the period after sunset.
- The use of phase change materials can raise the daily productivity of the distiller between (50-125) %.
- New phase change materials comprising (PVP K30: polyvinyl pyrrolidine, and PAA: polyacrylic acid) may increase the working hours of the distiller (3-4) hours after sunset. Thus, the amount of production increased between (50-75%).

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