Review on Enhancement of Fresh Water Production in Solar Still Using Phase Change materials

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Abstract: - **Solar distillation uses the heat of the sun directly in a simple piece of equipment to purify water. The equipment, commonly called as solar still, consists primarily of a shallow basin with a transparent glass cover. The sun heats the water in the basin, causing evaporation. Moisture rises, condenses on the cover and runs down into a collection trough, leaving behind the salts, minerals, and most other impurities. The only nearly inexhaustible sources of water are the oceans, which is of high salinity. However, the separation of salts from seawater requires large amounts of energy which, when produced from fossil fuels, can cause harm to the environment. Therefore, there is a need to employ environmentally friendly energy sources in order to desalinate seawater. Phase change materials (PCM's) are widely used in different solar applications to store the solar radiations during sunny hours and releases the stored heat after sunset. Different phase change materials (Paraffin wax, ParaffinC18, Paraffin 52-58, Bees wax, Paraffin oil, Lauric acid, Stearic acid, Bitumen, Capric-palmitic, Calcium chloride hexa hydrate, Sodium Thiosulphate Penta hydrate etc.) have been used for different solar applications due to their various properties like low melting points, high heat of fusion and low cost. In solar distillation, use of PCM is simple and cost effective method to store the solar energy at high insolation hours and releases at evening/night hours. In solar distillation phase change materials help to enhance the distillate output and its performance.**

Keywords: **Distillate output, Fresh water, phase change materials, solar still.**

I. INTRODUCTION

1.1 Background

Solar energy is one of the crucial sources of renewable energy which does not cause any pollution of nature. One alternative to pure water is solar distillation, which characterized by free energy, ease of use, operation and low economic cost, compared to other sources. Some improvements are made to increase efficiency and productivity by adding thermal energy storage materials or modifying the design of the solar distiller [1, 2-5]. The pure water availability decreased rapidly by the usage of water for individual living purpose. The growth of industries also mainly depends on the water. The world was surrounded by 70% of saltwater. However, a human being cannot use that saltwater directly. That is the reason led the world looked for an alternative method to produce pure water. In solar water desalination, the production rate of water quantity depends on climate and intensity of temperature level. The need to develop small-size solar distillation units is shown to be more efficient in producing pure water in residential areas. This is the purpose of research in other ways of desalination non-pure water. The essential difficulties we encounter during the use of solar energy is the method of storing during the night, used the phase change materials [6, 7-24]. The phase change materials can be utilized in the electric motors, thermal administration of computers, the thermal safeguard of electronic apparatus, and solar power stations [25]. The experimental results showed that there is a clear difference in the using of water only as of the medium of storage and used of phase change material with water as a storage medium. The investigated experiment determined the heat transfer and enthalpy change properties of the novel PCM. The results appeared that the values of normal heat transfer parameters are higher in periods of phase change compared with water. Depending on the conditions in which the temperature passes, it increases by five times. The perfect thermal storage range is overlapped between the high values of the heat transfer coefficient and the temperature separator [26].

1.2 Desalination technology:

Solar distillation considered away in the purification of the saltwater is used, and make it suitable for drinking water in remote areas [27]. Two main groups are classified as water desalination systems depending on transport phenomena that include the separation of impurities and salts. This is a result of the evolution of purification and water desalination technology, membrane techniques, and thermal techniques (or phase change) [28].

1.2.1 Thermal technologies

To push the process depends on the addition of heat to change phase liquid-vapor. The distillation process seawater is heated to evaporate the water partially, and the generated vapor is then condensed back to freshwater, leaving behind high concentrated salts in the waste brine. Through the resulting vapor, the evaporation temperature will be maintained as latent heat. The latent heat released from vapor at condensation is utilized to preheat seawater or the evaporation of water at the next stage. The water produced in this process had higher pureness, best quality, and more freshness than the water in membrane processes. There are three main methods of the distillation processes, compression of vapor (VC), multistage flash (MSF), and multiple effect distillation (MED) in addition to solar distillation techniques[28]. For the production of water, and the generation of electricity is based on thermal desalination techniques integrated, and more technically with thermal power plants[27].

1.2.2 Membrane technologies

In this way, the membranes are very porous, where the separation of impurities and salts is achieved by passing water through these semi-permeable membranes. Through the mechanism of high-pressure differentials obtained on membranes, the separation process is completed, and this type is called reverse osmosis (RO), to disperse the osmotic pressure. In Electrolysis (ED), the driving force is to be the same electrical charge difference used on a couple of separation membranes. In this process, the consumption of thermal processes is higher than the waste of energy to produce pure water in the same quantity due to no change in phase. Other types, such as micro and nanofiltration membranes are used for water quality improvement [28, 29].

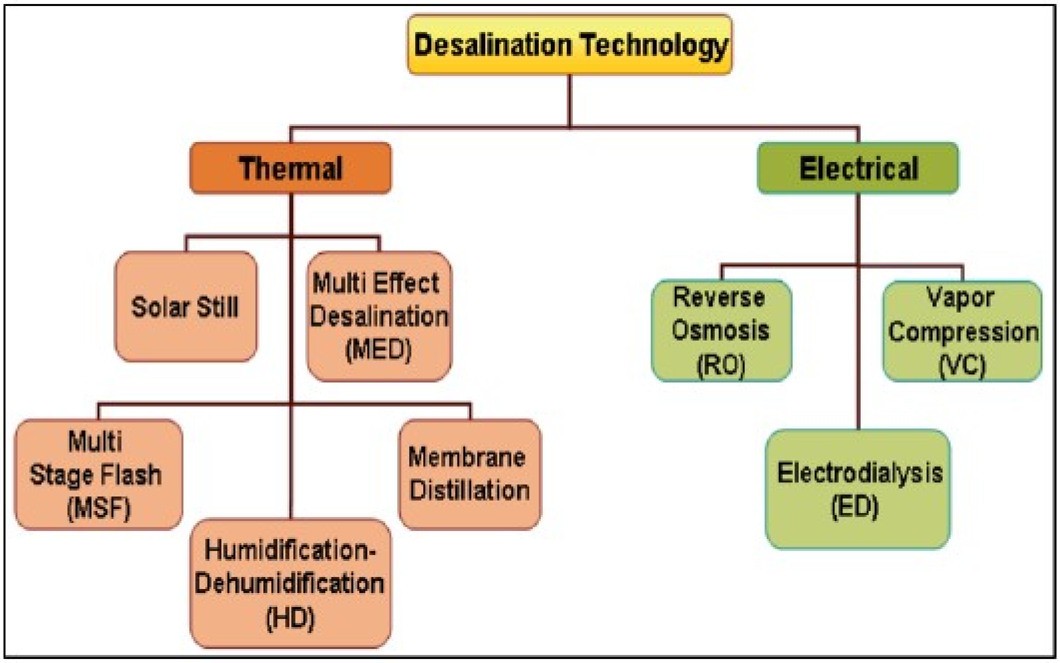

Figure (1.1) Classification of Desalination Processes

1.3 Solar desalination

There are two main types of solar distillation, divided into two types depending on the kind of manufactory set up. Moreover, the first type is the direct type where the solar collector inside the solar still basin; in this type, the solar radiation receives directly by basin to heat and evaporate the basin water. The second type, where the solar collector, is separated from the solar still and is called this type indirectly, and the example of this type is humidification-dehumidification (HDH) [28]. Solar thermal energy arriving is used for a saltwater pond in the heating of the upper layer. The top layer of the pond is heated, and the water evaporates and condenses on the cover. The impurities and salts are separated during water evaporation, while the concentration of salts remains high in the pond, and the water condenses to be usable [30].

1.3.1 Conventional solar stills

One of the simplest methods of water desalination is the used of solar stills that simulate the hydrogen cycle in nature. The principle of its work depends on the evaporation of water when exposed to air. Hot water vapor rises from the top layer of the solar still water basin, and the vapor condenses due to the temperature difference between the inner and outer surface of the lid, producing water free from impurities and with low salts. The solar still is usually made up of a basin containing undrinkable water and an outer covering that is transparent to allow sun rays to pass, to be made of transparent glass or plastic, and a channel to collect the resulting water from distillation[28].

1.3.2 Humidification-Dehumidification Technique (HDH)

Depending on the principle which is used in the indirect type for solar water desalination it's led to improved efficiency, and decreased in the particular assembly area. This is due to several factors, the turbulent flow of mass transfer coefficients between water and air, large vaporization surfaces, enhancement of heat, and energy retrieved techniques [31-46].

1.4 Phase Change Materials (PCMs):

Phase change materials can store and re-edit energy, as well as their using the heat of fusion. Heat energy is absorbed or released when the material changes from solid to liquid phase and vice versa. During the phase change, the temperature of the substance remains constant, and it is possible to store and release large amounts of energy, The method of storage heat from the most efficient ways because of their properties on the conservation, and liberalization of thermal energy in sample quantities [47]. In the 1940s, Telkes and Raymond, studied materials with the ability to maintain heat they are called Phase Change Materials (PCMs). The real interesting in these materials emerged during the energy crisis of the end of the 1970s, to be used in many applications, particularly in solar-based heating systems. Phase change materials have been used on wide ranges in other areas including electronic cooling, air conditioning system, recovery heat of waste, food preservation system, and heating systems. Many phase change materials have been identified, and the melting/freezing point has been widely studied over the past decades [53].

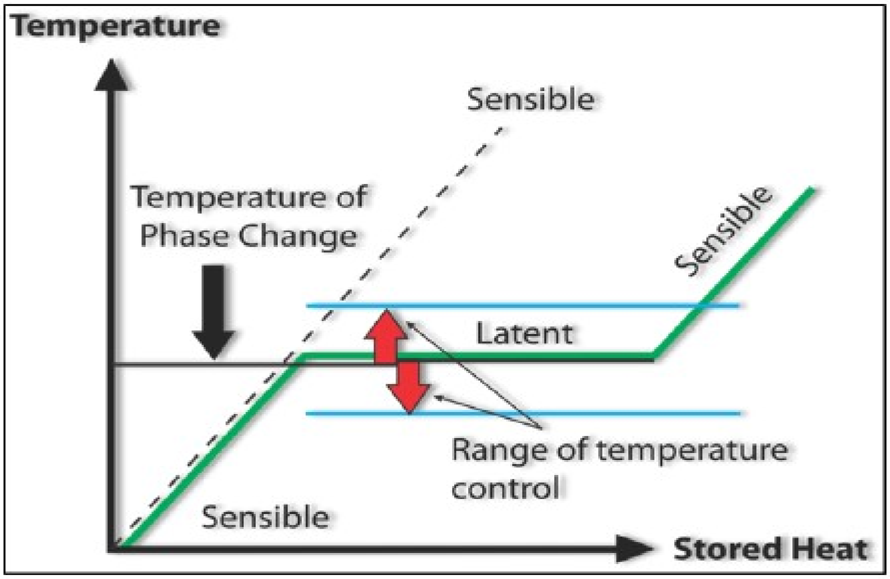

Figure (1.2) Sensible Heat, Latent heat and Temperature Control During the Phase Change

1.5 Classification of PCMs

Phase change materials are classified into three types (organic, inorganic, and eutectic). This classification includes broad ranges of requisite temperature ranges. Depending on the latent heat of the fusion and melting point, many organic and inorganic substances can be considered as phase change materials. A person can use the available materials and improve some of their properties when makeup designing a suitable system because there is no substance containing all the ideal characteristics for used as a storage medium for thermal energy. For example, to raise conductivity of the thermal in PCMs can be utilized metallic fins [54].

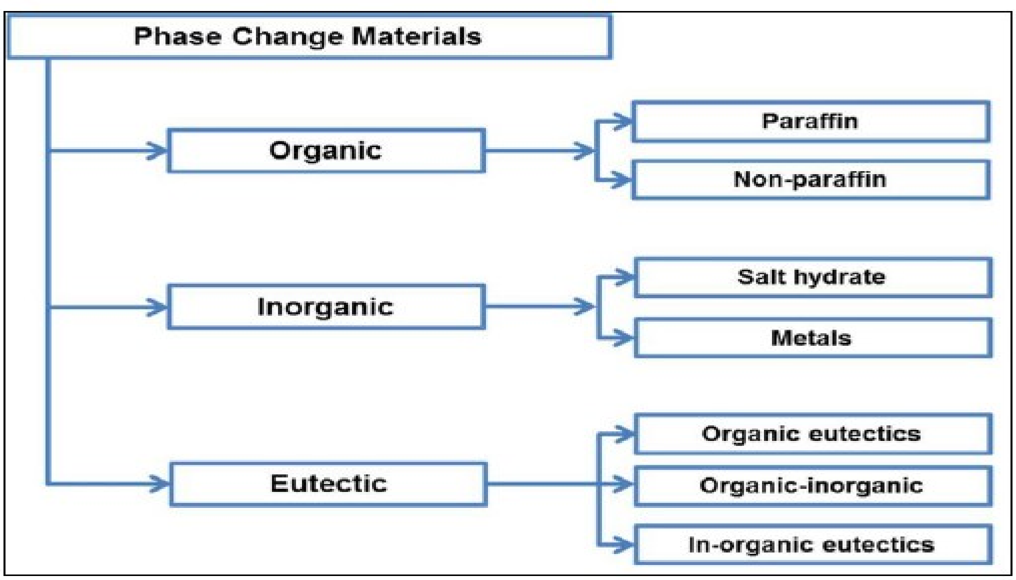

Figure (1.3) Classification of PCMs

1.5.1 Organic Phase Change Materials

Organic materials are substances that enter the element of carbon in its atomic composition and includes kinds of paraffin and non-paraffin. These materials are characterized by their ability to melt and freeze over and overtimes without any impact on their properties during phase change. Which it is called congruent melting and the accompanying of heat change potential for fusibility. These materials are usually resistant to corrosion conditions and crystallize without any cooling process or with few cooling; this means the self-nucleation [54].

1.5.2 Inorganic Phase Change Materials

Inorganic substances comprise both salts, metals, and salt hydrates phase change materials. It is characterized by its high density, which leads to rising enthalpy per volume, covering an extensive range of temperatures the phase change. At the same time, they have the detriments lack of thermal stabilization, corrosion, segregation, and separation of the phase, and sub-cooling [47,48-51, 52].

1.5.3 Eutectics

A eutectic is defined as a combination consisting of two or more substances, are divided to either organic, inorganic, and organic-inorganic. It can be noted for a low melting point called the point of eutectic. Each component melts and freezes similarly to make up mixture the crystals of components [54].

1.6 Thermophysical properties of PCMs

Table (1.1), shows the main characteristics of phase change materials, that have been obtained through the researches that have been conducted [55].

Table (1.1) 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	

1.7 Thermal stability of PCMs:

The physical properties of PCM are one of the essential factors investigated by many reviewers in recent years to an improve the system of conservation and storage of thermal energy as well as heat transfer mechanisms due to the long-term stabilisation of these properties. More than 150 materials have been listed as phase change materials in addition to their other thermal properties. The extensive use of these materials studied for their physical and thermal characteristic in the solid and liquid states. Results related to the latent heat and the melting temperature of phase change materials obtained from the studies carried out varied considerably. Some of these conclusions showed that the widely utilized of the thermal storage system was specific because of the lack of sufficient stability for storage materials in the long term [56].

1.8 Major applications of Phase Change Materials

The utilize of phase change materials is not limited to the storage of thermal energy in applications of the cooling and heating solar system. Still, it is used in other fields and applications [57].

It can be listed as:

- Save and store the latent energy of solar thermal during indirect contact.
- They are used in heat exchangers on way direct connection in thermal storage.
- They are used in applications and fields building.
- They are used in electric power fields.

II. LITERATURE REVIEW

2.1 Theoretical works:

Tiwari et al. [58]studied theoretically the solar distillation system and the role actions in the long term. Addressing the aspects of drinking water desalination methods and their sources of supply and the factors responsible for improving the tests of solar modules by discussing the heat and their relationship to mass transfer. The use of reinforced plastics and fiber in addition to the possibilities of double slope in improving the efficiency of solar distillers in the long term. It concluded that the solar distillation type with a dual-slope is more effective to increase the potable water. Because of the advantages of ease of operation, no need for skilled hands in maintenance, low cost of manufacturing, long life of the process, and in addition to its appropriate in rural areas.Sharma et al. [54]explained how the storage systems that used phase change materials might conserve thermal energy for use in full applications. The author took into consideration the thermal influence of the physical properties of PCM through the process of melting on the fraction of melt. A grid-level was used scale (32 × 32) (2 mm × 2 mm), while PCM was used grid level (30 × 30). Both the temperature of the wall and the temperature of the PCM have been imposed, since the melting temperature was less than the temperature of the heating wall, which fixed at (15 °C), and was (5 °C) higher than the temperature of the PCM. To demonstrate the improvement in passive thermal energy storage systems, the effect of physical, thermal properties of different types of PCMs investigated, and the calculations were made with various models of heat exchangers. One of the essential factors that influence the melt fraction was chosen and determined the thermal conductivity for each of the PCMs. The material of the container of heat exchanger reduced the needed time for melting completely of the PCM material when the material has thermal conductivity increases. An important factor on the melt fraction is influence thickness of the heat exchanger container's material. The effect of the temperature of the boundary wall is vital in the melt fraction, unlike the initial temperature of the PCM. Medugu and Ndatuwong[60]conducted a theoretical study and used the solar still in water distillation. To determine the results of some variable measurements during the day, the accuracy of the equations was based on the theoretical analysis. The recorded curves temperature for both water, ambient and glass were 69.0° C, 31.6° C, and 45.0° C respectively. Due to the various heat flow amount that passed and transmitted through the glass (by radiation convection, evaporation, and convection), it is observed that the temperature of the glass and water raised to maximum levels. The study showed that there is an agreed favourably between theoretical analysis and water produced by solar distillation. Badran[61]studied theoretically the most important factors related to improve the productivity of solar still by validate the experimental and theoretical results for validation. Depending on the following factors: solar radiation intensity, total heat loss coefficient, transmissivity and efficacious absorptivity, the difference between external cover temperatures, water speed and wind, and the influence of changing the thickness of the insulation of 1, 2.5 and 5 cm, evaluate the performance of the single-slope solar still associated with the solar collector. External conditions affect the overall productivity of solar distillation as they increase by increasing the temperature of the basin water, utilizing the latent heat to increase distillation, as well as increasing the difference between the temperature of condensation surface and evaporation. Bhardwaj et al. [62]studied the water production from solar distillation, and the effect of the type of cover material was used. They concluded that glass is the best materials as a condense surface; however, it does not necessarily a significant cause of increased productivity. The results found that the most critical factors in determining the type of surface condensation material for solar distillation were the contact angle. Also, one of the phenomena which affect the difference in water production is the phenomenon of reflected radiation from the surface of the cover. Materials are classified relative to the contact angle to (hydrophobic). The material possesses a large contact angle such as a polyethylene terephthalate (PET), and (hydrophilic) materials that have a low contact angle such as glass that allows solar radiation. Ansari et al. [63]conducted a study on the storage system of thermal energy placed under the basis of the solar distillation device and depends on passive solar still for saline water desalination with the assistance of using mathematical models transient. When changing its state from solid to liquid, phase change materials store and conserve heat energy. Energy balance equations are formulated for different elements in solar still, and PCM to find the numerical solution. Three types of PCM were used at various melting temperatures and make their statistical calculations. The analytical expression, the temperature of salty water and the existing results in the literature were compared to validate the simulation. The results showed that the excess energy during the day time is stored in the phase change materials to be used through the night. In addition to the above, the dependents chosen to the phase change materials based on the maximum temperature which brackish water can reach in the basin. Reddy Sharon [64]presented a hybrid solar still, which can generate both potable water and hot water has been proposed, and its performance has been simulated using transient mathematical modeling. The proposal included the using of both the conventional basin and the inclined still. In the hybrid still system, solar distillates compared to the traditional system increased by 107%. The average rate of temperature for hot water has been the output of the solar distillation during the winter and summer were 45.09 ° C and 56.28 ° C respectively. The water depth in the basin 0.01 m, the optimum thickness of the film of fluid is 0.001 m. The perfect gap among condensing and evaporating surface is 0.10 m. The total efficiency of the unit through the winter and summer is about 59.61% and 67.018% respectively. Chaichan and Kazem[26]used paraffin wax as a phase change material to store thermal energy. Increasing the efficiency of the system concentration to about 41.63%. Found the water temperature in the solar distilled is approximately 50.47%, with tracing sun in the concentration dish. They found an increase in the productivity of the system by about 180%. Increase the efficiency of the heating system of approximately 37.33%. System operation time increases when phase change materials are added to about 3 hours. Enhanced efficiency concentration system to about 21.64% increases the output of the system by about 53.21%. They are increasing the efficiency of the heating system of about 36.33%. Increase the operating time of the system with about 5 hours**.** Agrawal [65]studied the distillation of water utilizing solar energy with PCM and made a comparative study between solar still with and without PCM. To compare the production of solar stills through the day, by manufactured two single-stepped solar still slopes to use one with phase change materials and the other without the phase change. The chosen phase change materials were paraffin wax. It was found that the production of solar distillation, which used phase change material, increased in the day by 30-35% and at night 127% for one that does not use phase change materials. This is due to the reduction in the mass of water in the basin with the high mass of phase change materials, which led to an apparent increase in the efficiency and production of daily distillate. Kabeel et al. [66]conducted the theoretical analysis of conventional solar still which storage thermal energy by using phase change materials, which shows an increase in the operating system time 2 to 3 hours, and increase the productivity of the solar still of about 120 to 198%. This increase depends on several factors, including thermal conductivity, the melting point of the PCM temperature. The capric-palmitic material was selected as phase change material, where their use leads to an increase in the productivity of solar distillation, the lower wage package interval provides fusion heat capable and sufficient. Mousa et al. [67]developed a theoretical model that simulates the solar still associated with the solar collector. Phase change materials were selected to store thermal energy as Sodium Thiosulfate Pentahydrate. Which used as suitable storage materials in the continuous production of drinking water during the night by providing thermal energy. The output decreased by up to 30% when the PCM mass increased to a basin water mass from 10 to 100%. Due to the use of PCM, the water of the basin remains at high temperature for additional. The cooling effect of the glass cover increases productivity by 37% when increasing the flow rate from 0.01 to 0.1 kg/s. This unit can be used in cold places to provide hot water and drinking water.

2.2 Experimental works

Al-Hamadani and Shukla [68]carried out an empirical study of solar still that stores thermal energy using phase change materials such as lauric acid to determine the increase in the efficiency of solar distillation and daily productivity of the effect of the basin water and PCM mass in external conditions. Reducing the mass of water in the solar still basin with the increasing mass of phase change materials leads to improve the efficiency and productivity of daily solar still by up to 30-35%. It reduces heat loss in the external environment. It was found that the lower the depth of basin water leads to increase productivity. Kalaivani and Radhakrishnan [69]studied the behavior of solar experimentally still with a pyramid shape and the latent heat of phase change materials depending on physical characteristics and exterior, and interior heat transfer modes. The influences on the performance of the utilizing of the latent wax heating materials were studied in the solar stills with the storage system. The heat transfer coefficients were calculated with the calculation daily and instantaneous efficiency. The analysis of the performance of the solar distillation system with a pyramidal cover with phase change materials showed a remarkable rise in productivity when compared to a single-slope still system. Sarada et al. [70]studied experimental results in the water distillation system utilizing solar energy in existing materials of energy storage materials, sodium acetate, and sodium sulfate. The drinking water production by solar still of the best ways and the simplest that not need to facilities of the technical. In this study, experimental, water production is better when sodium sulfate (Na2SO410H2O) as a phase change material in water compared to sodium acetate (C2H3NaO2) because of the temperature of the melting point of sodium sulfate (884°C) higher than the temperature of sodium acetate (324°C).Gugulothu et al. [71]conducted a practical investigation of the performance of the solar distillation system using different types of phase change materials. The active area of the basin solar distillation made of stainless steel is 1 m2. The top cover of the solar distillation was of clear glass painted with black paint for absorption to allow the most significant amount of solar radiation to pass at a tilt 32°. The results of experimental with utilizing various phase change materials are Magnesium Sulfate Heptahydrate ($MgSO_4$ $7H_2O$), Potassium dichromate ($K_2Cr_2O_7$), and sodium acetate (CH_3COONa). The results showed that the best production of pure water obtained by using Magnesium Sulfate Heptahydrate ($MgSO_4$ $7H_2O$).Sonawane et al. [72]studied the use of phase change materials in solar still of saline water desalination. Experiments have shown that the use of PCM and different distillation angle are useful in terms of producing potable water, cost, improved thermal conductivity, and evaporation rate. PCM materials are a daytime heat source and an energy source at night. The PCM material is placed inside a steel box and closed during use. The results showed improved performance of water production from solar distillation comparative with conventional still distillation and the increase reached 62%. The best production angle was at 34°.Sundaram and Senthil[73]used solar still of saline water desalination with phase change materials and without it. Paraffin wax was used as a phase change material and a study of the effect of changing the depth of the basin water 30 mm, 20 mm, 10 mm. The distillation device was used consists of a single basin and had a double inclination. The effect of changing the thickness of the glass cover was studied 12 mm, 8 mm, and 4 mm, with the use of three devices of the solar distillation of equal size. The results showed that the best water productivity could be obtained when using the lowest depth of water basin 10 mm with the minimum thickness of the glass cover 4 mm compared with the other dimensions. The results showed an increase of 11.6% when paraffin wax was used to store thermal energy. Patil and Dambal [74]used solar still consisting of a single basin with a double slope. Black pebbles were used as a material to store the sensible heat and paraffin wax as phase change materials. Experiments were conducted in external conditions, and aluminum sheets were used in the manufacture of the solar distillation basin, which was 0.7 m2. The results compared with experiments, the production of solar distillation when using paraffin wax was 1100 ml, productivity was when the distillation basin was painted black 795ml, and the productivity was when using black gravel 954 ml. Experiments showed that the lowest production of solar distillation obtained when using black gravel with paraffin wax was 13%. While the highest productivity when coating the distillation basin and the used of paraffin wax is 30%, and the used of black gravel with coating the distillation basin is 18%.Kuhe and Edeoja[75]improved the performance of water productivity in solar still associated with parabolic dish concentrator solar. Solar still consists of a basin with a single slope. They used phase change materials such as beeswax in quantity 14 kg, below the solar distillation basin plate to store heat energy and maintain the temperature of basin water for continuous water production during the night. To increase the absorption of solar radiation, the solar distillation basin was coated in black. 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. Faegh and Shafii [76]stored the latent thermal energy of condensate water vapor within solar still by using phase change materials. Paraffin wax is used as a material for the storage of thermal energy. In this experimental work, there is no direct contact between phase change materials and solar distillation basin water. Water vapor is generated by solar energy absorbed within the solar distillation. It is then transferred to an external capacitor containing the PCM to preserve and store the latent thermal energy during condensation to be used during the night. Heating pipes are used to transfer stored power from the PCM to the solar distillation water to continue the production of potable water. The results showed that the use of PCM in the external condenser with heating pipes in the solar still connected to the solar evacuated tube collectors improves water production during the night. The increase of output86% compared to the absence of the PCM. The system efficiency 50%, and water productivity at 6.555 L/m^2 day. Kumar et al. [6]studied drinking water production in the solar distillation system with using of TiO^2 and phase change materials. The process of preparing the solar distillation system included the introduction of saltwater into the distillation basin and the used of phase change materials such as paraffin wax, as well as placing pieces of black stones in the distillation basin to increase the absorption of energy. They mixed each of paraffin wax and titanium oxide, and the mixture placed inside copper tubes, and then the cells are placed in the solar distillation basin. Polyurethane foam is used in insulation to minimize energy losses. The paraffin wax stores thermal energy during the day and re-released during the night. The results showed that the used of black stones improves productivity at no cost and the used of titanium oxide with paraffin wax in solar distillation gives water production 1.635 liters/day of 12 liters of water is not usable. Pakdel et al. [75]studied two kinds of solar still one as target solar still (TSS), and the other as the control unit solar still (CUSS). Each consisting of a transparent glass cover allowing solar radiation to heat the water in the solar still basin. The base of the solar still basin is painted black color to absorb as much of the radiation. A solar flat-plate collector is used to preheating the water entering the solar still basin. The results showed a clear improvement in the productivity of target solar still (TSS) where the daily efficiency of about 81.72% compared to conventional control unit solar still (CUSS).

2.3 The Theoretical and Experimental Works

Kabeel et al. [77]provided a practical and theoretical study to improve potable water production in solar distillation using a stepped basin instead of a conventional basin. A vacuum tube solar collector was used to raise the temperature of the saltwater before entering the solar still basin. Two solar stills, one of which was built from a stepped basin and the other with a conventional basin, were manufactured. They showed that there is a good affinity between the theoretical and experimental results. The results showed that the best productivity of the water could be obtained when using the solar distillation stepped basin in the dimensions of the width of the stepped 120 mm, the depth of the stepped 5 mm, and the productivity was higher than the conventional basin about 57.3%.Arunkumar et al. [78]provided a practical and theoretical study of the performance of solar distillation connected to a solar concentrator hemispherical with and without the effect of phase change materials. Adding phase change materials as a material for storage of heat energy during the day and to benefit from them after the solar sunset for the continuity of production of potable water. The results showed an improvement in the productivity when using phase change materials with solar concentrator where it reached at 4460 ml /m^2/day compared to without of PCM 3520 ml / m^2 / day; the increase was 26%.El-Agouz [79]suggested a practical and theoretical investigation to develop the performance of solar distillation using a stepped still basin with the possibility of circulation water at same conditions. Two types of water were used seawater with total dissolved solids (TDS) entering 57100 mg / l, and salty water, with (TDS) reaching 2370 mg / L before desalination. The effect of using each of black and cotton was studied with the stepped still basin. The results showed improved water production improved when using saltwater and seawater with black absorption compared with conventional still about 48% and 43%, respectively. While the creation of water when using saltwater and seawater with cotton was 47% and 53%, respectively, the increase in efficiency up to about 20% higher than the conventional still. Samuel et al. [80] supplied a practical and theoretical investigated to improve the productivity of single-slope solar still using low-cost materials for storing thermal energy. Spherical salt balls and sponge pieces are used as heat storage materials. The results showed that the use of salt balls with solar distillation gives the highest yield of drinking water compared with the use of sponge pieces and without using any of the storage materials, water production was 3.7 L/m2, 2.7 L/m2 and 2.2 L/m2 respectively. Finally, the use of materials and low cost with solar distillation produces water at the expense of less.

III. CONCLUSION

Phase change materials are the substances that stores energy in form of latent heat by changing its phase at certain temperatures of melting and solidification. These substances have high heat of fusion that are capable of storing and releasing high amount of heat during liquefaction and solidification respectively. The following conclusions were obtained:

1. Daylight productivity is decreased a little bit using PCM while night hours productivity and total productivity is increased.
2. The cost per liter for hybrid solar distillation system using PCM is little bit higher as compared to conventional solar stills.
3. Efficiency of the system is enhanced by the use of PCM in the solar stills.
4. The total productivity of still with phase change material is slightly higher than the still without phase change material.
5. Preliminary tests on the distilled water proved that the distilled water is suitable for domestic usages.

REFERENCES

[1] Farell, A.J., Norton.B., Kennedy, D.M., ―Corrosive Effects Of Salt Hydrated Phase Change Materials Used With Copper And Aluminum,‖ Journal of Material Processing and Technology, 175,198-205, 2006.

[2] Abbas SahiShareef, FarhanLafta Rashid, HasanFathiAlwan " Water solar distiller productivity enhancement using solar collector and phase change material (PCM)" IOP Conference Series: Materials Science and Engineering, 671 no.1 (2020):1-13, doi:10.1088/1757-899X/671/1/012150.

[3] FarhanLafta Rashid, Abbas SahiShareef, HasanFathiAlwan," Enhancement of Fresh Water Production in Solar Still Using New Phase Change Materials ",Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 61, Issue 1 (2019): 63-72.

[4] Abbas SahiShareef, FarhanLafta Rashid and HasanFathiAlwan," EXPERIMENTAL STUDY OF NEW DESIGN SOLAR STILL IN KARBALA-IRAQI WEATHERS", International Journal of Mechanical Engineering and Technology, Volume 9, Issue 13, December 2018: 1465–1472.

[5] FarhanLafta Rashid, Abbas SahiShareef, &HasanFathiAlwan, " Performance Enhancement of a New Passive Solar Still Design for Water Desalination", Journal of Mechanical Engineering Research and Developments, Vol. 43, No. 3,2020: 75-85.

[6] M.T. Chaichan, H.A. Kazem, ―Water solar distiller productivity enhancement using concentrating solar water heater and phase change material (PCM)‖, Case Studies in Thermal Engineering 5, 151–159, 2015.

[7] Abbas SahiShareef, FarhanLafta Rashid, AseelHadi and Ahmed Hashim," Water-Polyethylene Glycol/ (SiC-WC) And (CeO_2Wc) Nanofluids For Saving Solar Energy",INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 8, ISSUE 11 (2019).

[8] FarhanLafta Rashid, AseelHadi, Ammar Ali Abid, Ahmed Hashim," Solar energy storage and release application of water-phase change material - (SnO2-TaC) and (SnO2–SiC) nanoparticles system", International Journal of Advances in Applied Sciences ,Vol. 8, No. 2, (2019): 154-156 . DOI: 10.11591/ijaas.v8i2.pp154-156

[9] AseelHadi, FarhanLafta Rashid, HasanQahtan Hussein and Ahmed Hashim, " Novel of water with (CeO2-WC) and (SiC-WC) nanoparticles systems for energy storage and release applications", IOP Conf. Series: Materials Science and Engineering 518 (2019) 032059.doi:10.1088/1757-899X/518/3/032059

[10] FarhanLafta Rashid, AseelHadi, NahedaHumood Al-Garah, Ahmed Hashim," Novel Phase Change Materials, MgO Nanoparticles, and Water Based Nanofluids for Thermal Energy Storage and Biomedical Applications", International Journal of Pharmaceutical and Phytopharmacological Research 2018 Volume 8 , Issue 1: 46-56.

[11] FARHAN LAFTA RASHID, KHUDHAIR ABASS DAWOOD & AHMED HASHIM," MAXIMIZING OF SOLAR ABSORPTION BY (TiO2-WATER) NANOFLUID WITH GLASS MIXTURE", International Journal of Research in Engineering & Technology (IMPACT: IJRET) ,Vol. 2, Issue 1, (2014): 87-90.

[12] Obaid, HN; Habeeb, MA; Rashid, FL; Hashim, A," Thermal energy storage by nanofluids",journal of engineering and applied sciences, vol.8, issue 5:143-145.

[13] Adil Mohammed Hashim , FarhanLafta Rashid and Ibrahim KaittanFayyadh," Preparation of Nanofluid (Al_2O_3-water) for Energy Storage", IOSR Journal of Applied Chemistry (IOSR-JAC),Volume 5, Issue 3 (2013): 48-49.

[14] FarhanLafta Rashid , Hani NajmObaid , Ahmed Hashim," Energy output of Geopressured Geothermal Reservoir for Electricity Generation", British Journal of Science, Vol. 3 (2) (2012).

[15] FarhanLafta Rashid, Ahmed Abdullettif, Ahmed Hashim," Geothermal Energy for Electricity Generation", British Journal of Science, Vol. 3 (2) (2012).

[16] FarhanLafta Rashid , AshwaqHilalMohamad and Ahmed Hashim," Power Production using Tidal Energy",British Journal of Science, Vol. 3 (2) (2012).

[17] HaiderNadhomAzziz Al Joda, Abbas SahiShareef, FarhanLafta Rashid," Experimental Investigation of the Heat Transfer for the Effect of Nanoparticles with Different Base Fluid and Solar Collector Tilt Angle", Journal of Engineering and Applied Sciences, 13(113):10614-10620.

[18] FarhanLafta, ShahidMahdy, AseelHadi, Ahmed Hashim, "Novel of thermal energy storage and release: water/ (SnO2 - TaC) and water/ (SnO2 –SiC) nanofluids for environmental applications", IOP Conference Series Materials Science and Engineering 454(012113):1-4.

[19] Zahraa Hussein Obaid, FarhanLafta, Majeed Ali Habeeb, Ahmed hashim, AseelHadi, "Synthesis of New Biomaterial Composite for Thermal Energy Storage and Release", Journal of Chemical and Pharmaceutical Sciences 10(3), 2017.

[20] FarhanLafta, Abbas Sahi, Hassan A. J., "The experimental investigation of a flat plate solar collector using water as a heat transfer agent", Nova Science Publishers 2016.
[21] FarhanLafta Rashid, KhudhairAbassDawood& Ahmed Hashim, " Maximizing of Solar Absorption by (TiO_2-Water) Nanofluid with Glass Mixture", International Journal of Research in Engineering & Technology, Vol. 2, Issue 1, Jan 2014: 87-90.
[22] FarhanLafta Rashid, Nada Mohammed Hassan, JafarAqelMashot, Ahmed Hashim, " Increasing water evaporation rate by magnetic field", International Science and Investigation journal 2(3), 2013: 61-68.
[23] FarhanLafta Rashid, Ahmed Abdullettif, Ahmed Hashim, "Geothermal Energy for Electricity Generation", British Journal of Science 3 (2), 2012: 118-130.
[24] FarhanLafta Rashid, Muhammad AsmailEleiwi , HishamAssi Hoshi, "Design Study of Nanofluid Solar Absorption Refrigeration system", International Journal of Innovative Research in Engineering & Science 2 (6), 2013: 66-73.
[25] Zalba B; Marín J M; Cabeza L F and Mehling H, ―Thermal energy storage with phase change materials, heat transfer analysis and applications‖, Appl. Therm. Eng., vol. 23, pp: 251–283, 2003.
[26] M. Ravi Kumar, M. Sridhar, S. Madhan Kumar, C. VigneshVasanth, ―Experimental Investigation of Solar water Desalination with Phase Change Material and TiO2, ‖ Imperial Journal of Interdisciplinary Research (IJIR), Vol-3, Issue-3, 2017.
[27] S. Kalaivani, S. RugminiRadhakrishnan, ―Improvement of pyramid type solar still performance using wax latent heat material,‖ International Journal of Current Research and Review, Vol. 04 issue 19, pp:69-77, 2012.
[28] Abdel Hakim M. A. Hassabou, ―Experimental and Numerical Analysis of a PCM-Supported Humidification-Dehumidification Solar Desalination System, ‖ Munich Technical University, 2011.
[29] AsaadSalimBded, FarhanLafta Rashid, " Effect of Multi Size Porous Media Properties on the Flow of Non-Darcy Regime" Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 68, Issue 1,2020: 63-72.
[30] TamimYounos, Kimberly E. Tulou, ―Overview of Desalination Techniques, ‖ Journal Of Contemporary Water Research and Education issue 132, pp: 3-10, 2005.
[31] Mohammed WahhabAljibory, Farhan L. Rashid and Shahid M. Abu Alais," An Experimental and Numerical Investigation of Heat Transfer Enhancement Using Annular Ribs in a Tube." IOP Conference Series: Materials Science and Engineering 433 no. 1 (2018): 1-20.
[32] Mohammed W. Al-Jibory , FarhanLafta Rashid, Shaheed Mahdi Talib," An experimental Investigation of Heat Transfer Enhancement in Elliptical Passage Fitted with Different rib Geometries." International Journal of Mechanical Engineering and Technology 13 no. 9 (2018): 1033-1048.
[33] FarhanLafta Rashid, Mohammed W. Al-Jibory, Shaheed Mahdi Talib," Numerical Investigation of Heat Transfer Augmentation in Elliptical Passage with Different rib Geometries and Aspect Ratios" International Journal of Mechanical Engineering and Technology, 9 (13) (2018): 1390-1409.
[34] Dr. FarhanLafta Rashid , Dr. HaiderNadhomAzziz, Dr. EmadQasem Hussein," Heat Transfer Enhancement in Air Cooled Gas Turbine Blade Using Corrugated Passages", Journal of Petroleum Research & Studies, vol. (20) (2018): 52-69.
[35] Mohammed W. Al-Jibory, FarhanLafta Rashid and ShahidMahdyTalib," Numerical Investigation of Heat Transfer Enhancement in Ribbed Elliptical Passage", Journal of Engineering and Applied Sciences, 13 (17) (2018): 7223-7234.
[36] Mohammed W. Al-Jibory, FarhanLafta Rashid, HasanQahtan Hussein," Cooling Enhancement in Gas Turbine Blade Rectangular Passages Using Circular Ribs", IEEE Communications Society Iraq Branch (2017): 163-168.
[37] ArkanAltaie, Moayed R. Hasan, FarhanLafta Rashid," Numerical Investigation in a Circular Tube to Enhance Turbulent Heat Transfer Using Opened Rings-Triangular Cross Section", Journal of Babylon University/ Engineering Sciences (2015).
[38] ArkanAltaie, Moayed R. Hasan, FarhanLafta Rashid," Heat Transfer Enhancement in a Circular Tube Using Ribs with Middle Arm", Elixir International Journal (2015).
[39] FarhanLafta Rashid, ArkanAltaie, Moayed R Hasan,"Numerical Investigation of Heat Transfer Enhancement in a Circular Tube Using Ribs of Separated Ports Assembly", European Scientific Journal (2014).
[40] ArkanAltaie, Moayed R. Hasan and FarhanLafta Rashid," Numerical Heat Transfer and Turbulent Flow in a Circular Tube Fitted with Opened Rings Having Square Cross Section", Journal of Basic and Applied Scientific Research 4 (11) (2014): 28-36.
[41] FarhanLafta Rashid, HasanQahtan Hussein, AsaadSalimBded, "Numerical Simulation of Fluid Flow and Heat Transfer in Wellbore", Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 60, Issue 1 (2019) 60-70.
[42] HaiderNadhomAzziz, FarhanLafta Rashid, HasanQahtan Hussein," Simulation and Modeling of Tower Diesel Power Station in Samawah Using Finite Element Method with MATLAB and COMSOL Programs", IOP Conf. Series: Materials Science and Engineering 671 (2020).doi:10.1088/1757-899X/671/1/012138
[43] Mohammed W. Al-Jibory, FarhanLafta Rashid and ShahidMahdyTalib," Numerical Investigation of Heat Transfer Enhancement in Ribbed Elliptical Passage", Journal of Engineering and Applied Sciences, 13 (17) (2018): 7223-7234.
[44] Mohammed Wahhab AL-Jibory, FarhanLafta Rashid , HasanQahtan Hussein, " Review Of Heat Transfer Enhancement In Air-Cooled Turbine Blades", INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 9, ISSUE 04, APRIL 2020.
[45] Mohammed Wahhab AL-Jibory, FarhanLafta Rashid, ShaheedMahdyTalib, "Review on Cooling Enhancement of Different Shape Gas Turbine Ribbed Blade with Thermal Barrier Coating", International Journal of Scientific Research and Engineering Development—Volume 3 Issue 1, Jan-Feb 2020.
[46] FarhanLafta Rashid, Falah Ali Jasim , AqelMashotJafar, "Reduce the Microwave Heating by Ceramic container for grain genetic mutation", International Journal of Innovative Research in Engineering & Science, 2 (9), 2013: 44-45.
[47] Socaciu, L.G., Leonardo Electr. J. Pract., ―Thermal Energy Storage with Phase Change Material, ‖. pp:75–98., 2016.
[48] FarhanLafta Rashid, SamahZakiNaji,"An Experimental Study for the effect of Water in Crude Oil on its Rheological Properties and Flow Characteristics", IOP Conf. Series: Materials Science and Engineering579 (2019) 012053. doi:10.1088/1757-899X/579/1/012053
[49] FarhanLafta Rashid, HaiderNadhomAzziz, Shaheed Mahdi Talib,"Experimental Investigation of Drag Reduction by a Polymeric Additive in Crude Oil Flow in Horizontal Pipe", Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 60, Issue 1 (2019): 15-23.
[50] EmadQasem Hussein, FarhanLafta Rashid, HaiderNadhomAzziz,"Aerodynamic Heating Distribution for Temperature Prediction of Fast Flying Body Nose Using CFD", Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 64, Issue 2 (2019): 183-195.
[51] FarhanLafta Rashid , Auda J. Braihi , Ahmed Hashim, AkramJassimJawad," Drag Reduction of Iraqi Crude Oil Flow in Pipelines by polymeric Additives", International Journal of Mechanical Engineering and Technology,Volume 9, Issue 13, December 2018: 1049-1060.
[52] FarhanLafta Rashid , Abdulsattar k. Abbas and Ahmed Hashim, "Theoretical Analysis of Eccentric Flow of Cylindrical Bodies in Pipelines", British Journal of Science, 3 (2), 2012: 1-10.
[53] Telkes M, Raymond E., ―Storing solar heat in chemicals—a report on the Dover house, ‖. Heat Vent;46(11):80–6., 1949.
[54] Atul Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, ―Thermal energy storage with phase change materials and applications, ‖ Renewable and Sustainable Energy Reviews 13. 318–345., 2009.
[55] Belen Zalba, Jose M. Marin, Luisa F. Cabeza, HaraldMehling, ―Thermal energy storage with phase change: materials, heat

transfer analysis and applications, ‖ Applied Thermal Engineering 23. 251–283., 2003.

[56] Manish K. Rathod, Jyotirmay Banerjee, ―Thermal stability of phase change materials used in latent heat energy storage systems, ‖ Renewable and Sustainable Energy Reviews 18, 246–258., 2013.

[57] Mohammed M. Farid, Amar M. Khudhair, Siddique Ali K. Razack, Said Al-Hallaj, ―Phase change energy storage: materials and applications,‖ Energy Conversion and Management 45, 1597–1615., 2004.

[58] G.N. Tiwari, H.N. Singh, Rajesh Tripathi, ―Present status of solar distillation, ‖ Solar Energy 75,.367–373. 2003.

[59] D. W. Medugu, and L. G. Ndatuwong, ―Theoretical analysis of water distillation using solar still, ‖ International Journal of Physical Sciences Vol. 4 (11), pp. 705-712., 2009.

[60] Omar Badran, ―Theoretical Analysis of Solar Distillation Using Active Solar Still, ‖ International Journal of Thermal & Environmental Engineering, Volume 3, No. 2, 113-120., 2011.

[61] R. Bhardwaj, M.V. ten Kortenaar, R.F.Mudde, ―Influence of condensation surface on solar distillation, ‖ Desalination 326, 37–45., 2013.

[62] Omar Ansari, Mohamed Asbik, Abdallah Bah, AbdelazizArbaoui, Ahmed Khmou, ―Desalination of the brackish water using passive solar still with a heat energy storage system,‖ Desalination 324, 10–20., 2013.

[63] K. S. Reddy, and H. Sharon, ―Performance investigation of combined solar desalination and hot water system, ‖ International solar energy society, 08 – 12., 2015.

[64] M. Ravi Kumar, M. Sridhar, S. Madhan Kumar, C. VigneshVasanth, ―Experimental Investigation of Solar water Desalination with Phase Change Material and TiO2, ‖ Imperial Journal of Interdisciplinary Research (IJIR), Vol-3, Issue-3, 2017.

[65] Sagar Suresh Agrawal, ―Distillation of Water- Using Solar Energy with Phase Change Materials, ‖ International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622., 2015.

[66] A.E. Kabeel, Y. A. F. El-Samadony, and Wael M. El-Maghlany, ―theoretical performance comparison of solar still using different PCM, ‖ Twentieth International Water Technology Conference, IWTC20, 18-20., 2017.

[67] Mousa Abu-Arabia, Mohammad Al-harahsheh, HasanMousa, ZobaidahAlzghoul, ―Theoretical investigation of solar desalination with solar still having phase change material and connected to a solar collector, ‖ Desalination 448, 60–68., 2018.

[68] A. A. F. Al-Hamadani, S. K. Shukla, ―Water Distillation Using Solar Energy System with Lauric Acid as Storage Medium, ‖ International Journal of Energy Engineering; 1(1): 1-8., 2011.

[69] S. Kalaivani, S. RugminiRadhakrishnan, ―Improvement of pyramid type solar still performance using wax latent heat material,‖ International Journal of Current Research and Review, Vol. 04 issue 19, pp:69-77, 2012.

[70] S.NagaSarada, BanothHimaBindu, Sri Rama Devi, and Ravi Gugulothu, ―Solar Water Distillation Using Two Different Phase Change Materials, ‖ Applied Mechanics and Materials Vols. 592-594, pp 2409-2415., 2014.

[71] Ravi Gugulothua, Naga SaradaSomanchia, Sri Rama Devi, and HimaBinduBanoth, ―Experimental Investigations on Performance Evaluation of a Single Basin Solar Still Using Different Energy Absorbing Materials, ‖ Aquatic Procedia 4, 1483 – 1491.,2015.

[72] DnyaneshwarSonawane, OnkarJadhav, ManasiPatil, VishvajitJambuti, ―Enhancing Solar Still Productivity by Optimizing Angle of PCM Embedded Absorber Surface, ‖ International Journal of Science Technology & Engineering, Volume 2, Issue 2.,2015.

[73] P. Sundaram, R. Senthil, ―productivity enhancement of solar desalination system using paraffin wax, ‖ International Journal Chem. Sci.: 14(4), 2339-23., 2016.

[74] Bharat Kumar Patil, Sanjay Dambal, ―Design and Experimental Performance Analysis of Solar Still Using Phase Changing Materials and Sensible Heat Elements, ‖ International Journal of Research in Mechanical Engineering & Technology, Vol. 6, Issue 2, 2016.

[75] AondoyilaKuhe, Alex OkibeEdeoja, ―Distillate yield improvement using a parabolic dish reflector coupled single slope basin solar still with thermal energy storage using beeswax, ” Leonardo Electronic Journal of Practices and Technologies, Issue 28, p. 137-146., 2016.

[76] MeysamFaegh, Mohammad BehshadShafii, ―Experimental investigation of a solar still equipped with an external heat storage system using phase change materials and heat pipes, ‖ Desalination 409, 128–135., 2017.

[77] Mohammad Ali Pakdel, Mahdi Hedayatizadeh, Seyed Mahmoud Tabatabaei, NaserNiknia, ―An experimental study of a single-slope solar still with innovative side troughs under natural circulation mode, ‖ Desalination 422, 174–181., 2017.

[78] A.E. Kabeel, A. Khalil, Z.M. Omara, M.M. Younes, ―Theoretical and experimental parametric study of modified stepped solar still, ‖ Desalination 289, 12–20., 2012.

[79] T. Arunkumar, D. Denkenberger, AmimulAhsan, R. Jayaprakash, ―The augmentation of distillate yield by using concentrator coupled solar still with phase change material, ‖ Desalination 314, 189–192., 2013.

[80] S.A. El-Agouz, ―Experimental investigation of stepped solar still with continuous water circulation, ‖ Energy Conversion and Management 86, 186–193., 2014.