Techniques of improving rate of heat transfer in Solar Still as a Solar-Thermal Desalination device – A Review

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ABSTRACT

Pure drinking water is an essential need of human being. Solar desalination is one of the simplest methods used for distillation of saline water and the devices are called solar stills. The desalination in single sloped solar still has very low output of water. Hence, the notion of double sloped solar still has been created to increase the performance of solar stills. There are many methods to increase the heat transfer inside solar stills, as use of Nanofluids and attaching different types and shapes of fins on the absorber plate. Nanofluids are more efficient heat transfer medium for utilizing thermal energy for solar applications. As the addition of fins attached to absorber plate increases water evaporation rate, various shapes of fins can used for maximized output. This paper reviews the various ways of enhancing the rate of heat transfer in solar stills as solar-thermal desalination devices.

Keyword: - *Desalination, Solar Energy, Solar Still, Nanofluids, Fins, Review.*

1. INTRODUCTION

Water is the most abundant and important substance on earth [1]. Purified water is basic necessity for all breathing entities to survive in nature. Over 97% of planet's water is saline; remainder 2.6% is sweet water and below 1% of fresh water is inside human reach [2]. Availability of pure drinking water is reducing progressively. Currently, clean water is a terrifying problem faced by mankind due to the swift advancement in world inhabitants and contamination of available environmental water reserves [3]. Most of the globe's populace does not have harmless and hygienic drinking water which is the main cause of waterborne diseases that kills on the average more than 6 million children each year [4]. Contaminated water generally contain viruses, bacteria, parasitic entities, liquefied and anonymous constituents, physical and chemical impurities which results in severe harm of human hygiene. Therefore, water available from various aquatic sources (rivers, lakes, oceans, rain, etc.) has to be refined. Such adulterations can be isolated using solar distillation. There are various techniques have been served for purification of water such as Reverse Osmosis (RO), Vacuum Distillation, Vapour Compression (VC), Multi Effect Distillation (MED) and Multi Stage Flash Distillation (MSF) [5]. Solar Desalination is the simplest technology that employs solar energy as an ample and renewable energy source for distillation of saline water. For solar desalination purpose solar stills are employed.

2. PRINCIPLE OF SOLAR STILL

In desalination, brackish or saline water is evaporated using thermal energy and resulting vapour is collected and condensed as final product. The simple device which converts the brackish or saline water into the fresh distilled water is known as solar still. It uses solar energy as energy source in the form of solar radiation to increase temperature of water. The Water in basin evaporated by the solar radiation and water vapour is transmitted on the glazing cover which is condensed by the wind. The condensed water on inside surface of glazing cover is collected by providing inclination to the glazing cover. Due to the simplicity of this device, it has various applications in the industrial as well as domestic sectors. The simple concept of this system is to use solar energy for getting drinkable fresh water from saline water.

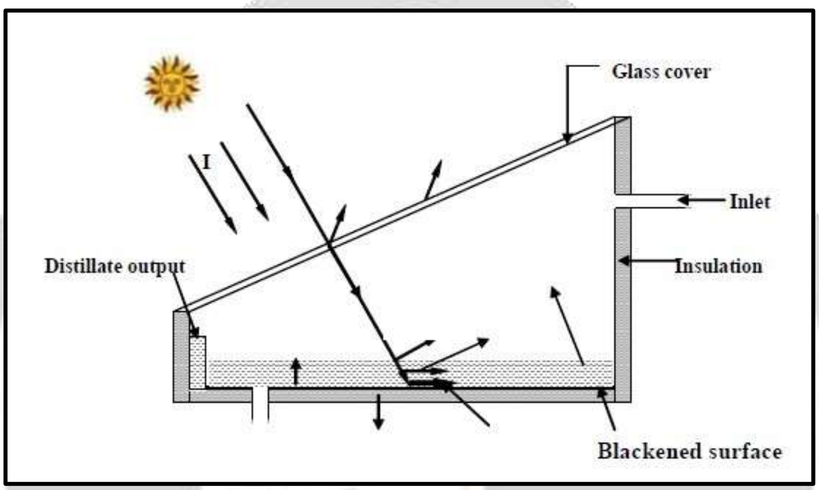

Fig -1 Single slope passive solar still [4]

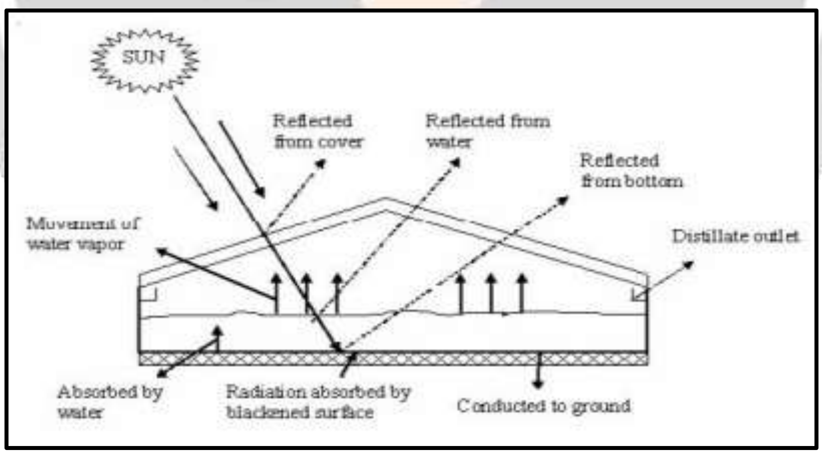

Fig .-2 Double slope passive solar still [4]

The ideal basin used for the solar distillation has shallow and wide structure with the black painted at the inner surface, wide to increase the surface area and black paint is use for to trap maximum amount of solar radiation. The painted surface is baked in the sun to free from the toxicity of color otherwise the toxic volatiles are also evaporated with the distilled water. The basin is painted black to increase water temperature so that rate of evaporation can be accelerated. For the collection and condensation of water the transparent cover is used. If the temperature difference between glass cover and basin plate temperature are increase than distilled output is increase. The glass cover kept the radiation inside the basin.

Dwivedi *et al.* (2009) [4] attempted to evaluate the internal heat transfer coefficient of single and double slope passive solar stills in summer as well as winter climatic conditions for three different water depths (0.01, 0.02and 0.03 m) by various thermal models. The experimental validation of distillate yield using different thermal models was carried out for composite climate of New Delhi, India (latitude 28°35′ N, longitude 77°12′ E). By comparing theoretical values of hourly yield with experimental data, it has been observed that Dunkle's model gives better agreement between theoretical and experimental results. Further, Dunkle's model has been used to evaluate the internal heat transfer coefficient for both single and double slope passive solar stills. With the increase in water depth from 0.01 m to 0.03 m there was a marginal variation in the values of convective heat transfer coefficients. It was also observed that on annual basis output of a single slope single slope solar still is better (499.41 l/m^2) as compared with a double slope solar still (464.68 l/m^2).

Fig -3 Photograph of the experimental single sloped solar still (Fronting due South) [4]

Fig -4 Photograph of the experimental double sloped solar still (Slopes fronting due East - West) [4]

Dev*et al.* (2011) [5] created a new approach to obtain the characteristic equation of a double slope passive solar still (DSPSS) based on experimental observations. The performance of DSPSS has been analyzed for the composite climatic condition of New Delhi, India. To obtain the characteristic equations under quasi-steady state condition, regression curves have been plotted for instantaneous gain and loss efficiencies with respect to a non-dimensional representative factor [{(Tw–Ta)/I(t)}/{(Tw–Ta)/I(t)}max] of climatic and operational parameters together. From the analysis, it has been concluded that non-linear characteristic curves are more accurate for analyzing the performance, thermal testing and further design modification depending upon various parameters associated with design, climatic and operational conditions.

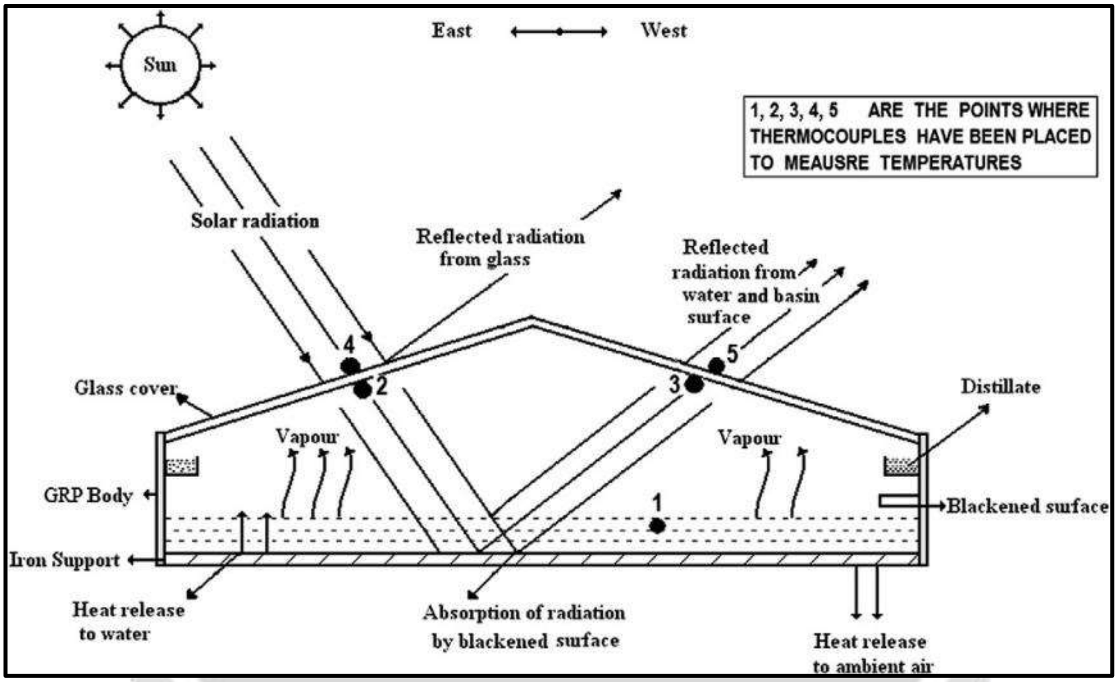

Fig -5 Depiction of double sloped passive type solar still [5]

2.1. SOLAR STILL WITH NANOFLUIDS

Nanofluids are a new class of fluids which promise to significantly enhance thermal properties of technological fluids. They are obtained by dispersing solid nanoparticles (diameter <100 nm) made by metallic oxides, metals, carbon nanotubes etc. in common fluids such as water, glycol, oils and refrigerants. The use of nanoparticles promise to get much more stable fluids, no obstruction, low wearing and huge enhancements of thermal conductivity and eventually of heat transfer coefficients with respect to the base fluid. The main reason for produce nanoparticles are its high surface area to volume ratio. In different liquid like ethylene glycol, water and oils nanoparticles are dispersed and nanofluid is to be obtained. Homogeneous and stable solution is the first requirement of nanofluids for the better performance in experiment. As compared to other nanoparticles Copper Oxide (CuO) and Aluminum Oxide (Al_2O_3) has lower cost. The selected nanoparticles are more reasonable in accordance with cost and thermal conductivity.

Kabeel *et al.* (2014) [6] studied the design modification of a single basin solar still has been investigated to improve the solar still performance through increasing the productivity of distilled water. The experimental attempts are made to enhance the solar still productivity by using nanofluids and also by integrating the still basin with external condenser. The used nanofluid is the suspended Nano-sized solid particles of aluminum oxide in water. Nanofluids change the transport properties, heat transfer characteristics and evaporative properties of the water. Nanofluids are expected to exhibit superior evaporation rate compared with conventional water. The results show that integrating the solar still with external condenser increases the distillate water yield by about 53.2%. And using nanofluids improves the solar still water productivity by about 116%, when the still integrated with the external condenser.

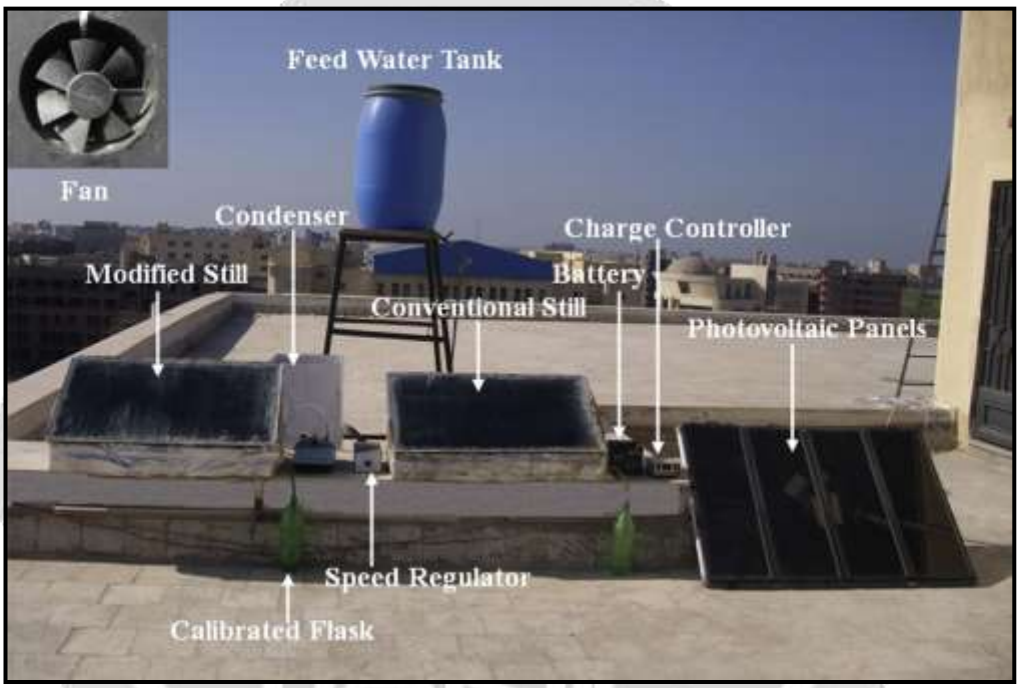

Fig -6 Photograph of experimental setup [6]

Omara et al. (2015) [7] conducted experimental studies with modifications on the ordinary solar still to investigate the performance of the solar still with nanoparticles on the same setup shown in figure 6. The productivity of the system is enhanced when using cuprous and aluminum oxides nanoparticles by an approximate percentages of 285.10% and 254.88% respectively.

Elango *et al.* (2015) [8] compared the performance of single basin single slope solar still with and without water nanofluid. Water nanofluids of Aluminum Oxide (Al_2O_3), Zinc Oxide (ZnO), Iron Oxide (Fe_2O_3) and Tin Oxide (SnO_2) of different concentrations were characterized for thermal and physical properties and suitable nanofluids were selected for performance testing in solar still. Two experimental stills of the same basin area was fabricated and tested with water and different nanofluids simultaneously. The still with Aluminum Oxide (Al_2O_3) nanofluid had 29.95% higher production and the still with Zinc Oxide (ZnO) and Tin Oxide (SnO_2) nanofluids had 12.67% and 18.63% more production respectively than the still with water.

Fig -7 Schematic of Pin Finned Solar Still test unit [8]

Sahota*et al.* (2016) [9] proposed an analytical expression of the characteristic equation of passive double slope solar still (DSSS) for three different nanofluids. The analysis has been carried out for optimized concentration (0.25%) of metallic nanoparticles.

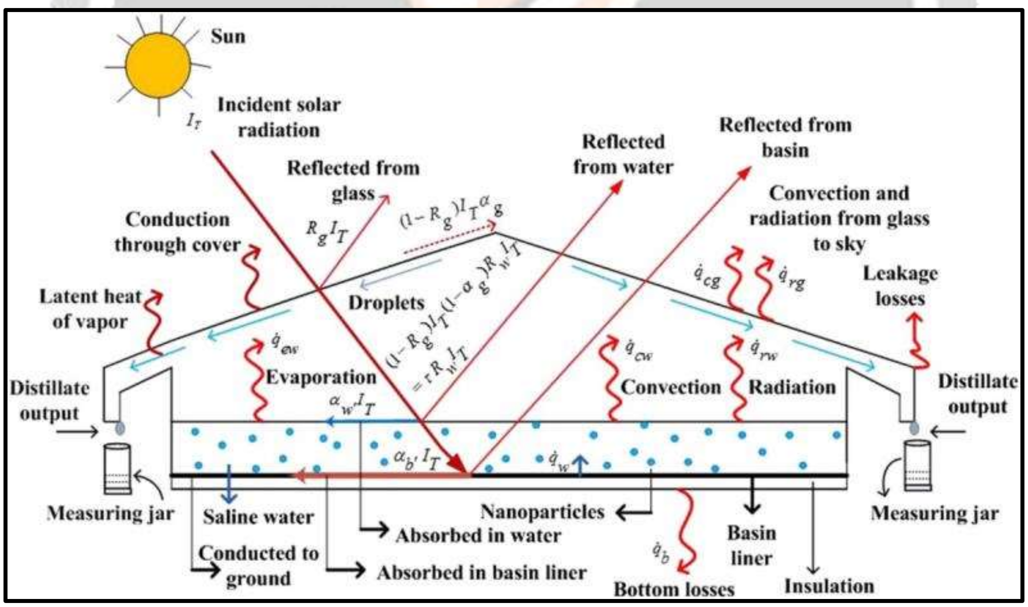

Fig -8 Depiction of passive type double slope solar still with suspended nanoparticles (Fronting due East - West) [9]

Higher thermal energy efficiency was obtained for nanofluids (Al_2O_3 50.34%; TiO_2 46.10%; and CuO 43.81%) in comparison to basefluid (37.78%). The thermal exergy was also higher for nanofluids (Al_2O_3 14.10%; TiO_2 12.38%; and CuO 9.75%) as compared to basefluid (4.92%). Productivity (yield) has also been evaluated for different weather conditions of the month of March using the proposed model.

2.2. SOLAR STILL WITH FINS

Fins are the extended materials attached on absorber plate for enhancing heat transfer rate between absorber plate and the basin water. Several researchers employed extended fins attached to the absorber plate for boosting the heat transfer rate in solar based thermal desalination apparatuses. Aimed at consideration of solar stills, the performance of single sloped single basin single slope finned solar still was examined by Velmurugan *et al.* [10]. The study indicates that, the water evaporation rate rises by 53% after having fins attached to the absorber plate [11]. Various kinds of fins are used for this purpose. The fins generally used for enhancing performance of solar still are:

- Simple Strip type Plate Fin
- Strip type Wavy Plate Fins
- Solid Pin Fins
- Hollow Pin Fins
- Porous Fins
- Wire mesh type Fins

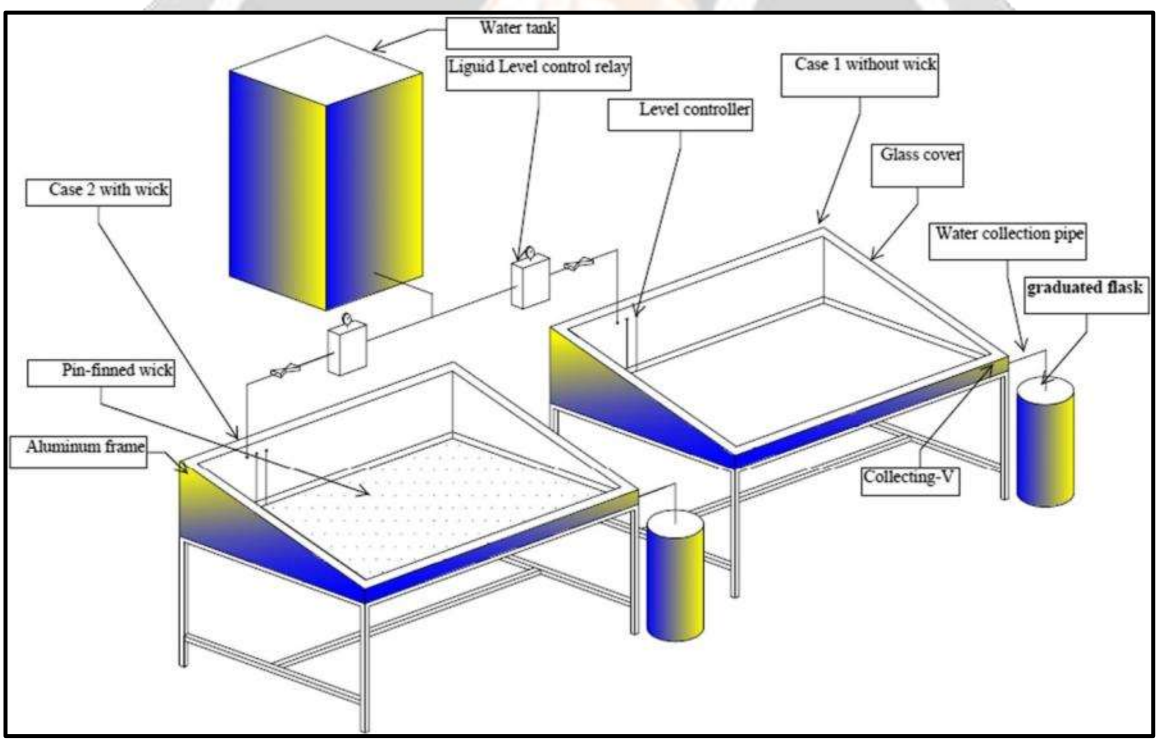

Fig -9 Schematic of Pin Finned Solar Still test unit [12]

The performance of fins depends upon many parameters such as geometry and pitch of fins, material of fin, shading effect generated by fins etc. The performance of simple and wavy strip fin depends upon thickness, height, number of fins and pitch (distance between two consecutive fins). Whereas the performance of pin fins whether it is solid type or hollow type[16] depends upon height, cross section shape, material of fins, thickness in case of hollow fins, pitch and pattern of arrangement of fins. Directional arrangement if strip fins have direct impact on the performance of fins.

Here, solid and hollow pin fins contains different cross section geometries such as circular, square, rectangular, triangular, elliptical etc. The patterns of arranging fins on absorber plate may be randomly of any type but generally simple straight type and zigzag type arrangement is used. The height of fin is decided on the bass of water depth in basin. The number of fins used is fixed by the amount of solar radiation falling and requirement of distilled water output. There is no standardized method or mathematical model to find out the optimum pattern and number of fins to be placed on absorber plate.

Omara *et al.* (2011) [12] conducted an experimental study to improve the productivity of basin solar stills by increasing the surface area of absorber (base of still) and rate of heat transfer between saline water and absorber. In view of this, three solar stills were designed and fabricated in order to study the performance of each still. The first one was a conventional type and the second was a finned still while the third one was corrugated still. The performance of the finned and corrugated solar stills were tested and compared with conventional still under the same climate conditions. The performance of different solar sills were tested under two cases; stills at the same water depth(50 mm) and stills at the same quantity of saline water (30 and 50 l). The results indicate that the productivity of finned and corrugated solar stills were higher than that for conventional still. Also it has found that at quantity of saline water 30 l the productivity increased, when finned solar still and corrugated solar still were used approximately by 40% and 21% respectively. In this case the daily efficiency for finned, corrugated and conventional solar stills were approximately 47.5%, 41%and 35% respectively.

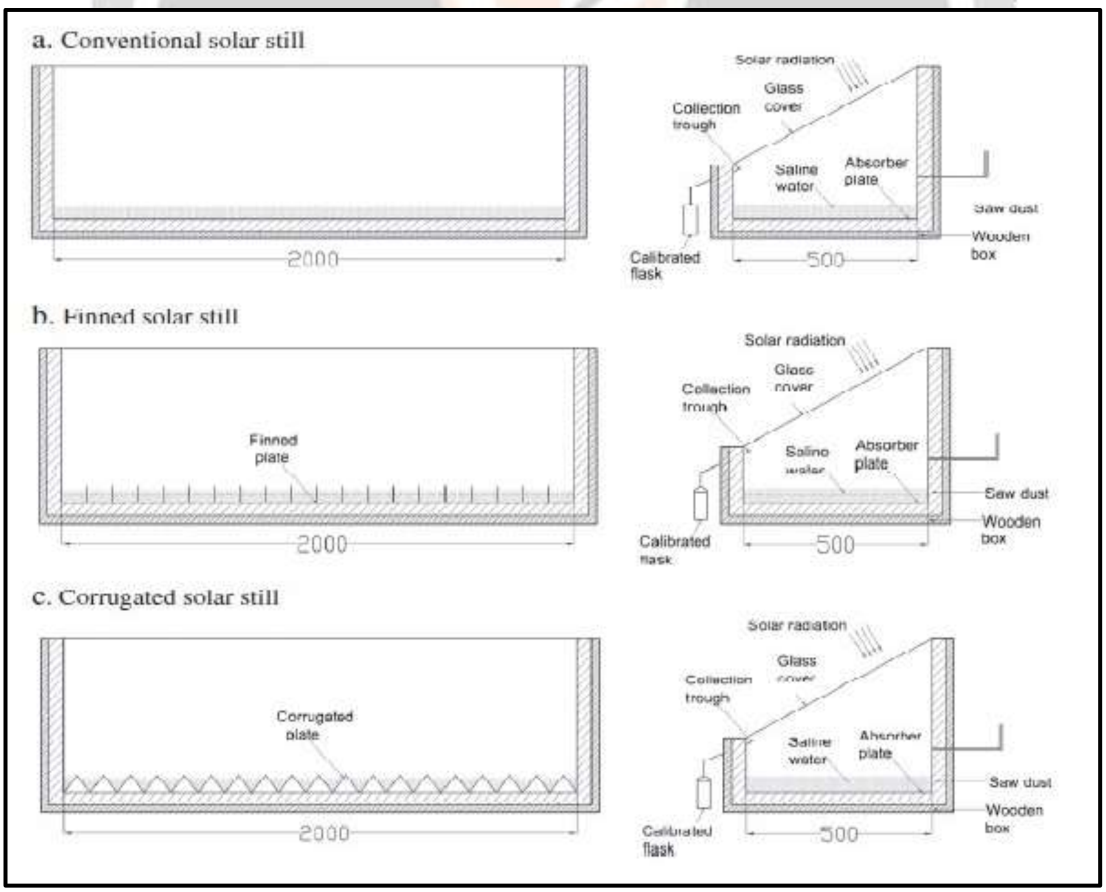

Fig -10 Schematic of Finned and Corrugated Solar Still Test Unit [13]

Fig -11 Photograph of experimental setup [13]

Ayuthaya *et al.* (2013) [14] presented an indoor experiment on developing a mathematical model for predicting the productivity of an ethanol solar still of basin type. The test still contained a horizontal evaporating surface and a condensing surface inclined 14^o to a horizontal. Various concentrations of ethanol-water solution were employed for the experiment. The distillation temperature range included boiling point. The collected data were used to estimate the mass-transfer coefficient and mass transfer conductance of the solar still. Accordingly, a mathematical model was developed based on the Spalding theory of convection and the Fick's law of diffusion. In order to increase the performance at the outdoor conditions, a basin solar still was integrated with a set of fin-plate fitting in the still basin for distillation of a 10%v/v alcohol solution. It was found that the productivity of the modified solar still was increased by 15.5%, compared to that of a conventional still. Moreover, the predicted still efficiency by the model could increase to 46% when a number of fins that raised an effective absorptance were increased. Condition of high concentration output and high productivity was investigated. Monthly mean productivity and efficiency of the still were found to increase with daily mean insolation.

Fig -12 Strip-fins attached on Absorber Plate [14]

Srivastava *et al.* (2013) [15] proposed a modified model for the single basin single slope solar still. Porous fins made up of blackened old cotton rags were partially dipped in the basin water, while the rest of the part extended above the basin water surface. The extended part of the fins receives most of the solar radiation with minimum shading. The basin water is relatively cooler, thus causing lesser base heat loss. Early morning start-up and higher operating temperatures were reached, giving enhanced heat transfer coefficients and evaporation rate. The basin water primarily acts as a thermal storage which supplements the evaporation process during low insolation, besides giving a reasonable nocturnal output. 56% higher day time distillate and 48% higher for 24 h duration was obtained in the month of February over conventional still, whereas, in the month of May, 23% higher day time and15% higher for 24 h was achieved. A maximum distillate output of about 7.5 kg/m^2 was achieved in the month of May in the case of the modified still made of expanded polystyrene foam with good insulation property. The distillate production increases with the decrease in the basin water depth. Experimental results are in fair agreement with that obtained by the thermal model. The modification can also be applied to deep basin type stills.

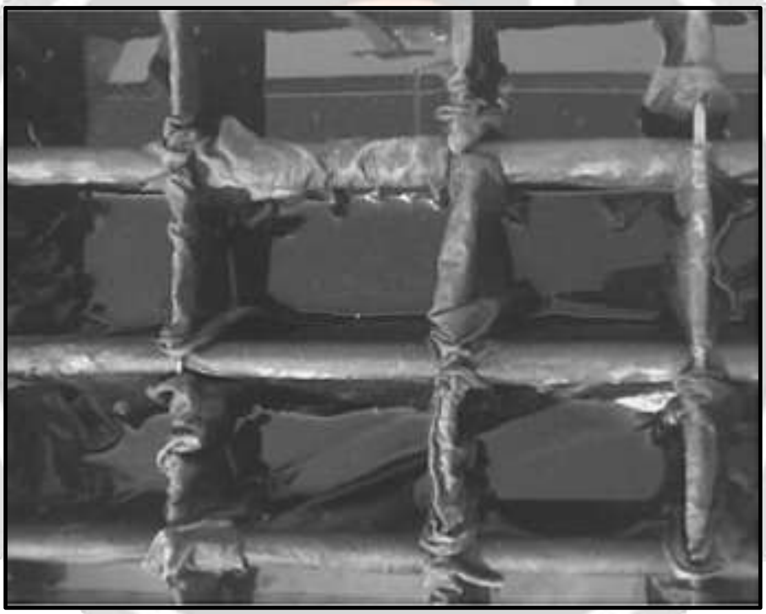

Fig -13 Photograph of the porous fins [15]

El-Sebai *et al.* (2015) [11] have done efforts to enhance the rate of heat transfer from the basin liner to the basin water; fins were integrated at the basin liner of the still. Experiments were performed on a finned plate solar still during June and August 2014 under Tanta (latitude 30° 47′ N, Egypt) weather conditions. For the first time, the dependence of the still efficiency and productivity on the fin configuration parameters such as the number, height and thickness was studied. Furthermore, the effect of the shadow area of the fins (by changing the fin number) on the amount of solar radiation available for water evaporation and hence, its effect on productivity was also investigated. It was found that, the productivity of the finned plate solar still (FBLS) increases with increasing the fin height; however, it decreases with increasing the fin thickness and fin number. A daily productivity of 5.377 (kg/m^2 - day) was obtained when the number, height and thickness of fins were equal 7, 0.04 m and 0.001 m, respectively.

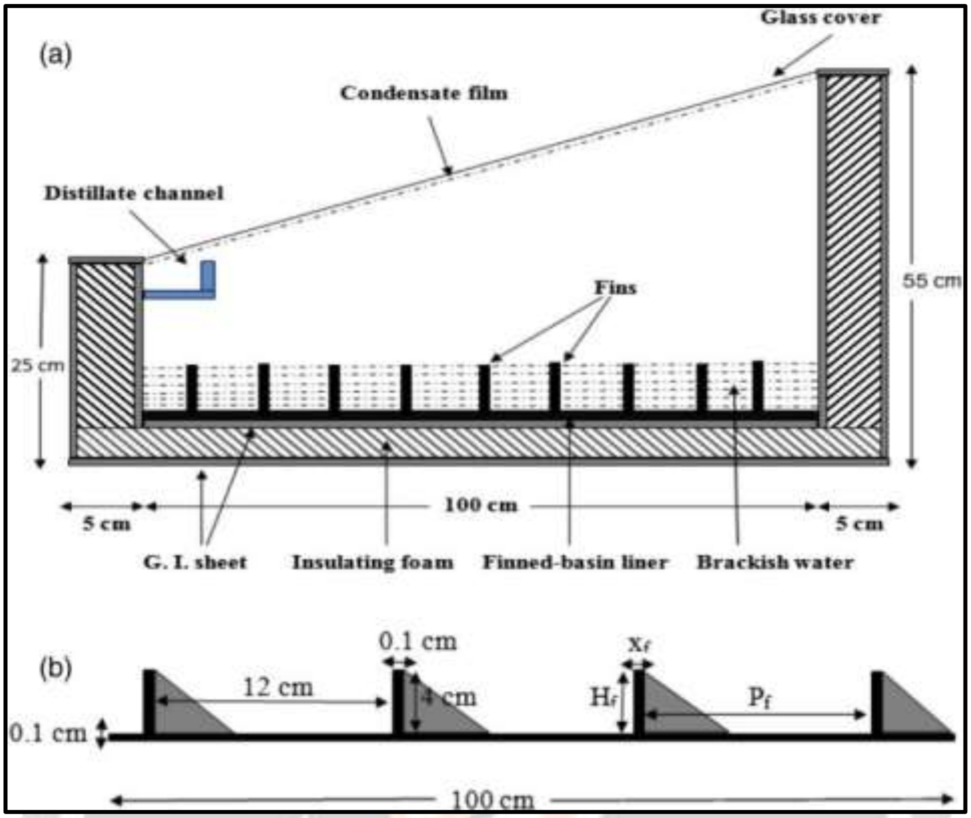

Fig -14 (a) graphical illustration of the finned absorber plate solar still (b) Specified dimensions of attached fins [11]

El-Sebai *et al.* (2016) [16] investigated the thermal performance of a finned single basin solar still experimentally and theoretically using finned basin liner made of different materials such as aluminum, iron, copper, glass, stainless steel, mica and brass. The theoretical model was validated experimentally with a finned basin liner made of copper as example.

Fig -15 The photograph of constructed solar still [16]

The year round performance of the still in terms of the monthly average of daily productivity and efficiency was performed. Furthermore, the year round productivity was employed to calculate the cost of one liter of the produced fresh water. It was also inferred that the fin material did not affect the still productivity. Therefore, it is advisable to construct basin liner of finned solar still from mica or glass where they do not corrode in contact with saline water.

Alaian *et al.* (2016) [12] presented an experimental investigation on the performance of solar still augmented with pin-finned wick evaporation surface. The experimental system involves two identical solar stills; one of the stills is conventional and the other has an evaporation pin-finned wick surface. The fins were supported vertically on the basin of the still using steel wires. Outdoor experimental tests are conducted to investigate the effect of using pin-finned wick on the still productivity.

Fig -16 Pin fin of wick elements placed on the absorber plate of solar still [12]

Fig -17 Experimentation apparatus [12]

Tests were carried out at wide range of ambient temperatures and solar radiation. Temperatures at different locations (glass surface, water in the still, wick surface and air–vapor mixture) as well as ambient temperature were recorded with time. Solar radiation as well as collected distillate was recorded during the experiments at different operating days. Experimental measurements indicate that the increase in distillate varies with ambient conditions. Enhancing the still productivity is proved when pin-finned wick is applied in the still. System efficiency of about

55% is recorded when pin-finned wick is used. An enhancement in the still productivity of more than 23% is recorded during this set of experiments.

3. CONCLUSION

The study of solar thermal-desalination devices as solar still using various methods of increasing heat transfer rate is been carried out. For enhancing the heat transfer rate in solar still, utilization of nanofluids and providing fins on the absorber plate is included in the study which gives promising results. The augmentations of glass cover and orientations of solar still are also considered for the survey. The review concludes that the use of nanofluid, wick material and extended fins boosts the heat transfer rate and hence the distilled output of the solar still. And the single sloped solar stills were used in the location having larger latitude angle, for the lower latitude angle near the equator, double slope solar still much more promising outcomes.

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