Performance improvement of double slope solar still using aluminium fins and phase change material

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Abstract
Double slope single basin passive solar still is the best choice for drinking water prone remote areas Investigations show its limitation because of its lower performance in terms of distillate output. The purpose of this study is to evaluate experimental results of double slope solar still using phase change material and circular fins. This work presents the characteristics and working principles of the double slope solar still by using phase change materials and circular fins and the researchers in this field are described from the viewpoint of experimental tests, theoretical analyses as well as practical applications. The objective of this present work is to improve the performance of a solar still through increasing the productivity of fresh water. In modified solar still $Mg_2SO_4.7H_2O$ is as phase change material and aluminum circular fins are used. The materials are added to the basin of the solar still to enhance the performance of solar still. For experimentation two identical solar stills of double slope having basin area of 0.5×0.5 m^2 were designed, fabricated and tested to compare the productivity of the solar desalination system. One of them is conventional solar still (without fins and PCM) and other one is of contains aluminum fins and for another day one modified solar still contains aluminum fins and second one contains 1 Kg of PCM. Experiments were conducted at water depth of 5 cm in climate conditions of Jabalpur (23° 10' N, 79° 59'E), Madhya Pradesh India. The experimental results show that, the daily freshwater yield for solar still with phase change material and aluminum fins has higher than that of conventional solar still. For the first day daily freshwater productivity approximately reached 1400 & 1700 ml/m^2 day for conventional solar still and modified solar still(with fins) and for second day daily freshwater productivity approximately reached 1560 & 1940 ml/m^2 day for modified solar still(with fins) and modified solar still(with 1Kg PCM) at 5 cm water depth respectively.

Key words: Solar still, Desalination, Double slope solar still, Aluminium circular fins, Phase change materials, Performance, Productivity.

Introduction

Water is an elixir of life. Due to the global warming and climatic changes the fresh water available is abating rapidly day by day. At the same time due to rapid growth of population in all over the world the requirement of fresh water is increased. Also on the other hand, there are many arid and desert regions in the world with less frequent rainfalls and ground water shortage. Therefore, the availability of good quality water is the major challenge in front of developing as well as developed countries. Water covers approximately three fourth of Earth's surface. About 97% is salty seawater with harmful bacteria and the remaining 2% is frozen in glaciers and polar ice caps [1]. Thus, only about 1% is available as fresh water. Brackish saline water can't be directly used as it may lead to serious damage. Hence there is a need for technically feasible and at the same time economically viable solution to purify the brackish and saline water [2].

Solar distillation is one of the most renewable methods. Solar distillation is used to provide potable water or to provide water for batteries, laboratories and in hospitals. It can be used in any place because it is portable. It is also used in deserts and in brackish areas where pure water is not available. The drawback of using solar still is its productivity .The main aim is to increase the productivity [3]. Till today, many experimental and theoretical studies are commenced to modify the solar still using different configurations and to improve its yield. **Mr. A. Prabakaran (2018) [4]** did an experimental study to improve the productivity of single basin single slope solar still with thermal energy storage. Two types of solar still were designed and fabricated, in order to study the performance of each still. The first one is a conventional type and the second one is a modified solar still which has squared fins and thermal energy storage material. The performance of two different solar still were tested under two cases. In the first case conventional solar still is compared with modified solar still which has square fins placed in the basin of solar still. In the second case conventional solar still is compared with modified solar still in which square fins packed with thermal energy storage material The result show that the modified still has improved the productivity by 41%,61%, than the conventional solar still under same climate conditions for the first and second case respectively. **Miqdam Tariq Chaichan (2018) [5] used** Nano particles were dispersed in paraffin wax (as a phase change material) to increase the thermal conductivity of the latter compared to the base material. The mixing of Nano particles with the wax changes the thermos-physical properties of the used wax. The thermos-physical properties as density, viscosity, and thermal conductivity showed increasing values in contrast to the specific heat where it reduced relatively. In this three distillers were made to study the effect of adding these Nano particles to simple solar distillers. The first of which was without any modification and the second had paraffin wax as additional material. In the third distiller, combination of paraffin wax with a nano-Al_2O_3 spread on it that was used to promote thermal conductivity. They observed that the addition of Nano particles to paraffin wax increased significantly the rate of heat transfer, resulting in higher yields of the solar distiller. Paraffin wax addition caused an increase in the daily distillation yield up to 10.38% while the addition of nano-Al_2O_3 to paraffin wax improved distillate yield up to 60.53% compared to the simple distiller yield due to continuous distillation after the sunset.**Nader Rahba (2018) [6]:** In this study, two types of solar stills, triangular and tubular one, had been experimentally tested under a real weather condition. Following the same procedure, the experiments were carried out over seven typical winter days and the effects of solar radiation and ambient temperature on water productivity and total efficiency of the stills has been experimentally investigated. Furthermore, to understand the detail structures of the air flow inside the enclosures, the fluid flow has been numerically simulated using computational fluid dynamics. Having the details of the fluid flow, the values of local entropy generation in the chamber have been obtained. The results indicated that the tubular still showed a better performance by 20% compared to the triangular one. **A. Muthu Manokar (2017) [7]**In this paper researcher presents a comparative study of single basin single slope aluminum finned acrylic solar still and single basin single slope galvanized iron solar still. By using acrylic sheet as casing as it has very low thermal conductivity, it reduces the loss of heat from the still basin to the bottom which leads to increase in the rate of evaporation of water. The daily productivity of single basin single slope acrylic solar still is 660ML/0.25M^2/day and galvanized iron solar still is 585 ML/ 0.25M^2/day. **S. Shanmugan (2017) [8]** Belongings of incorporating (Al_2O_3) Nano particles of wick materials in the solar still of a PCM charity in the basin for TES organization have been probed in this study. It is an innovative organization of techniques by a drip button to decant saline water drop by drop on absorbing materials in the basin. It (summer and winter) has been established with the dripping of saline water on altered absorbing materials like CW, FWCW, JW and FWJW as the basin liner. Diurnal variations of drip button temperature, T_g, T_b, T_w and mass of the output have been verified. Vitality equilibrium equations for the moist air inside the still, glass cover and wick material have been solved to get the analytical expressions for the instantaneous efficiency of the anticipated structure. **S. Joe Patrick Gnanaraj et.al (2017) [9]** during the analysis attempt was made to optimize the performance of double basin solar still. The dimension of the lower basin was 100 × 140 cm2 and the dimension of the upper basin was 100 × 100 cm^2. So the lower basin was 100 × 20 cm^2 glass cover in both the sides of the still to receive direct sunlight. They uses external energy sources such as reflectors, flat plate collector and mini solar pond. The productivity of single basin still, double basin still with no external modifications, double basin still with reflectors, double basin still with reflectors coupled with flat plate collector and mini solar pond was 2745, 4333, 5650 and 6249 ML/day respectively. The productivity of double basin still, double basin still with reflectors and double basin still integrated with flat plate collector and mini solar pond was 57.83%, 105.8% and 127.65% respectively higher than the single basin still. These modifications increased the performance of lower basin and upper basin. But the relative contribution of lower basin improved from 29.75% to 35.22% and to 40.6%. **Ibrahem Altarawneh ET. Al (2017) [10]:** In this research work, the annual performance of single basin single slope, double slope and pyramidal shaped solar stills has been investigated experimentally and theoretically. Figure 4shows single basin single slope solar still. Experiments were performed in Ma'an area in Jordan throughout the year from January 2015 to December 2015 on clear days using solar stills with different orientations and different tilt angles of 15°, 30° and 45°. And the mathematical models of solar radiation and solar desalination were developed to simulate the availability of solar radiation and the performance of the solar stills. The average basin area was found to be of 0.64 m^2 and 0.82 m^2 in January and July, respectively. Annual optimal tilt angles of 30.3°, 45°, and 65° were suggested for south oriented single slope, double slope and pyramidal shaped solar stills, respectively. Under optimal settings, the single slope solar still was found to be the best system with improvement in productivity of about 28%.**A. Muthu Manokara (2016) [11]** This paper presents a comparative study of single basin single slope aluminums finned acrylic solar still and single basin single slope galvanized iron solar still. By using acrylic sheet as casing as it has very low thermal conductivity, it reduces the loss of heat from the still basin to the bottom which leads to increase in the rate of evaporation of water. The daily productivity of single basin single slope acrylic solar still is 660ML/0.25M2/day and galvanized iron solar still is 585 ML/ 0.25M2. **Hasan Mousa (2016) [12]** In this paper The results showed that the presence of PCM with 40 ºC melting point maintains higher water temperatures after sunset but negatively affects the productivity. Decreasing the feed flow rate from 10 L/hr. to 1 L/hr. improved the fresh water productivity by 49%. When the maximum solar intensity increased from 400 to 1000 W/m^2, the fresh water productivity increased from 0.75 L/day to 2.1 L/day. **Chendake A.D. (2015) [13]**Here in this work the sun's energy is used to heat the water and increases the rate of evaporation. As the water evaporates, water vapor rises and condenses on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The purpose of this research is to design a water distillation system that can purify water from nearly any source. The designed model produces 1.6 liters of pure water from 12 liters of dirty water during eight hours. The TDS in the pure water was 30 ppm. The efficiency was 22.33 % at water depth of 0.02 m. **T. A. Babalola (2015) [14]**As the increasing demand for potable water, researchers have developed various technologies to meet this target. In this research, the productivity of water by a double slope solar still was determined by varying the water depth and surrounding temperature for nine days in the premises of Lagos State University, Ojo, Nigeria at 6.5ºN, 3.35ºE. It was observed that at a depth of 2.0cm the maximum output of The solar still was obtained and a maximum efficiency of 25.3%.**T. Elango (2015) [15]:** This paper presents a new approach to increase the productivity of the solar still by using glass as the basin material. And they were performing the experiments by varying the water depths from 1 to 5 cm under both insulated and un-insulated conditions. They observe that the production of single basin is more than the double basin during the heating period and double basin is more during the cooling period. The performance of the double basin double slope solar still was higher than the single basin double slope solar still under insulated and un-insulated conditions. The productivity of the stills was more at the lowest water depth of 1 cm. At 1 cm water depth, double basin insulated and un-insulated stills gave 17.38% and 8.12% higher production than the single basin still**. Rajaseenivasan (2013) [16]** In his research paper a new approach to enhance the productivity of a solar still by introducing an additional basin in the double slope solar still. Single basin and double basin double slope solar still shown in figure 7 & 8.The author modelled two solar stills, single basin double slope and double basin double slope with the same basin area and tested They performed experiments with various depths of water, different wick materials, porous material and energy storing material. They observed in double basin still, a mass of water in upper basin is constant for all experiments. For both stills, water production decreases with increase of water depth. The production rate is higher for both the stills, when mild steel pieces are used as storing material in the basin. For the same basin condition, double basin still production is 85% more than single basin still. **Gajendra Singh (2011) [17]** Here in this work researcher design and fabricate a modified photovoltaic thermal (PVT) double slope active solar still for remote locations. systems performance has been experimentally evaluated under field conditions in natural and forced circulation mode (series and parallel).they has been used Photovoltaic operated DC water pump between solar still and photovoltaic (PV) integrated flat plate collector to re-circulate the water through the collectors and transfer it to the solar still. The production rate has been accelerated to 1.4 times than the single slope hybrid (PVT) active solar still and obtained highest (7.54 kg/day) for the parallel configuration in forced mode in the month of October, 2010. The daily average energy efficiency of the solar still was obtained as 17.4.

About Solar Energy

The sun radiates the energy uniformly in the form of electromagnetic waves in all directions. When absorbed by body, it increases its temperature. It is a clean, inexhaustible, abundantly and universally available renewable energy [18]. Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy could be used, it will be the one of the most important supplies of energy, especially when other sources in the country have depleted. This solution is solar water distillation. It is not a new process, but it has not received the attention that it deserves. This is because it is such a low-tech and flexible solution to water problems. Nearly anyone is capable of building a still and providing with completely pure water from very questionable sources. 3.8x1024 joules of solar radiation is absorbed by earth and atmosphere per year. Solar power where sun hits atmosphere is 1017 watts and the total demand is 1013 watts. The sun gives us 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times what the world will require. The energy radiated by the sun on a bright sunny day is 4 to 7 Kwh per m2 [19].

Solar distillation

Solar distillation systems (Solar Stills) are classified broadly into two categories: passive and active solar still. Passive system in which solar energy collected by structure elements (basin liner) itself for evaporation of saline water. In the case of active solar still, an additional thermal energy by external mode is required for faster evaporation. To accomplish this goal by utilizing and converting the incoming radioactive power of the sun's rays to heat and distill dirty and undrinkable water, converting it into clean drinkable water.

Solar still

Solar still is a device that produces pure water without the use of any conventional source of Energy. A large use of solar stills is in developing countries where the technology to effectively distill large quantities of water has not yet arrived. Solar distillers can be used to effectively remove many impurities ranging from salts to microorganisms and are even used to make drinking water from seawater. Sol Aqua stills have been well received by many users, both rural and urban, from around the globe. Sol Aqua solar distillers can be successfully used anywhere the sun shines.

Experimental setup:

Solar still is a simple device which can convert available water or brackish water into potable water by using solar energy. The experimental setup consists of two double slope solar stills namely conventional and modified solar still. The modified solar still is contains fins and phase change materials**.** Two identical solar stills were designed, fabricated and constructed to compare the distillate output of the solar desalination system. Basin surface of all solar still are having size of 0.5×0.5 m^2 and painted in black to increment the solar radiation absorption. The elevation of the high-side wall in the middle of still has been kept at 0.27 m and the elevation of the low-side wall has been kept at 0.12 m. Also, the basin of the conventional solar still is insulated through the side and the bottom by a 1 mm thick thermo-col sheet insulation to reduce the loss in heat energy from the still to the ambient. All solar stills are made up of rectangular Grey Cast Iron sheet of 1 mm thickness. And 10 mm thick plywood is used to provide support at outside of solar still. The still cover is made of 4 mm thick glass plate, and it is inclined by 23° to the horizontal. Glass putti is used as a bonding material to prevent any leakage. All the solar stills are kept at obstacle free roof and the experiments for the present study using double slope solar still is made in such a way that the glass cover facing North-South Direction so as to receive the maximum solar intensity falling on the inclined surface.

The condensate water is collected in galvanized iron channel fixed at the lower end side of the glass covers both side. Set up is well equipped with instruments such as k type thermocouple and digital display thermometer to measure the temperatures of various sections of each still. Solar radiation meter (range 0-2000 w/m^2) is used to measure solar radiation available at glass. Measuring flask of capacity (0-1000) ml was used to measure distillate output from both stills.

Experimental procedure

The experiments were conducted in the month of November at Jabalpur City, Madhya Pradesh State in India. One of the stills is the conventional solar still and the other solar stills with Al fins with water depth (5cm) taken constant for all the experiments. For the first time one solar still is conventional and other contains Al fins. Experiments have been executed to compare distillate yield of modified solar still at same water depth. The performance is also compared with conventional solar still kept at same ambient condition at the beginning of the experiment; the water depth of 5 cm was maintained inside both the basins. Hourly measurements were taken from 8 am to 6 pm. Variables measured in the present experiments were ambient temperature, water temperature, inside and outside glass temperature, vapour temperature, and productivity, the output is measured for a day at every hour till sunset and collectively for the night at next day morning. Sky condition was also observed for the duration of conducting the experiments so that results pertaining to clear sky conditions. For the second time one solar still contains fins and another contains PCM and whole process mentioned above and all parameters mentioned are measured.

Fig.1 (a) Photographic view of the experimental setup.

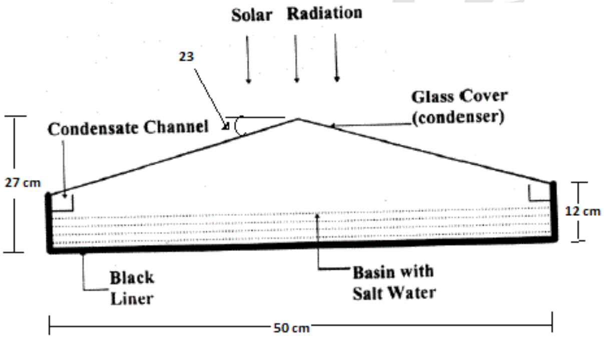

Fig.1 (b) Schematic Diagram of Solar stills

Table 2.1: Properties of Aluminum fins

S.no	Properties	Value
1	Density fins	2700 kg/m^3
2	Fins length fins	20mm
3	Internal dia. fins	5mm
4	Outer dia. fins	7mm
5	Weight of fins	1.5 g each
6	Weight of base material	170 g

Fig.2 (a) Photographic view of single fin used in experiment

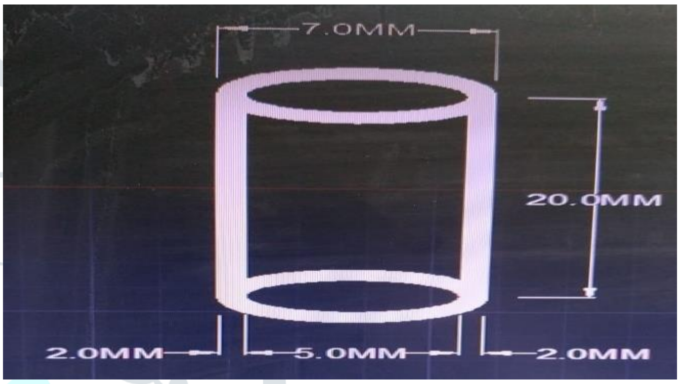

Fig.2 (b) Dimensions of fin used in experiment

Fig.2 (b) Photographic view of the fins with base material used in experiment.

Table 2.2: Properties of $MgSO_4.7H_2O$

S.no.	Properties	Value
1	Density	2.66 g/cm^3
2	Molar mass	246.47 g/mole
3	Odor	Odorless
4	Soluble in water	1139/100ml (20°C)

5	Tmelting	48.5 °C
7	Latent heat	202 KJ/Kg
8	Reflective index	1.433

Fig.2 (c) Photograph of the PCM used.

Result and discussion

Hourly variation of ambient parameters

Fig. 3a and b show typical variation of hourly solar radiation, ambient temperature at Jabalpur on two typical days corresponding to conventional still and modified still. The depth of water in the basin was maintained 5 cm and one of modified solar still contain fins and amount of PCM 1.0kg. From the figure it is observed that both solar radiation intensity and ambient temperature Increase to the utmost level at the midday and steadily decrease after that. It can be concluded from the plot

Solar variation is parabolic in nature that peaks 730W/m^2, 750w/m^2 at around 1 pm and 1 pm respectively on 01/11/2017 and 08/11/2017 and becomes zero at 6 pm on respective days. Peak ambient temperatures are observed 33.5 °C and 34.3 °C at 1pm and 1pm respectively on 01/11/2018, 04/11/2018 and 08/11/2018

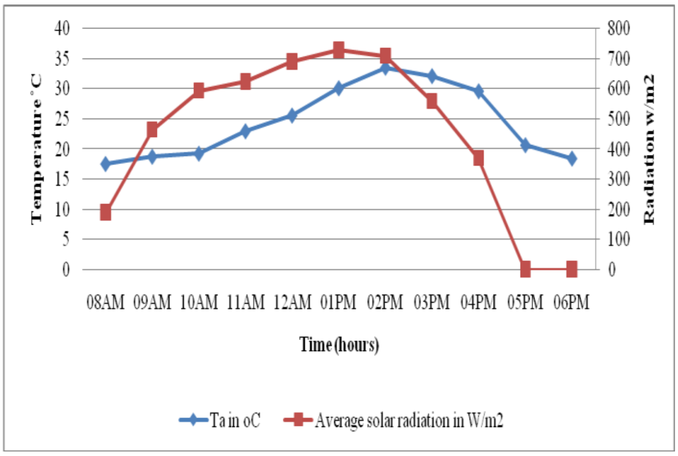

Fig.3 (a) Hourly variation of solar insolation, ambient temperature on 01/11/2018

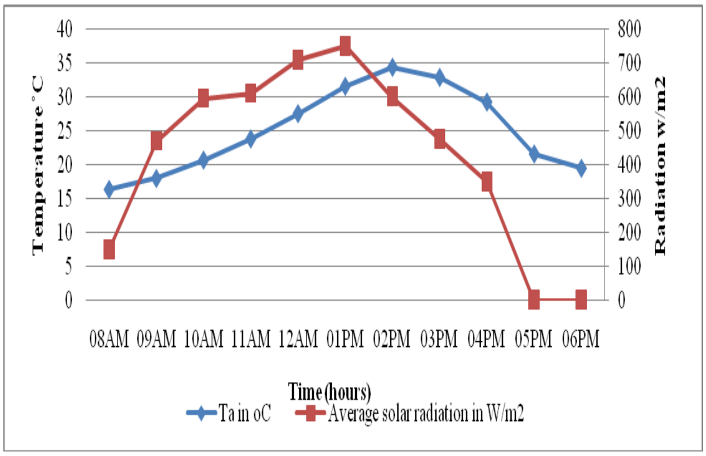

Fig.3 (b) Hourly variation of solar insolation, ambient temperature on 01/11/2018

The effect of the solar radiation intensity on the behavior of the solar still

Fig 4(a) shows variation of water temperature in conventional solar still on a typical days corresponding to ambient temperature and solar radiation. The depth of water in the basin was maintained 5 cm. from the figure it is observed that solar variation is parabolic in nature that peaks 730W/m^2 around 1 pm and ambient temperature increase to 33.5˚C at 1 pm it is observed that highest T_g, T_{gi}, T_v, T_w temperatures is observed 38˚C, 48˚C, 47˚C,49˚C respectively for conventional solar stills.

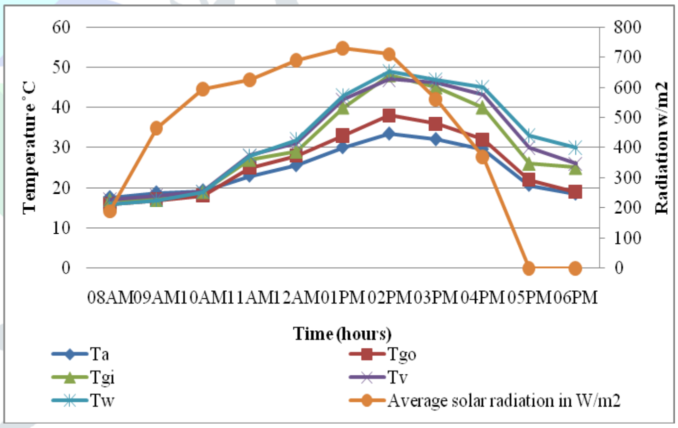

Fig.4 (a). Variation of temperatures for conventional still without PCM

Fig 4(b) shows variation of water temperature in modified solar still with fins on a typical days corresponding to ambient temperature and solar radiation. The depth of water in the basin was maintained 5 cm. from the figure it is observed that solar variation is parabolic in nature that peaks 730W/m^2 around 1 pm and ambient temperature increase to 33.5˚C at 1 pm it is observed that highest T_g, T_{gi}, T_v, T_w, T_{pcm} temperatures are observed 38˚C, 47˚C, 49˚C, 50˚C respectively for modified solar still.

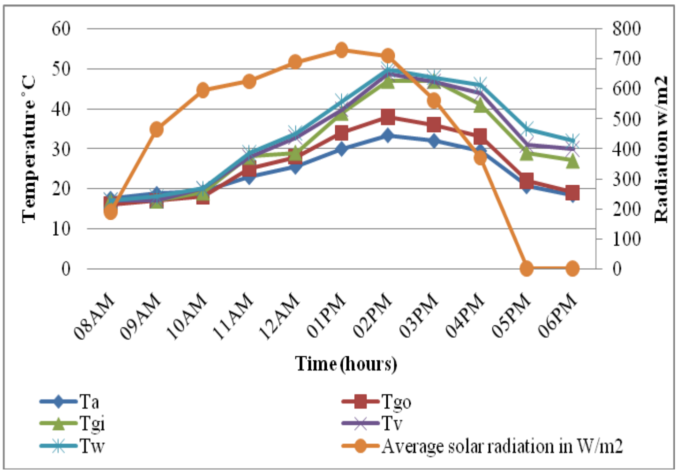

Fig.4 (b). Variation of temperatures for modified still with fins

Fig 5 (a) shows variation of water temperature in modified still with fins on a typical days corresponding to ambient temperature and solar radiation. The depth of water in the basin was maintained 5 cm. from the figure it is observed that solar variation is parabolic in nature that peaks 750W/m^2 around 1 pm and ambient temperature increase to 34.3˚C at 1 pm it is observed that highest T_g, T_{gi}, T_v, T_w temperatures is observed 40˚C, 47˚C, 48˚C, 50˚C respectively for modified still with fins.

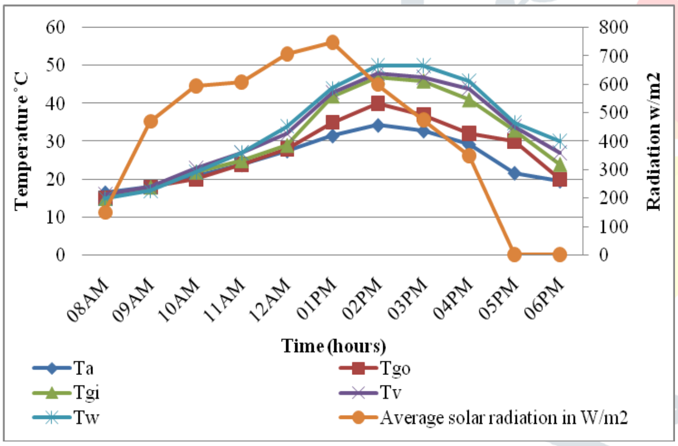

Fig.5 (a). Variation of temperatures for modified still with fins

Fig 5 (b) shows variation of water temperature in modified solar still with PCM(1 Kg) on a typical days corresponding to ambient temperature and solar radiation. The depth of water in the basin was maintained 5 cm. from the figure it is observed that solar variation is parabolic in nature that peaks 750W/m^2 around 1 p.m. and ambient temperature increase to 34.5˚C at 1 pm it is observed that highest T_g, T_{gi}, T_v, T_w, T_{pcm} temperatures are observed 39˚C, 45˚C, 47˚C, 49˚C, 52 ˚C respectively for modified solar still.

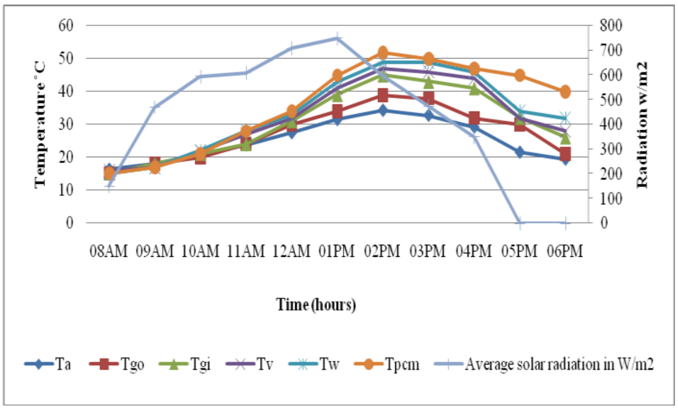

Fig.5 (b). Variation of temperatures for modified still with PCM of 1 Kg

Hourly output variation with daylight time

Time basis reading of water yield were observed in Fig 7 (a) shows the Comparisons between the hourly freshwater productivity for both solar still with PCM and conventional solar still corresponding to water depth of 5 cm during the period from 8:00 am to 6:00 pm.

The area under the curve indicates the daylight productivity of respective stills for all. For units with and without PCM, highest hourly productivity is observed at 2 pm. It can be seen that maximum output for conventional solar still and solar still having PCM is 310ml, 375 ml respectively.

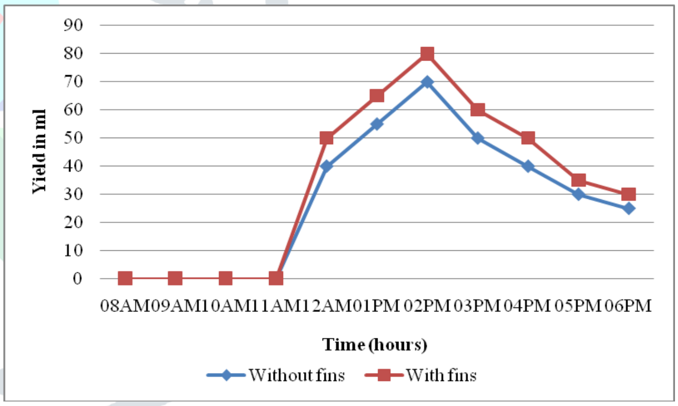

Fig7 (a). Hourly variation of distillate of both still for 5 cm water depth on 01/11/2018

Time basis reading of water yield were observed as shown in Fig 7 (b) shows the Comparisons between the hourly freshwater productivity for both solar still with PCM and conventional solar still corresponding to water depth of 5 cm during the period from 8:00 am to 6:00 pm.

The area under the curve indicates the daylight productivity of respective stills for all. For units with and without PCM, highest hourly productivity is observed at 2 pm. It can be seen that maximum output for modified solar still with fins and solar still having PCM is 330 ml, 360 ml respectively.

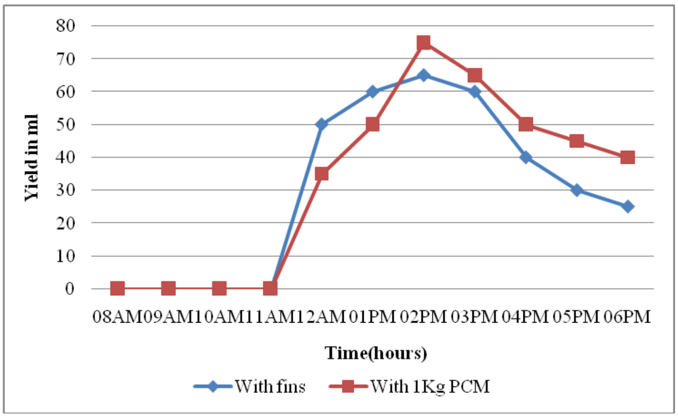

Fig7 (b). Hourly variation of distillate of both still for 5 cm water depth on 04/11/2018

Daily productivity

Fig 8 (a) shows the accumulated freshwater yield is approximately up to 425 ml/0.25m^2 day for the solar still with fins while its value was 375 ml/0.25m^2 day for the conventional solar still at water depth of 5 cm(08 am to 08 am). And 350 ml/ 0.25m^2 day for the modified solar still with PCM and 310 ml /0.25m^2 day for the conventional solar still at 5cm water depth in a day time.

Fig 8 (b) shows the accumulated freshwater yield is approximately up to 485 ml/0.25m^2 day for the solar still with PCM while its value was 360 ml/0.25m^2 day for the conventional solar still at water depth of 5 cm(08 am to 08 am). And 390 ml/0.25m^2 day for the modified solar still with PCM and 330 ml /0.25m^2 day for the modified solar still with fins at 5cm water depth in a day time.

Fig 8 (c) shows the accumulated freshwater yield is approximately up to 408,485 ml/0.25m^2 day for the solar still with fins and PCM of 1 Kg respectively while its value was 350 ml/0.25m^2 day for the conventional solar still at water depth of 5 cm (08 am to 08 am).

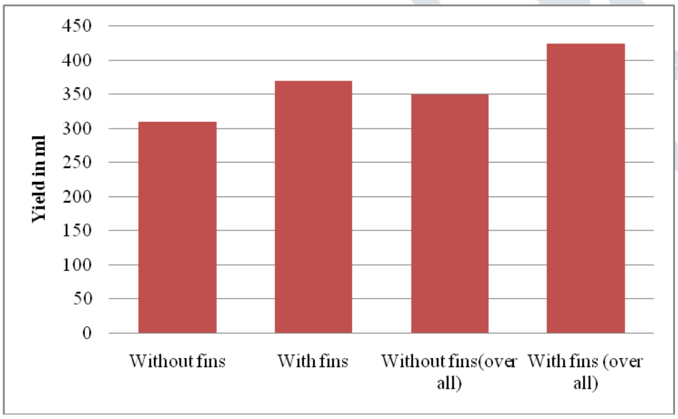

Fig.8 (a) Variation of distillate productivity in 10 hours (8 am to 6 pm) and 24 hours at 5cm water depth.

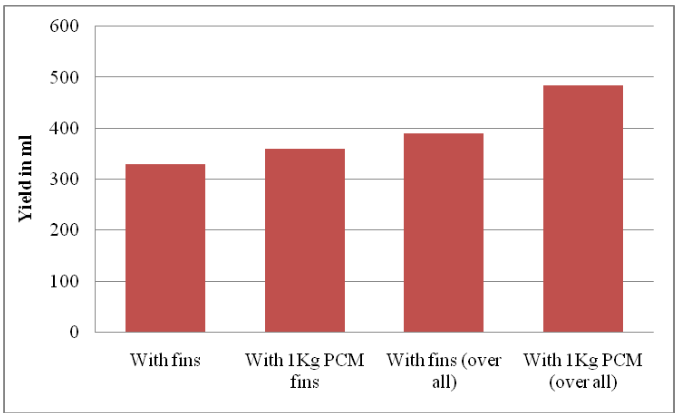

Fig.8 (b): Variation of distillate productivity in 10 hours (8 am to 6 pm) and 24 hours at 5cm water depth.

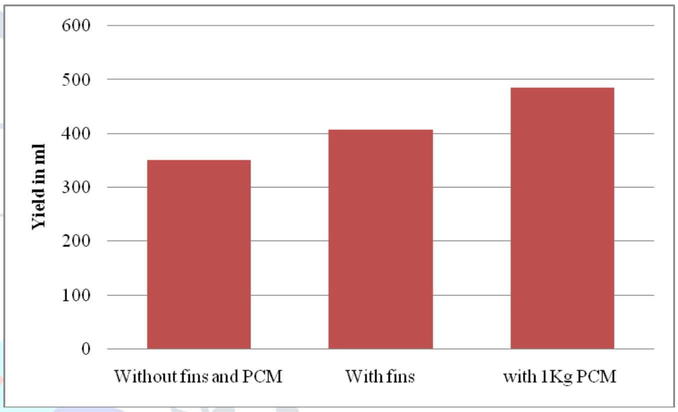

Fig.8 (c): Variation of distillate productivity in 10 hours (8 am to 6 pm) and 24 hours at 5cm water depth for all the three solar stills.

Conclusion

Experiments were conducted with aluminum circular fins and $MgSO_4.7H_20$ as Phase change material in a double slope single basin solar still. Their performance is compared with the conventional solar still i.e. without PCM and fins. The following conclusions are drawn.

1. Phase change material and aluminum fins in basin water increases thermal conductivity and convective heat transfer coefficient and hence the evaporation rate.
2. first day Modified solar still with aluminum fins 1500 ml/m^2-day at daytime and 1700 ml/m^2-day over all while conventional solar still gives1240 ml/m^2-day at daytime and 1400 ml/m^2-day over all at water depth of 5 cm
3. second day Modified solar still with aluminum fins 1320 ml/m^2-day at daytime and 1560 ml/m^2-day over all while another modified solar still gives1440 ml/m^2-day at daytime and 1940 ml/m^2-dayover all at water depth of 5 cm.
4.The daytime and overall productivity of modified still is higher in 50g capsule(1 Kg of PCM) solar still as compared to other two modified solar stills(with fins) and conventional solar still.
5.overall productivity of modified solar still is contains 50g capsules of PCM(1 Kg PCM) 38.57% higher than conventional still and 18.87 % higher than modified solar still which contains aluminum circular fins.

Nomenclature

Ta	Ambient temperature, °C
Tw	Water temperature, °C
Tv	Vapour temperature, °C
Tpcm	PCM temperature, °C
Tgi	Inside glass surface temperature, °C
Tgo	Outside glass surface temperature, °C
Ig	Solar radiation, W/m^2
PCM	Phase change material

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