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Productivity Enhancement of Single Basin Solar Still using Nanoparticle and Phase Change Material

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ABSTRACT
This experiment is based on enhancing the productivity of a conventional solar still by using techniques that have newly materialized. The modifications include using Aluminum Oxide (Al_2O_3) nanoparticle to produce Nanofluid (0.2% concentration) and Paraffin Wax as Phase change material (PCM) together in the still which is expected to facilitate production of more fresh water. The outdoor performance of modified solar still is studied to assess its potential for real application. It is compared with the results of a conventional solar still to better understand the effects of the modifications. It was observed that, on consecutive days, the conventional still had an efficiency of 10.15% whereas the modified still had a daily efficiency of 13.15%, 16.40% and 14.47% for three consecutive days under similar conditions of environment.

Keywords: Desalination, Solar still, Nanofluid, Phase change material (PCM).

1. Introduction

About 70 % of Earth's surface is made up of water. Of that, about 97 % is in the oceans. That only remaining 3% can be considered as freshwater. Of that small amount almost 2% is locked up at the North and South poles as glaciers and ice. The remaining 1% of freshwater is mostly ground-water, with a small fraction filling the world's lakes and rivers. So to meet the demand of freshwater for survival, it is high time to look for alternative sources of freshwater. And the most easily available source of water is the oceans. If it is possible to separate the freshwater content from the seawater then it would be a great means for eradicating freshwater crisis. But the major problem in desalination of water is that, it requires a lot of energy. Salt is easily soluble in water and it forms strong chemical bonds, which are difficult to break. Energy and the technology to desalinate water are both expensive, which makes desalinating water pretty costly.

The Earth receives an incredible supply of solar energy. It provides enough energy in one minute to supply the world's energy needs for one year. Solar energy is a free, inexhaustible resource, yet harnessing it is a relatively new idea. This tremendous source of renewable energy can also be used to desalinate seawater and obtain freshwater from it. One of the many ways of doing so is using a solar still.

A solar still is a device that is used to distill brackish or seawater, using the heat of the Sun to evaporate, cool then collect freshwater. The sun's energy heats water to the point when it starts to evaporate. As the water evaporates, the water vapor rises, condenses into water again on the glass cover as it cools and is then collected. This process leaves behind impurities, such as salts and heavy metals, and eliminates micro-biological organisms. The end result is pure distilled water. In a solar still contaminated water is contained inside the basin where it is evaporated by sunlight shining through clear plastic or glass. The pure water vapor condenses on the cool inside surface of the glass cover and then drips down due to the action of gravity. Then it is collected and removed from the system to be used. The major downside of this system is its productivity and the increased cost that is added while using different improvement methods to the system. Performance of a solar still can be increased by the help of various enhancement techniques of which use of PCM and Nanoparticles are noteworthy ones. Experiments have been conducted to increase the productivity of solar still using Nanoparticles as well as PCM of different kinds. This experiment is intend to use both Nanoparticles and PCM together in a solar still and try to estimate its overall efficiency escorted by a comparative study between the performances of the conventional and the modified solar still.

2. PREVIOUS STUDIES

Different methods for enhancing performance of solar stills have been introduced so far. The use of Phase Change Materials (PCM) or Nanoparticles is noteworthy in modern performance enhancement techniques. These elements perform as heat storage that absorbs heat from the sun during the day, stores it and then supplies the heat during the night so that the process of evaporation may continue for a longer period. Numerous work has been done so far using this two elements in pursuit of increasing the efficiency of a solar still.

2.1 Phase change material (PCM)

PCM is used to deliver heat during nighttimewhich was kept as solar thermal energy collected by the system at daytime as latent heat, thus allowing uninterrupted process.Over the last 40 years different classes of

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materials have been considered as feasible PCMs, including hydrated salts, paraffin waxes, fatty acids, the eutectics of organic and non-organic compounds and polymers.According to Fath [1], the latent heat thermal energy storage systems have many attributes that makes them a better choice over sensible heat storage system. For example, the steady temperature for charging and discharging and the vast energy storage bulk per unit volume. Radhwan [2], performed a study of a temporary enactment of a stepped solar still with compacted latent heat thermal energy storage for warming and humidifying of agronomic greenhouses (GH). In addition, he discussed the impact of paraffin wax thickness as a PCM. The total output was that of about 4.6 L/m^2 with an efficiency of nearly 57%. Naim et al. [3], placed an Energy Storage Material (ESM) in the still tray during its constructionresulting in increasing the still productivity. Aluminum turnings were added to a blend comprising of paraffin wax, paraffin oil and water to increaseheat conduction then, save during the hours of daylight and finally release it at night. The arrangement was used as a special phase change material. It improved the production to a maximum value of nearly 851 ml/m^{2}h when the amount of briny water was 40 ml/min. Systematic study of a still with and without PCM was done by Dashtban and Tabrizi [4]. The everydayyield reached 6.7 and 5.1 kg/m^2 with and without PCM, respectively.Ansari et al. [5] examined a still assimilated with a PCM under the basin. The results show that the heat energy storage increasesfavorably both the yield of the fresh water and the efficiency of the distillation method.

2.2 Nanoparticles

Many scientists have carried out severalstudies on solar stills enhanced with Nanoparticles which have become available means for improvement of a solar still performance. Nijmeh et al. [6] used violet dye and studied the efficiency of the solar still. The outcomes showed that the productivity was enhanced by 29%.Elango et al. [7] examined an experimentally used various Nanoparticles in a solar sill. When using the aluminum oxide (Al_2O_3) Nanoparticles the productivity increased by 29.95%, while the solar stills with tin oxide (SnO_2) and zinc oxide (ZnO) Nanoparticles gave 18.63% and 12.67% higher productivity than that without Nanoparticles, respectively.Mahian et al [8] demonstrated the effectsof the addition of carbon nanotubes (CNTs) to the water inside a single basin solar still. Results showed an escalation by about 50% in the productivity. Kabeel et al. [9] [10], presented an investigational study to increase the still yield by mixing the aluminum oxide Nanoparticles with the inlet water to the still. The results revealed that using Nanoparticles with providing the vacuum fan increased the solar still water productivity by about 116%. Sharshir et al. [11] utilized graphite and copper oxide micro-flakees with various fixations, distinctive basin water depth, and diverse film cooling stream rates to research the efficiency of a solar still. The micro-flakes concentrations were ranged from 0.125% to 2% and the basin Nanoparticles depths are ranged from 0.25 to 5 cm. The productivity was enhanced by about 44.91% and 53.95% using the copper oxide and graphite micro-flakes, respectively, compared with the conventional solar still. Furthermore, 38% and 40% increase in daily efficiencies were obtained when using copper oxide and graphite, respectively.

3. Statement of the problem

Solar desalination is the way toward changing over the polluted water into consumable drinking water utilizing sun's energy. The sunlight based desalination strategies have been utilized by the mankind for many years. In fact, solar stills were the primary technique which was utilized on a smaller scale to change over tainted saline water to consumable water. Be that as it may, the fundamental downside of the sun powered desalination technique is its low efficiency.

Determining a suitable area of absorption and identifying the minimum water depth which leads to the maximum daily yield was the major concern.Wasil Jamal and Prof. M. Altamush Siddiqui [12] conducted their experiments using a water depth of 2cm, 3cm, 4cm and 5cm respectively and finally concluded that the productivity was maximum for a shallow depth of water in the basin. Further, the yield decreased as the water depth was taken more being least at 5cm depth. With accordance to this research a water depth of 2cm was used in this experiment. Then, for the minimum water depth productivity improvement techniques were adopted. For this purpose, Aluminium oxide nanoparticles were added to the base fluid and Paraffin Wax was used as PCM under the basin tray.

The objectives of the research includes-

- To determine the productivity of the conventional solar still.
- To determine the productivity of the solar still in addition with nanoparticles in the water and Paraffin wax under the basin.
- To compare both of the daily yield and hourly yield of the system and thus finding out the productivity enhancement.

4. System Description

To develop a solar still with enhanced productivity Phase Change Material (PCM) and Nanoparticles were used. Paraffin wax was used as the PCM and Aluminum Oxide (Al_2O_3) Nanoparticles was used for the experimentation. The Nanoparticles was directly dispersed into the water to be desalinated and stainless steel pipes with PCM encapsulated inside was put on the basin liner to store the energy. The area of the still basin was 0.37 m^2 (0.762 m length × 0.483 m width). The stills was made of wood and a galvanized steel basin was placed inside the wooden frame where the brackish water mixed with Nanoparticles was placed. The brackish water was filtered as far as possible. A glass of 3mm thickness was used as the cover through which solar radiations will enter the still and it was kept in an inclined position. A sectioned PVC pipe inside the still was used to collect the fresh water from the glass cover, a plastic pipe was connected to the PVC pipe for draining the water to an outside bottle. The brine was drained outside of the still through another hole at the bottom. Tap water was used to work as the sea water in this experiment.

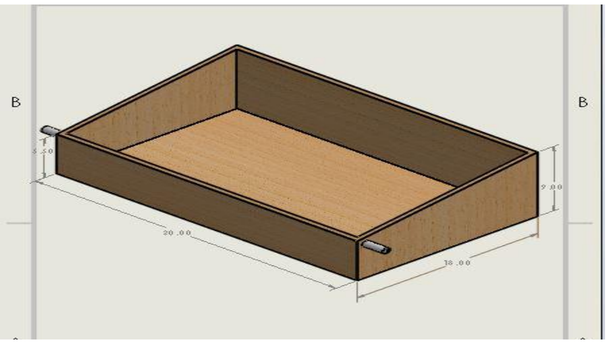


Fig.1 Experimental setup (3D view)

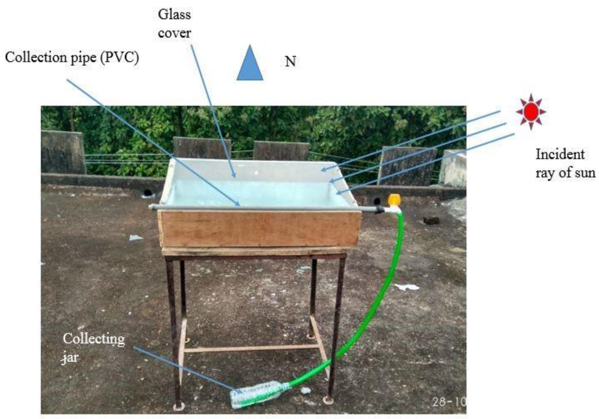


Fig.2 Fabricated system equipped with PCM and Nanofluid.

The inside basin was made of galvanized steel so that it could prevent corrosion due to constant use of water. The basin had a surface area of 0.37 m^2 (0.762 m length × 0.483 m width) and a height of 4 inches all around. A galvanized sheet of 2mm thickness was cut and shaped to the desired specification and the corners were gas welded.

The steel basin is placed inside the wooden frame and the conventional setup is thus completed by placing the glass cover of 3mm thickness over the wooden frame. The glass cover was then perfectly sealed using Silicon gum as sealant which would prevent the vapor from going to the neighborhood. Using this setup the readings were taken for productivity of potable water from brackish water using a graduated cylinder.

4.1 Addition of modifications

Addition of Paraffin Wax (PCM): In this experimentation paraffin wax was used as Phase Change Material (PCM) due to its low cost and easy availability. The wax was encapsulated inside stainless steel hollow cylinders of 19 inch length consisting of 0.5 inch internal diameter. Around 1.2 kg of wax was encapsulated in six such tubes. These tubes were placed under the steel basin so that it could gain the heat of the basin from bellow it. The tubes were sealed on both sides so that there were no leakage or loss of the wax.

Addition of Nanoparticles (Al_2O_3) to the working fluid: In the present study, Aluminium oxide Nanoparticles were used because of its high heat transfer co-efficient and availability. The aluminium oxide Nanoparticles were added in 0.2% concentration. The Nanoparticles were added with the brackish water by the help of stirrer and Nanofluid was prepared. This Nanofluid was introduced to the basin and the daily and hourly yields were measured.

4.2 Collection of data

Initially all data were taken considering the still to be a conventional one. After that modifications were added to the still and the new sets of data were taken. Data were collected for the whole day starting from 9:00 am in the morning up to 5:00 pm. The overnight productivity of the stills were measured on the next day at 8:00 am.The still was placed facing the south so that it could receive as much solar radiation as possible throughout the entire day. The data of the experiment was taken both on an hourly basis and daily basis. The amount of water which was obtained after distillation was collected in a graduated bottle and it was measured in a sensitive weight measuring device. Thus the actual amount of water obtained was found. The amount of solar intensity was determined by the help of a digital Solar Radiation Meter on an hourly basis. With the change of solar intensity the productivity of the stills were determined. From the two sets of measured data, one without any modification and other with PCM and Nanoparticles the productivity enhancement was compared. It was found that the daily yield increased while Aluminium oxide nanopartciles were added to the base fluid and due to the presence of Paraffin wax.

Fig.3 Collection of droplets of distill water condensed on the inner wall of the glass-cover.

5. Results and discussion

The data were collected during four consecutive solar days (21^{st}-24^{th} October), Day-1 (21^{st} Oct) being the data for conventional still and Day-2, 3 and 4 (22^{nd},23^{rd} and 24^{th} Oct) respectively being that for the modified still.

These data were plotted against time in order to understand the variations of results through eachhour of the day as well as the effect of the modification on the productivity.

a) Variation of Solar Intensity of four consecutive days of experimentation-

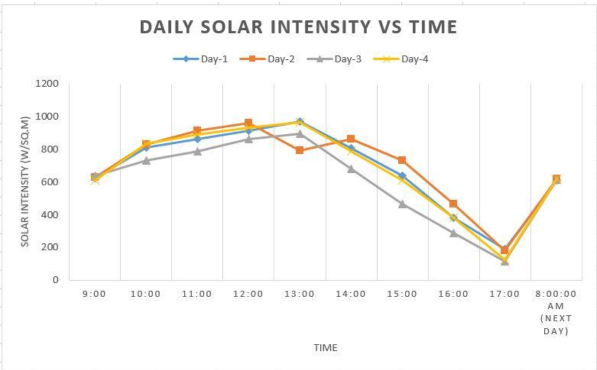


Fig.4 Comparison of the change of solar intensity for the days on which experimentations were conducted.

The data of the Solar Intensity of each day which was collected in an hourly basis was plot against time in the same graph to understand the variation of solar intensity during the entire span of the experimentation. From the figure it can be said that maximum intensity was obtained during the time period of 11:00 am to 1:00 pm. It may also be deduced that the variation of solar intensity for those days was minimum and its effect on the productivity may be ignored for the sake of comparison.

b) Variation of hourly yield of the solar still with respect to the variation of solar intensity-

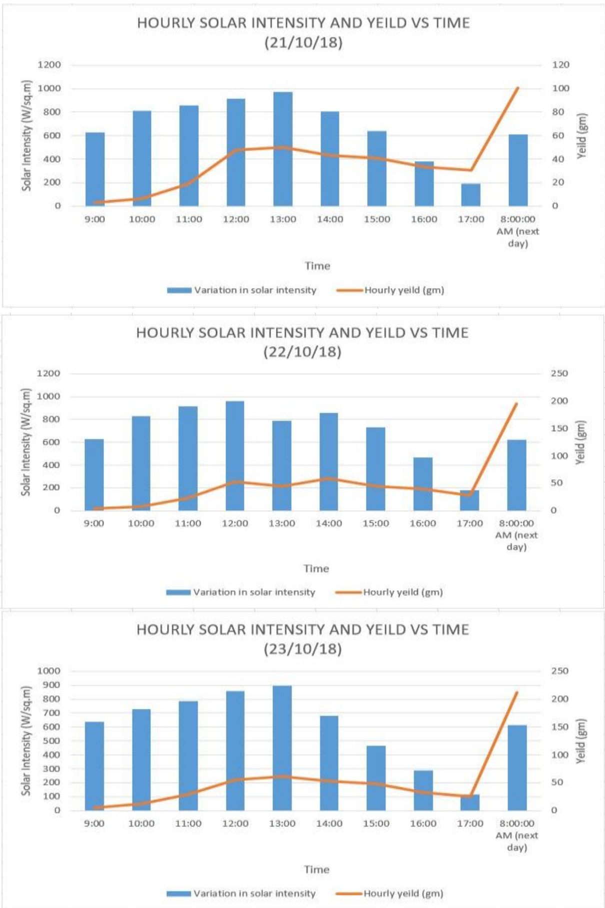
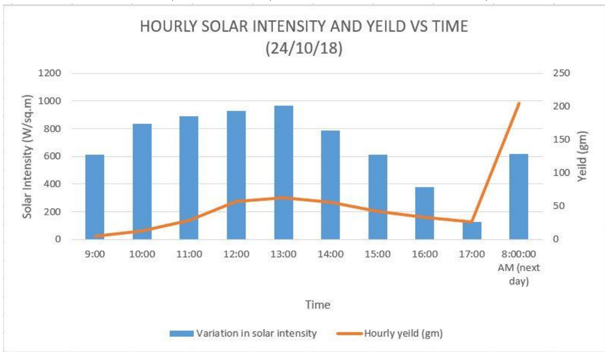


Fig.5 Comparison of the change of hourly yield of each day compared to the hourly solar intensity for both conventional (21/10/18) and modified still (22/10/18,



23/10/18 and 24/10/18)

Here the hourly yields of the still on consecutive days along with the hourly measure of solar intensity were plotted against time. The graph shows the change of the amount of yield of the conventional and modified still compared to the solar intensity variation on an hourly basis. Here it can be seen that the yield increased as the day advanced and in all the cases maximum output was obtained during 12:00 pm to 1:00 pm. The yield then gradually decreased during the end of the day as the solar intensity decreased.

c) Variation of hourly yields of conventional and modified solar still-

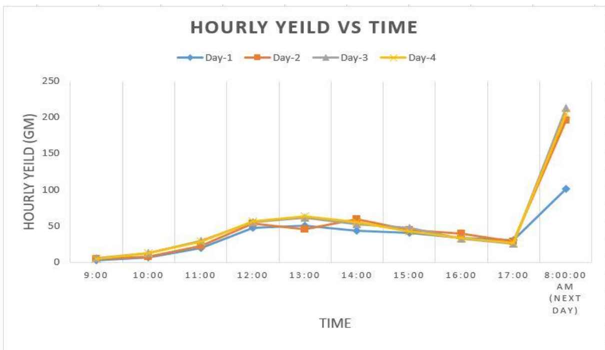


Fig.6 Comparison of the hourly yields of the conventional (Day-1) and modified (Day-2, 3 and 4) solar still.

The hourly yields from both the conventional still and the modified still were plotted against time in the same graph. The trend obtained from the graph shows that use of PCM and Nanofluid as modifications to the solar still has resulted in a better output each hour of the day. The data were collected up to 5:00 pm each day and the overnight productivity was measured at 8:00 am the next day. This difference in hourly yield of the solar stills will result in an increased daily yield which is the main purpose of the experiment. Here we see that the hourly yield of the conventional still is always lower than the modified one which is an indication of the effectiveness of the PCM and Nanofluid.

d) Variation of accumulated yield of conventional and modified solar still-

Fig.7 Comparison of the accumulated yields of the conventional (Day-1) and the modified (Day-2, 3 and 4) solar still.

Here the accumulated yields of the still, with and without modifications, were plotted against time. This graph provides a better evidence to the fact that using of PCM and Nanofluid has resulted in better overall productivity of the still. The blue line representing Day-1 shows the accumulated yield of the conventional solar still while the other lines, indicating Day-2, Day-2 and Day-4, show that for a modified one. Since the data were taken for the whole day, we see that, at 8:00 am the next day the accumulated amount of water is higher for the modified still on each day. This makes the modified still a better choice over the conventional one.
The daily efficiency of the solar is given by [13] –

$$\eta_d = \frac{\sum m_d \times h_{fg}}{\sum A_{eff} \times I \times t} \times 100\%$$

Where,
Latent heat of vaporization of water, h_{fg} = 2230 KJ/Kg
Net effective area of solar still basin, A_{eff}= 574 inch^2= 0.37 m^2
Time interval, t = 1 hour = 3600 s
m_d= mass of distillate water, ml
I= Intensity of solar energy, W/m^2
η_d= Daily efficiency, %

- ✓ Daily efficiency of conventional solar still,

$$n_d = \frac{(3+6+19+48+50+43+40+33+30+101)\times 2230}{0.37(625+810+860+915+970+805+640+380+190+610)\times 3600} \times 100\%$$

=10.15%

- ✓ Daily efficiency of the modified solar still on consecutive days were= 13.15%, 16.40% and 14.47%respectively.

6. Conclusion

The hourly and accumulated yield of the conventional and modified solar still for four consecutive days are shown in the figure-7 and figure-8.

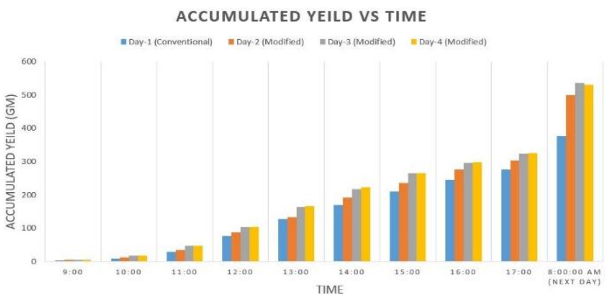


Fig.8 Bar chart representing the variation in hourly accumulated yields of the conventional and modified solar still for the whole day.

Here the hourly variation of yield of the solar still for four consecutive days have been represented in the form of bar chart. The blue bars represent the output of the conventional still while the red, gray and yellow bars are those for the modified ones. One can observe from the above figure that the accumulated yield of the conventional still always falls short compared to the productivity of the modified still. It can also be observed that the trend of hourly yield of the modified still is quite similar for all the three days. So it can be deduced that the process is stable and will produce a constant result if put to continuous use.
The figure-24 is a better indication of the final outcome of the experiment. In this figure the yellow bar represents the final yield of the conventional solar till considering the whole day and the overnight production. The blue bars represent the final yield of the solar still packed with modifications for three consecutive days. The experiment was conducted for 4 days so that the results can be verified and compared to one another.

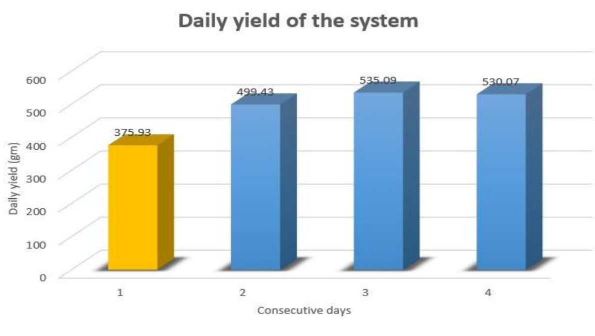


Fig.9 The final output of each day

The graph indicates that the modified still always gives a better result compared to the conventional one. Though the productivity of the modified still varied during the period of experiment due to various factor, but it can be said the results were quite similar to one another. Since the effect of various factors of the environment are responsible for the overall yield of the solar still, variations in the yields were observed.

If one observes the figures given above carefully it can be deduced that the modified still has advantages in both hourly and overall productivity. The hourly productivity of the modified still was enhanced due to the presence of Nanoparticles, which retained the solar energy and helped to increase the temperature of the basin water to a great extent. On the other hand the overnight productivity rise in the modified solar still has also contributed to the overall yield. This increase in overnight productivity was due to the presence of Paraffin wax acting as Phase Change Material (PCM). The PCM used under the basin liner received the heat lost by the basin from below and when it melted during the day time. The melted wax trapped the heat as latent heat and then released it during the night. This heat was used to continue the evaporation process of the water in the basin during the night time. The condensation rate was also higher at night since it was cooler around the basin. As a result better productivity was obtained. The types of modification used in the solar still will make the total cost of the system higher than a conventional one but this will also result in better output. Here it can be seen that around 160 gm of more water was obtained from the modified still which is noteworthy considering the size of the still and other limitations. If a bigger still was fabricated than the overall productivity would have been more. But for the sake of experimentation the size was kept small so that it could be handled easily and sealing could be done more precisely. And the results from the comprehensive study lead to the following conclusions-

- The hourly productivity of the modified solar still is higher than the conventional one even though the solar intensities were not the same.
- The overall productivity of the still enhanced with PCM and Nanofluid was greater than the conventional still due to the modifications made to it.
- The overnight productivity rose significantly as a result of the action of the PCM which resulted in a better daily yield.

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