International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 02 February 2025
Page No: 138-145
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0018

Advancing Solar Still Performance with Nano-Integrated Thermal Energy Storage Systems

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Abstract
Obtaining safe drinking water is still a major worldwide concern, especially in resource-limited regions. Solar distillation provides an eco-friendly and cost-effective solution and this study advances the field by integrating innovative materials into hybrid solar still systems. By combining phase change materials (PCMs) such as stearic acid, lauric acid, and Paraffin wax with nanoparticles like CuO and TiO_2, the research introduces a groundbreaking approach to optimizing heat transfer and enhancing water productivity. The experimental setup features a solar still connected to a solar water heater, employing advanced materials to boost energy efficiency and distillate output. This novel integration significantly improves exergy performance, pushing the boundaries of conventional solar still technologies. The results reveal a transformative leap in water production efficiency, demonstrating the potential of sustainable, innovative solutions to tackle global water scarcity. This study redefines the capabilities of solar distillation systems, showcasing how the synergy between PCMs and nanoparticles can revolutionize water purification in a practical, scalable, and environmentally responsible manner.

Keywords: *Solar Distillate, Energy, Nano particles, PCM, Solar Still*

1. Introduction

Pure drinking water is an important role in daily life of a human being and all living species. But now a day it is difficult to be obtained pure form of water from natural resources due to alarmingly increasing water pollution mainly in rural area and remote locations where scarcity of resources also the places where industries emitting waste. The industrial waste increasing day by day and alarming the society to reach the worst scenario. Though various modern water filtration technologies like RO, UV and other filtration techniques etc are available, still the major problem concerned with these technologies is that They depend on electricity, which is mostly produced by gas or coal-based power plants. which also cause environmental pollution and dangerous for society. Also cost of producing pure water is very high. Hence an environment friendly, economical and effective water purification technology like solar distillation is highly needed for addressing the issue of water scarcity today. A solar still's productivity is influenced by both design specifications and weather. The heat and mass transport inside the solar still has been expressed by Tiwari et al. [1] as a function of the tilt of the condensing lid. Dwivedi and Tiwari have created an analytical thermal model for an active solar still [2]. Sorayan and Shukla [3] have justified the agreement between thermal model and outcomes of solar still experiments conducted in both summer and winter climates. Dev and Tiwari [4] have established characteristic equations for a single slope solar still for varying water depths. and inclinations. Dev [5] has analyzed so many passive and active solar distillation systems to formulate their characteristic equations. The objective of this paper is to design and develop a modified Single Slope Solar Still (MSSSS) which replaces simple solar still to modified solar still as it implemented pcm and nano particles. Also solar water heater coupled with flat plat collector is attached with solar still to supply water in heated form. This gives novelty of the research problem. In order to match the new design, a thermal model has been created. The yield of MSSSS for the climate conditions at MMIT, Kushinagar, India, has been experimentally tested using it. In order to compare the yield during summer weather conditions, the impact of solar radiation on the productivity of the MSSSS has been examined. For the finding of productivity of the still experiments are performed in the month April 2024 on dated between 19 april to 23 april. And observations are done from morning 8 am to evening 7 pm. Direct solar radiation is one of the most important sources of renewable energy utilized in many parts of the world. The scientists are in search to develop energy storage devices for solar energy. The energy storage One of the challenges facing technologists today is finding appropriate forms that can be transformed into the desired form. In addition to lowering the imbalance between supply and demand, energy storage enhances system performance and dependability [32]. By lowering energy waste and capital costs, it saves fuel and increases the systems' cost-effectiveness. PCMs are one of the newest methods for storing thermal energy.

2. Experimental Work

2.1.Design of Proposed Solar Still

There are many air particles and water vapor molecules in the area that the solar still encloses. Due to their random motion, these molecules may come into touch with the interior surfaces of the walls and the glass cover. When the sun rises in the morning, sunlight strikes the water within the solar still through the clear glass material. The as the still's internal temperature rises, kinetic energy causes molecules to move more quickly. As a result, the molecules collide with one another quickly. Consequently, the vapor molecules near the walls adhere to it and undergo a phase transition from vapor to liquid by releasing heat through condensation [8,10]. As a result, solar radiation causes yielding to begin relatively early, producing distillate only when glass coverings receive enough sunlight (because of opaque toughened transparent glass sheet and sides of the walls). More solar radiation enters through the glass coverings and walls as the sun advances west due south. Because of their high absorptivity, the wall and the basin liner absorb a large portion of this radiation. Convection transfers heat from the basin to the water, causing the water to evaporate [14]. Through molecular collision, the vapor molecules come into touch with the glass coverings and walls, and the condensation process proceeds. The collecting jars outside are where the condensate is directed by the troughs.

3. Preparation and Analysis

Fig. [1] illustrates the isometric view of an experimental setup for a Solar Still System (SSSS), featuring a box-shaped basin with a base area of 2 square meters.The walls of the solar still have varying heights, with the back ends standing at 0.12 meters and the center at 0.38 meters. The base and side walls are constructed using 0.005-meter-thick GI sheets, with their interiors painted black to improve solar radiation absorption. The South, West, and East walls are composed of 0.003-meter-thick GI sheets, designed to minimize heat loss.To ensure safe and reliable operation, toughened glass is used for the glass covers, measuring 1.03 x 1.03 x 0.004 cubic meters. These glass covers are inclined at an angle of 45 degrees to maximize irradiation reception from the sun and to efficiently direct the condensate by utilizing the combined effects of cohesion, adhesion, and gravity. An entrance on one of the side walls allows brackish water to enter the solar still. It's crucial to remember that the vapor molecules hitting the rear wall acquire extra heat from t, therefore no condensate is produced. his surface [11]. Figure 1 shows Isometric View of Single Slope Solar Still (SSSS).

Figure 1 Isometric View of Single Slope Solar Still (SSSS)

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Figure 2 Isometric View of Modified Single Slope Solar Still (MSSSS)

Fig. [2] depicts the isometric view of the experimental set up of MSSSS consisting of a box-shaped basin with six slots for PCM's filling and three tubes for using Nano additives. The rest specification is the same as SSSS with base area of $2m^2$. The height of the solar still walls is 0.12 m at the back ends and 0.38 m at the center. The base and sidewall are made of same as the previous one. The size of six slots is 0.050 m in diameter and the tube for nano additives of 0.010 m dia. Figure 3 shows Isometric View of Single Slope Solar Still (SSSS) Coupled with Flat Plate Collector Solar Water Heater. [1-10]

Figure 3 Isometric View of Single Slope Solar Still (SSSS) Coupled with Flat Plate Collector Solar Water Heater

Figure 4 Isometric View of Modified Single Slope Solar Still (MSSSS) Coupled with Flat Plate Collector Solar Water Heater

Fig. [3] depicts the isometric view of experimental set up of SSSS connected with solar water heater. Solar water heater is coupled with flat plate collector to use of solar energy to maintain the novelty of experiment and reduce the electricity consumption. Fig. [4] depicts the isometric view of experimental set up of MSSSS connected with solar water heater. Solar water heater is coupled with flat plate collector to use of solar energy. Figure 4 shows Isometric View of Modified Single Slope Solar Still (MSSSS) Coupled with Flat Plate Collector Solar Water Heater.

4. Result and Discussions

Fig [5] shows the comparison of hourly yield productivity of solar still from morning 8:00 hrs to evening 19:00 hrs and shows the hourly productivity variation different constrain employ on still. It compares the yield in the cases when without PCM, with paraffin as a PCM and paraffin and copper oxide (CuO) as nano additives. These yields are found in SSSS and MSSSS without the use of solar water heater. While doing experimentation it is found that use of PCM and CuO combined gives better yield and gives maximum output at 3 pm afternoon.it is also found that use of PCM in still gives more yield as compared to without use of PCM. As a result, solar radiation causes yielding to begin relatively early, producing distillate only when glass coverings receive enough sunlight (because of opaque toughened transparent.

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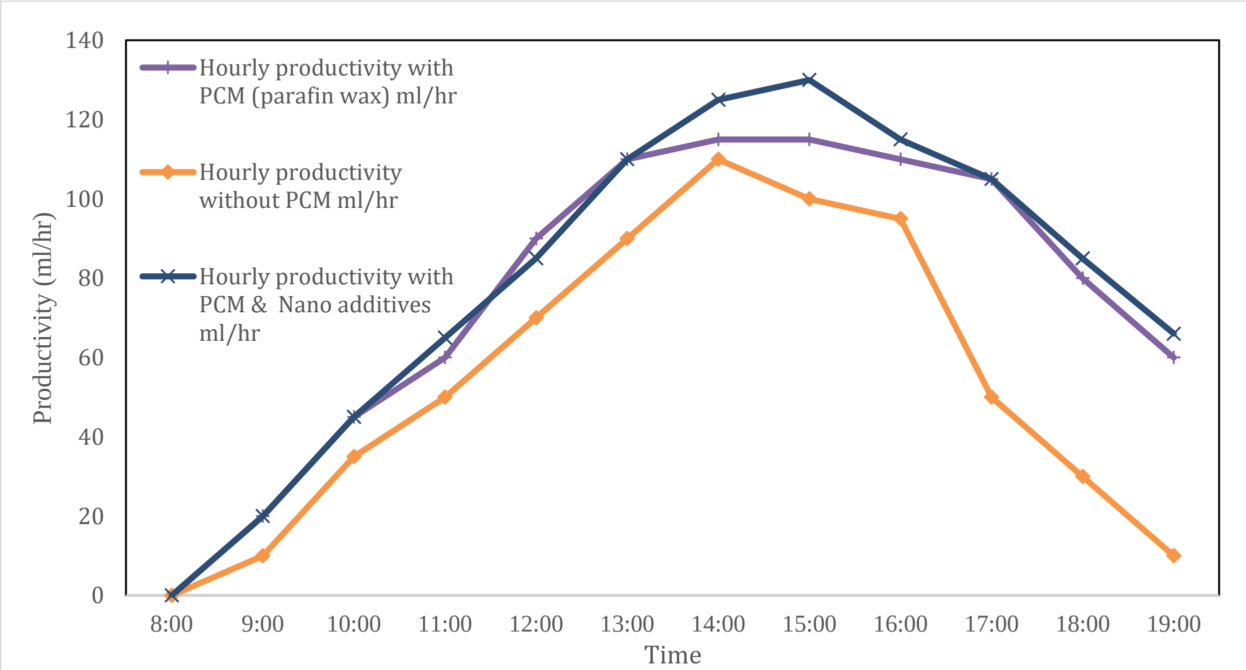

Figure 5 **Yield of Still Without PCM, With PCM and with PCM +Nano Additives**

Also, the yield examines with stearic acid, paraffin wax, Lauric acid and combined paraffin wax with CuO. All the parameter and timing remain same as previous one. On experimentation it is found that hourly production yield of still is maximum 3.15 pm for paraffin wax and CuO. This yield is maximum because in afternoon the solar intensity is high so evaporation takes places higher. Figure 5 SHOWS Yield of Still Without PCM, With PCM and with PCM +Nano Additives Figure 5 shows Yield of Still Without PCM, With PCM and with PCM +Nano Additives. [11-20]

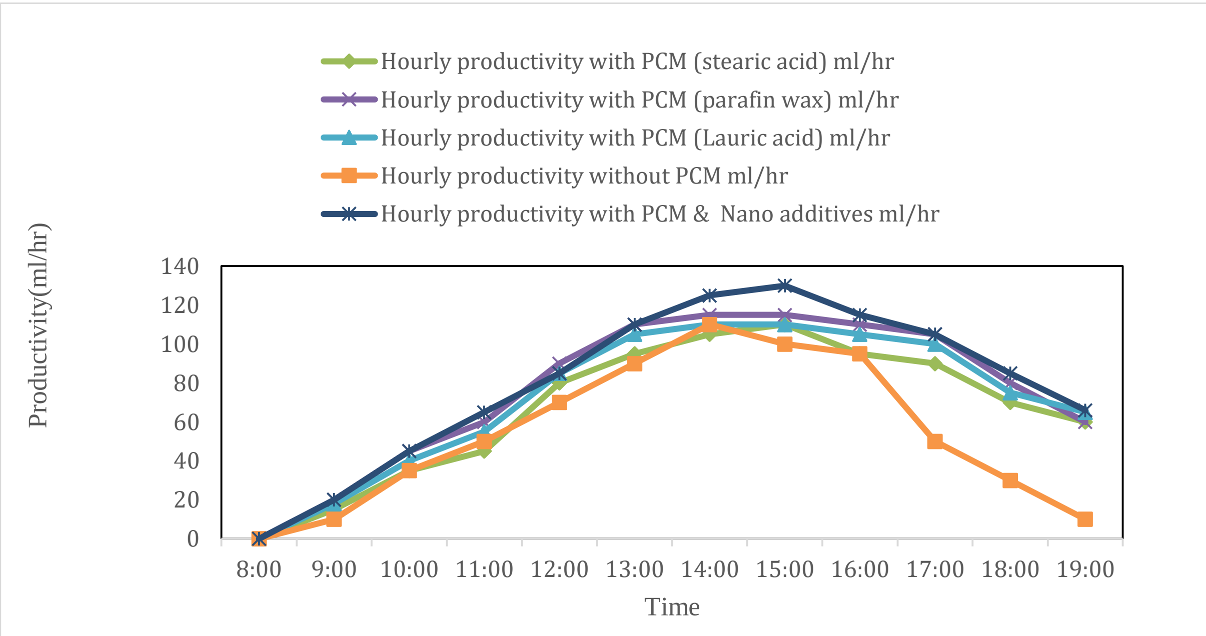

Figure 6 **Yield of Still with Stearic Acid, Paraffin Wax, Lauric Acid and Combined Paraffin Wax with CuO**

On using stearic acid with in both still with and without solar water heater ,it is found that with the use of solar heater productivity of still increases in marginal and having maximum yield is at 3 pm. Figure 6 shows Yield of Still with Stearic Acid, Paraffin Wax, Lauric Acid and Combined Paraffin Wax with CuO Figure 7 shows Hourly Yield of Solar Still with Stearic Acid with and Without Solar Water Heater. Figure 8 shows Hourly Yield of Solar Still with Lauric Acid with and Without Solar Water Heater. [21-25]

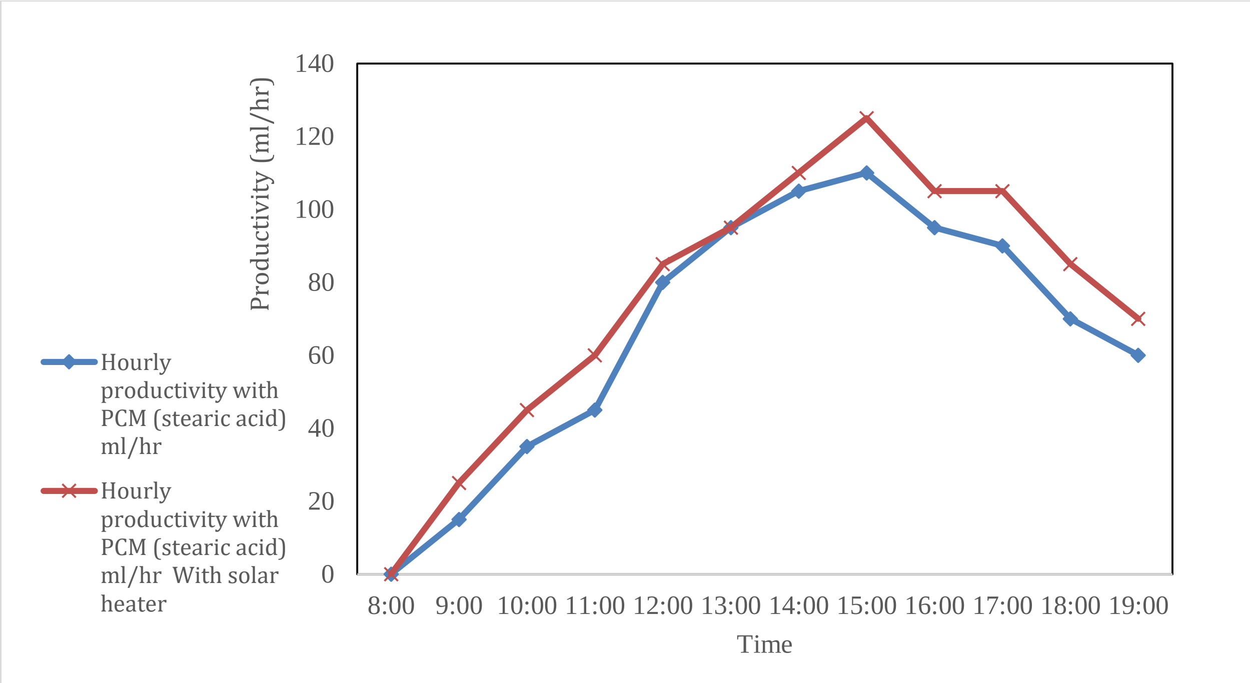

Figure 7 **Hourly Yield of Solar Still with Stearic Acid with and Without Solar Water Heater**

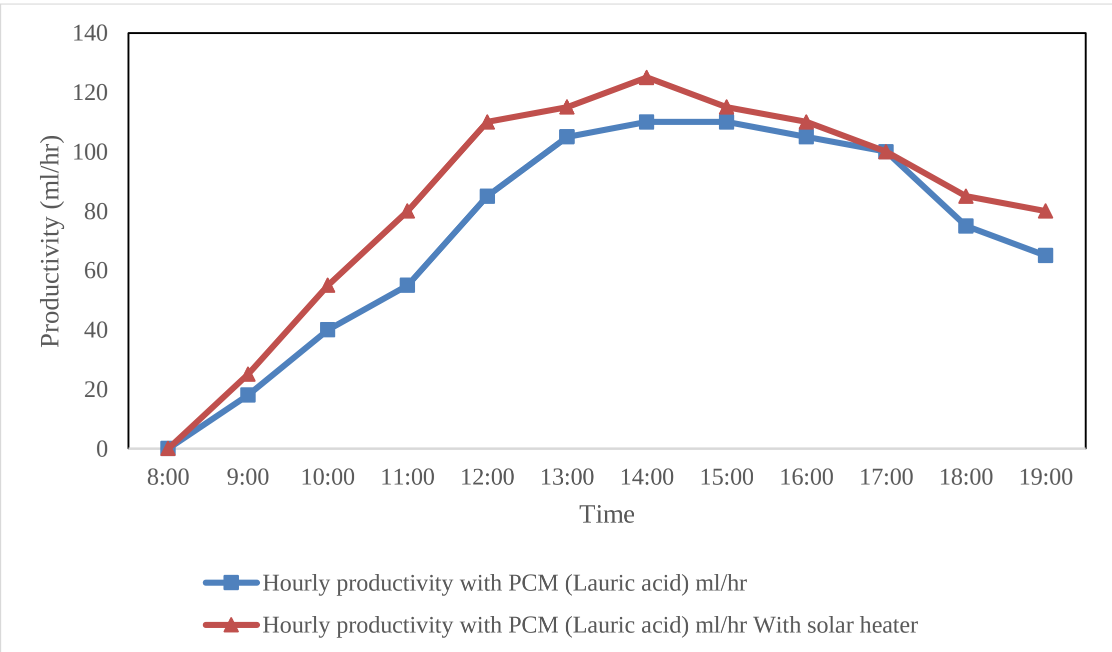

Figure 8 **Hourly Yield of Solar Still with Lauric Acid with and Without Solar Water Heater**

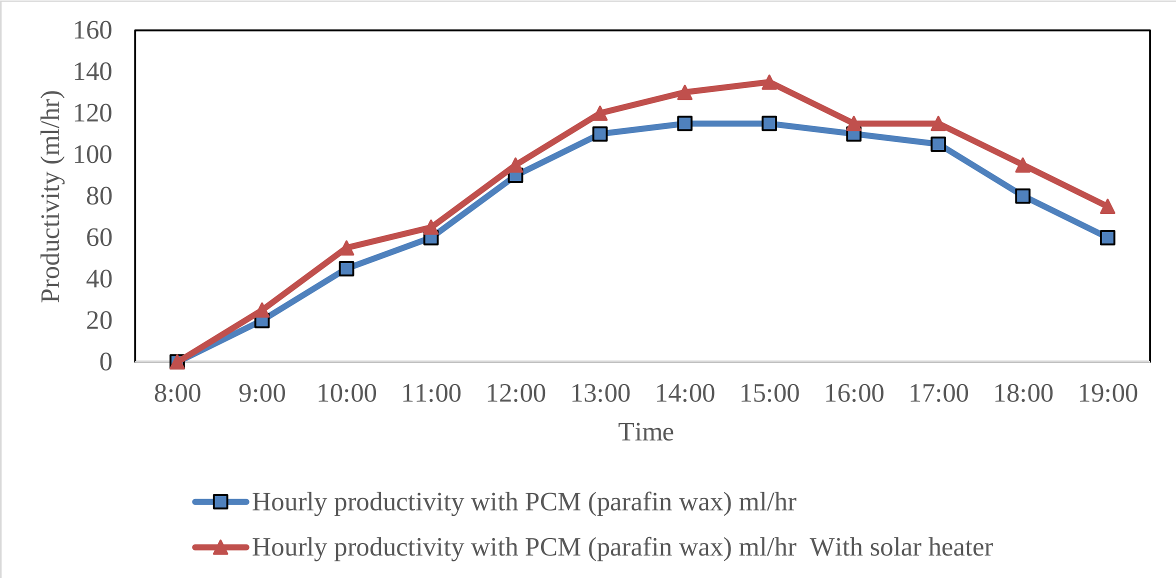

Figure 9 **Hourly Yield of Solar Still with Paraffin Wax with and Without Solar Water Heater**

After using we uses Paraffin wax to find the productivity of still in both cases i.e with and without solar water heater .Paraffin wax is uses as a PCM. On experimentation it is found that productivity is increases little bit in noon but more in evening because PCM stored energy and releases when it is needed. Figure 9 shows Hourly Yield of Solar Still with Paraffin Wax with and Without Solar Water Heater. [26-32]

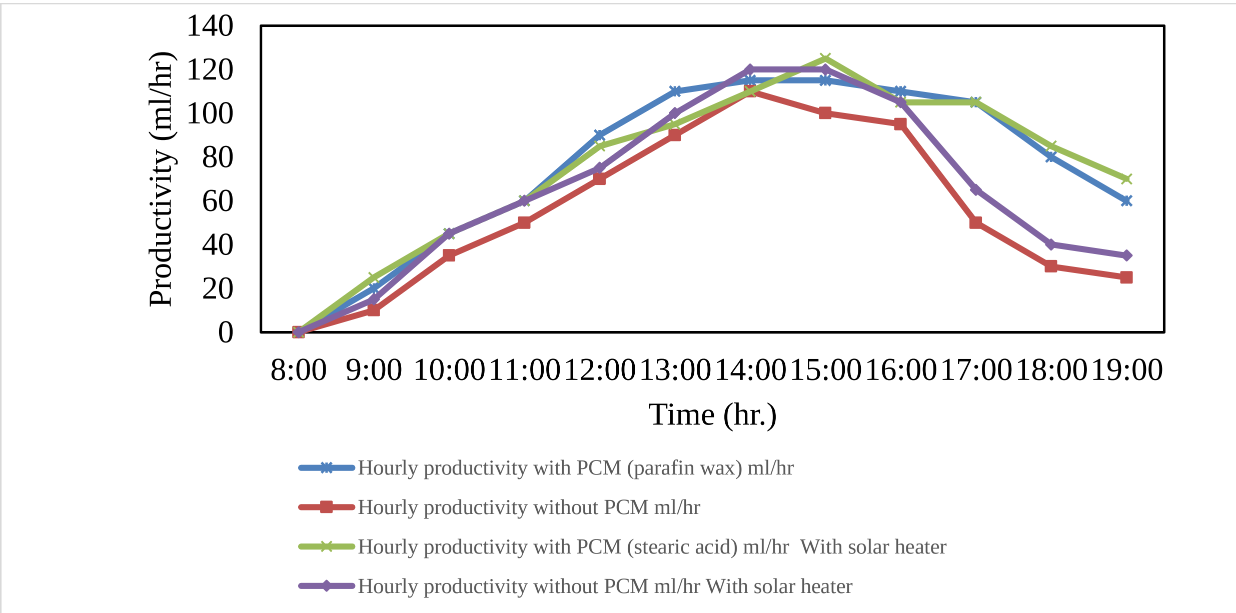

Figure 10 **Hourly Yield of Solar Still Without PCM and with Paraffin Wax (With and Without) Solar Water Heater**

Then compared both paraffin wax and stearic acid simultaneously in both the cases. After experimentation fig. 10 potted between productivity on y-axis and Time on x-axis. Figure 10 shows Hourly Yield of Solar Still Without PCM and with Paraffin Wax (With and Without) Solar Water Heater

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Conclusions

The experimental setup designed in this work was capable of producing desalinated water with low salinity under village weather conditions in Kushinagar India. Three tubes containing copper oxide as nano addictive and various PCM like stearic acid, paraffin wax and lauric acid were placed beneath the basin liner in the box provided to extend productivity, flat plate coupled solar heater is used. From the results, the following conclusions are drawn:

- The selected PCM worked well to supply pure water without energy consumption.
- The productivity of the unit is found to depend on the solar radiation received from sun and water condition.
- The productivity of the unit increases with the use of solar water heater connected to flat plat solar collector.
- The PCM becomes more effective to increase the productivity of water in the basin.
- The highest daily productivity of the unit achieved experimentally at the noon around 3pm.
- The external solar collector improved the productivity of the system.
- A theoretical study on the effect of the basin water level was obtained. There is a good agreement between the theoretical and experimental effect.

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