Enhancement of Solar Water Desalination Using Nanoparticle

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Abstract

Energy, particularly renewable energy, is central to sustainable development. This thesis explores solar still technology enhanced with nanofluids to improve water desalination efficiency. Solar stills, simple devices that use solar energy to purify saline or brackish water, are a sustainable technology especially suited for water-scarce regions with abundant sunlight. The primary objective of this research is to enhance the thermal performance of a conventional single-slope solar still (SBSS) by incorporating aluminum oxide (Al_2O_3) nanoparticles into the basin water to improve heat transfer, evaporation rates, and overall productivity. A single-basin solar still (SBSS) design is used for experimentation, due to its simplicity and widespread use. Solar stills traditionally suffer from low productivity due to limitations in heat retention and slow evaporation rates. The experimental work undertaken in this study addresses these limitations by leveraging the higher thermal conductivity of Al_2O_3 nanoparticles, which are suspended in the basin water. The nanoparticles improve the thermal conductivity of the water, leading to more efficient absorption of solar energy and faster heating. The experimental setup involved a comparative analysis of two solar stills: one operating without nanoparticles and one enhanced with Al_2O_3 nanoparticles. Both stills were evaluated under identical environmental conditions at the Radharaman Institute of Technology and Science, Bhopal (23.26°N, 77.41°E).

The experiments, conducted over three days, measured solar radiation, relative humidity, wind speed, basin temperature and accumulated productivity. The experimental data and results show that using nanoparticles leads to higher basin temperatures, facilitating faster water evaporation and condensation. The relative humidity inside the solar stills decreased as the basin temperature increased, leading to better water vapor saturation. The greater reduction in humidity enhances evaporation rates, as the air can hold more water vapor. The addition of Al_2O_3 nanoparticles increased the basin water temperature by 9% compared to the still without nanoparticles. The experiment showed a maximum basin temperature of 64.8°C for the nanoparticle enhanced still, compared to 57.6°C for the traditional still. This temperature enhancement is due to the higher thermal conductivity of Al_2O_3 (37 W/m·K) compared to that of water (0.6 W/m·K). The accumulated productivity of distilled water over the experiment also increased by 13-22% due to the higher thermal conductivity of the Al_2O_3 nanoparticles. The productivity of the solar still with nanoparticles was consistently 13% to 22% higher than that of the conventional still, with the most significant gains observed during periods of high solar radiation.

Key Words: *Solar Still, Desalination, Single Basin, Thermal Conductivity, Nanoparticle, Al_2O_3*

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1. INTRODUCTION

Energy is one of the essential requirements of a country. It is the most universal and primary measure of every type of work by nature and human beings. Everything that is possible in the world is nothing but energy flow from one form to another one. Generally it is believed that the word energy co-relates to the energy input in human body, machines and thinking about electric power and fossil fuels. Out of that seventy one percentage, ninety seven percentage of all the earth water is contained within the ocean and sea salty water, while the remaining three percentage is fresh water from lakes and frozen water [1]. A need of pure water is an important phenomena in day to day life, as the population and industrialization is increasing day by day so the demand of fresh water is also increases [2]. The water scarcity by 2025 will be increased by 2 billion people approximately as the report of UNO 2019 [3]. The TDS value which is permitted by the WHO is 500 parts per million for safe drinking water, but the sea water is having 35000 – 45000 parts per million. So we have to purify this water which involved the removal of dissolved, undissolved and harmful microbes. The undissolved substance can be removed by sand filtration and the microbes are killed through chlorination and by boiling. Desalination is the process which does all the three function and by using solar energy that devices is known as solar still [4].

1.1 Solar Desalination

The above mentioned technique is broadly classified on the management of solar energy. Hence, it is widely dissolved into two main categories: a) Direct: The absorption process and desalination takes place in the same apparatus. b) Indirect: Both absorption of solar energy and desalination are done through different processes and systems. The conventional methodology involving basin solar still is the most used method from ages and is hassle free for aspects related to convenience and maintenance. The basin which is covered up with a see-through cover and contains saline water which is unveiled in presence of solar radiation, is usually black stained to facilitate maximum radiation [5]. Once water changes its state of form (due to evaporation), it is made to condense once its particulates come in contact with the cover. Finally, the residual water is thereafter circulated to different facilities through proper mediums. However, major limitations involved in this simplified apparatus are its significant low efficiency due to liberated latent heat of condensation and thereafter-slow rise in water's evaporation temperature [6].

1.2 General Classification of solar still designs

The designs of solar stills are distinguished into two major categories i.e. Active and Passive stills altogether depending upon the process involved in heat source used for evaporation of saline water. Usually solar heaters, Photovoltaic thermal hybrid solar collectors and concentrators are used for this purpose. Nanoparticle To improve the solar still performance in the form of fresh water yield, nanoparticles, solid particles having the diameter in the range of 1 – 100 nm, are used from last two decades, and certainly a new approach among others. The ability of attaining the required thermo – physical properties of nanoparticles, by the variation in the particle size, shape and concentration, rewarded them as one of focused area of research in the solar still.

2. LITERATURE REVIEW

Seyed Sina Adibi Toosi et al. [7] performed the Experimental investigation on stepped solar still with Fe3O4 + graphene oxide + paraffin as nanofluid under constant magnetic field. The thermal conductivity of hybrid NPCM has been improved by the utilization of a constant magnetic field. The daily efficiency of State I, State II, and State III was about 6.9 %, 9.6 %, and 12.3 %, respectively, and reaches 13.6 % by using hybrid NPCM under the magnetic field. By considering the cost per liter and payback period of freshwater yield, it can be derived that the usage of hybrid NPCM under the magnetic field in the SSS is a cost-effective.
Bekele A et al. [8] investigated the modified pyramid solar still has a unique combination of modifications such as a v-corrugated absorber surface, a nano-coated absorber surface, internal reflective mirrors and nano-embodied phase change material. The experimental test result of the system gives a daily yield of 2.95 and 5.73 l/m^2 distilled water from conventional and modified solar still, respectively. This shows a yield improvement of 94.2%. Finally, the water quality is tested and drinkable as per the WHO standard. Bekele A et al investigated the
Ewelina Radomska et al. [9] investigated the influence of water mass and PCM mass on the long-term performance of a solar still (SS. The results of simulations for average days for each month show that the maximum productivity of the SS is in July (3039 mL/m2/day with 5 kg of water), while the lowest is in October (900 mL/m2/day). The greatest annual SS productivity is 488.8 L/m2/year in Poland and is achieved with 5 kg of water and without PCM. The daily productivity is inversely proportional to the mass of water and the mass of PCM. The PCM reduces productivity by up to 11%.
Varun Kumar Sonker et al. [10] developed a frugal solar still with cylinders filled with paraffin wax and blended with nanoparticles; significant enhancement in distillation output has been observed. The yield of solar distillate increased by 43.50% when PCM has been used, as compared to the base case when no PCM has been used. The yield increased by 32.90% when PCM and nanoparticles have been used, as compared to the case when only PCM has been used. The evaporative heat transfer coefficient has been increased in the case of NPCM. The proof of concept on a novel frugal solar still has been established and it has been observed that the cost of distilled water reduced from Rs. 5/L to Rs. 3/L (40% reduction in cost). It has also been observed that the payback period for our proposed novel economic model (SSNPCM) is 4.3 years which justifies the deployment of our solar still in resource constrained setting. This will also facilitate commercialization of the product.
Dsilva et al. [11] performed the numerical study on solar still with nanoparticles and latent heat storage material. The titanium oxide was used as nanoparticles and paraffin wax were used as latent heat storage material. The 6.6 L/m2 per day output were increased by using titanium oxide with paraffin wax as compared to plain paraffin wax. The 88% more output were obtained from still when energy storage materials with nano particles were used as compared to traditional solar still.

Shafieian et al. [12] performed the experimental studied on thermal based solar still using aluminium oxide nanoparticles. The 18% and 22% of fresh water output was increased when nanoparticles was used during hot and cold weather respectively.

Behura et al. [13] also performed the experimental studied on solar still having phase change material with nanoparticles. The experimental setup consist of v corrugated absorber plate having paraffin wax combined with copper oxide nanoparticles. They revealed that when 0.1% weight concentration of nanoparticles were used, 440 ml/0.25m2 per day output was obtained. Similarly when 0.2% and 0.3% weight concentration of nanoparticles were used the 455ml/0.25m2 per day and 510 ml/0.25m2 per day was found. The result also revealed that when nanoparticles were used the output was increased by 62.74% as compared to traditional still.

Panchal et al. [14] performed the experimental studied on stepped solar still using nanoparticles. The Magnesium oxide and Titanium oxide of different concentration was used for experimentation. The range of nanoparticles concentration used for experimentation was 0.1% to 0.2%. From results it was found that for magnesium oxide with 0.1% concentration, 33.33% more fresh water was obtained, whereas for 0.2% concentration 45.38% was obtained. Similarly for Titanium oxide with 0.1% concentration 4.1% fresh water was produce and for 0.2% concentration 20.4% was produce. The high thermal conductivity and low specific heat capacity of Magnesium oxide as compared to Titanium oxide leads to higher fresh water output from still.

Sathyamurthy et al. [15] performed the experimental studied on stepped solar still layered using fumed silica nanoparticle in black paint. The concentration of nanoparticles varies from 10-40% and it is found that when the concentration of nanoparticles increased from 20% there is no effect in the output. During experimentation it was found that when 10% concentration of nanoparticles were used the output was increased by 27.2% as compared to normal black paint. Similarly when 20%, 30% and 40% concentration of nanoparticles were used the output was increased by 34.2%, 18.3% and 18.4% respectively as compared to ordinary black paint.

Nazari et al. [16] performed the experimental studied on single slope solar still consisting of thermoelectric cooling channel and copper oxide nanoparticles. They found that when 0.08% of copper oxide nanoparticles were used in solar still with thermoelectric cooling channel the 81% more output of fresh water was found whereas 80.6% more energy efficiency was produce.

3. EXPERIMENTAL SETUP

Experiments were conducted at the Radharaman institute of Technology and science Bhopal location (23.26°N. 77.41°E). The experiments were performed in March-2024 and carried out 10:00 to 16:00 Hrs. The direct and diffuse solar radiations as well as reflected radiation are transmitted through the glass cover and absorbed by the black painted base. The absorbed solar radiation heat up the water and evaporates. The evaporative water come in contact with glass cover and gets condensed. This condensed water slides toward the glass inclination and collected through the collecting channel.

The experiments were start up at 10:00 AM. Solar still is placed toward the direction found by magnetic compass. A water tank with capacity 20 litre placed on iron stand and filled the water. Toughened glass cover placed solar still and sealed by the rubber beat and adhesive tape. Measuring cylinders placed at outlet of the still to collect the distillate water. Thermocouples are connected. Solar radiation was measured with the help of pyranometer. Temperature was measured with the help of temperature indicator. All the readings are taken hourly.

Nanoparticles Al_2O_3 have high thermal conductivity. They have been used as a pond fluid to increase the performance of the solar still. Single slope single basin solar still was fabricated using 0.3mm aluminium sheet by keeping the height of the lower vertical side at 0.16 m. For a 23° inclination of the window glass cover, the required height of the other vertical side was 0.584 m. The absorber area of basin stills was 1 m × 1 m ($1m^2$). The experimental setup with instrumentation of single slope solar still is shown in Fig. 3.1. The inner side of the basin was painted black to maximize the absorption of solar radiation. The bottom and sides of the basin were well insulated with a thermocol layer of 0.028m thickness. The outer structure is made from plywood of 0.012m thickness. An ordinary transparent window with a glass of 0.004 m thickness was used as the top cover of the solar still and was sloped at an angle of 23°.

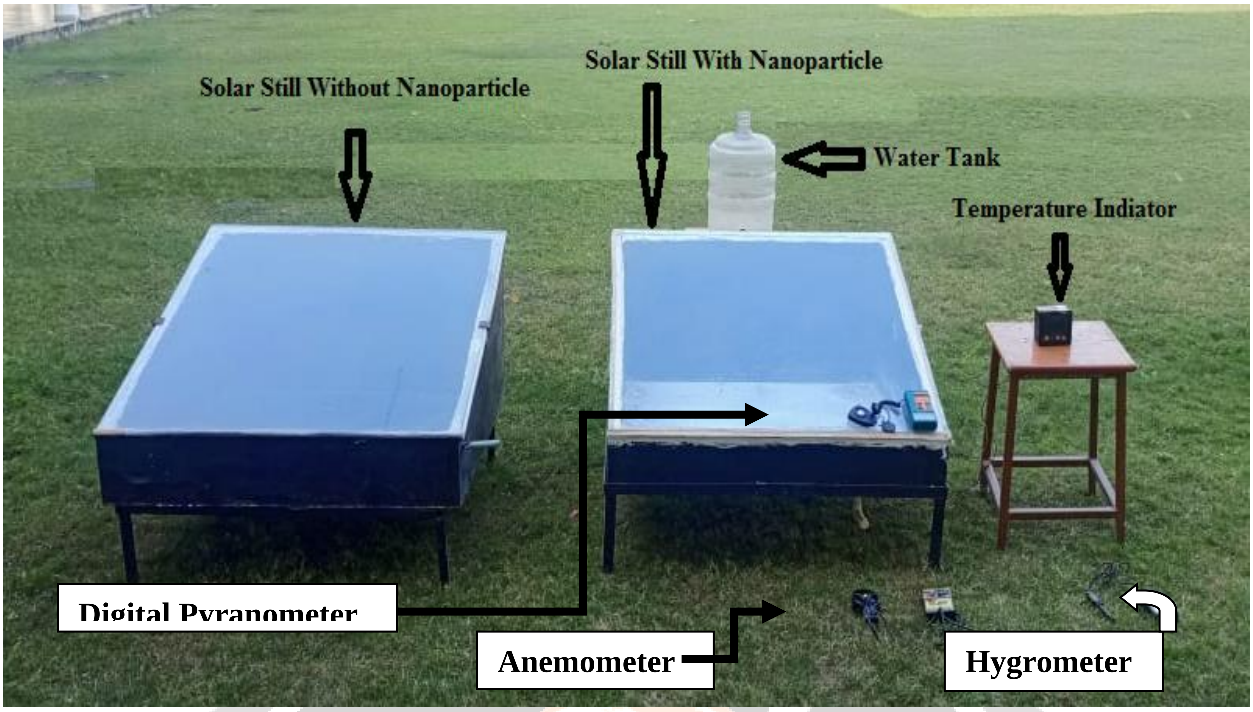

Fig. 3.1 Experimental setup with instrumentation

4. RESULTS AND DISCUSSION

The experiment have two single slope solar still are compared i.e. solar still without nanoparticle and solar still with nanoparticle. The nanoparticle used was Al_2O_3 because of its high thermal conductivity. The experiment was carried out at Radharaman Institute of Technology and Science Bhopal. The readings were taken keeping same radiation level at 1hr interval. Results were tabulated, graphically represented and discussed below.

4.1.1 Variation of solar radiation intensity with time for Day 1

Variation of solar radiation intensity with time for Day 1 is shown in Fig. 4.1.

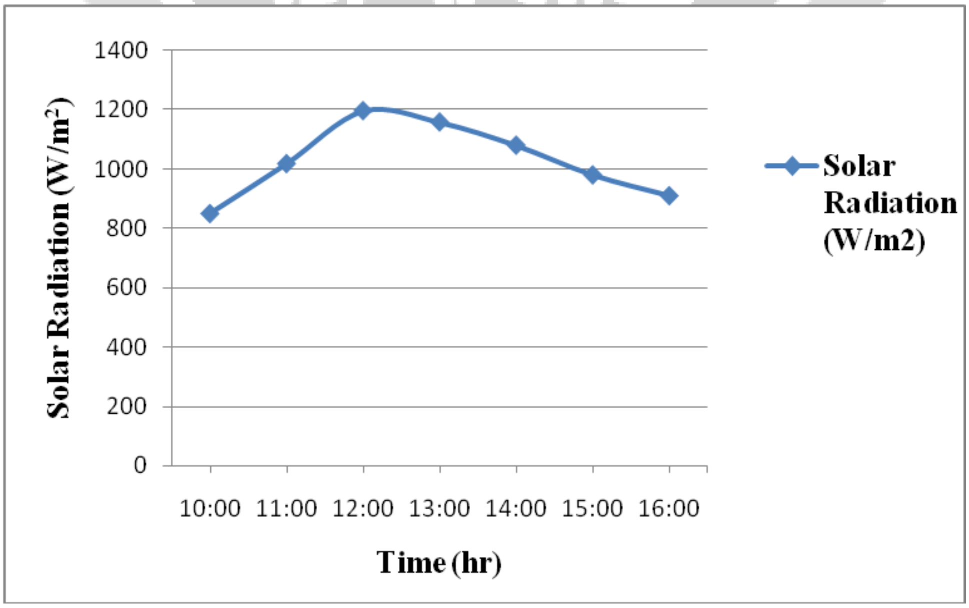

Fig. 4.1 Variation of solar radiation intensity with time for Day 1

Fig. 4.1 shows the variation of solar radiation intensity with time for Day 1. Solar radiation is 800 W/m², which is the minimum radiation at 10:00hr**,** and increases steadily, reaching a maximum radiation of 1250 W/m² at 12:00hr. After this maximum, the radiation remains relatively stable for the next hour but begins to decrease gradually after 13:00 hr. At 16:00 hr, the radiation drops to about 850 W/m²**.** The system's efficiency is directly tied to this variation in radiation, as higher solar input leads to increased heat absorption in the solar still, driving water evaporation [17]. The midday peak in radiation provides the most significant energy for the system, making this period critical for maximizing productivity [18].

4.1.2 Variations of relative humidity with time for Day 1

A variation of relative humidity with time for Day 1 is shown in Fig. 4.2. Figure shows the variation of relative humidity with time for solar still without nanoparticle and with nanoparticle for Day1. In solar still without nanoparticle, the relative humidity remains relatively stable from 10:00 to 13:00hr. After 13:00hr, it begins to decrease. While in solar still with nanoparticle, shows a continuous decline in relative humidity over time. Starting at around 94% at 10:00, it drops steadily to about 75% by 16:00. The enhanced heat retention in the nanoparticle setup accelerates evaporation, causing a more rapid reduction in humidity [19]. Lower humidity inside the still creates a more favorable condition for evaporation, as dry air can hold more water vapor, further enhancing productivity [20].

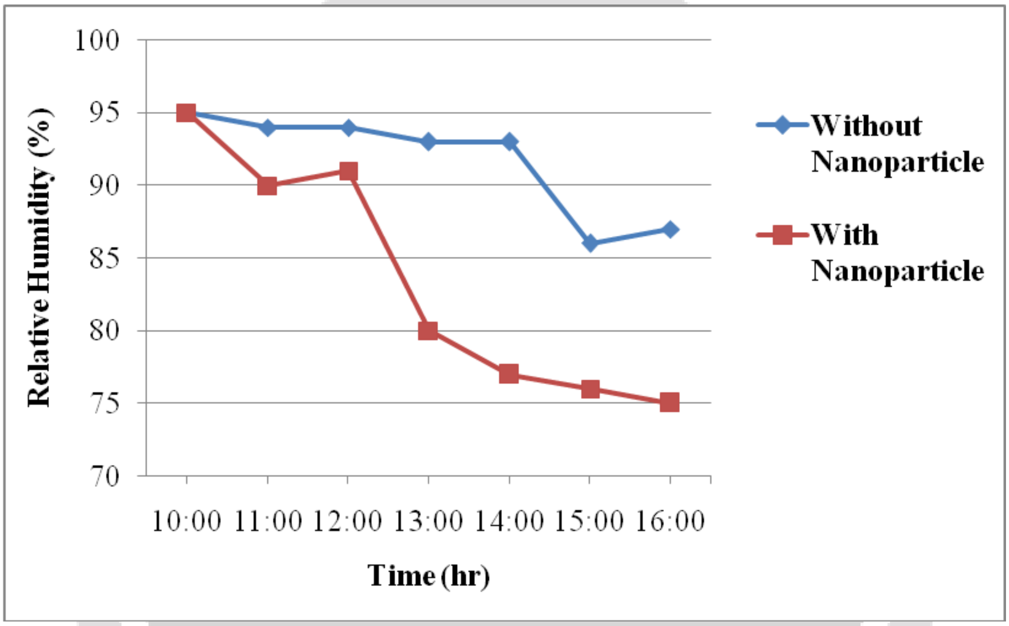

Fig. 4.2 Variation of relative humidity with time for Day 1

4.1.3 Variation of wind velocity with time for Day 1

Variation of wind velocity with time for Day 1 is shown in Fig. 4.3.

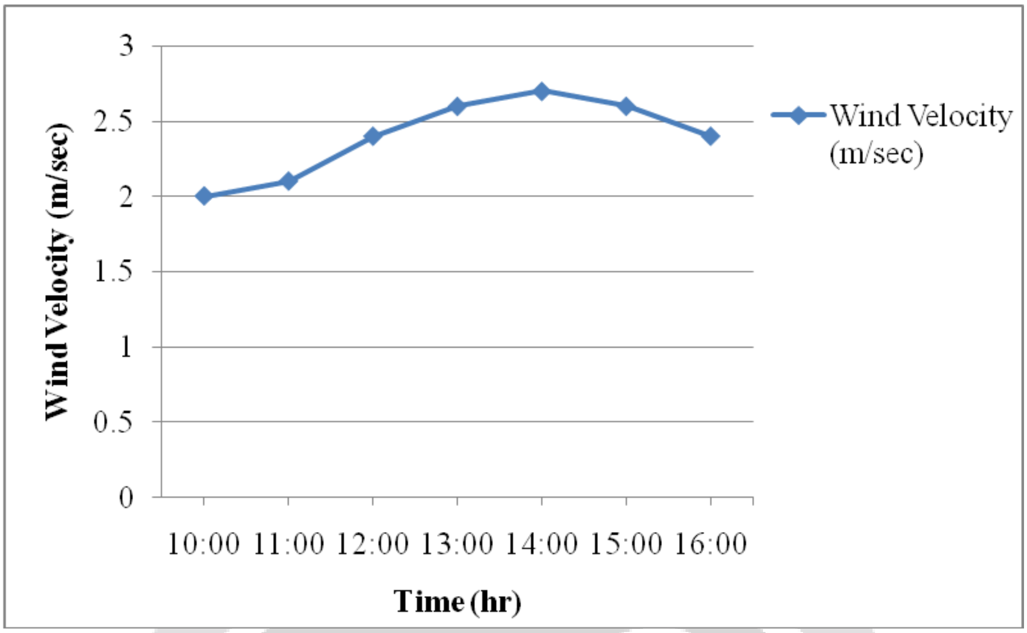

Fig. 4.3 Variation of wind velocity with time for Day 1

Fig. 4.3 shows variation of wind velocity with time for Day 1. The wind velocity was 2 m/sec at 10:00 AM and gradually increases, reaching a maximum velocity of 2.7 m/sec around 13:00 hrs. After this maximum, the wind velocity remains relatively steady for the next two hours but begins to decrease after 15:00 hr. At 16:00 hr, the wind velocity drops to about 2.4 m/sec. Wind speed affects the cooling rate of the solar still's exterior and the overall efficiency of evaporation [21]. A moderate wind speed increases heat loss through convection, reducing the system's internal temperature slightly [22]. However, the observed wind speeds are relatively low, so the impact on heat loss is minimal, allowing the nanoparticle-enhanced system to retain more heat and maintain productivity.

4.1.4 Variation of basin temperature for solar still without and with nanoparticle with time for Day 1

Variation of atmospheric temperature, basin temperature of solar still without nanoparticle and basin temperature of solar still with nanoparticle with time for Day 1 is shown in Fig. 4.4.

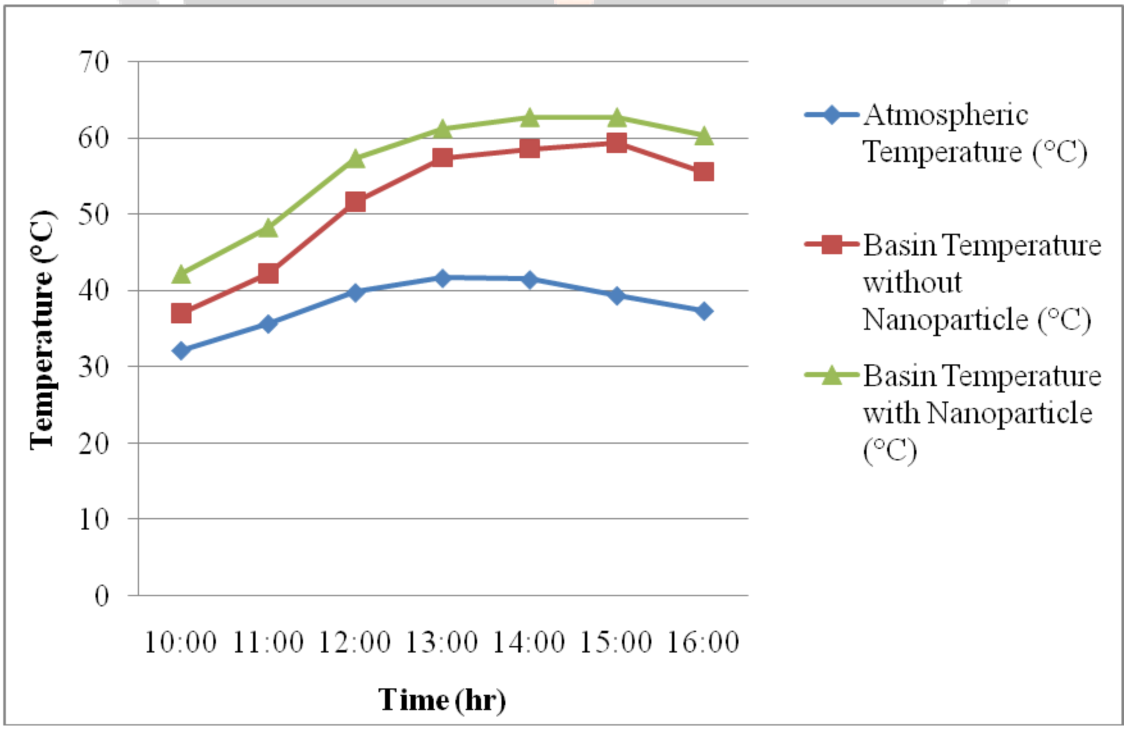

Fig. 4.4 Variation of basin temperature for solar still without and with nanoparticle with time for Day 1

Fig. 4.4 shows the variation of atmospheric temperature, basin temperature of solar still without nanoparticle and basin temperature of solar still with nanoparticle with time for Day 1. The atmospheric temperature was 35°C at 10:00hr and gradually increases to maximum temperature about 42°C at 13:00hr, then remains relatively stable before slightly decreasing by 16:00hr. The basin temperature of solar still without nanoparticle, was 40°C at 10:00hr, increasing steadily to reach maximum temperature of around 55°C at 13:00hr, and then slowly decreases to 50°C by 16:00hr. While the basin temperature of solar still with nanoparticle, shows a similar trend but consistently increase in higher temperatures. It has 45°C at 10:00hr, reaches to maximum temperature of 60°C at 13:00hr, and then gradually decreases to around 55°C by 16:00hr.

The addition of nanoparticle to solar still leads to increase the basin temperature by around 9% higher as compared to the solar still without nanoparticle, indicating an enhanced heat absorption or retention effect [23]. Which shows that using nanoparticle, the temperature of basin fluids is more as compared to without nanoparticle. The nanoparticle is used as a solar absorber and the thermal conductivity of nanoparticle is more when compared to normal water [24]. The higher thermal conductivity of nanoparticle leads to absorb more amount of solar radiation and releases it to water [25]. The higher thermal conductivity of Al_2O_3 nanoparticle further enhance the temperature of solar still. Furthermore, when compared to atmospheric temperature, the basin temperature with nanoparticle is approximately 43% higher, while the basin without nanoparticle is about 31% higher than atmospheric temperature.

4.1.5 Variations of accumulated productivity for solar still without and with nanoparticle with time for Day 1

Variations of accumulated productivity for solar still without and with nanoparticle with time for Day 1 are shown in Fig. 4.5.

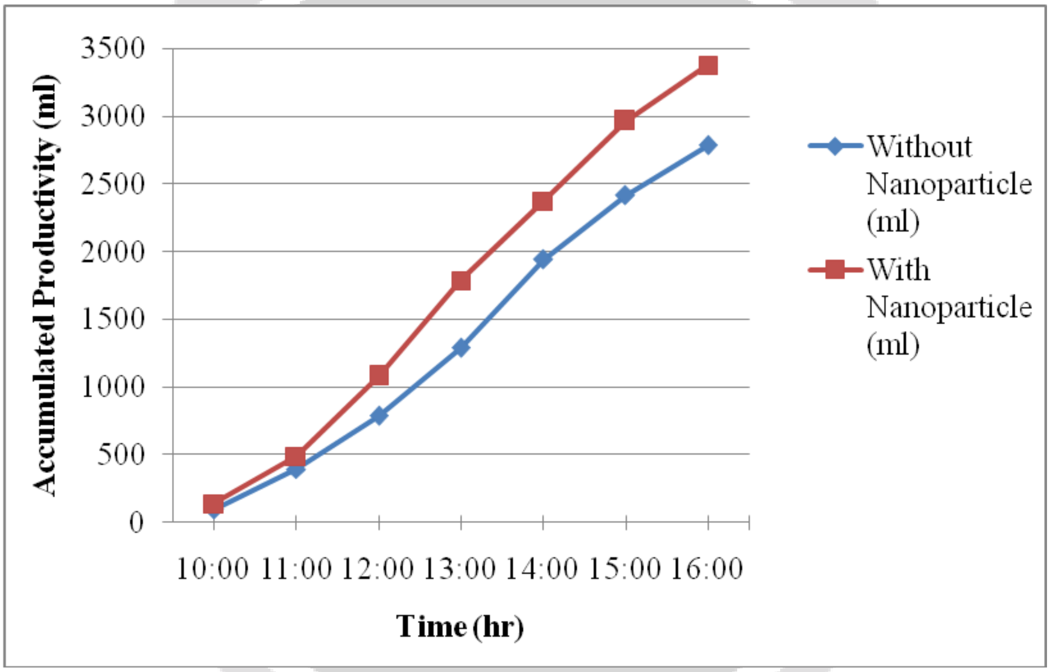

Fig. 4.5 Variations of accumulated productivity for solar still without and with nanoparticle with time for Day 1

Fig. 4.5 shows the variations of accumulated productivity for solar still without nanoparticle and solar still with nanoparticle with time for Day 1. Both productivity levels increase throughout the day. The reason behind this is that the temperature of water in the still is low in the morning time and more time is required for water to warm up. The productivity of solar still with nanoparticles consistently higher than the productivity of solar still without nanoparticles by a range of approximately 20-25%. It has been reported that the productivity of solar still with nanoparticles is about 22% higher than the productivity without nanoparticles. This increased productivity can be attributed to the improved heat absorption and retention provided by the nanoparticles [26]. By maintaining higher basin temperatures for longer periods, the system can distill more water

5. CONCLUSIONS

1. Studies have shown that solar still performance is highly dependent on the intensity and duration of solar radiation, as higher radiation levels directly increase water evaporation rates. The peak radiation at midday is vital, as it provides the most energy for water distillation.

2. The basin temperature with nanoparticles is consistently higher, showing about a 9% increase compared to the setup without nanoparticles. This improvement is due to the high thermal conductivity of Al_2O_3 nanoparticles, which enhances heat transfer. Nanoparticles increase thermal efficiency by absorbing more solar radiation and distributing it more effectively across the water body, leading to higher evaporation rates.
3. Relative humidity decreases throughout the day, but the drop is more pronounced in the system with nanoparticles. Nanoparticles enhance evaporation rates by increasing the basin temperature, which lowers the relative humidity inside the still. Lower humidity increases the air’s ability to hold water vapor, improving distillation rates.
4. Moderate wind speeds, as observed, improve heat dissipation from the surface of the solar still, affecting internal heat retention. However, the low wind speeds recorded in this experiment limit its negative impact on overall performance. Moderate wind speeds can slightly enhance condensation but may reduce basin temperature if excessive.
5. The basin temperature with nanoparticles is about 43% higher than the atmospheric temperature, compared to 31% for the system without nanoparticles. This increase in thermal efficiency is a direct result of the superior heat absorption and transfer capabilities of Al_2O_3 nanoparticles. Nanoparticles increase the system’s ability to absorb and retain solar heat, promoting a higher temperature gradient that drives evaporation.
6. The productivity of the solar still with nanoparticles is approximately 22% higher on Day 1 and 13% higher on Day 2 compared to the system without nanoparticles. This increase can be explained by the enhanced thermal conductivity of nanoparticles, leading to greater heat retention and higher evaporation rates.
7. Both systems show a steady increase in productivity throughout the day, but the system with nanoparticles consistently delivers higher output (by 20-25%). The higher temperatures achieved in the nanoparticle-enhanced system result in higher evaporation rates, leading to proportional increases in water yield throughout the day.

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