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PERFORMANCE ANALYSIS OF SOLAR STILLS USING AG CYLINDERS WITH VARIOUS NANOFLUIDS

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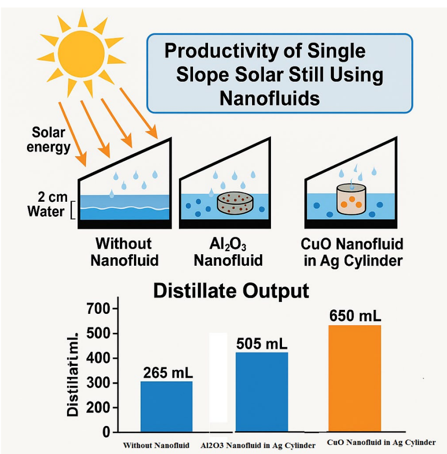
Veerendra Singh[a], Narendra Kumar[a*], Rajendra Kumar[b]

[a]Department of Mechanical Engineering, Faculty of Engineering and Technology, Rama University, Kanpur, Uttar Pradesh, India
[b]Department of Physics, Sardar Patel University, Balaghat, Madhya Pradesh, India

*Corresponding author
drnarendra.fet@ramauniversity.ac.in

Graphical abstract



Abstract

Due to the irregular availability of solar energy, the increment in the effective working period of the distillation process is a big challenge. Since nanofluids are highly efficient heat transfer carriers for harvesting solar energy to be used in the solar distillation process. Therefore, the present research work has been carried out to analyze the productivity of single slope solar still using two different nanofluids of Al_2O_3 and CuO along with base fluid (water). In this experiment, the comparison of the performance of solar stills at 2cm water depth without and with Al_2O_3 nanofluid, as well as CuO nanofluid of 0.2% concentration in a floating cylinder of silver (Ag), has been done. The results show that the nanofluids enhance the evaporation rate and the distillate output as 505ml and 650ml using Al_2O_3 and CuO nanofluid, respectively while without nanofluid, the output was 265 ml. It has also been found that solar still with CuO nanofluid in Ag cylinder has greater solar still efficiency than solar still with Al_2O_3 nanofluid and without any nanofluid.

Keywords: Solar still, Brackish Water, Nanofluid, Distillate, Solar energy

1.0 INTRODUCTION

Water is a vital and essential substance for life on Earth. It is crucial for all forms of life on Earth. It has a fundamental component of living creatures and plays a central role in various biological processes. For the general public's health, sanitation, and well-being, access to clean, safe drinking water is crucial. Contaminated water can harbor pathogens and toxins that cause waterborne diseases, causes of illness, morbidity, as well as death, especially in sensitive groups such as older people and children [1]. Most of Earth's water is in the form of saltwater in the oceans, which is not suitable for drinking or agriculture without desalination. Freshwater, found in rivers, lakes, and underground aquifers, is essential for various human and ecological needs [2]. Due to continuous increase in population and high pollutions of different forms, causes water scarcity day by day. Mostly a large quantity of the water on earth is contaminated which is to be purified by different processes such as reverse osmosis (RO), forward osmosis, electro dialysis and solar desalination etc. Solar distillation is the one of the economical, low maintenance, low cost process. Since this process uses solar energy for its operation so it is an environment friendly process. The main disadvantage of this process is its low efficiency. Therefore increasing its performance various technologies are incorporating with the solar still process. The most important technology used in solar still is the use of nanofluid which effectively works on the overcoming of these shortcomings. These nano fluids have extraordinary properties of highly efficient heat transfer carriers which enhance the efficiency of solar still [3].

Today, nano particles in nano fluid have various unique properties of ultrafast heat transfer carriers which contain remarkable thermal properties. [4, 5]
They investigated the effect of various parameters like ambient temperature, air velocity and basin water depth in solar still. (Sahota and Tiwari, 2016) performed their work on different concentrations of Al2O3 nanofluid mixed with 35kg and 80kg of water based fluid on investigating the thermal properties of

passive solar still. They studied three different nano particles Al_2O_3, TiO2 and Cu_2O on the effectiveness of passive double slope solar still [6].

They investigated the graphite and CuO micro-flakes which mixed these nano particles with water at different concentration to form nano fluid. Due to these nano fluids total yield around 53.95% and 44.91% was obtained respectively whereas for conventional solar still around 30% total yield obtained [7].

They studied the TiO_2 nano fluid at various concentrations 0.5%-5% used in solar still. This arrangement gave better thermal conductivity and enhanced up to 29.7% due high concentration and temperature [8].

They studied about the performance of single slope solar still by utilizing Cu_2O-based nano fluid. The result indicated that total yield was received higher in case of Cu_2O-based nano fluid than solar still without nano fluid [9].

They searched that addition of nano particles enhance water productivity due to increase in heat energy in a solar still by using nanofluids [10].

He investigated that using nano fluid with condenser coil externally enhances the water output around 116% where as in conventional solar still water distillate is very low [11].

They studied that using nano fluid increases the distillate output and also the evaporation rate. This arrangement improved solar still distillate output by 24.3% while using Al2O3 nanofluid [12].

Nazari, S., Safarzadeh, (2019) studied the copper oxide water based nanofluid and attaching with a condenser which will enhance the solar still total distillate [13, 14].

Abdullah, A.S. (2019) investigated on solar still by attaching a solar water heater, a condenser and rotating drum at speed of 0.1 rpm, filled with CuO nano fluid. This Experiment was given result that maximum 4.49 times fresh water received than that of conventional solar still [15].

Higher evaporation rates and fast heating are the consequences of hybrid nanofluids enhanced heat transmission from the solar absorber to the water due to this better thermal stability and less energy losses in distillation process that make it possible by synergistic effect. Due to high specific heat capacity of Al_2O_3 (0.775 J/g·K) and CuO (0.53 J/g·K gives better heat storage and distribution. This assures continuous evaporation even in varying solar conditions [16].

An investigation was carried out a comparative study of the performance of solar stills with and without the use of CuO-based nanofluid of different concentrations such as 0.1%, 0.2% and 0.3% at 2 centimeter basin water depth has been carried out. The results showed that nano fluid increases the total yield as 560 ml, 675 ml and 510 ml by using CuO nanofluid at concentration of 0.1%, 0.2% and 0.3%, respectively as compared to without nanofluid which was 280 ml. It is found that a maximum improved distillate of 58% obtained at 0.2% concentration of CuO nanofluid as compared to conventional solar still [17].

A modification was carried out on the conventional solar still to demonstrate the consequences of different nanoparticle applications on the thermal efficiency of traditional still. According to the findings, using cuprous oxide (Cu_2O) as well as aluminum oxide (Al_2O_3) nanoparticles during daylight accelerated the rate of water productivity [18].

The experiments were carried out for various nanoparticle volume fractions such as two sizes of 7 nm and 40 nm nano particles, two basin water depths 4 and 8 cm as well as three mass flow rates of nanofluids in different weather conditions.

The results revealed that use of heat exchanger at lower temperatures below 60 °C is not beneficial and total water yield is very low as compare to using without the heat exchanger. Even though, use of nanofluids in the heat exchanger improved the parameters about 10% of still [19].

An experiment was conducted in which a novel solar desalination device was used, which was concentrated by solar light on the surface. In this analysis mainly focus on the essential parts like brine water, flash chamber and condenser. This experiment used saline water from eastern area of Saudi Arab. The results indicated on device performance under various levels of salinity from 15,000 ppm to 35,000 ppm [20].

An experiment assessed a spray flash desalination system in which concentrated solar power used that focusing on enhancing condenser exit temperature, boiler exit temperature, and distillate production. Mainly factors analyzed included flow rate (0.2–0.4 LPM), salinity (15,000–35,000 PPM), feed water temperature (30–50 °C), and vacuum pressure (0.1–0.5 bar). For Analysis a mathematical models and response surface methods were utilized for optimization. Results revealed that higher feed water temperatures and vacuum pressures improved condenser and boiler temperatures, whereas salinity and flow rate had a negative impact. Flow rate, feed water temperature, and vacuum pressure positively affected total distillate [21].

He investigated the comparative analysis of the performance of solar stills using CuO-based nanofluid at different concentrations of 0.1%, 0.2%, and 0.3% with a traditional solar still, focusing on a basin water depth of two centimeter. Findings indicated that at 0.2% CuO nanofluid concentration results in a 58% increase in distillate compared to the traditional model, highlighting its superior efficiency for future research [22].

The study investigated the performance enhancement of a solar still using Al2O3-CuO hybrid nano fluid, focusing on basin water depths of 2 centimeter, 3 centimeter, and 4 centimeter. The highest yield of 689 ml was achieved at a 2 centimeter depth with a 0.1% concentration. The results indicate that the hybrid nano fluid significantly enhances evaporation rates and total yield at the 2 centimeter depth, outperforming both conventional solar stills and other nano fluids [23].

This study was carried out for improving productivity of passive double slope solar still (DSSS) with Al2O3 nanoparticles in the water as a base fluid in two different masses 35 kg and 80 kg respectively. The analysis was shown for the base fluid without nanoparticle as well as using nanofluid at three concentrations such as 0.04%, 0.08% and 0.12%. At 0.12% concentration of Al2O3 nanoparticles, the improved total yield for 35 kg and 80 kg water 12.2% and 8.4% respectively [24].

The novelty of the present study lies in the introduction of a new heat-transfer enhancement approach in which Al_2O_3 and CuO nanofluids are stored inside a floating high-conductivity silver (Ag) cylinder rather than being mixed directly with the basin water, as commonly reported in earlier works. This configuration allows rapid and efficient solar heat transfer to the distillate without altering the chemical properties of the basin water, avoiding stability concerns, sedimentation, or contamination issues associated with mixed nanofluids. The study experimentally demonstrates that this method significantly enhances evaporation and productivity, with CuO nanofluid achieving 650 ml of distillate and 46.75% efficiency—far higher than both Al_2O_3 nanofluid and the conventional still. Therefore, the novelty is in (i) the use of an Ag-cylinder-based thermal booster for nanofluids, (ii) achieving major performance improvement without modifying the still design, and (iii) providing experimental verification of comparative performance for Al_2O_3 and CuO nanofluids under identical operating conditions.

2.0 METHODOLOGY

The experimental setup of single slope solar still is shown figure 4 & 5. It is made up of wooden block. It consists of mainly solar basin, solar collector, and single glass cover. The front side of basin is south facing. Its basin size is 50x50 cm^2, basin surface is attached with aluminum plate and painted with black colour to improve absorption of the solar energy, while, it's height from front and back are 12 centimeter and 60 centimeter respectively.

2.1 Nano Materials

A nanofluid is a type of fluid in which nanometer-sized particles (1 nm–100 nm sized) are dispersed within a base fluid, such as water, oil, or another liquid. These nanoparticles can be made of various materials, including metals, oxides, carbides, and polymers. Nanofluids have gained attention in recent years for their unique thermal and heat transfer properties.

One of the primary reasons nanofluids are of interest is their enhanced heat transfer properties. The nano particles significantly improve the fluid's thermal conductivity, making it more efficient at dissipating heat or conducting heat in various applications. Nanofluids can exhibit changes in their viscosity due to the presence of nanoparticles. In some cases, the viscosity may increase, while in others, it may decrease, depending on factors like the type and concentration of nanoparticles used.

It is important fact that performance of nanofluids can be affected by various factors like, choice of nanoparticles, their concentration, and the specific application. Researchers continue to study and develop nanofluids for various industries to harness their unique properties for more efficient heat transfer and other applications.

2.2 Al_2o_3 Nano Fluid

Al_2O_3 nanofluids can be used in solar stills to enhance their efficiency and productivity. Solar still utilizes incident solar insolation to decontaminate water by evaporating it and then condensing the vapor to produce fresh, clean water. Al_2O_3 nanoparticles have a high absorption capacity for solar radiation. When these nanoparticles are added to the water in a solar still, they can absorb more sunlight, which in turn increases the temperature of the water. This enhanced heat absorption accelerates the evaporation process.

When the water evaporates inside solar still and comes near with a condensation surface, the enhanced thermal properties of the Al_2O_3 nanofluid help with condensation. This results in a more efficient conversion of water vapor back into liquid water, improving the freshwater yield.

Using Al_2O_3 nanofluids in solar stills can be particularly beneficial in arid regions or areas with limited access to clean drinking water, where solar stills are used as a sustainable and low-energy method for water purification. This technology can help increase the daily freshwater production from solar stills, making them more practical and reliable for meeting the water needs of communities and individuals in water-scarce environments.

2.3 CuO Nano Fluid

CuO nanofluid, or copper oxide nanofluid, is a type of nanofluid in which nanometer-sized copper oxide (CuO) particles are scattered in a water based fluid or another liquid. The use of CuO nanoparticles in nanofluids is highly observed due to its high thermal conductivity.

CuO nanoparticles have a relatively high heat capacity, which allows them to store and release thermal energy effectively.

2.4 Formation Of Nano Fluid

The formation of a nanofluid involves the dispersion of nanometer-sized particles (nanoparticles) into a base fluid to create a stable mixture. The nanoparticles can be made of various materials, such as metals, oxides, carbides, or polymers. The formation of nano fluid is completely based on its applications which will become right mixing of nanoparticles and the base fluid. Here are the general steps involved in forming a nanofluid:

The formation of nanofluids is a careful and controlled process to ensure that nanoparticles and base fluid are uniformly and maintain stability.

For preparation of nano fluid, nanoparticles are stirred by magnetic stirrer at 1000 RPM for 45 minutes into the base fluid. Sonication or mechanical mixing is often employed to disperse the nanoparticles uniformly by the ultrasonicator at 45^0C - 47^0C for2 hours, as shown in figure 1, figure 2 and figure 3 respectively.

Thus formed Al_2O_3 nanofluid and CuO nanofluid is shown in figure 6 & 7.

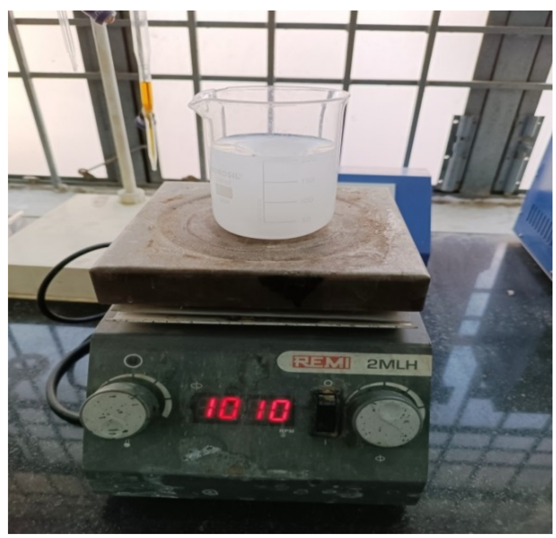


Figure 1 Mechanical mixing of Al_2O_3 nano particle by mechanical stirrer

Figure 2 Mechanical mixing of CuO nano particles by mechanical stirrer

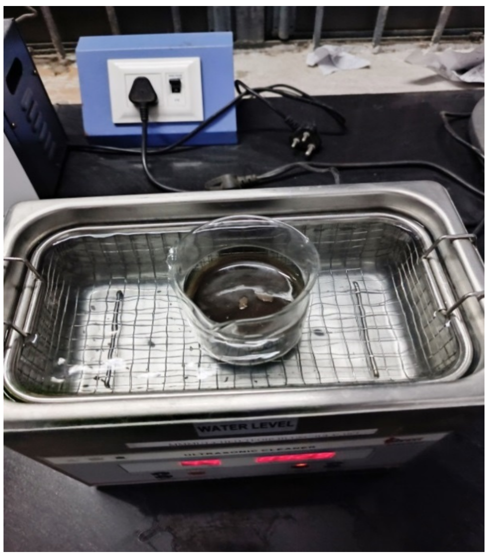


Figure 3 Mixing of Al_2O_3 and CuO nano particle by Ultra Sonicator

Figure 4 Solar still filled with nano fluid in Silver (Ag) cylinder

Figure 5 Conventional type single slope solar still setup

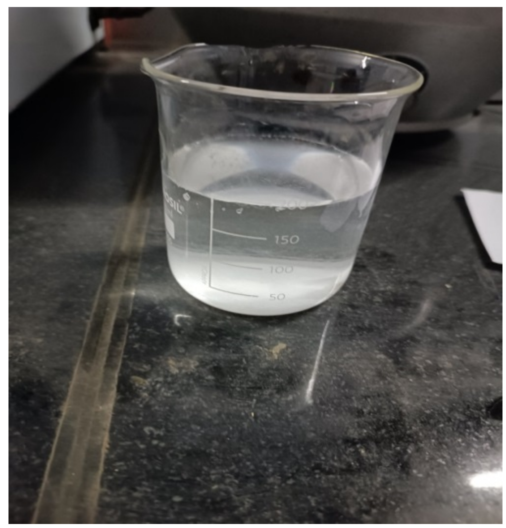


Figure 6 Al_2O_3 Nano Fluid

Figure 7 CuO Nano Fluid

3.0 RESULTS AND DISCUSSION

The experimental work is carriedout at Mechanical Engineering Department, Madan Mohan Malaviya University of Technology, Gorakhpur Uttar Pradesh, India (Latitude 26.7304, Longitude 84.4325) and readings were recorded at every half an hour in the month of May, 2023.

This Experimental analysis is done on the comparative study of performance of conventional solar without using nano fluid and solar still with using Al_2O_3 nano fluid, as well as CuO nanofluid of 0.2% concentration in a floating cylinder of silver (Ag) at 2 cm water depth and studied the effective variation of the total yield and overall efficiency of conventional solar still.

3.1 Hourly Variation Of Solar Intensity Throughout Day On 30 May 2023

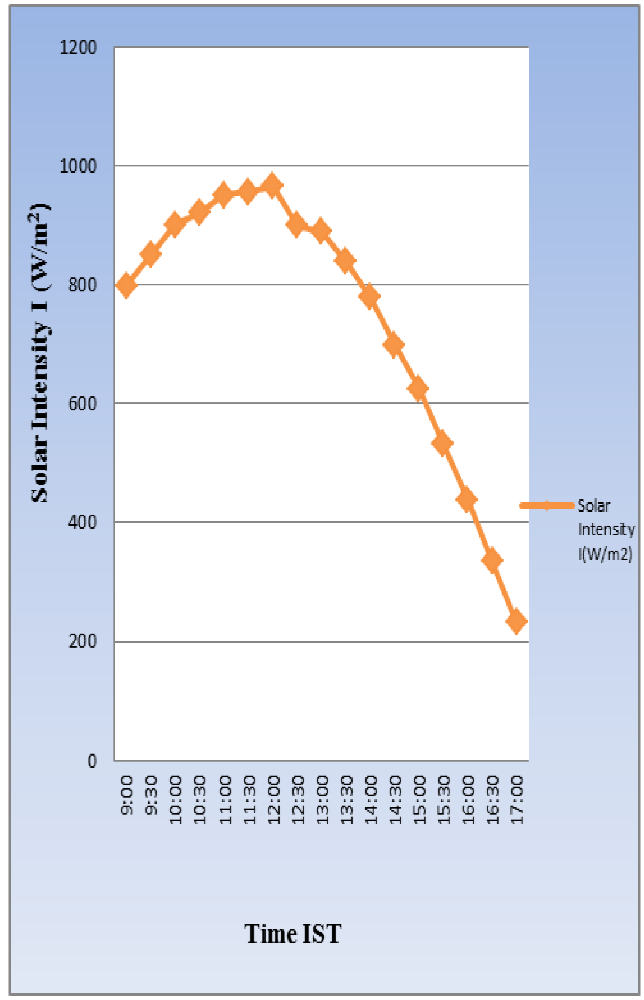


Figure 8 Graphical representation of solar insolation on May 30, 2023

Figure 8 shows graphical representation of solar insolation with time till 5 PM. This experiment is conducted on May 30, 2023. The trend shows that solar irradiance increases from 9 AM to 12 AM, after that it starts decreasing from 12 AM to 5 PM. This trend also shows that when sunset occurred, solar intensity remains zero. The maximum solar intensity was 965 W/m^2 at 12PM. Due to increase in solar irradiance, ambient temperature increases and also increases absorber surface temperature which will further increase the water temperature (T_w) inside basin. This increased basin water temperature (T_w) leads towards higher evaporation and the total yield increases. Solar intensity is the irradiation coming from the Sun in the form of Sun rays. It is measured by Pyranometer.

Maximum solar intensity (I) observed is 965 W/m^2 at 12 PM Minimum solar intensity (I) observed is 232 W/m^2 at 5 PM Maximum ambient temperature (T_a) observed is 50°C Maximum wind velocity (V_w) observed is 1.8 meter/second Minimum wind velocity (V_w) observed is 0.9 meter/second

3.2 Graphical Representation Of Basin Water Temperature With And Without Using Nano Fluid Filled With Ag Cylinder

Figure 9 shows graphical representation of temperatures of water inside basin and silver (Ag) cylinder filled with Al_2O_3 and CuO nano fluid. Since from graph it is clearly shown that basin water temperature Tw (^{0}C) for Cuo nano fluid at 0.2% concentration is very high in comparison to using Al_2O_3 nano fluid and conventional solar still without nano fluid. The reason behind is, CuO nano fluid has highly efficient heat transfer carriers, filled with high conductive silver (Ag) cylinder, it enhances highly heat transfer rate which causes high evaporation rate of basin water and thus increases maximum yield. Since silver (Ag) metal is very high conductive material, therefore it transfers maximum incident solar irradiation to nano fluid without any heat loss and heat transfer carriers of nano fluid increases the basin water temperature immediately.

Maximum basin water temperature (T_w) without nano fluid is 52^{0}C.
Maximum basin water temperature (T_w) with Al_2O_3 nano fluid is 62^{0}C.
Maximum silver (Ag) cylinder temperature (T_n) filled with Al_2O_3 nano fluid is 65^{0}C.
Maximum basin water temperature (T_w) with CuO nano fluid is 66^{0}C.
Maximum silver (Ag) cylinder temperature (T_n) filled with CuO nano fluid is 68^{0}C.

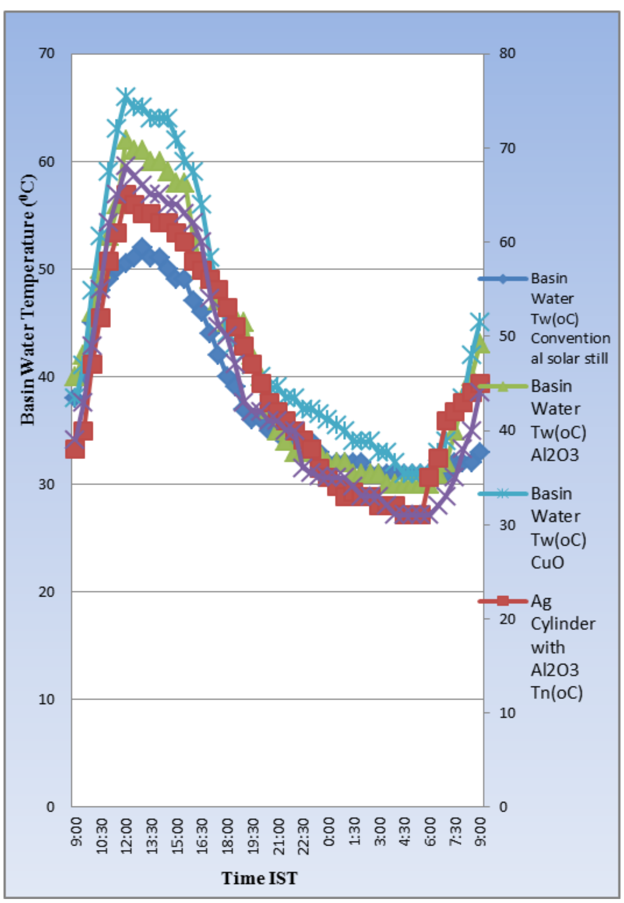


Figure 9 Graphical representation of water temperature (T_w) inside basin and Ag cylinder filled with Al_2O_3 and CuO nano fluid with time

3.3 Hourly Variation Of Total Yield For Conventional Solar (Without Using Nano Fluid)

Figure 10 shows the graphical representation of hourly and accumulated total yield (ml) of conventional solar still without any nano fluid with time. Hourly maximum yield of 32 ml is received at 12.30 AM. The total distillate output of 265 ml is received for the conventional solar still.

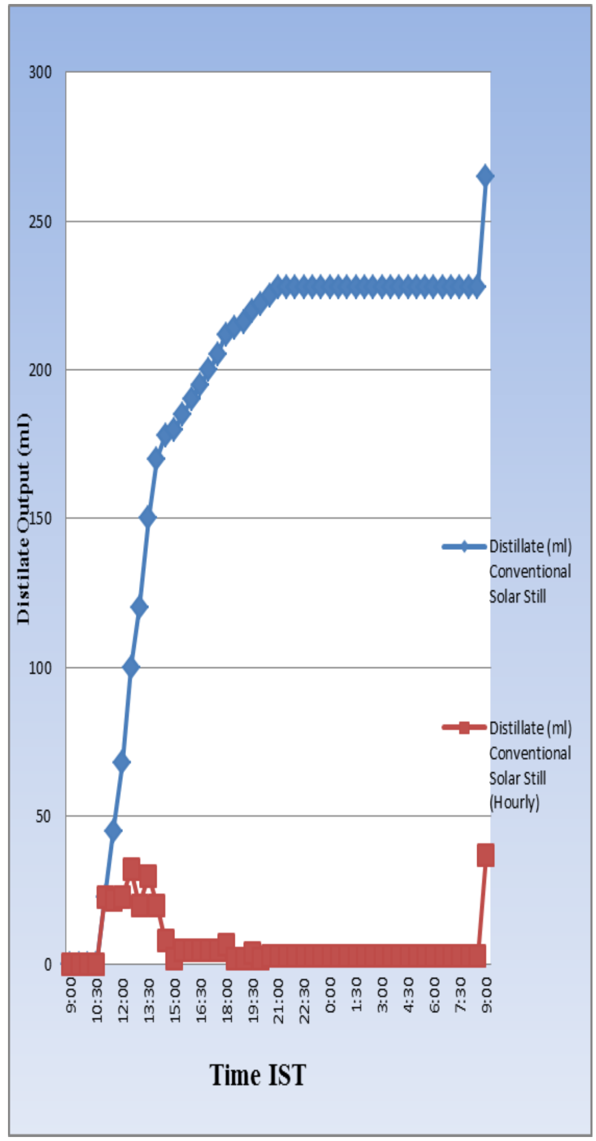


Figure 10 Graphical representation of accumulated & hourly total yield (ml)

3.4 Variation Of Total Distillate For Solar Still (With & Without Using Nano Fluid)

Figure 11 shows the graphical representation of total output (ml) of solar still with and without using of Al_2O_3 nano fluid as well as CuO nano fluid at 0.2% concentration. Figure 12 the blue line graph shows variation of yield (ml) in conventional solar still. The red line graph represents the variation of yield (ml) in solar still using Al_2O_3 nano fluid, whereas green line graph shows the variation of hourly total output (ml) of solar still using CuO nano fluid at 0.2% concentration. The above trend clearly shows that maximum yield 650 ml is obtained for CuO nano fluid at 0.2% concentration.

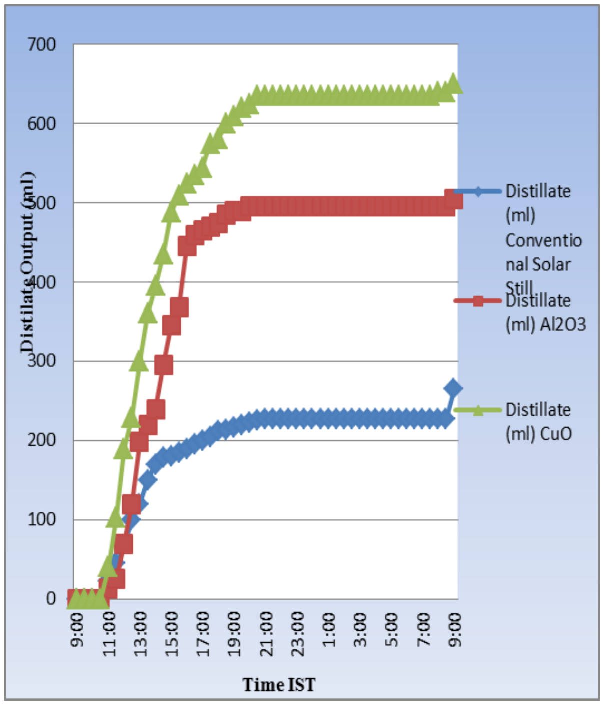


Figure 11 Variation of total yield (ml) of solar still with & without using nano fluid

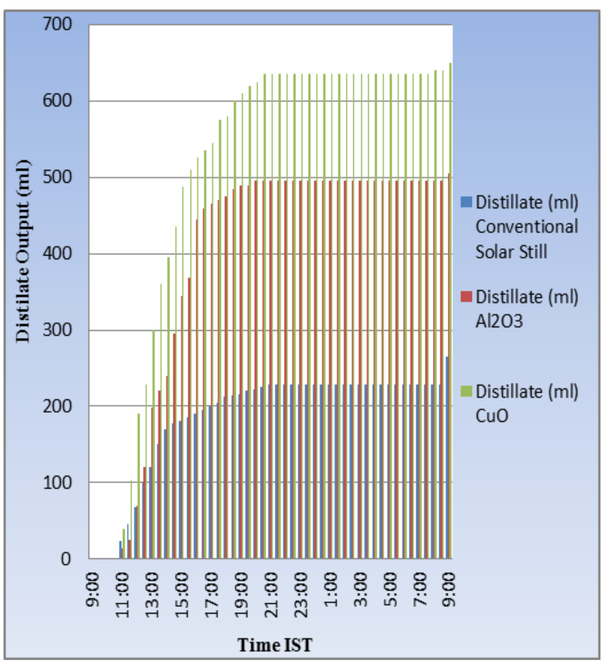


Figure 12 Hourly Variation of total yield (ml) of solar still with & without using nano fluid

3.5 Total Distillate Output for Conventional and Solar Still with Use of Al_2O_3 Nano Fluid As Well As Cuo Nano Fluid At 0.2% Concentration

From the above trend shown in Figure 13 it is clearly shown that:

Total distillate water for CuO nano fluid at 0.2% concentration is 650 ml.

Total distillate water for Al_2O_3 nano fluid at 0.2% concentration is 505 ml.

Total distillate water for conventional solar still is 265 ml.

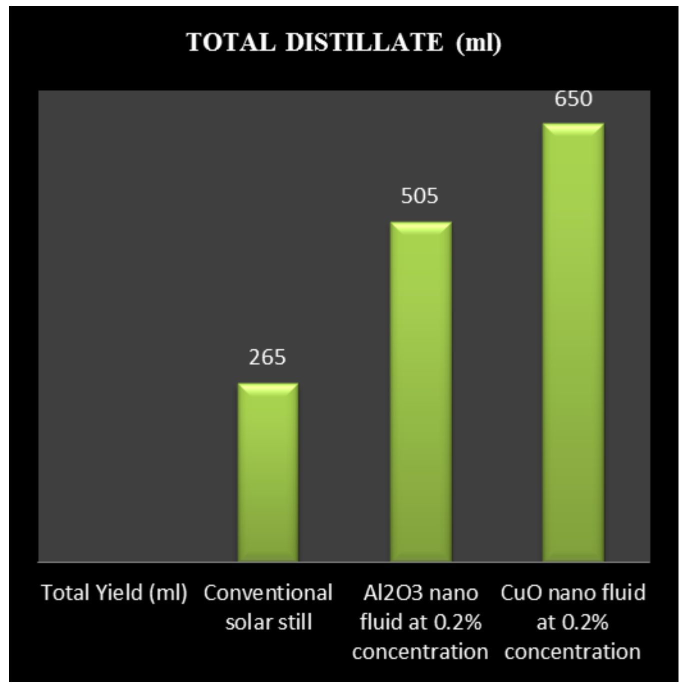


Figure 13 Variation of productivity of conventional and solar still with different nano fluid at 0.2% concentration

3.6 Calculation of efficiency

Overall efficiency of solar still is,

$$\eta = \frac{[m \times L]}{[I(t) \times Ac \times 3600]} \times 100\%$$

Where,

η = Single slope solar still efficiency (%)

m = mass of distillate water (ml/hr.),

L = Latent heat of vaporization for water (J/kg) = 2.20×10^6 J/kg

Ac = Area of acrylic sheet cover (m^2)

= 50 cm × 50 cm

= 2500 cm^2

= 0.25 m^2

I (t) = Solar insulation (W/m^2)

Table 1 Calculate Value from Above Efficiency Formula for Different Solar stills

Maximum Efficiency (%)	Conventional Solar Still (without Nano Fluid)	Solar Still using Al_2O_3 Nano Fluid	Solar Still using CuO Nano Fluid
	5.9	11.55	46.75

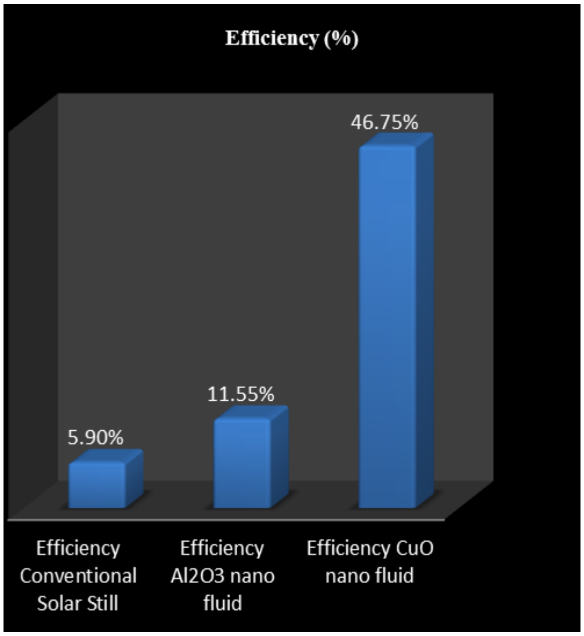


Figure 14 Variation of efficiencies for conventional and solar still with different nano fluid at 0.2% concentration

Figure 14 illustrates variation of efficiencies for conventional and solar still with the use of Al_2O_3 as well as CuO nano fluid at 0.2% concentration. It is clearly seen that solar still using of CuO nano fluid is highly efficient than Al_2O_3 nano fluid as well as conventional. The overall thermal efficiency of solar still using CuO nano fluid is 46.75% is achieved which is higher than others as shown in Table-1..

3.7 Uncertainty Analysis

Uncertainty estimation was performed by following ISO-GUM uncertainty propagation principles.

3.7.1 Uncertainty Model And Propagation (ISO-GUM Approach) Quantity Of Interest (Primary): Overall Thermal Efficiency

$$\eta = \frac{[m \times L]}{[I(t) \times Ac \times Etot]} \times 100$$

where

- m = mass of collected distillate during the test (kg). In your paper you reported daily volumes: Conventional 265 ml, Al_2O_3 505 ml, CuO 650 ml. Convert ml → kg using water density ~1 kg/L (so 1 ml = 0.001 kg).
- L = latent heat of vaporization of water (L= 2.20×10^6 J/kg).
- Ac = area of the glass cover (m^2). 50 cm×50 cm = 0.25 m^2.
- $Etot \approx \int_{t0}^{tf} I(t)dt$ = total incident solar energy on the cover (J/m²) during the experiment (day). Since recorded irradiance I(t) every 30 minutes, use numerical integration (trapezoidal rule):

$$Etot \approx \sum_{k=1}^{N-1} \frac{I_k + I_{k+1}}{2} \Delta t$$

where I_k are irradiance samples and Δt is interval in seconds. Assume input quantities are uncorrelated. Then the relative standard uncertainty in η is

$$\left(\frac{\delta\eta}{\eta}\right) = \sqrt{\left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta L}{L}\right)^2 + \left(\frac{\delta Ac}{Ac}\right)^2 + \left(\frac{\delta Etot}{Etot}\right)^2}$$

and the absolute uncertainty in percent points is δη = η×(δη/η).

Typical instrument uncertainties:

- Distillate measurement (graduated cylinder / balance): δm = ±1 ml (±1 ml = 0.001 kg).
- Pyranometer / irradiance integration: δEtot / Etot ≈ 5%
- Area measurement: measured as 50 cm × 50 cm with calipers ±1 mm → δAc / Ac ≈0.28%.
- Latent heat: negligible uncertainty for this context — δL / L = 0.1% (can be neglected).

Also report expanded uncertainty (k = 2) for 95% confidence: multiply single-sigma uncertainty by 2.

3.7.2 Numeric Example Propagation

Input experimental totals from manuscript:

- Distillate (total for whole day): Conventional = 265 ml, Al_2O_3 = 505 ml, CuO = 650 ml.
- Reported efficiencies in manuscript: Conventional Efficiency (η) = 5.90%, Al_2O_3 Efficiency (η) = 11.55%, CuO Efficiency (η) = 46.75%.

Using the instrument uncertainty assumptions above (δm = 1 ml, δE/E = 5%, δA/A = 0.283%, δL/L = 0.1%), the propagated uncertainties are shown in Table - 2:

Table 2 Uncertainty Analysis of the Reported η Values for Different Cases

Case	m (ml)	η (reported)	Relative uncertainty (k=1)	Absolute uncertainty (k=1, percentage points)	Expanded uncertainty (k=2)
Conventional	265	5.90%	5.02% (relative)	±0.30 pp (k=1)	±0.59 pp (k=2)
Al_2O_3	505	11.55%	5.01% (relative)	±0.58 pp (k=1)	±1.16 pp (k=2)
CuO	650	46.75%	5.01% (relative)	±2.34 pp (k=1)	±4.69 pp (k=2)

Interpretation: for the CuO case the efficiency should be reported as

η=46.75% ± 2.34 pp (k=1) or 46.75% ± 4.69 pp (k=2).

For yields, with δm = ±1 ml the absolute uncertainty is simply ±1 ml, so:

- CuO: 650 ml ±1 ml (±0.15%)
- Al_2O_3: 505 ml ±1 ml (±0.20%)
- Conventional: 265 ml ±1 ml (±0.38%)

An uncertainty analysis was performed for the main experimental outputs (distillate mass and overall efficiency) following the ISO-GUM propagation approach. The overall thermal efficiency was calculated as $\eta = mL/(Ac\ E_{tot})$. Uncertainties in the input quantities were taken from instrument specifications and measurement resolution: distillate volume ±1 ml (graduated cylinder/readability), pyranometer/irradiance integration uncertainty ≈ ±5% (manufacturer specification), cover-area measurement ±1 mm, and latent heat uncertainty ≈ 0.1%. Propagation of these uncertainties gives relative expanded uncertainties (k = 2, ~95% confidence) in the efficiency of approximately ±0.59 percentage points for the conventional still (η = 5.90% ± 0.59 pp), ±1.16 pp for the Al_2O_3 case (η = 11.55% ± 1.16 pp), and ±4.69 pp for the CuO case (η = 46.75% ± 4.69 pp). The collected daily yields have an absolute uncertainty equal to the volume-reading resolution (±1 ml); i.e., 650 ml ±1 ml for the CuO case. The dominant contribution to the efficiency uncertainty is the irradiance integration (solar energy) uncertainty; improved pyranometer accuracy or repeated runs would reduce the uncertainty.

4.0 CONCLUSION

This study experimentally evaluated the performance of a single-slope solar still enhanced with silver (Ag) floating cylinders filled with Al_2O_3 and CuO nanofluids at a 0.2% concentration. The incorporation of nanofluids significantly modified the heat transfer behavior inside the basin, resulting in higher basin water temperatures, faster evaporation, and improved distillate productivity.

The findings indicate that CuO-based nanofluid offers the most effective thermal enhancement, achieving an overall efficiency of 46.75%, compared with 11.55% for Al_2O_3 nanofluid and 5.90% for the conventional still. Similarly, the CuO-enhanced configuration produced a maximum distillate yield of 650 mL, which is more than double that of the conventional system. These results suggest that nanofluid-assisted thermal storage inside Ag cylinders can provide a practical route to overcoming the low productivity that typically limits passive solar stills.

However, the study also has several limitations that should be considered when interpreting the outcomes. The experiments were conducted under a single climatic condition and at a controlled water depth of 2 cm, which may not represent seasonal or geographical variations. Only one nanofluid concentration (0.2%) was tested, and long-term operational issues such as nanoparticle sedimentation, stability, corrosion of the Ag cylinder, and potential environmental impacts of nanofluids were not evaluated. Additionally, reproducibility across multiple days or trials was not analyzed in depth, which could influence statistical strength.

The results nevertheless provide important implications for the design of low-cost desalination systems. The demonstrated thermal enhancement indicates that nanofluids can serve as highly effective heat transfer carriers, enabling solar stills to achieve higher water output without major structural modifications. Such improvements could contribute significantly to freshwater generation in off-grid or rural regions.

Based on the observed performance and identified limitations, the following future research directions are recommended:

1. Multi-season and multi-location testing to evaluate how climatic variability affects nanofluid performance.
2. Optimization of nanofluid parameters, including higher or hybrid nanoparticle concentrations, surface functionalization, and stability-enhancing additives.
3. Long-term durability studies focusing on nanoparticle agglomeration, material compatibility, and corrosion of the Ag container.
4. Environmental and economic assessments, addressing nanoparticle recovery, safe disposal, and overall cost–benefit analysis.
5. Integration with advanced solar still designs, such as wick-type, multi-effect, or hybrid PVT-assisted systems, to further increase distillate productivity.

In summary, the study confirms that CuO nanofluid in a silver cylinder provides a robust and effective means of boosting solar still performance. Addressing the identified limitations will be essential for transitioning from laboratory-scale demonstration to reliable real-world desalination applications.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Veerendra Singh, Rajendra Kumar, 2022, "A review on research trends in single slope solar still system for increasing its efficiency" *NeuroQuantology, 20(13): 3611.* DOI: 10.14704/nq.2022.20.13.NQ88444.

[2] Z.M. Omara, Mofred H. Hamed, A.E. Kabeel, 2011, "Performance of finned and corrugated absorber solar stills under Egyptian conditions" *Desalination, 277:281–287.*

[3] Hossain Md. Fazle Rabbi, Ahmet Z. Sahin, 2021, "Performance improvement of solar still by using hybrid nanofluids" *Journal of Thermal Analysis and Calorimetry, 143(2): 1345-1360.* DOI: https://doi.org/10.1007/s10973-020-10155-6.

[4] Xie, H., Wang, J., Xi, T., Liu, Y., Ai, F., Wu, Q., 2002, "Thermal conductivity enhancement of suspensions containing nanosized alumina particles" *Journal of Applied Physics, 91:4568-4572.*

[5] Yu, W., France, D. M., Routbort, J. L., Choi, S.U., 2008, "Review and comparison of nanofluid thermal conductivity and heat transfer enhancements" *Heat Transfer Engineering, 29:432-460*.

[6] A. K. Tiwari, G. N. Tiwari, 2007, "Thermal modeling based on solar fraction and experimental study of the annual and seasonal performance of a single slope passive solar still: The effect of water depths" *Desalination, 207(1–3):184–204*.

[7] Sharshir SW, Peng G, Wu L, Yang N, Essa FA, Elsheikh AH, et al, "Enhancing the solar still performance using nanofluids and glass cover cooling: Experimental study" *Applied Thermal Engineering, 113:684-693.* DOI: http://dx.doi.org/10.1016/j.applthermaleng.2016.11.085.

[8] S.M.S. Murshed, K.C. Leong, C. Yang, 2005, "Enhanced thermal conductivity of TiO_2- water based nanofluids*" International Journal of Thermal Science, 44(4): 367–373.* DOI: 10.1016/j.ijthermalsci.2004.12.005

[9] H. Hafs, A. Zaaoumi, Z. Bouramdane, O. Ansari, A. Bah, M. Asbik, M. Malha, 2018, "A Performance Analysis Study of a Single Slope Solar Still with Integrating Fins and Nanofluid for Productivity Enhancement" *Proceedings International Conference of Computer Science and Renewable Energies, ISBN: 978-989-758-431-2.*DOI: 10.5220/0009773203420348.

[10] Bait, O., Si-Ameur, M., 2018, "Enhanced heat and mass transfer in solar stills using nanofluids: a review" *Solar Energy 170:694–722.* DOI: https://doi.org/10.1016/j. solener.2018.06.020.

[11] Kabeel, A.E., Omara, Z.M., Essa, F.A., 2014, "Enhancement of modified solar still integrated with external condenser using nanofluids: an experimental approach" *Energy Conversion and Management,78:493-498.*DOI: https://doi.org/10.1016/j. enconman.2013.11.013.

[12] Thakur, A.K., Khandelwal, P., Sharma, B., 2018, "Productivity Comparison of Solar Still with Nano Fluid and Phase Changing Material with Same Depth of Water" *Springer, Cham, 119–129.* DOI: 10.1007/978-3-319-63085-4_17

[13] Nazari, S., Safarzadeh, H., Bahiraei, M., 2019, "Performance improvement of a single slope solar still by employing thermoelectric cooling channel and copper oxide nanofluid: an experimental study" *Journal of Cleaner Production, 208:1041–1052.*DOI: https://doi.org/ 10.1016/J.JCLEPRO.2018.10.194.

[14] Nazari, S., Safarzadeh, H., Bahiraei, M., 2019, "Experimental and analytical investigations of productivity, energy and exergy efficiency of a single slope solar still enhanced with thermoelectric channel and nanofluid" Renewable *Energy, 135:729-744.* DOI: https:// doi.org/10.1016/j.renene.2018.12.059.

[15] Abdullah, A.S., et al., 2019, "Rotating-drum solar still with enhanced evaporation and condensation techniques: comprehensive study" *Energy Conversion and Management 199:112024.* DOI: https://doi.org/10.1016/j.enconman.2019.112024.

[16] Veerendra Singh, Rajendra Kumar, 2025 "Enhancement of distillation using solar still with CuO-based nano fluid stored in silver (Ag) cylinder" *American Institute of* Physics, *Conference Proceedings, 3254(1): 020013.* DOI: https://doi.org/10.1063/5.0247076.

[17] B. Gupta, P. Shankar, R. Sharma, P. Baredar, 2016, "Performance enhancement using nano particles in modified passive solar still" *Procedia Technology, 25:1209–1216.* DOI: https://doi.org/10.1016/j.protcy.2016.08.208.

[18] A. E. Kabeel, Z.M. Omara, F.A. Essa, 2014, "Improving the performance of solar still by using nanofluids and providing vacuum" *Energy Conversion and Management, 86: 268–274.* DOI: https://doi.org/10.1016/j.enconman.2014.05.050.

[19] Mahian O, Kianifar A, Kalogirou SA, Pop I, Wongwises S., 2013, "A review of the applications of nanofluids in solar energy" *International Journal of Heat and Mass Transfer, 57: 582–94.*

[20] Faizan Ahmed, MohdSharizal AbdulAziz, Feroz Shaik, C.Y. Khor,"Salinity impacts on a unique desalination system embedded with concentrated solar energy for cleaner production" *Journal of Cleaner Production: 140223.* DOI: https://doi.org/10.1016/j.jclepro.2023.140223.

[21] Faizan Ahmed, Mohd Sharizal Abdul Aziz, Feroz Shaik, C.Y. Khor, 2023, "Optimization of a novel spray flash desalination system integrated with concentrated solar power utilizing response surface methodology" *Desalination, 558 :116640.* DOI: https://doi.org/10.1016/j.desal.2023.116640.

[22] Veerendra Singh; Rajendra Kumar, 2025, "Enhancement of distillation using solar still with CuO-based nano fluid stored in silver (Ag) cylinder" *American Institute of* Physics, *Conference Proceedings, 3254(1):020013* DOI: https://doi.org/10.1063/5.0247076.

[23] Veerendra Singh, Narendra Kumar, Rajendra Kumar, 2025,"Performance enhancement of solar still using Al_2O_3–CuO hybrid nanofluid: A comparative study at varying basin water depths" *Research on Engineering Structures and Materials, 12(3): 1419-1438.* DOI: http://dx.doi.org/10.17515/resm2025-826ma0418rs.

[24] L. Sahota and G. N. Tiwari, 2016, "Effect of Al_2O_3 nanoparticles on the performance of passive double slope solar still," *Solar Energy, 130:260–272.* DOI: https://doi.org/10.1016/j.solener.2016.02.018