Augmentation of Solar Still Distillate Productivity using Different Concentrations of CuO Nanofluids: An Experimental Approach

Dheerandra Singh, Mahfooz Ahmad*, Azharuddin*, Ahmed Sabeeh

Department of Mechanical Engineering, Madan Mohan Malaviya University of Technology Gorakhpur, Uttar Pradesh, 273010, India

*Corresponding author's e-mail: ahmadmahfooz169@gmail.com, azharuddinkhan99@gmail.com

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ABSTRACT

A device used to convert saline water into freshwater popularly known as solar still (SS). It is not popular in the market due to its low productivity. In this paper, efforts were put to enhance yield of single slope solar still (SSSS) by mixing copper oxide (CuO) nanoparticles having different concentrations into the base water. The performance of SS with and without nanoparticle were compared. Further, convective and evaporative heat transfer coefficients were evaluated. An experimental arrangement having inclination 27º of glass cover & 0.25 m² basin area is engineered & investigated in environmental situations of Gorakhpur city. It is founded that SS with CuO nanofluid results 56.64% higher productivity as compared to SS without nanofluids. Convective & evaporative heat transfer coefficients for 0.15% CuO concentration were found to be 8.53 and 13.18 W/m²K respectively. SS with CuO gives 41.75 ml/day of distillate whereas without nanofluid it gives 18.1 ml/day. The distilled water obtained for 0.05%, 0.10%, 0.15% and 0.20% concentrations are 39 ml/day, 42 ml/day, 45 ml/day and 41 ml/day respectively. Comparative results show that CuO nanofluid at 0.15% concentration have higher productivity than others.

Keywords: Single Slope Solar Still, Nanofluid, Copper Oxide, Heat Transfer Coefficient, Productivity.

1 Introduction

Distillation via solar is a process to get fresh and drinkable water free from contaminations. In present time electricity and other non-renewable energy is costly so it is beneficial to go with renewable energy sources. Purification of water using sun energy is found to be good for environment due to its zero emission. Solar still (SS) is not complex device to produce desalinate H_2O. Its output is limited and depend on weather condition such as sun shiny or cloudy day [1]. SS found useful device to remove impurities from brackish water which can be further used in our daily life [2]. People living in rural or desert areas, where ground water level is very low and supply of potable water by transportation is expensive. Some areas have hazardous water due to pollution, so the water is unfit for use. Different methods have been applied in past few decades to purify the impure water, but all methods require a huge amount of energy [3]. Due to no environmental impact, free availability of solar energy and zero maintenance cost make this device very usable for obtaining fresh water [4]. Many researchers have made efforts to improve the solar still productivity by using different techniques which are discussed as: Thakur *et al.* [5] conducted experiment on SS with CuO and ZnO nanoparticles. Result shows that distillate, heat transfer coefficients (HTC) of CuO was better than that of ZnO. Modi *et al.* [6] compared productivity of Al_2O_3 nanoparticles with and without in solar stills having various weight concentrations. It is found that productivity increases as concentration of nanoparticles increases. Sahota and Tiwari [3] analyzed the impact of using three discrete concentration of Al_2O_3 nanoparticles on thermal conductivity, fluid temperature & HTCs with double slope solar still (DSSS). Jathar and Ganesan [7] taken 0.1% and 0.2% volume concentrations of three different nanoparticles i.e., TiO_2, Al_2O_3, and MgO to evaluate the productivity of concave type stepped SS. Kabeel

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et al. [8] painted SSSS walls with black paint having CuO nanoparticles in it to increase rate of desalination. Modi *et al.* [9] worked on single basin DSSS with Al_2O_3 and CuO nanoparticles with varying water depth. Shoeibi *et al.* [10] evaluated the behavior of continuous usage of thermoelectric heating & cooling by using different nanofluids. Abdullah *et al.* [11] studied effects of reflectors (internal type) & phase change material (PCM) added with CuO nanoparticles in a tray SSSS. Panchal *et al.* [12] experimentally investigated SSSS to increase yield using MnO_2 nanoparticle. Nallusamy [13] analyse thermal conductivity by using CuO nanofluids. Preparation and characterization were also performed. Sathyamurthy *et al.* [14] investigated stepped SS using MgO & TiO_2 nanofluids to augment quantity of drinkable water.

After going through above mentioned augmentation techniques, it is found that there is very few work available on the augmentation of SSSS productivity using different concentration of CuO/water as a nanofluid. Therefore, the current is based on the comparison of SSSS with different concentrations of CuO nanoparticles with water.

2 Experimental Setup and Methodology

Three SSSS setups of same dimensions were made and insulated with plywood having glass cover tilted at an angle of 27° considered for investigation. Experiments were performed at MED, MMMUT Gorakhpur (26.76 °N, 83.37 °E) India, in December 2022. Still's basin area, maximum height is 0.25 m² & 0.15 m respectively. An apparent glass of thickness 3.0 mm is used to cover the solar still which allows solar radiation to forward inside setup. Absorber plate is 0.6 mm thick galvanized iron (GI) sheet and covered with black paint for more heat absorption and an aluminium foil is attached on the front wall for reflection of solar rays that trapped inside the basin. Four thermocouple wires are installed inside the basin which measure temperatures of bottom of still surface, water surface temperature, inner-side glass temperature and inner basin wall temperature. A pipe of 6.35 mm diameter is set to collect distilled water and is attached to the glass slope. One more pipe used for contaminated water inlet. There is also a pipe at the bottom of the wall to clear out the waste. Solar energy is harnessed between 10:00 IST - 18:00 IST to produce fresh water. Firstly, nanoparticles were mixed with base water to make nanofluids having weight concentration of 0.05%, 0.10%, 0.15% and 0.20%. Then prepared nanofluids were mixed with impure water and put in the base of still. 5000 ml of impure water was taken initially. Water gets heated up when radiation falls on it through glass cover. Condensation phenomenon takes place after the evaporation of water through glass cover. Distillate gets collected in the storage tank through the pre fitted pipe [15]. Figure 1 shown is the actual experimental setup. Solar Still parts, materials, and their dimensions were shown in Tables 1 and 2 respectively.

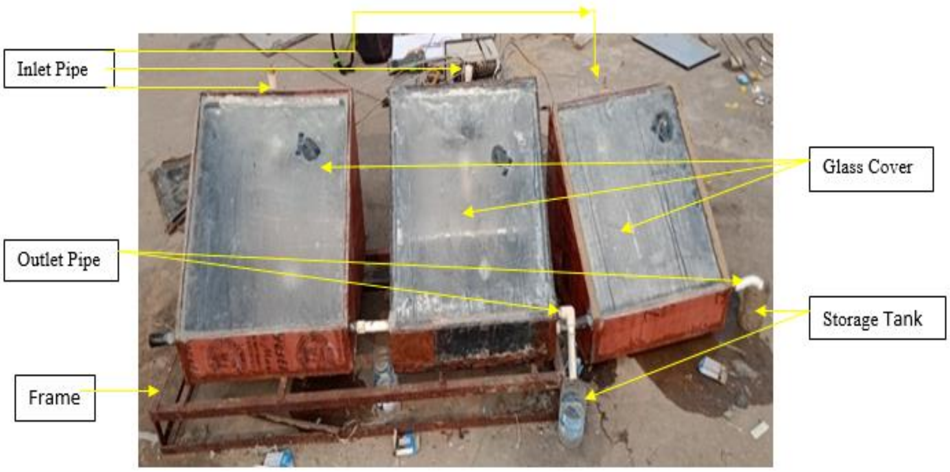

Figure 1: *Single slope solar still*

Table 1: *SS parts & their materials*

Solar still parts	Materials used
Transparent cover	Glass
Still basin	Galvanized iron sheet
Absorbing material	Black oil paint
Reflector	Sliver foil
Outer enclosing structure	Wooden ply

Table 2: *Dimensions of experimental setup*

Solar still parts	Dimensions
Basin area	0.25 m^2
Height of still	0.15 m
Slop angle	27°
Transparent cover	3 mm
Still basin	0.6 mm
Reflector	0.1 mm
Outer enclosing structure	12 mm

3 Preparation of Nanofluid

CuO nanoparticles utilised in this experimentation because of its low cost and superior thermal conductivity [16]. In Table 3, properties of nanoparticles were mentioned. Nanoparticles are of hydrophobic nature; they are insoluble in water, to make nanofluids out of this magnetic stirrer is used for an hour to mix water and nanoparticles. The ultrasonic vibrator machine is used to sonicate for a period of 30 minute. Ultrasonic machine is given coil temperature at 45 °C to 50 °C. Nanoparticles weight concentrations are selected as 0.05%, 0.10%, 0.15%, and 0.20% [6]. Nanoparticles were purchased from market for experimental use. Nanoparticles were added with base fluid (water) to prepare nanofluids using two step method without surfactant. Amount of nanoparticles needed to prepare each concentration is shown in Table 3. Nanoparticles, weighing machine, magnetic stirrer, and ultrasonic machine are shown in Figure 2 (a), (b), (c), and (d), respectively.

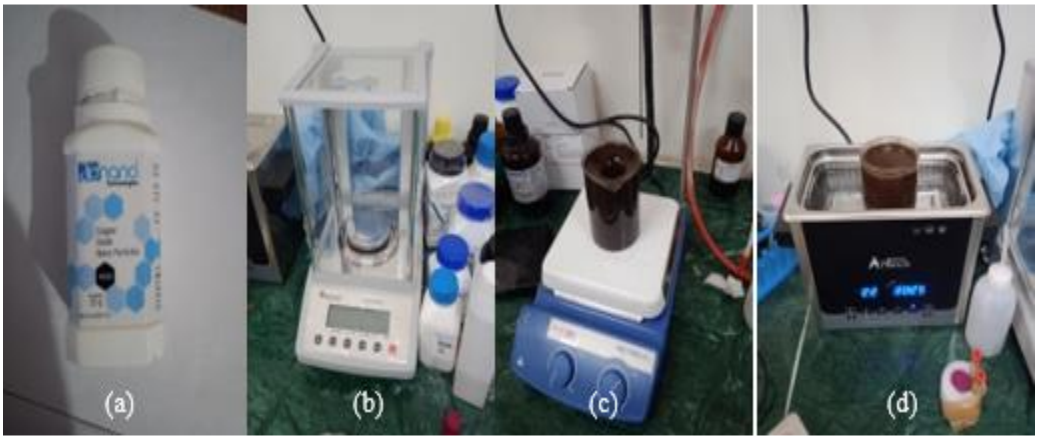

Figure 2: (a) *Nanoparticles,* **(b)** *Weighing machine,* **(c)** *Magnetic stirrer,* **(d)** *Ultrasonic machine*

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Table 3: *Properties and weight of nanoparticles* [6]

Properties	CuO nanoparticle	Weight concentration of nanoparticle	Amount of nanoparticles required	Amount of nanofluids used in solar still
Thermal-conductivity	40 W/mK	0.05%	2.5 gm	75 ml
Density	6400 kg/cm^3	0.1%	5.0 gm	150 ml
Specific heat	531 J/kgK	0.15%	7.5 gm	225 ml
Molecular mass	79.6 gm/mole	0.2%	10 gm	300 ml

4 Mathematical Formulation

In this section mathematics related to different heat transfer were discussed.

4.1 Convective Heat Transfer

Fluid exists within solar still that cause convective heat transfer (CHT) loss that appears between surface of water & glass cover inner side. Hence CHT is evaluated by following relations: [5].

$$q_{ci} = h_c (T_w - T_{gi}) \quad (1)$$

Where, T_w, T_{gi} = water & glass temperature (℃), q_{ci} = heat transfer flux (W/m^2), h_{ci} = convective HTC (W/m^2℃).

$$h_c = 0.884 \left[(T_w - T_{gi}) + \frac{(Pw-Pgi)(Tw+273)}{268.9\times10^3 - Pw}\right]^{1/3} \quad (2)$$

Vapor pressure (saturated) on water, inside glass (P_{gi}-N/m^2) surface evaluated as:

$$P_w = e^{\left(25.317 - \frac{5144}{Tw+273}\right)} \quad (3)$$

$$P_{gi} = e^{\left(25.317 - \frac{5144}{Tg+273}\right)} \quad (4)$$

4.2 Evaporative Heat Transfer (EHT)

EHT is calculated using below relations: [17].

$$q_e = h_e (T_w - T_{gi}) \quad (5)$$

where, h_e = Evaporation HTC (W/m^2 ℃),

$$h_e = 0.0163\, h_c \frac{Pw-Pg}{Tw-Tg} \quad (6)$$

4.3 Radiative Heat Transfer

Radiative HTC (h_r) is calculated using below relations: [5].

$$q_r = h_r (T_w - T_{gi}) \quad (7)$$

where, h_r = Radiative HTC,

$$h_r = \sigma \in [(T_w+273) + (T_g+273)] \times [(T_w+273)^2 + (T_g+273)^2] \quad (8)$$

Where, $\in_{eff}$ = Effective emissivity, σ = 5.67×10^{-8} $WK^{-4}m^{-2}$.

$$\in_{eff} = \left[\frac{1}{\varepsilon w} + \frac{1}{\varepsilon g} - 1\right]^{-1} \quad (9)$$

Where, ε_w = emissivity of water, ε_g = emissivity of glass cover.

5 Result and Discussion

In this section various heat transfer coefficient were plotted and discussed:

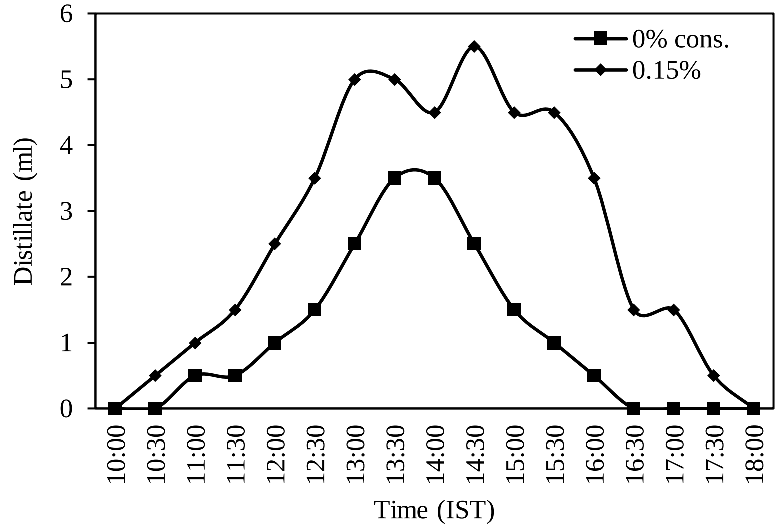

Figure 3: *Variation in distillate at 0% and 0.15% conc. of nanofluid w.r.t time*

Figure 3 represent the productivity of fresh water at two nanofluid concentrations i.e., 0% and 0.15%. The total yield at 0.15% conc. of nanofluid reaches up to 45 ml/day, while without using nanofluids (0%) it is 18.2 ml/day. Such surge in distillate is caused by increased surface area per unit volume exposed to solar radiation & that results in faster heat transfer. Plot also represents that highest productivity is 5.5 ml when nanofluids are used, and without it, it is 3.5 ml.

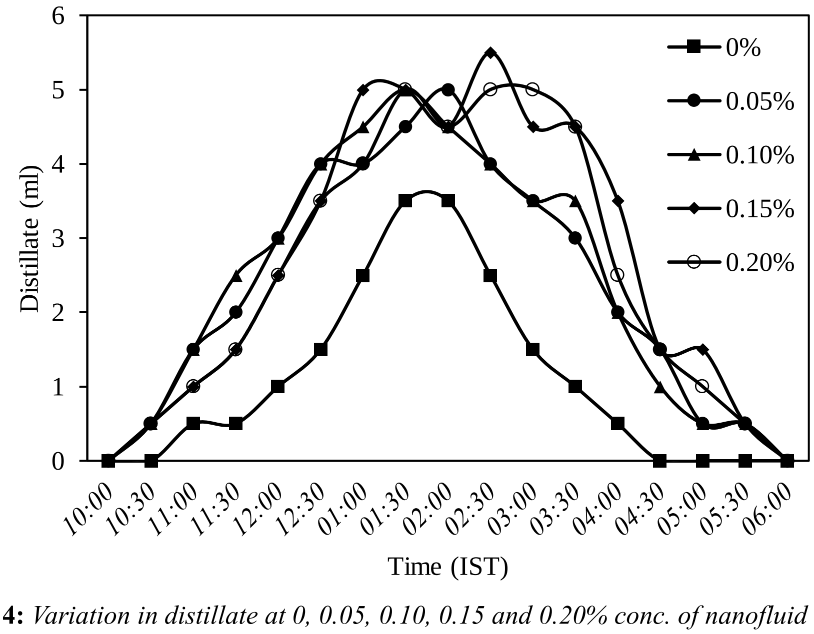

Figure 4: *Variation in distillate at 0, 0.05, 0.10, 0.15 and 0.20% conc. of nanofluid w.r.t time*

Figure 4 shows the comparison of all concentrations 0.0%, 0.05%, 0.10%, 0.15% and 0.20% of nanofluids. Highest distillate found to be 5.5 ml at 0.15% concentration, while at 0.0% concentration the maximum yield is 3.5 ml. Surge in distillate found upto 0.15% concentration due to greater exposure of surface area per unit volume, while further increase in concentration results in greater losses in heat transfer due to surface agglomeration.

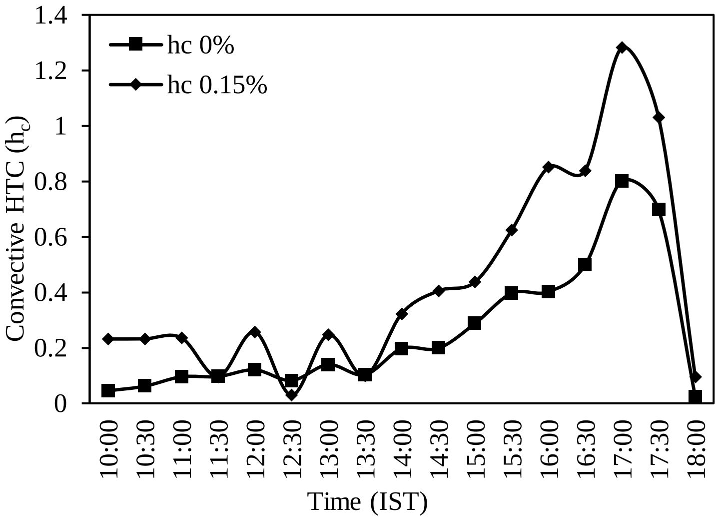

Figure 5: *Variation of convective HTC for 0%, 0.15% concentration of nanofluid w.r.t time*

Figure 5 shows the comparison between convective heats transfer coefficient (h_c) of maximum and minimum productivity concentrations (0.0% and 0.15%). Heat transfer coefficient (HTC) at 0.15% of concentration is found to be highest that is 1.28 W/m² ºC and at 0% concentration it is 0.80 W/m² ºC.

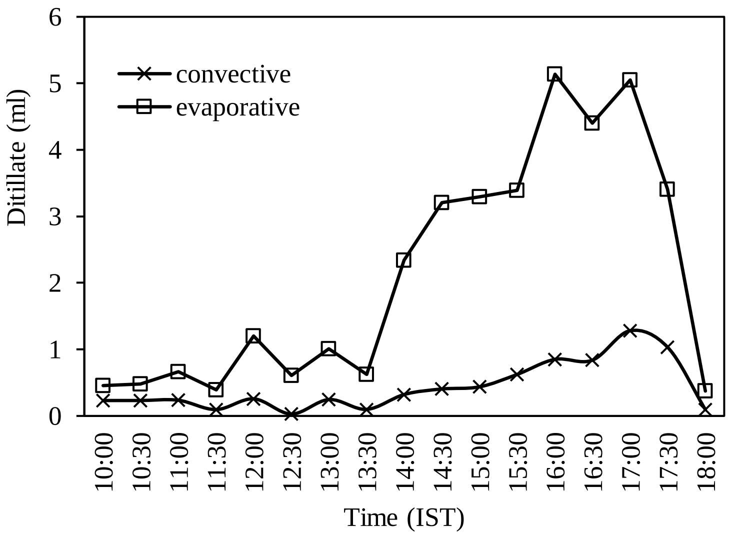

Figure 6: *Distillate variation of convective, evaporative HTC at 0.15% concentration w.r.t time*

In this figure 6 comparison of evaporative and convective HTC at the highest distillate conc. (0.15%) is shown. Evaporative HTC found maximum as 5.13 W/m² ºC and convective HTC found maximum as 1.28 W/m² ºC.

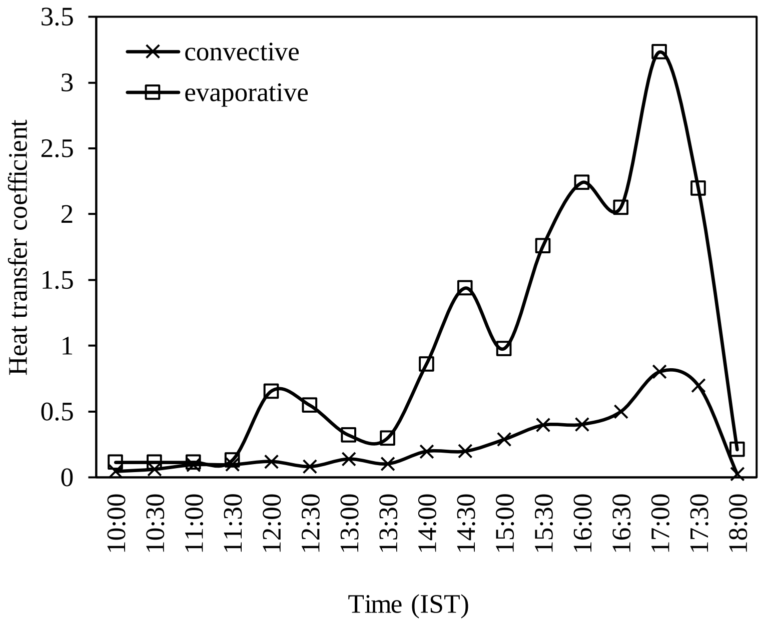

Figure 7: *Variation of convective and evaporative HTC at 0% concentration w.r.t time*

In figure 7 comparison of convective and evaporative HTC at the highest distillate conc. (0.0%) is shown. Evaporative HTC found maximum as 3.23 W/m² °C and convective HTC found maximum as 0.80 W/m² °C.

6 Conclusion

In current experiment, different concentrations of CuO nanofluids was prepared i.e., 0%, 0.05%, 0.10%, 0.15% and 0.20%. It is found that SS with CuO nanofluids results 56.64% higher productivity compared to solar still without nanofluids. CuO as nanofluids possess highest thermal conductivity at 0.15% as compared to other concentrations. CHT and EHT coefficients for 0.15% were found to be 8.53 and 13.18 W/m² °C respectively. SS with CuO results 41.75 ml/day fresh water however with 0% it was 18.1 ml/day. Distilled water obtained for 0.05%, 0.10%, 0.15% and 0.20% concentrations are 39 ml, 42 ml, 45 ml and 41 ml/day respectively. The comparative result shows that CuO nanofluids at 0.15% concentration have higher productivity than others.

7 Declarations

7.1 Acknowledgements

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7.2 Competing Interests

There are no competing interests.

7.3 Publisher's Note

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How to Cite

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