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Improving the yield of fresh water from conventional and stepped solar still with different nanofluids

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ABSTRACT

This experimental work intensively studies the effect of nanoparticle concentration on conventional and stepped solar still. An experimental study was conducted with concentration ranging from 0.05 to 0.2% with Al_2O_3, CuO and TiO_2 both on conventional and stepped solar still. Results showed that by incorporating nanoparticles in the base fluid improves the yield of fresh water from conventional and stepped solar still by 50 and 67% respectively while using Al_2O_3 nano fluid. The temperature of water with Al_2O_3 nanofluid using 0.1 and 0.2% were improved by 3 and 7% respectively, while the improvement in water temperature of CuO and TiO_2 were found to be 5 and 6% respectively for maximum concentration of 0.2% concentration of nano particles. Similarly, the average water temperature of conventional solar still is higher with 0.2% concentration of Al_2O_3 inside the basin.

Keywords: Concentration ratio; Enhancement; Nanofluids; Water temperature; Yield

1. Introduction

Water has become one of the important phenomena for the survival of human life. Especially people living in the coastal area is suffering a lot for fresh drinking water and this increases water-borne diseases and even death. According to the latest survey, in many developing countries nearly 1 million people suffer to get safe and fresh drinking water. In many developing countries and especially in the urban cities are getting safe drinking water rather than remote villages. People in the rural villages get water from the ponds, lakes, and rivers while they are still unaware in the processing of uncontaminated water from these sources. In many villages washing of clothes and dumping of municipal waste were done in these types of water resources [1–13]. The average yield of an conventional solar still is around 2 to 2.5 kg/m^2. Furthermore, the yield of fresh water from the solar still is improved by additional accessories such as heat pipe, flat plate collector, parabolic trough collector. Though these methods improve the yield of fresh water, the cost of

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fresh water produced per liter is higher and not feasible to the local community.

Omara et al. [14] studied the effect of nanofluids in a corrugated wick absorber solar still by creating a vacuum inside the evaporating and condensing chamber. Results showed that the improvement in yield of fresh water is increased up to 285% than conventional solar still with CuO nanofluid inside the basin (d_w = 0.01 m). Similarly, the yield of fresh water with Al_2O_3 nanofluid increased up to 255% by adding internal mirrors and external condenser (d_w = 0.01 m).

El-Samadony et al. [15] experimentally studied the stepped solar still with and without reflector and external condenser. Results showed that the effect of condenser increased the yield by 66% whereas in the case of solar still with both condenser and reflectors was found as 165% than conventional solar still. The maximum yield from stepped solar still with condenser alone was found as 0.97 kg/m^2 whereas, the maximum yield from solar still with internal and external reflector was found as 1.1 kg/m^2. Similarly, the yield from solar still with both reflectors and condenser was found as 1.23 kg/m^2. The cost of fresh water produced from the modified solar still was estimated as $0.049/L.

Sahota and Tiwari [16,17] experimentally investigated the effect of CuO, TiO_2 and Al_2O_3 nanoparticle under varying concentration on improving the yield of fresh water from a conventional double slope solar still. Results showed that the freshwater yield improvement depends on the volume concentration of nanoparticle in the base fluid. Also, the yield from the east side glass is higher as compared to the west side glass with varied water mass of nanofluid inside the basin. Similarly, the yield of water linearly increases with increase in the concentration of nanofluid. Sharshir et al. [18] enhanced the solar still performance using graphite and copper oxide nanofluid and cover cooling technique. Variation in mass flow rate of nanofluid in the cover and water depth in the basin was the parameters analyzed for optimization. The optimized water mass with different nanofluids in the solar still was found to be 0.5 cm, while the increase in water depth decreases the day time yield from the solar still. As compared to the day time yield, the night time yield increases with increase in water depth from 0.5 cm to 5 cm. The maximum day and night time yield from the solar still is higher in the case of graphite nanoparticle in the basin. With cover film cooling and graphite nanofluid, the maximum yield from the solar still was found as 225 ml for 4 kg/hr of film flow over the cover.

Elango et al. [19] used different nanofluid in a single slope solar still. Experimental revealed that the nanofluid is higher in the case of 0.1% concentration of Al_2O_3, ZnO, SnO_2 nanoparticles. Results showed that due to the improved thermal conductivity of nanofluid, the performance (yield) of single slope solar still improved by 29.95, 18.63 and 12.67% for Al_2O_3, SnO_2 and ZnO nanofluids. Similarly, the concentration of nanoparticle with 0.05 and 0.1% were stable with increased thermal conductivity. Kabeel et al. [20] enhanced the fresh water yield from a conventional solar still with an external condenser and nanofluid inside the basin. Results showed that with continuous operation of the fan with 1350 rpm constant speed, external condenser, and nanofluid enhanced the yield of fresh water by 116% than conventional solar still. Similarly, the yield was improved with are duced speed of the fan for external condensation. Kabeel et al. [21] improved the yield of conventional solar still with nanofluid and vacuum. Results showed that the yield of solar still was improved with cuprous oxide by 133 and 93% for continuous operation of the fan and without fan respectively, whereas the yield is improved by 125 and 89% for aluminum oxide nanoparticle for the same operating condition. Similarly, by providing vacuum inside the solar still the cost of fresh water produced using cuprous oxide will be $0.035 and 0.045/L for still with and without operating fan, respectively.

From the literature, it is identified that the use of nanofluids in stepped solar still were not carried out. In this work, a detailed experimental analysis is carried out on the conventional and stepped solar still with different nanofluid concentration were studied. Furthermore, the average water temperature of conventional and stepped solar still were determined.

2. Experimental methodology

2.1. Preparation of nanofluid

Nanofluids are prepared by dispersing the nanoparticle with water by volume concentration. For the present study, three different concentration ratio of three different nanoparticles were chosen. Al_2O_3, TiO_2, and CuO nanoparticles were purchased with an average particle size of 25 nm and dispersed in water with a concentration of 0.05, 0.1 and 0.2% by volume. Nanoparticle-dispersed in water is subjected to sonification process for even distribution of nanoparticle in water using an Ultrasonicator for 2 h for better stability. The sonicated nanofluid is again sintered by means of a magnetic stirrer for almost 30 min to avoid the agglomeration of nanoparticles. The detailed thermophysical properties of nanoparticle are given in Table 1.

2.2. Conventional solar still and stepped solar still

Fig. 1 shows the schematic diagram of stepped and conventional flat basin single slope solar still. The experimental setup consists of a storage tank, flat and stepped absorber for conventional and stepped solar still respectively. For

Table 1
Thermophysical property of nanoparticle

S.No	Property	Nanoparticle		
		Al_2O_3	TiO_2	CuO
1	Thermal conductivity (W/mK)	38	11.2	15.3
2	Density (kg/m^3)	3800	4123	6234
3	Specific heat capacity (J/kgK)	883	657	534
4	Appearance	White	White	Black

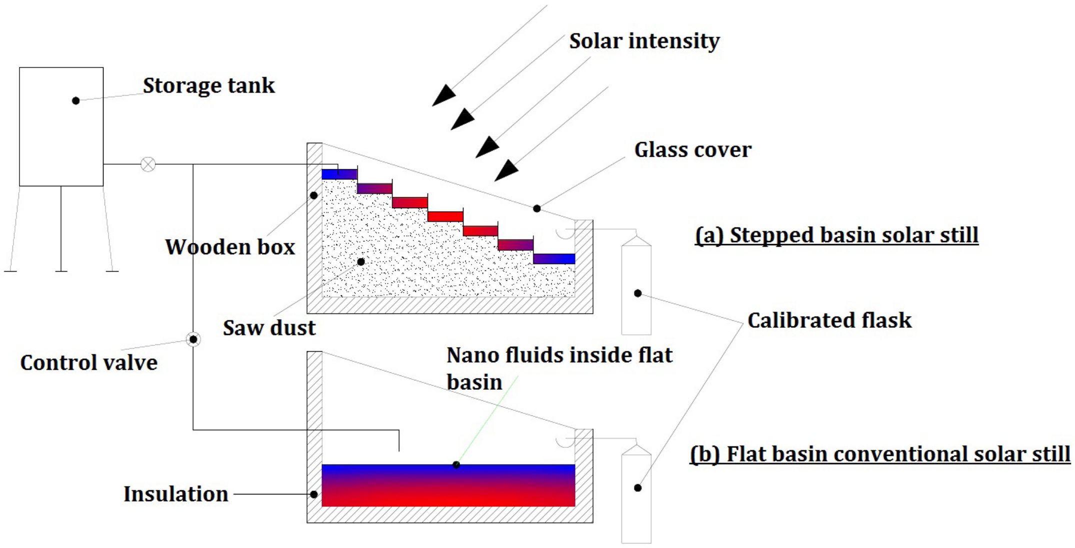

Fig. 1. Schematic diagram of stepped and conventional single slope solar still.

Table 2
Uncertainty, standard uncertainty, error and measuring range of instruments

Instrument	Accuracy	Range	Error (%)	Observed error (%)	Standard uncertainty
Thermocouple	±1°C	0–100°C	0.25	1.2	±0.57°C
Solar power meter	±1 W/m²	0–2500 W/m²	2.5	3.1	±0.57 W/m²
Anemometer	±0.1 m/s	0–45 m/s	10	6.8	±0.05 m/s
Beaker	±10 mL	0–1000 mL	10	8.3	±5.77 mL

regulating the mass flow inside the absorber control valve is provided. The fresh water is collected through the distillate collector placed at the end of the inclined glass cover. The water is manually fed into the basin by adjusting the flow control valve. A constant water depth of 0.02 m is kept inside the basin as many researchers have concluded that the optimum water depth is 0.02 m. Measuring instruments includes AM4836 cup-type anemometer, TES 1333R solar power meter, calibrated flask, temperature indicator and PT100 (RTD) sensors for measuring wind velocity, solar intensity, fresh water,the temperature of different elements of solar still, respectively. The detailed uncertainty, standard uncertainty, error, and measuring range of instruments used are given in Table 2.

3. Results and discussion

Figs. 2a,b show the hourly variation of solar intensity and wind velocity measured during the experiment. It can be observed that the maximum solar intensity occurs during the noon and the average maximum value of solar intensity is measured as 1013.2 W/m² during the month of March. Similarly, the variation of wind velocity measured during the experiment is observed with lower wind velocity and increasing during the off shine hours. The average wind velocity during the sunshine and off shine hours are found as 1.3 m/s and 2.1 m/s, respectively.

Figs. 3a–c show the variation of water temperature inside the stepped solar still with Al_2O_3, CuO, and TiO_2 nanofluid. It can be observed from Fig. 3a that the water temperature is 40% higher as compared to conventional single slope solar still with 0.05% Al_2O_3 concentration during peak intensity. Due to the higher thermal conductivity of Al_2O_3 nanofluid, the water temperature increases by 15 and 17.7% with 0.1 and 0.2% concentration respectively. During off shine hours, the temperature of water temperature is higher for nanofluids as compared to base fluid due to higher energy absorption with lower specific heat capacity. The maximum water temperature of solar still with Al_2O_3 with maximum concentration is found as 75°C. From Fig. 3 bit is clear that the increase in the concentration of CuO nanoparticle has only a marginal deviation of about 2% with respect to water temperature as the thermal conductivity of nanofluid is lesser as compared to that of Al_2O_3 nanofluid inside the basin. It is observed from Fig. 3c that the effect of TiO_2 nanofluid is having a marginal increase in the temperature of water. Similarly, the water temperature of TiO_2 nanoparticle increases only by 3% as compared to that of CuO nanofluid. Due to the variation in specific heat content of the fluid, the temperature of nanofluid inside the stepped basin varies. Also, it is observed that the increase in nanoparticle in the basin increases the temperature. The off shine hour water temperature of the stepped basin in all the cases is found to be higher and have a similar trend.

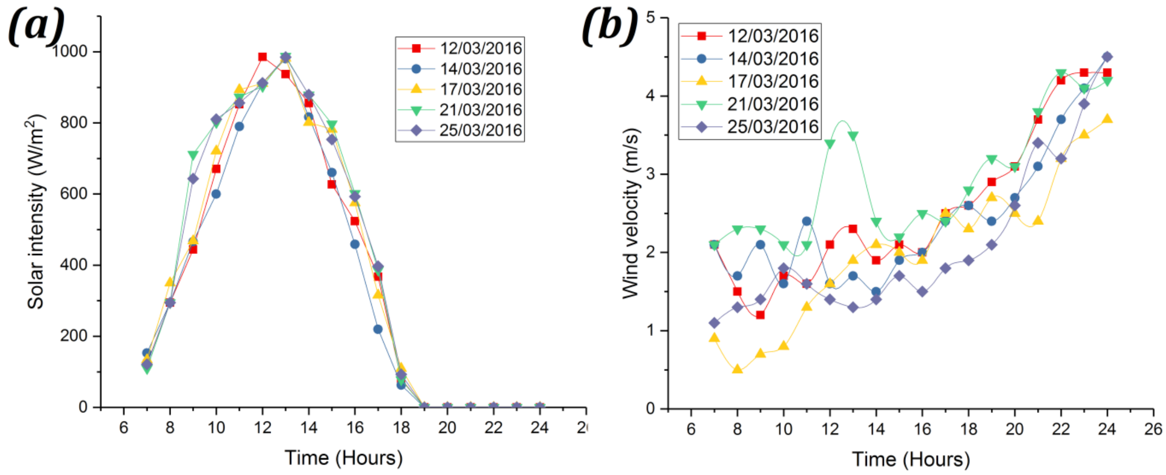

Fig. 2. Hourly variation of (a) solar intensity and (b) wind velocity.

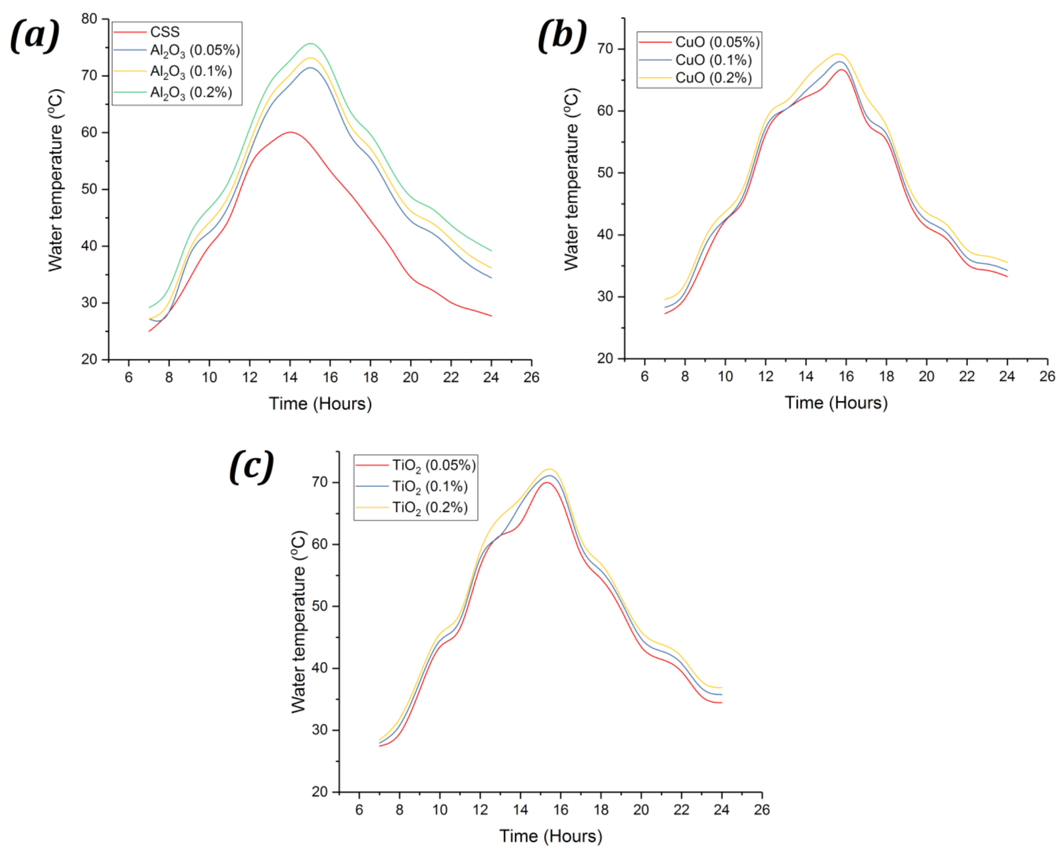

Fig. 3. Hourly variation of water temperature inside stepped solar still with (a) Al_2O_3, (b) CuO and (c) TiO_2 nanofluid.

Figs. 4a–c show the hourly variation of yield from stepped solar still under different concentration of nanofluid. The maximum hourly yield from the solar still with Al_2O_3 nanoparticle in the base fluid is observed as 0.5, 0.35 and 0.34 kg/h for 0.2, 0.1 and 0.05% respectively; while the maximum yield from the conventional single slope solar still is found as 0.1 kg/h. The increase in the yield of fresh water using Al_2O_3 nanofluid is found as 70.58, 71.4 and 80% with 0.05, 0.1 and 0.2% concentration of nanoparticle in the fluid as compared to conventional solar still without nanofluid (Fig. 4a). Due to the lower specific heat content in CuO nanofluid, the yield of fresh water increases by only 33.33, 50 and 52.38% for 0.05, 0.1 and 0.2% concentration respectively (Fig. 4b). Even though the water temperature of CuO

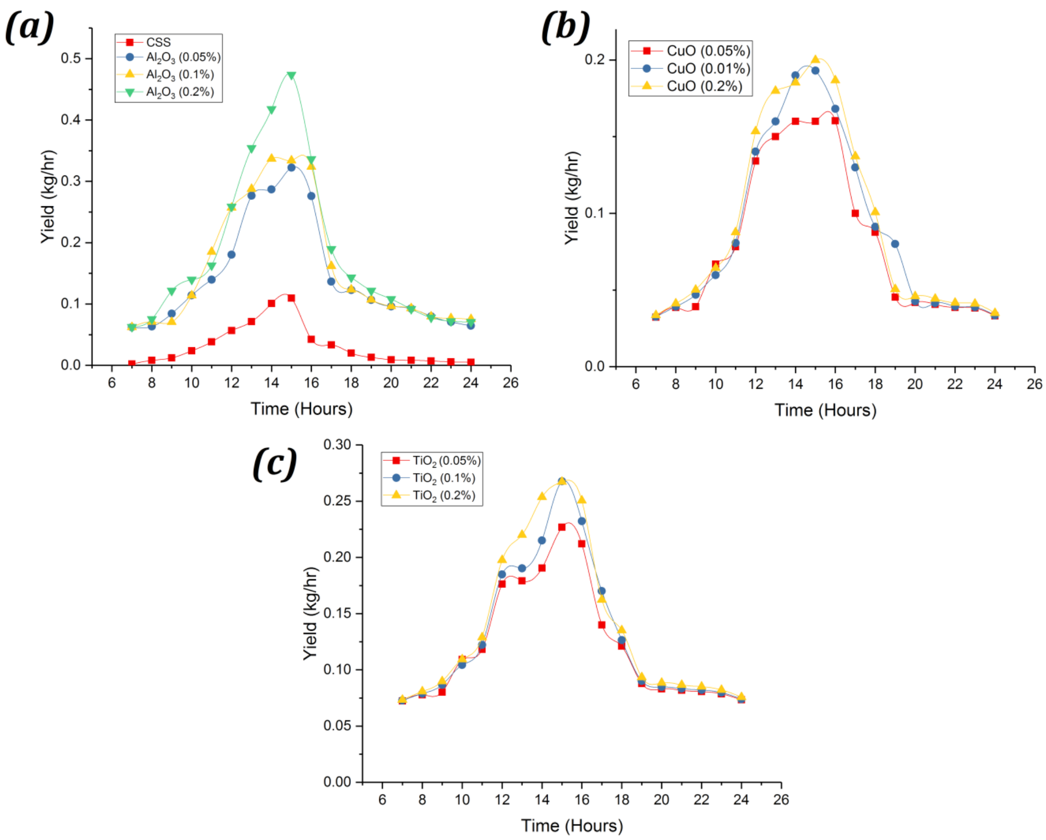

Fig. 4. Hourly variation of yield from stepped solar still with (a) Al_2O_3, (b) CuO and (c) TiO_2 nanofluid.

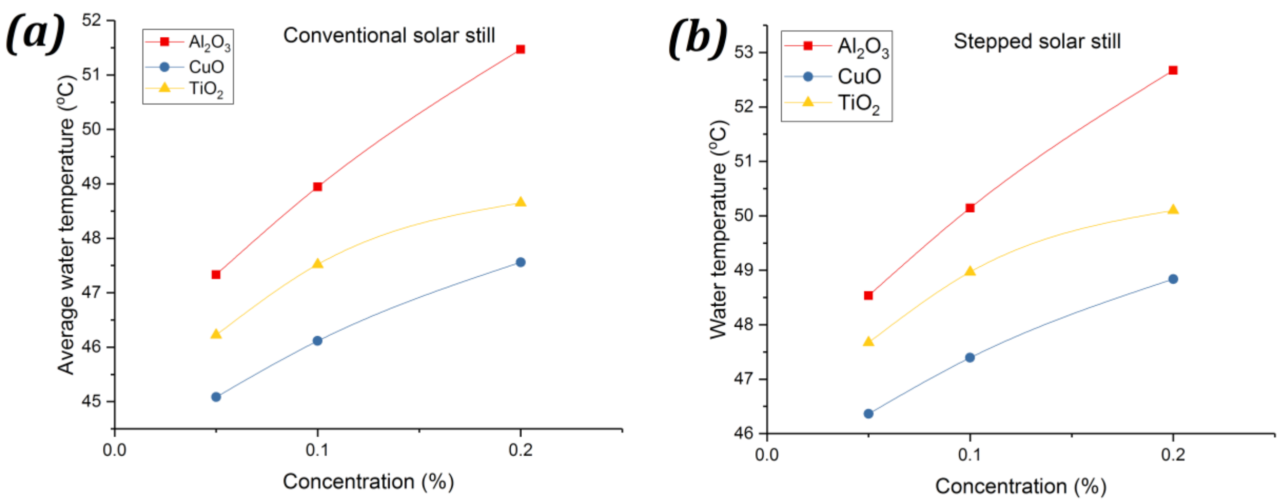

Fig. 5. Variation of average water temperature of (a) Conventional solar still (b) Stepped solar still under different concentration of nanofluid.

nanoparticle is almost equal to the temperature of TiO_2 nanofluid, the yield is lower and for the same experimental condition while comparing it with other different nanofluid used inside the stepped basin. Also, the decrease in the yield of fresh water from the stepped solar still is majorly due to the higher density of nanoparticle in the fluid. The evaporation of water from the top liner of the solar still is lower also due to its thermophysical characteristics of nanofluid. Fig. 4c depicts the variation of hourly yield from stepped basin using TiO_2 nanofluid. The maximum hourly yield from the stepped basin is found as 0.24, 0.26 and 0.27 kg for 0.05, 0.1, and 0.2% respectively. While analyzing the yield of fresh water during off shine, the average yield is found as 0.075 kg for almost operating the solar still for 6 h after sunset, whereas, the average yield for Al_2O_3 and CuO nanofluids for different concentrations were found as 0.1 and 0.045 kg, respectively. Due to the excellent heat carrying capacity and thermophysical properties of Al_2O_3 nanoparticles the yield of fresh water during off shine hours increased up to 25 and 55% for TiO_2 and CuO nanofluid.

Figs. 5a,b show the variation of water temperature of conventional and stepped solar still under different concentration of nanofluid inside the basin. It is observed that there is an increase of about 1.5°C in average water temperature in stepped solar still as compared to conventional single slope solar still. With the increase in the concentration of nanoparticle in the fluid, the average water temperature increases linearly for Al_2O_3, CuO, and TiO_2 nanoparticle. The maximum average water temperature inside flat and stepped basin with Al_2O_3 nanofluid is found as 51.5 and 53°C.

The variation of daily efficiency of stepped solar still under different nanofluid and concentration is plotted in Fig. 6. It can be observed that the daily efficiency of stepped solar still with Al_2O_3 nanofluid gave the better efficiency as compared to that of TiO_2 and CuO nanofluid. Similarly, the efficiency of solar still increases with increase in the concentration of nanoparticle in the base fluid. The increase in the concentration of nanoparticle in the base fluid, the thermal conductivity of fluid increases with a decrease in specific heat energy absorption. Due to the higher thermal conductivity and lower specific heat capacity of nanofluid water gains the maximum heat to evaporate the water from the top surface layer. The maximum daily efficiency with a maximum concentration of nanofluid inside the solar still with Al_2O_3, TiO_2 and CuO nanoparticle are found to be 68, 56 and 38%, respectively. Table 3 shows the comparison of present and previous model solar still on the yield using different nano fluids.

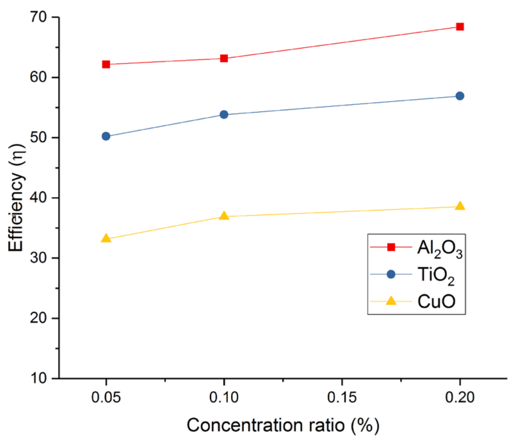

Fig. 6. Variation of daily efficiency of stepped solar still under different concentration of nanofluid.

4. Conclusion

From the experimental study, the following conclusions are arrived:

- With increase in thermal conductivity of Al_2O_3 nanofluid, the water temperature increases by 15 and 17.7% with 0.1 and 0.2% concentration respectively
- The maximum hourly yield from the solar still with Al_2O_3 nanoparticle in the base fluid is observed as 0.5, 0.35 and 0.34 kg/h for 0.2, 0.1 and 0.05% respectively
- With lower specific heat content in CuO nanofluid, the yield of fresh water increases by only 33.33, 50 and 52.38% for 0.05, 0.1 and 0.2% concentration respectively
- The maximum average water temperature of Al_2O_3 nanofluid is found as 53°C and higher than 1.5°C as compared to conventional solar still with the same concentration of nanoparticle in the fluid.
- The maximum daily efficiency is higher in the case of Al_2O_3 nanofluid inside the stepped basin. Similarly, the daily efficiency of TiO_2 is higher than that of CuO nanofluid and lower than that of Al_2O_3 nanofluid with maximum concentration.

Table 3
Comparison of present and previous model solar still on yield

S.No.	Method	Author	Yield (kg/m²)	Remarks
1.	Conventional solar still single slope solar still	Elango et al. [19]	3.74	Use of Al_2O_3 with maximum concentration of 0.1% inside the basin of 0.25 m²
2.	Conventional single slope solar still	Sharshir et al. [18]	4.08	Nano fluids were placed in the basin of conventional single slope solar still with additional cover cooling improved the yield. CuO nano fluid is used in a conventional solar still with cover cooling method.
3.	Double slope solar still	Sahota and Tiwari [16,17]	2.66	Improvement in yield with Al_2O_3 was found to be maximum with 0.12% concentration of nano particles in the base fluid under constant fluid mass of 35 kg.
4.	Conventional solar still	Present study	4.4	Without cover cooling and maximum concentration of Al_2O_3 nano particle
5.	Stepped solar still	Present study	5.75	Without cover cooling and maximum concentration of Al_2O_3 nano particle

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