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Performance Enhancement using Nano Particles in Modified Passive Solar Still

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Abstract

Conventional single basin passive solar still has low productivity. In this context, productivity of passive solar still is increased by using nanoparticles in modified still. Modified still has white painted sidewalls. Nanoparticles enhance thermal characteristics of the fluid by increasing surface area for heat transfer. CuO nanoparticles have been used in modified still to increase productivity and efficiency. Experiments have been performed at water depth of 5 cm and 10 cm with nanoparticles added 0.12% by weight. The performance is compared with the conventional solar still kept at same place (Jabalpur, India, 23° 10' N, 79° 59' E) in same ambient conditions. Modified solar still with added nanoparticles produces 3445 ml/m^2-day and 3058 ml/m^2-day at water depth of 5cm and 10 cm respectively, while conventional solar still yields 2814 ml/m^2-day and 2351 ml/m^2-day for respective water depth. In this experimental work, error analysis and cost analysis has also been carried out.

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Keywords: solar still; desalination; white paint; nano particles; cuprous oxide.

1. Introduction

Solar still uses the solar energy to purify saline or contaminated water using principle of distillation. Solar stills using additional energy devices such as fan, pump or solar collectors for increase productivity are called active solar stills, while others are passive solar stills. To increase the productivity of the conventional solar stills, several modifications have been proposed.

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Sakthivel and Shanmugasundaram [1] analysed the effect of black granite gravel as storage medium in the single basin solar still. Black granite gravel of size 6 mm was used in the basin for different depth. They concluded that still yield is increased by 17-20% compare to conventional solar still. Tiwari et al. [2] experimented on multiple wick solar still with double condensing effect and observed that the developed arrangement gives nearly 20 % higher yield than simple wick solar still. They further reported that during low solar intensity condition both stills show almost a similar performance. Singh and Tiwari [3] have studied a double effect multi wick solar still with water flow into the basin. They concluded that double effect distillation is effective at low flow velocity and overall thermal efficiency decreases with an increase of mass flow rate. Dutt at el. [4] investigated the effect of adding dyes in basin water and suggests that addition of dyes increases the daily productivity and efficiency of the system about 10%. Kumar et al. [5] concluded that double basin solar still gives better performance than the single basin still due to better utilization of latent heat of vaporization. Tiwari and Suneja [6-7] have experimented with an inverted absorber solar still. They observed that inverted absorber solar still gives about double output of the conventional still and also concluded that evaporative heat loss is a strong function of the operating temperature. Gnanadasan et al. [8] have fabricated a single slope solar still made up of copper plate and fitted with vacuum pump. They performed experiments by adding carbon nanotubes in copper basin and concluded that the new modified still increases the productivity by 50%. Nano particles oppose sedimentation, as compared to larger size particles, due to Brownian motion and acquire a lot higher surface area (approximately 1,000-time) which increases the heat conduction of nano fluids since heat transfer occurs on the surface of the fluid. The adding nano particle in the fluid was exclusively for experiment purpose and after completion we use to remove water containing sediments by using bottom valve.

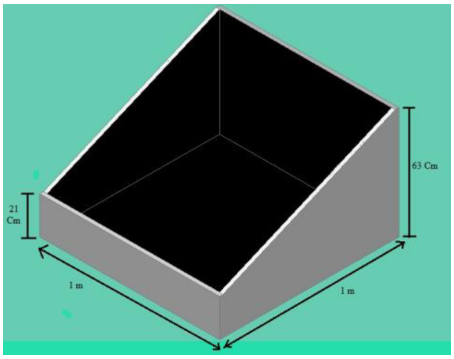
Sindal et al. [9-10] has uses ZnO and CuO nanoparticles as photo catalyst and concluded that productivity as well as quality of the raw water increases to remarkable extent. Panitapu et al. [11] have studied the effect of adding TiO2 in basin water of still and studied the variations of water temperature, vapour temperature, glass inside and outside temperature during sunshine. Kabeel et al. [12] have studied the effect of adding Al2O3 on productivity of still with and without external condenser. They observed that external condenser increases the distillate water yield by 53.2% and adding Al_2O_3 increases the productivity by 116%. Adding Al_2O_3 alone increases yield by 76% when fan is switched off. Kabeel et al. [13] studied the effects of mixing CuO and Al_2O_3 Nano fluids in various concentrations in basin water. They concluded that using CuO nanoparticles increased the distilled productivity by 133.64% and 93.87% while Al_2O_3 nanoparticles enhanced the distillate by 125.0 % and 88.97 % with and without the fan respectively. Tenthani et al [14] has studied the performance of white painted sidewalls on daily output. They found that the modified still is 6.8 % more efficient than conventional still.

In this context, effect of adding nanoparticles in single slope solar still with white painted side walls has been analysed. Cuprous oxide (CuO) is used as nanoparticles in this experiment. Experiment is performed at different water depth and output is compared with conventional solar still placed in same ambient conditions. Effects of nanoparticles at different water depth in white painted solar still is critically analysed in this experimental work.

2. Experimental setup

Two solar stills with same dimensions are designed and fabricated. Basin surface of both solar still is painted in black and having area 1 m^2. Front wall and rear wall have height of 21 cm. and 63 cm. respectively (Fig.1). Sidewalls of one is painted in white and named as modified solar still (Fig.2). Other solar still is painted in black and it is conventional. Both stills are made up of Grey Cast Iron sheet of 1 mm thickness. 10 mm thick thermo-col sheet is applied for insulation from side and bottom of the still. Still is supported by 10 mm thick plywood from outside. Basin is covered by 4 mm thick glass plate and is inclined at an angle of 23^0. Inlet valve and outlet valve arrangement makes the flow across basin simple.

Setup is well equipped with instruments to measure values of various parameters at different points (Fig.3). K-type thermocouple with 8 point digital display is attached with setup to measure water temperature, vapour temperature, glass inside temperature and glass outside temperature. Ambient temperature is measured by using alcohol thermometer. Solar power meter (range 0-2000 w/m^2) is used to measure solar energy available at glass. Beaker of capacity (0-1000) ml was used to measure hourly distillate from both stills. Both the stills are kept at obstruction free roof and facing towards south.



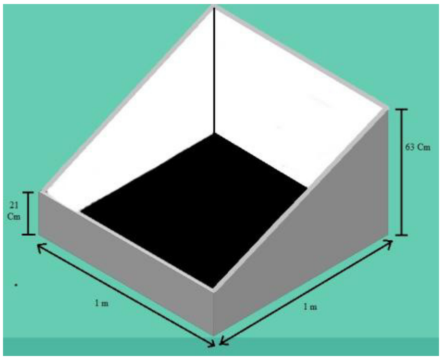


Fig.1. Perspective view of conventional still. Fig.2. Perspective view of modified still.

Fig.3. Photograph of experimental setup.

3. Experimental Procedure

Experiments have been performed to compare distillate output of modified solar still at different water depth keeping same weight concentration of nanoparticles. The performance is also compared with conventional solar still kept at same ambient condition. In first experiment, both the stills have been filled up with water up to depth of 10 cm before sunshine. In modified still 120 gm of CuO nanoparticles are added (0.12% by weight concentration). At this concentration the passive solar still gives the optimum output [13]. As solar radiation increases, water temperature, vapours temperature, and glass inside and outside temperature increases. Water in the still starts evaporating and vapour formation started simultaneously. Vapour moves upward and condensation on inner surface of glass takes place. Condensed water collected in a channel and ultimately filled the beaker. During experiment ambient temperature, water temperature, vapour temperature, glass inside temperature and glass outside temperature are measured hourly till sunset. Distillate is measured for a day, hourly till sunset and collectively for night at next day morning. Experiment has been performed in month of April, 2015 at Jabalpur Engineering College, Jabalpur, India. The same procedure has been adopted for the next experiment in which water is filled up to depth of 5 cm. 60 gm of CuO is added with water in modified solar still to keep weight concentration constant. Again the distillate output from both the still is compared. Ambient temperature, water temperature, vapour temperature, glass inside temperature and glass outside temperature have been measured.

4. Error Analysis

Different parameters are measured to calculate the effectiveness of solar stills. Bain water temperature, vapour temperature, glass inner surface and outer surface temperature are measured by using copper constantan type thermocouple (±1^{0}C) attached to digital temperature indicator. Solar radiation was measured on glass surface level by solar power meter (0-2000 W/m^2) with accuracy of ±1 W/m^2. Ambient temperature was measured by alcohol thermometer manually. Distillate yielded has been measured by beaker of capacity 1000 ml (with accuracy of 5 ml) daily. Uncertainty in measurements has been measured by procedure proposed by Kline and McClintock [15]. Based on the accuracy of measuring equipments maximum uncertainty in the measurement has been found about 2%.

5. Results and Discussion

The performance has been recorded for different water depths i.e. 10 cm and 5 cm.

5.1 Water depth 10 cm.

Incident solar radiation increases gradually till midday to 852 W/m^2 and then starts decreasing. Ambient temperature also shows the same behaviour and increases up to 36^{0}C at 15:00 hrs. (Fig.4). In passive solar still, solar radiation is the only parameter which affects the performance. Fig.5 (conventional still) and Fig. 6 (modified still) shows that temperature at various points varies with solar radiation in the same fashion.

Water in basin receives heat from blackened base plate. Sunrays enter in the basin, get traps due to greenhouse effect and provide energy to darkened base plate. In conventional still, sidewalls are also painted black and absorb more energy. Due to scattering, white painted sidewalls provide less heat energy to water and nanoparticles in basin. So, water temperature of conventional still is marginally greater than water temperature of modified still as shown in Fig.7 (a). As temperature of water increases, evaporation starts. Vapour formed in the basin captures more heat from sunlight as vapour is a greenhouse gas. Vapour temperature depends largely on water temperature and as a result vapour temperature of modified solar still is marginally less than conventional (Fig.7 b). Main advantage of using white colour is that, it minimizes heat loss from vapour to sidewalls and consequently to atmosphere. It is seen that inside glass temperature of modified still is higher than that of conventional still as shown in Fig. 7 (c). As a result, heat transfer from modified solar still to the atmosphere is larger and consequently the condensation. Fig.7 (d) shows the variation in glass outer surface temperatures for both solar stills. It is marginally less for modified still and this increases the temperature difference between inside and outside glass surface and furthers the condensation for modified still. Yielding started at 12 hrs and increases simultaneously. Fig.8 shows the variation of distillate output from conventional solar still and modified solar still with added nanoparticles with respect to solar radiation during sunshine. In the night nanoparticles releases energy to water and evaporation takes place inside still and as a result there was more output from modified still during night. The yield is tabulated in Table.1. Overall thermal efficiency for both stills are calculated and compared. The relation used for calculation [16] is

$$E = \frac{Q \times h}{A \times I} \tag{1}$$

Where,
E = overall thermal efficiency
Q = daily output (litre)
h = latent heat of vaporization (2.260 MJ/l)
A = area of the glass surface of the solar still (m^2)

I = average daily solar radiation (MJ/m^2)
Using the above relation, efficiency of stills are calculated and tabulated in Table.1.

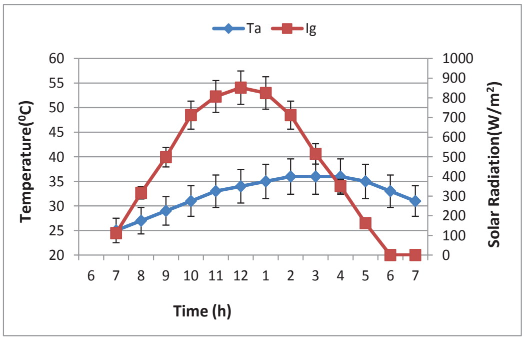


Fig.4. Ambient temperature with solar radiation.

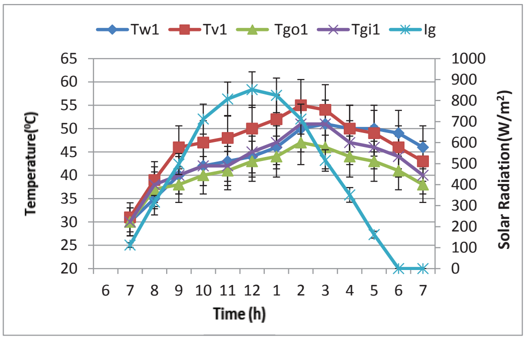


Fig.5. Variation of temperatures for conventional still.

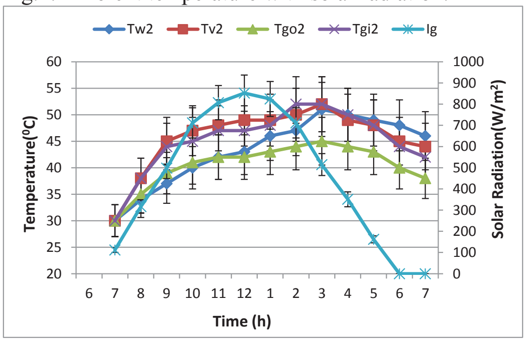


Fig.6. Temperatures for modified still.

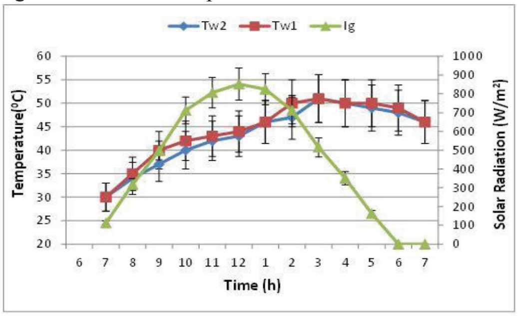


Fig.7 (a). Hourly variation of water temperatures of both stills with solar radiation.

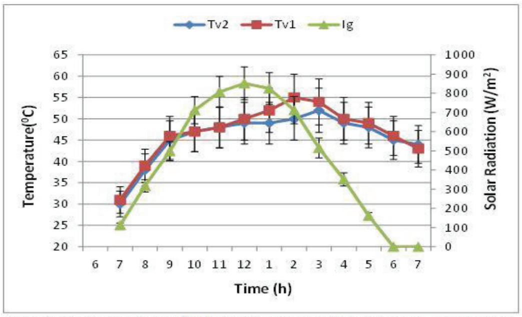


Fig.7 (b). Hourly variation of vapor temperatures of both stills with solar radiation.

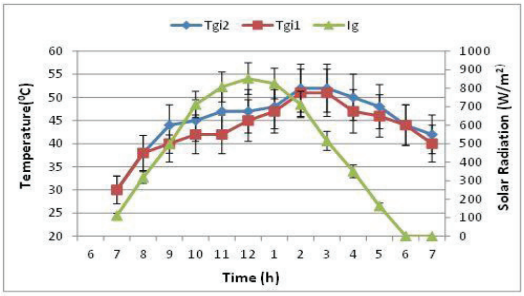


Fig.7 (c). Hourly variation of glass inner surface temperatures of both stills with solar radiation.

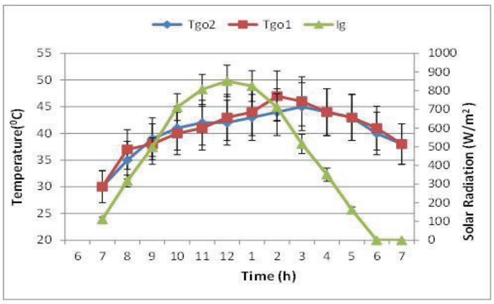


Fig.7 (d). Hourly variation of glass outer surface temperatures of both stills with solar radiation.

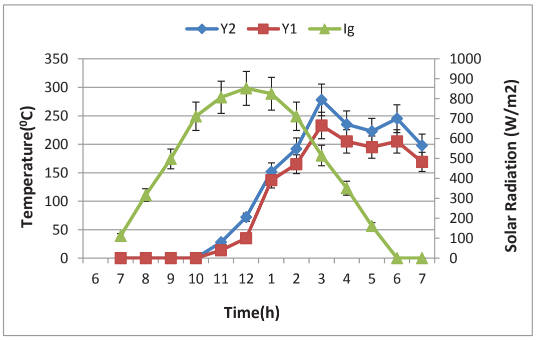


Fig. 8. Hourly variation of distillate for both still at 10 cm.

5.2 Water depth 5 cm.

In this experiment both stills have been filled up with water up to depth of 5 cm. Temperature at different points, solar radiation and distillate output are observed similarly as in previous experiment. Output from both the solar stills has been compared and concluded. Solar radiation as well as ambient temperature first increases and then decreases rapidly. Solar radiation has been observed 881 W/m^2 at 12.00 hrs while ambient temperature reached maximum at 15.00 hrs. Water temperature, vapour temperature, glass inner surface and outer surface temperature varies in similar fashion as solar radiation. Same trends are depicted for modified solar still. Water temperatures of both the solar stills are compared. In both stills water temperature first increases and then decreases but for conventional still it is marginally greater due to high absorbing capacity of black colour. High water temperature is the reason of high vapour temperature in conventional still. In contrast, modified solar still has high glass inner surface temperature rather than in conventional solar still, which may be due to the low heat loss to environment in white painted still. Fig. 8 shows the variations in distillate output from both solar stills. The yield is measured for a day and tabulated in Table.1. Overall efficiency of both solar stills is calculated using above equation and tabulated in Table.1. The density of CuO nanofluids for various volume concentrations are measured by using Hygrometer they are as follows, % Volume fraction 0.1 to 0.7 and their Experimental density, (ρ) kg/m^3 obtained are 1028.86, 1037.18, 1043.57, 1047.78, 1054.32, 1062.58 and 1068.84 kg/m^3 respectively.
The CuO nanofluid is poured in the viscometer sample chamber. The spindle immersed and rotated at speed ranging from 387 to 540 rpm in steps of 15 seconds. Viscosity measurements were started at 300 K and temperature was gradually reduced to 250 K. The measured absolute viscosity Pa s of the CuO nanofluids was observed 32, 18, 12, 09, 07, 05 and 03 to be decreasing exponentially with an increase in the nanofluid temperature ranging from 10 to 60^0 C. The quantity of CuO nanoparticles required for preparation of nanofluids is calculated using the law of mixture formula. A balance with a 0.1mg resolution is used to weigh the CuO nanoparticles. The weight of the nanoparticles for preparation of 100 ml CuO nanofluid of a volume concentration, using water-propylene glycol base fluid is calculated by using the following equation

$$\%\ Volume\ concentration = \frac{\frac{W_{CuO}}{\rho_{CuO}}}{\frac{W_{CuO}}{\rho_{CuO}}+\frac{W_{bf}}{\rho_{bf}}} = \frac{\frac{W_{CuO}}{6300}}{\frac{W_{CuO}}{6300}+\frac{100}{1036}} \quad (2)$$

Volume concentration, (%) 0.1 to 0.7 and their Weight of nano particles (W_{Cuo}), Grams obtained are0.6172, 1.2265, 1.8391, 2.4220, 3.062, 3.680 and 4.2656 respectively.

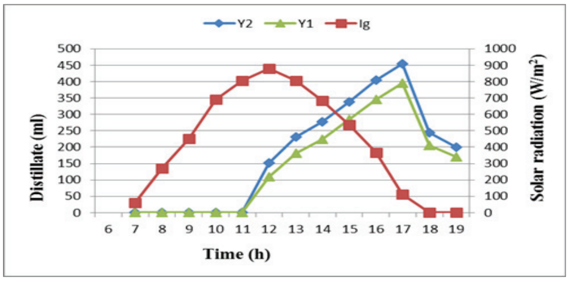


Fig.9. Hourly variation of distillate of both still for 5 cm water depth.

Table 1. Comparison of distillate and efficiency for both still at different height.

	Conventional solar still		**Modified solar still with nanoparticles**	
	10 Cm water depth	**5 cm water depth**	**10 cm water depth**	**5 cm water depth**
Yield (ml)	2351	2814	3058	3445
Overall thermal efficiency (%)	24.805	30.55	32.10	37.40

6. Cost Analysis

Economic viability is the most important criteria which decide the success of the project. In Table.2 components and other utilities cost are described. Life of the setup is assumed to be 10 years. In a year we will get sunshine for 300 days approximately. In case of 10 cm water depth in basin, water has been obtained at cost of Rs 0.61/L and Rs 0.53/L for conventional and modified still respectively. When water depth in basin is kept at 5 cm the cost of water is Rs 0.51/L for conventional still and Rs 0.40/L for modified still respectively. Larger total fixed cost for modified still with nanoparticles is compensated by high productivity.

Table.2. Cost of fabricated solar stills.

Material Units	**Cost of modified solar still with nanoparticles (INR)**	**Cost of conventional solar still (INR)**
Iron sheet (1mm thick)	1200	1200
Glass cover	540	540
Paints	270	270
Plywood	720	720
Insulation	125	125
Support legs	780	780
Fabrication cost	700	700
Nanoparticles 180 gms. (120gm +60gm)	600	0
Total fixed costs (F)	4935	4335

7. Conclusion

Experiment and analysis of its results leads to following conclusions:

1. Nanoparticles mixed with basin water increases thermal conductivity and convective heat transfer coefficient and hence the evaporation rate. They worked as heat storage material and releases energy to water and increase the productivity at night.
2. White painted side walls reduces heat loss to environment and increases the productivity of modified still by increased condensation.
3. Modified solar still with added nanoparticles and conventional solar still produces 3445 ml/m^2-day and 2814 ml/m^2-day at water depth of 5 cm while 3058 ml/m^2-day and 2351 ml/m^2-day at depth of 10 cm respectively. Productivity of modified still is 22.4% higher than conventional still at water depth of 5cm while 30% higher at water depth of 10cm. This implies that yield is always better in modified still with nanoparticles.
4. The estimated cost are Rs 0.61/L and Rs 0.53/L for conventional and modified still at 10 cm water depth in basin, and for 5 cm water depth in basin it is Rs 0.51/L for conventional still and Rs 0.40/L for modified still respectively.

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Nomenclature

T_a	Ambient temperature, ^{0}C
T_w	Water temperature, ^{0}C
T_v	Vapour temperature, ^{0}C
T_{gi}	Inside glass surface temperature, ^{0}C
T_{go}	Outside glass surface temperature, ^{0}C
I_g	Solar radiation, W/m^2
M	Distillate output, Kg
η_h	Hourly efficiency
η_o	Overall efficiency
A	Area of glass, m^2
ΔT_g	Temperature difference between inside and outside glass surface, ^{0}C.

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