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Improving the Yield of Freshwater and Exergy Analysis of Conventional Solar Still with Different Nanofluids

This experimental work intensively studies the effect of nanoparticle concentration and exergy of a conventional solar still. Experimental studies were conducted with concentration ranging from 0.05 to 0.2% with Al_2O_3, CuO and TiO_2 on conventional solar still. The results show that the effect of nanoparticles improves the yield of freshwater from conventional solar still. The water temperature of conventional solar still with different concentration of nanofluids improved by 3 and 5% for CuO, 4.2 and 6% for TiO_2 and, 3 and 7% for Al_2O_3. Similarly, the average water temperature of conventional solar still is higher with 0.2% concentration of Al_2O_3 inside the basin. There is increase in the yield of freshwater about 50% for conventional solar still respectively with Al_2O_3 nanofluids (φ=0.2%). The maximum exergy efficiency from the system is found as 11.12% with Al_2O_3 nanofluid (φ=0.2%). There is a greater possibility of negative efficiency during the start of the experiment while the ambient temperature is lower than water temperature (T_a>T_w). The daily exergy efficiency increases by 20% with increase in concentration of nano–particles in fluid (Al_2O_3).

Keywords: *Nanofluids; Concentration ratio; Enhancement; Yield; Water temperature; exergy efficiency*

1. INTRODUCTION

Water is nature's gift, and it plays a vital role in day-to-day life survival for all human beings. On the earth, around 97% of water is in the ocean, 2% in the form of glaciers and only 1% of water is readily available for drinking purpose. Freshwater is available from the ground either surface or underground. Due to the lack in annual rainfall and drastic reduction in ground water level people living in many countries are facing water related problems and hence the requirement of potable water has been increasing [1]-[5]. In the present scenario, health issues increase drastically due to the non-availability of clean drinking water. Water obtained from rivers and lakes cannot be used directly for drinking purpose as these waters are getting polluted by domestic, municipal and industrial waste. Hence, water from these sources must be treated so that impurities like microorganisms and other harmful substances can be removed [6]-[10].

Solar energy is available in abundant in nature and hence solar desalination is the best solution for getting fresh potable water in the present scenario. This technique is a simpler one and more economical when compared to earlier methods of obtaining freshwater.

Basin type or conventional solar still is the most traditional and conventional method of getting freshwater by utilizing solar energy. Saline water is fed into the basin, and an inclined glass cover is placed over the basin. Solar radiation heats up the water inside the basin to make it evaporate from the top layer. The evaporated vapour inside the still rejects its latent heat through the cover for condensation. This is to attain thermal equilibrium with surroundings and poor conductivity of the cover material. Since the cover is inclined, the condensed water making a droplet on the cover, the droplets slide through it to the distillate collector due to the smooth cover surface [11], [12]. Only a few researches are carried out in incorporation of nano–particles in single and double slope solar still. Elango et al. [13] experimentally investigated a single slope solar still with different nanoparticless in a single slope solar still. They used Zinc oxide (ZnO), Tin Oxide (SnO_2) and aluminium oxide (Al_2O_3) nanoparticless with water for improving the yield of freshwater. Results show that the yield of freshwater improves with Al_2O_3 nanofluids inside the basin. Similarly, the payback period of the modified system was about 2.85 years while comparing it with solar still without modification. Sahota and Tiwari [14] analyzed a simple double slope solar still with different nanofluids inside the basin. Results showed that the yield of freshwater from glass improved by 14.4 % than solar still without nanofluid. Sahota and Tiwari [15] analyzed the energy and exergy efficiency of double slope solar still with different working fluid and concentration ratio of nanoparticles. Results showed that the maximum thermal exergy of 14.1 % was achievable using Al_2O_3

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nanoparticles. While the exergy efficiencies of TiO2 and CuO nanofluids were found to be 12.38 and 9.75% respectively.

In the present study the use of Al_2O_3, CuO and TiO_2 nanoparticless are dispersed in water with three different concentration ratio (φ-0.05, 0.1 and 0.2%) by volume and used as a fluid medium in the single slope solar still. Furthermore, exergy analysis of the system with nanofluids on the single slope solar still is carried out.

2. PREPARATION OF NANOFLUIDS

Nanofluids are prepared by dispersing the nanoparticle with water by volume concentration. For the present study three different concentration ratios of three different nanoparticless were chosen. Al_2O_3, TiO_2, and CuO nanoparticless were purchased with an average particle size of 25 nm and dispersed in water with concentration of 0.05, 0.1 and 0.2% by volume. Nanoparticles dispersed in water is subjected to sonification process for even distrubion of particle in water using an Ultrasonicator for 2 hours for better stability. The sonicated nanofluid is again sinterred by means of magnetic stirrer for almost 30 minutes to avoid the aggloromation of nanoparticless. The detailed thermo physical properties of nanoparticles are given in Table 1.

3. EXERGY ANALYSIS OF SOLAR STILL WITH NANOFLUIDS

It is possible to evaluate the second law efficiency of the system (destruction of energy) that is for the possible input to the system how much of work can be extracted from the system. Many researches carried out the exergy analysis (η_{exe}) for active and passive solar still. Till now no researcher worked on the exergy of the solar still with different nanofluid.

The hourly exergy efficiency of the system is mathematically expressed as [16],

$$\eta_{exe} = \frac{Ex_{output}}{Ex_{input}} \quad (1)$$

Table 1. Themo physical property of nanoparticles

S.No	Property	Nanoparticles		
		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

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

Instrument	Accuracy	Range	Error (%)	Observed error (%)	Standard Uncertainty
Thermocouple	±1^{o}C	0-100^{o}C	0.25	1.2	±0.57 ^{o}C
Solar power meter	±1W/m^2	0-2500 W/m^2	2.5	3.1	±0.57 W/m^2
Anemometer	±0.1m/s	0-45 m/s	10	6.8	±0.05 m/s
Beaker	±10mL	0-1000mL	10	8.3	±5.77 mL

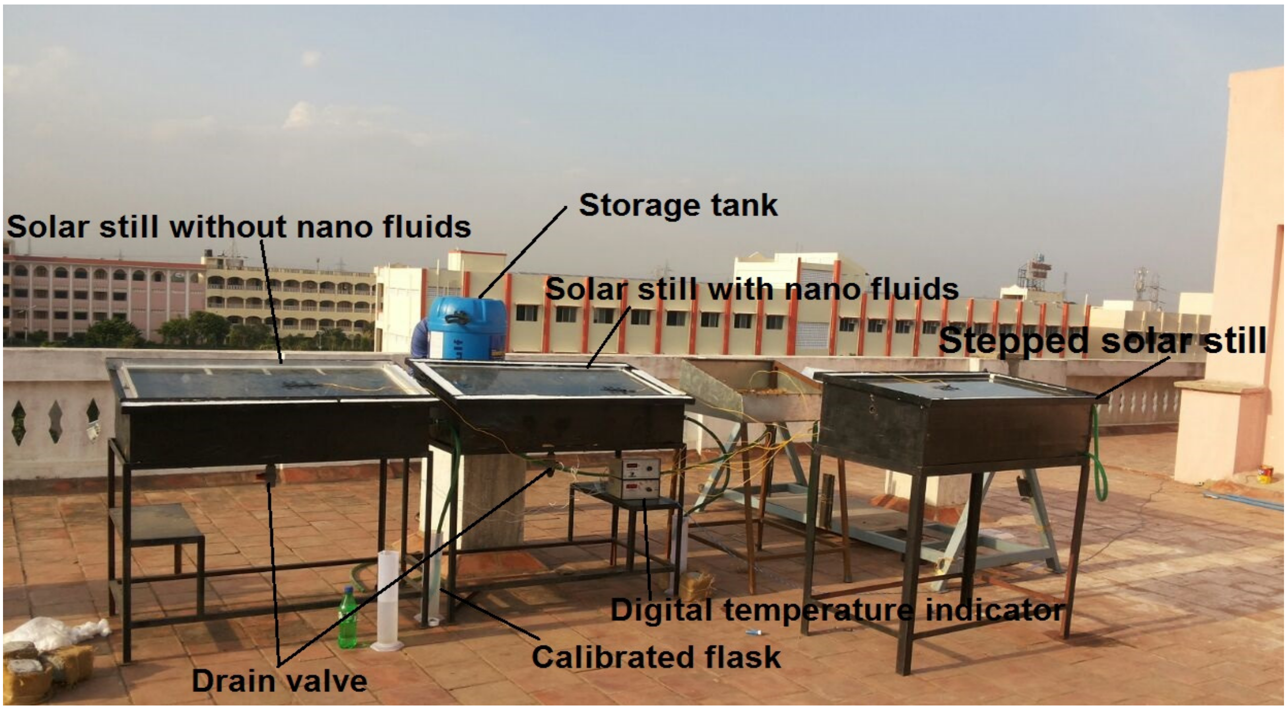

Figure 1. Experimental photograph of different solar still arrangement

The hourly exergy output of the system is expressed as [17],

$$Ex_{output} = \frac{m_{ew} L_{fg}}{3600} \times \left[1 - \frac{T_a}{T_w}\right] \quad (2)$$

where m_{ew} is the amount of freshwater collected in the collecting jar (kg/hr), L_{fg} is the latent heat of vaporization (J/kgK) and T_a and T_w are the ambient and water temperature in Kelvin, respectively.

The exergy input of the system is expressed as [17]-[19],

$$Ex_{input} = A_w I^{'}(t) \times \left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \quad (3)$$

where A_w is the area of water (m^2), I'(t) is the solar intensity falling on the inclined surface of the solar still and T_s is the sun temperature (K) (T_s=6000 K).

4. EXPERIMENTAL METHOD AND UNCERTAINITY

Figure 1 shows the experimental photograph of conventional solar still. The experimental setup consists of a storage tank, flat absorber conventional solar still, control valves, ditillate collector. 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 as 0.02 m. Measuring instruments include AM4836 cup type annemometer, TES 1333R solar power meter, calibrated flask, temperature indicator and PT100 (RTD) sensors for measuring wind velocity, solar intensity, freshwater, 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.

5. RESULTS AND DISCUSSION

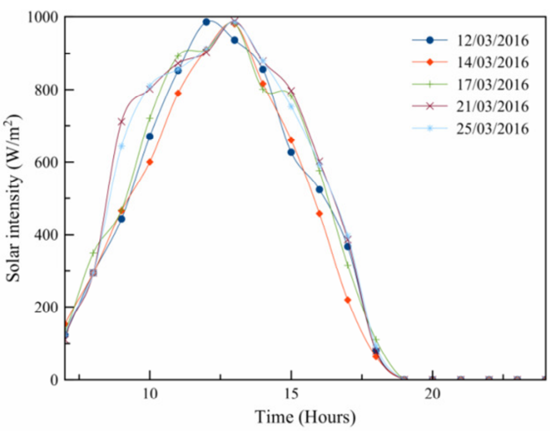

Figure 2. Hourly variation of solar intensity during experimentation

Figure 2 shows the hourly variation of solar intensity and wind velocity during the experiments. The maximum intensity was observed as 982 W/m^2 during the month of March, and the hourly intensity was observed with the experiments conducted for similar solar intensity. Similarly, the observed wind velocity during the experiments was found to be increasing during the offsine period and the maximum wind velocity occurred during the mid night and the average wind velocity during the offshine period was found as 3.2 m/s. During the sun shine hours the average wind velocity was found as 2.1 m/s (Figure. 3).

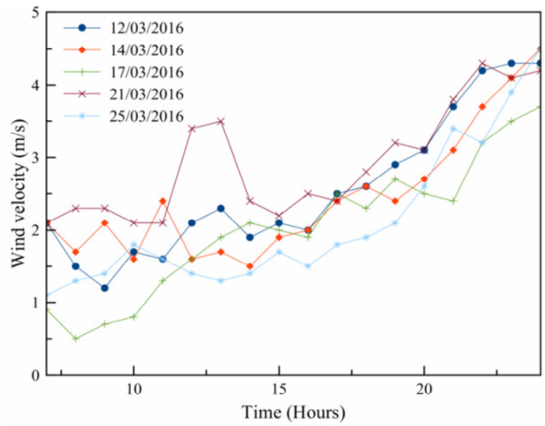

Figure 3. Hourly variation of wind velocity during the experimentation

5.1 EFFECT OF AL2O3 NANOFLUID IN CONVEN–TIONAL SOLAR STILL

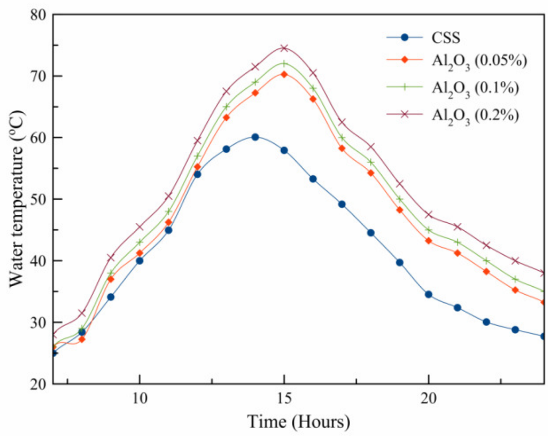

Figure 4. Effect of Al_2O_3 nanofluids on water temperature at different concentration

Figure. 4 shows the variation of water temperature from conventional solar still with and without nanofluid inside the basin. The maximum water temperature of 60°C was observed in the basin without any nanofluid. The water temperature inside the basin increases with increase in nanofluid with increase in the concentration of nanoparticless with the base fluid. The maximum temperature of 75°C was achievable with 0.2% concentration of nanoparticless with the base fluid. Similarly, the maximum temperature of water was found ass 70 and 60°C with concntration of nanoparticless 0.1% and 0.05% respectively. From Figure. 5 it can be clearly seen that the increase in concentration of nanofluids increases the hourly yield during the mid noon. With a possible increase of concentration from 0.1 to 0.2% the maximum acheivable hourly yield was found as 0.27 and 0.4 kg respectively. The increase in yield is due to the effect of higher concentration of nanoparticles in the fluid which tends to the decrease in specific heat capacity of nanofluid. The energy requirement for nanofluids is lesser as compared to the base fluid. The yield of conventional solar still with 0.05% and 0.1% was similar during the offsine hours (when there is no intensity). During the strating of experiments it was found that the yields were similar and the yield was gradually increasing with respect to the concentration of nanoparticless. In this case it was found that due to the shadow from the side walls the yield was lower as the thermal equillibrium with water is disturbed. During the offshine hours the yield was higher (10%) compared with the solar still without any nanoparticles as the energy will be stored in the fluid for continuous operation during the night hours.

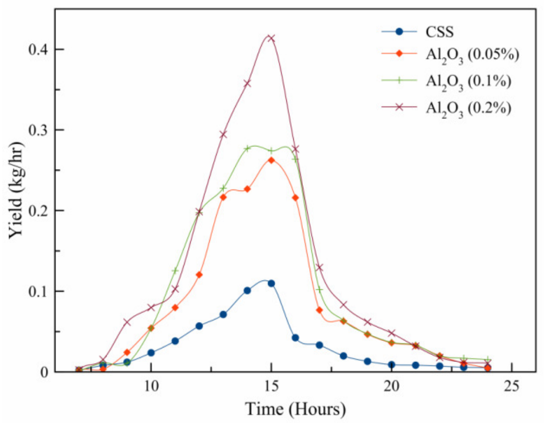

Figure 5. Variation of yield from solar still with different concentration of nanofluid (Al_2O_3)

5.2 EFFECT OF CUO NANOFLUID IN CONVEN–TIONAL SOLAR STILL

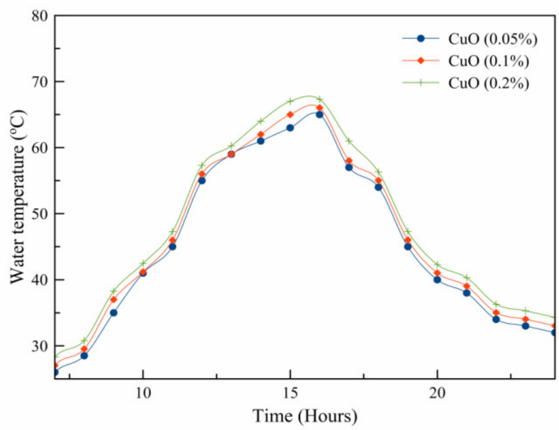

Figure 6. Effect of CuO nanofluids on water temperature at different concentration

The effect of copper oxide nanofluid concentration on water temperature is shown in Figure. 6. It can be observed that the effect of CuO nanoparticles increased the water temperature by 7.14% and it is lower as compared with Al_2O_3. Due to the higher density particle (ρ = 6234 kg/m^3) inside the basin the temperature of water is decreased. Similarly, with decrease in nanoparticless the temperature of water reduces. The variation of yield from conventional solar still with CuO is shown in Figure 7. It is clearly seen that the effect of nanoparticless augment the yield of freshwater, and the maximum yield is found to be 0.12, 0.15 and 0.16 for 0.05, 0.1 and 0.2% respectively. Also, it is seen that the observed yield is higher as compared to solar still without nanoparticles and lower compared to that of Al_2O_3. From Figure 7 it was observed that the yield of morning and evening hours are almost the same as it is due to the lower thermal equilibrium throughout the water mass.

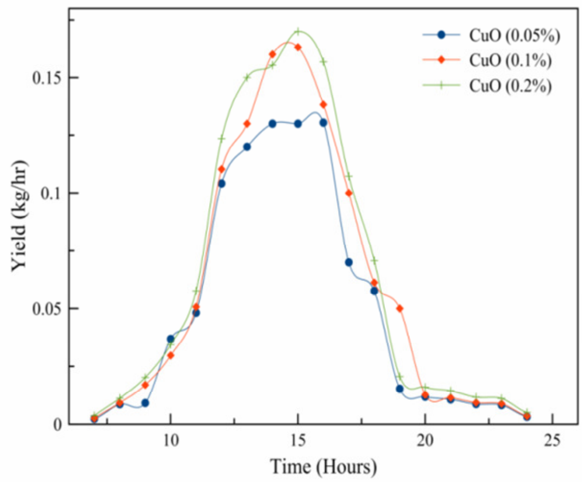

Figure 7. Variation of yield from solar still with different concentration of nanofluid (CuO)

5.3 EFFECT OF TIO2 NANOFLUID IN CONVEN–TIONAL SOLAR STILL

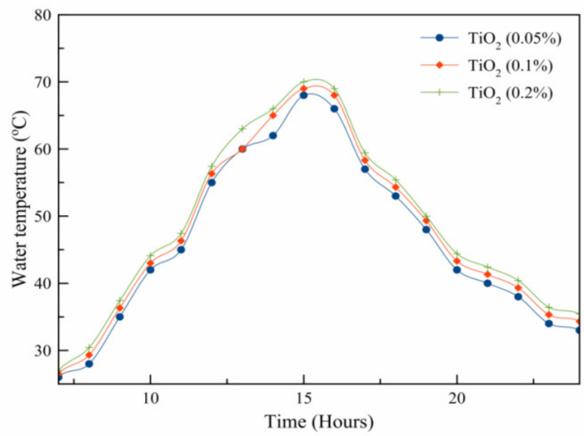

Figure 8. Effect of TiO_2 nanofluids on water temperature at different concentration

The hourly variation of water temperature with different concentration of TiO_2 nanoparticles is shown in Figure. 8. It is observed that the increase in concentration of nanoparticless and higher particle loading increase the temperature of water by 4% with respect to 0.05%. The maximum water temperature in the solar still with 0.05, 0.1 and 0.2% concentration of TiO_2 is found as 65.6, 68.2 and 69.4^{o}C respectively. Relatively, this is 9% lesser and 12 % higher as compared to the solar still with Al_2O_3 nanofluid (φ=0.2%) and conventional single slope solar still. The variation of hourly yield from the solar still with TiO2 nanofluid is shown in Figure. 9. The maximum yield is observed as 0.19, 0.18 and 0.15 for 0.2, 0.1 and 0.05% concentration of TiO_2 nanoparticles. The yield from the solar still is higher than using CuO nanoparticles, as it is due to the lower density. The relative decrease in the thermal conducitity of TiO_2 nanoparticles is found to be 15% lesser as compared to CuO. Due to this effect the yield is higher with increased concentration and also it is due to the energy absorbance by the nanofluid during the peak intensity.

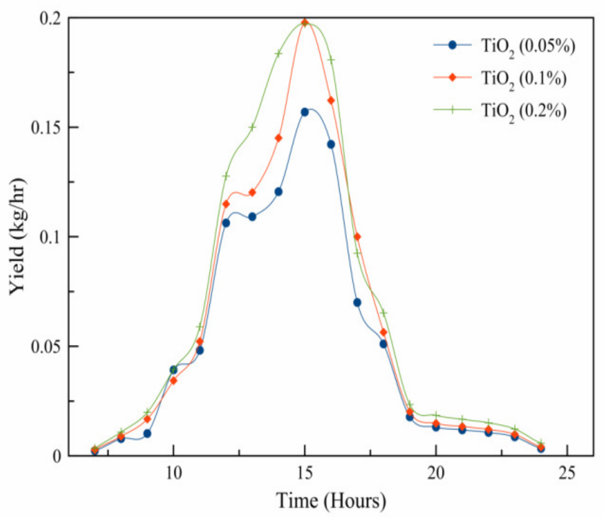

Figure 9. Variation of yield from solar still with different concentration of nanofluid (TiO_2)

5.4 VARIATION OF AVERAGE WATER TEMPERA– TURE FROM CONVENTIONAL SOLAR STILL

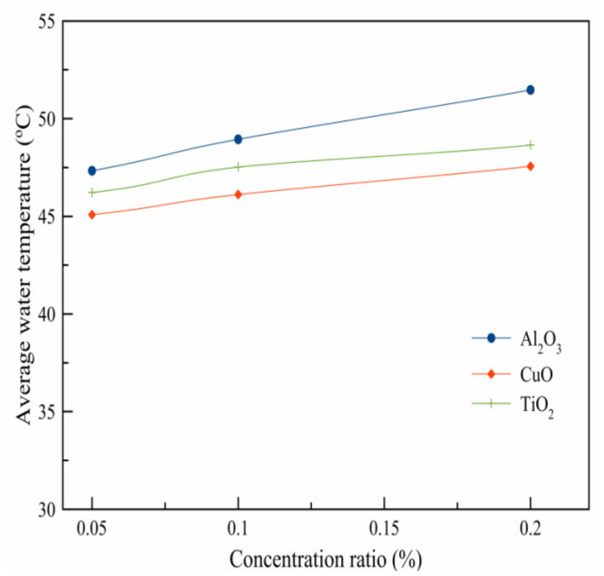

Figure 10. Variation of average water temperature with different nanoparticles and concentration

The variation of average temperature of water in conventional solar still with different nanofluids is plotted in Figure 10. It can be clearly seen that the due effect of higher concentration of nanoparticless in the base fluid the average temperature of water is increased by 2.23 % (TiO_2) and 5.5 % (Al_2O_3) from CuO. Also, the increase in average water temperature is due to the lower heat capacity of Al_2O_3 nanofluid.

5.5 COMPARISON OF YIELD OF SOLAR STILL WITH AND WITHOUT NANOFLUIDS

Table 3 shows the comparison of day time yield, night time yield and efficiency of the solar still with and without nanofluids. It can be seen that the yield from solar still with Al_2O_3 nanofluids with maximum concentration increased by 74.19% than solar still without nanofluids. Similarly, the total yield of maximum concentration of nanoparticless is found as 2.17, 2.44 and 4.03 kg/m^2 for TiO_2, CuO and Al_2O_3 nanofluids respectively. While comparing the improvement in night time total yield, Al2O3 with higher concentration is higher as compared to solar still with other nanofluids and without nanofluids. The percentage increase in freshwater yield from solar still with higher concentration of Al_2O_3, CuO, TiO_2 nanoparticless are found to be 74.27, 54.1 and 51.17 % respectively (Table. 4). The maximum efficiency of the system with maximum concentration of nanofluids was found to be 37.44, 20.22 and 21.23% for Al_2O_3, TiO_2 and CuO respectively.

5.5 EXERGY EFFICIENCY OF THE SYSTEM

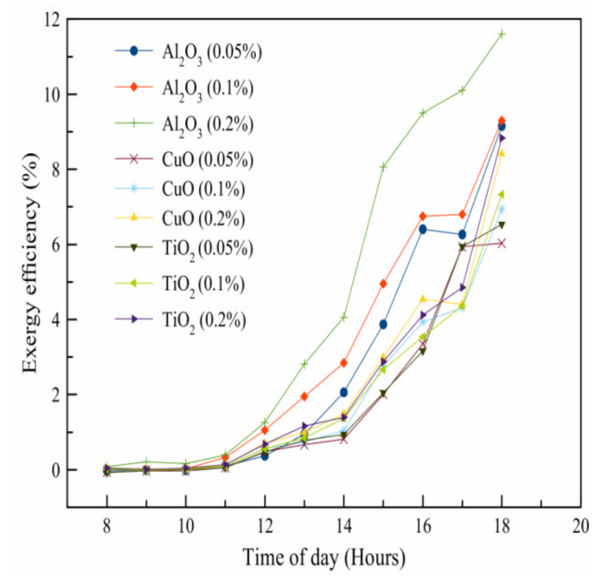

Figure 11. Exergy efficiency of different concentration of nanofluids in the solar still

The hourly variation of exergy efficiency of solar still with nanofluids is plotted in Figure 11. It can be clearly seen that the exergy efficiency with respect to time and it is almost similar during the sunshine hours (8 AM- 12 PM). There are also negative exergy efficiencies found during the start of the experiments with different nanofluids, especially at the concentration of φ=0.05% as the water temperature is lower as compared to the ambient temperature (T_w<T_a) between 8 AM and 11 AM. The maximum exergy of the system is higher when the system (solar still) basin is filled with Al_2O_3 nanofluids with maximum concentration (η_{exe}=11.12%). Many researchers concluded that the exergy efficiency of the system is infinite after the sunset as there is no energy input into the system (I=0). The least exergy of the system with nanofluids is found as 7.53% with TiO_2 nanofluid (φ=0.05%).

Table 3. Comparison of total yield, Night time yield and Day time yield from solar still with and without nanofluid

Parameter	CSS	CuO			TiO_2			Al_2O_3		
		φ=0.05%	φ=0.1%	φ=0.2%	φ=0.05%	φ=0.1%	φ=0.2%	φ=0.05%	φ=0.1%	φ=0.2%
Total yield	0.56	0.92	1.08	1.22	0.90	1.06	1.13	1.49	1.77	2.19
Average solar intensity (W/m^2)	587	563.37	534.38	587	587	618.5	611.5	563.3	534.38	587
Average ambient temperature (^oC)	38.7	35.5	38.3	38.7	38.7	39.4	38.9	35.5	38.3	38.7
Efficiency (%)	9.66	17.18	21.17	21.67	16.06	18.95	20.22	25.49	30.29	37.44
Yield($kg//m^2$)	1.13	1.85	2.17	2.44	1.81	2.13	2.27	2.99	3.55	4.39
Night time yield ($kg//m^2$)	0.09	0.13	0.14	0.18	0.11	0.19	0.15	0.30	0.33	0.36
Day time yield ($kg//m^2$)	1.03	1.72	2.02	2.25	1.69	1.94	2.12	2.69	3.21	4.03

Table 4. Comparison of percentage improvement in yield from solar still with and without nanofluids

Mode of operation	CuO			TiO_2			Al_2O_3		
	φ=0.05%	φ=0.1%	φ=0.2%	φ=0.05%	φ=0.1%	φ=0.2%	φ=0.05%	φ=0.1%	φ=0.2%
Total yield improvement	38.96	47.76	53.54	37.34	46.88	50.23	62.09	68.10	74.19
Day time Yield improvement	25.81	34.67	47.05	16.15	49.38	38.38	67.76	71.27	73.36
Night time yield improvement	39.96	48.72	54.07	38.78	46.64	51.11	61.46	67.76	74.27

6. CONCLUSIONS

From the above study the following conclusions are arrived at:

- The maximum yield from solar still with Al_2O_3, CuO and TiO_2 nanofluid were found to be 4.03, 2.25 and 2.17 kg/m^2 respectively for maximum concentration of 0.2%.
- There is an increase in the water temperature of about 3 and 5% for CuO nanoparticless. While the maximum water temperature of water is increased by 7% with Al_2O_3 nanofluid and concentration of φ=0.2%.
- The maximum exergy efficiency from the system was found as 11.12% with Al_2O_3 nanofluid (φ=0.2%). There is a greater possibility of negative efficiency during the start of experiment while ambient temperature less than water temperature (T_a>T_w).
- The daily exergy efficiency increases by 20% with increase in concentration of nanoparticles in fluid (Al_2O_3).

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ПОВЕЋАЊЕ ПРИНОСА СЛАТКЕ ВОДЕ И ЕКСЕРГИЈСКА АНАЛИЗА КОНВЕНЦИОНАЛНОГ СОЛАРНОГ ПОСТРОЈЕЊА ЗА ДЕСАЛИНИЗАЦИЈУ МОРСКЕ ВОДЕ РАЗЛИЧИТИМ НАНОФЛУИДИМА

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Овај експериментални рад се бави проучавањем учинка концентрације наночестица и ексергије конвенционалног соларног постројења за десалинизацију морске воде. Експериментална истраживања су вршена са концентрацијама 0,05 – 0,2% Al_2O_3, CuO и TiO_2 у соларном постројењу. Резултати показују да наночестице повећавају принос слатке воде из соларног постројења. Температура воде у конвенционалном постројењу при различитим концентрацијама нанофлуида се повећала за 3 и 5% код CuO, 4,2 и 6% код TiO_2 и 3 и 7% код Al_2O_3. Слично томе, просечна температура воде у конвенционалном постројењу је већа и износи 0,2% код концентрације Al_2O_3 у базену. Постоји повећање приноса слатке воде од приближно 50% код конвенционалног постројења са наночестицама Al_2O_3 (φ=0,2%). Утврђено је да је максимална енергетска ефикасност система 11,12% са Al_2O_3 нанофлуидом (φ=0,2%). Постоји велика могућност негативног учинка на почетку експеримента када је собна температура нижа од температуре воде ($T_\alpha > T_w$). Дневни ексергијски учинак се повећава за 20% са повећањем концентрације наночестица у флуиду (Al_2O_3).