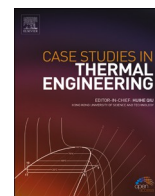


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Experimental investigation on the yield of solar still using manganese oxide nanoparticles coated absorber

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ABSTRACT

Present research expresses an experimental investigation on nanoparticle use to enhance Solar still (SS) yield. Manganese Oxide (MNO₂) is selected as a nanoparticle material and used in SS. The nanomaterial is added with the black chrome paint of the SS walls to increase the yield. The weight concentrations (WC) of MNO₂ have been used from 20% to 50 to see its effect on SS yield. It has been observed that the heat transfer and water temperature enhanced by the use of the MNO₂ nanoparticle with black chrome paint. The use of the MNO₂ nanoparticle has improved the yield of the SS. It has also observed that the yield of SS enhanced by 19.5% compared with alone SS by use of WC of 20–50%. The SS with MNO₂nanoparticle's payback time is 82 days at 20% WC than the alone SS of 98 days.

1. Introduction

Potable water is considered one of the essential priorities in the world today. The potable water sources are deficient, and the consumption remains very high in industries and household drinking purposes (Panchal and Mayavanshi 2017). Water is available in the sea called the saline water, but it is not fit to drink. The sunlight's availability also a fair amount in the many parts of the world [1, 2]. Therefore, the researchers have worked on many technologies to produce potable or clean water from the saline water [3]. Desalination is also considered one of the essential technologies for producing potable water from the seawater [4]. solar still (SS) is a simple apparatus used to convert potable water from seawater [5]. The yield of SS remains low due to the various losses shows the excellent motivation for researchers to improve the yield (Panchal and Shah 2014).

Naveen Kumar et al. [6] used the inclined SS type. They tested it during and without day and night during Chennai climate conditions. They concluded that the yield increased during daytime and improved during nighttime due to the low water and storage

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Nomenclature

Wc	Weight concentration
SS	Solar still
MSS	Modified solar still

content. Panchal et al. [7] used the triangular SS pyramid with baffle and studied the energy and exergy. The payback time of 5 INR/kg for the triangular pyramid form SS was also estimated based on their experiments. Panchal et al. [8] used the double basin SS, with solid fins, combined with evacuated tubes to improve both the surface area and the yield. They also compared it with fins and without them and found an improvement of 25% due to fins. The improved configuration of the SS was used by Shinde et al. (2019) to increase the yield by experimental study. They concluded that the improved solar design only increases the yield by 17%. The porous fins used in the SS to increase their surface area by Panchal and Sathyamurthy [9] and compared them to Traditional SS. The experiments found that the average SS yield with and without porous fins was 3.8 and 2.67 L/day. Joy et al. [10] performed experiments on-air blower SS to increase the evaporation rate by bubbling effect. They concluded that the SS improved thermal efficiency and yield with the application of the blower. The SS efficiency study for using energy storage materials was investigated by Panchal et al. [11,12]. They used marble and sandstones, tested them under patan climatic conditions and obtained a higher SS yield with sandstones. Iqbal et al. [13] tested the efficiency of SS using a solar air heater and base coating. The solar air heater was introduced to increase water's evaporation rate by delivering hot air and covering the SS base. Panchal and Patel (2017) compared and obtained a strong agreement between SS and ANSYS CFX software's experimental results. Panchal et al. [1,2] investigated several methods for raising SS such as flat plate collector, evacuated tube collector, different concentrators etc. They concluded that the use of different methods improves the yield by using the hot water source. Panchal et al. [11,12] checked and compared various active solar stills in conjunction with the yield obtained. Abdullah et al. [14] analyzed the different SS wick type researchers. They clarified the working theory and numerous studies by different scientists on wick type SS well. Finally, they also clarified potential research on Wick type SS. Centred on their study's experimental days, Panchal [15] had conducted the life cycle cost analysis of dual basin SS with evacuated tubes. The lowest payback time of 45 days was estimated when the drinking water market price was around 20 INR. Yadav and Raut [16] analyzed the SS double exposure efficiency study numerically with traditional SS. They found that double exposure SS efficiency is far higher than traditional. Vishal et al. [17] numerically and experimentally studied the SS's output with evacuated pipes via thermosyphon mode to see the night yield. SS and evacuated tubes by thermosyphon mode increased the nocturnal performance due to the availability of hot water. They also found a strong consensus between the experimental and numerical findings. Karthik et al. [18] tested SS's efficiency by applying vacuum pressure supply to see its output effect. They obtained 5 L per day by applying a vacuum pressure of 0.6 bar in the SS. They also proposed that the electrical supply be used as potential SS applications. Venkatsamy et al. [19] conducted an experimental investigation into SS using baffles in the Chennai, India climate conditions. They also conducted numerical analysis and compared the results of the experiments and found a strong consensus. Analytical tests foreseen freshwater production are 3.50 kg/m² per day, with a minimum flow rate of 0.0833 kg/min. Experimental yield per day is 2793 kg/m². The saltwater inlet also affects yield, the latter being 48.5 °C highest. The experimental work on double path SS was done by Ganaraj et al. (2018) using internal and external changes. They found that internal and external improvements increased the yield of the traditional SS by 40.86%. The performance analysis of the stepped and traditional design of SS was compared by Shyora et al. [20] in Gandhinagar, Gujarat climate conditions. They concluded that Stepped SS' yield increased by 23.88% relative to standard nature. The Tetrahedral sponge cubes in the SS were used by Narayana and Raju [21] to increase capillary action and evaporation speeds. They measured sponge cubes of different sizes and found that 5 cm is best for improving the performance. Nithyanadam et al. [22] tested the SS in summer weather using blue metal stones. They tested 6–20 mm of blue metal stones in their experimental work compared to the conventional SS. Arun Kumar et al. [23] have used different water samples as raw water to analyze drinking water collected from SS after distillation in SS. Dumka and Mishra [24] performed an interesting analysis of SS to use various concentrations of salt. They concluded that theoretical and experimental findings provide a better output of 1% of the salt concentration in SS. Indra Mohan et al. [25] examined many solar designs still developed by various researchers. Sriram et al. [26] performed a double-slope SS experiment with the Fresnel lens. For the experimental work, industrial wastewater was used as raw water in the SS. They concluded that the Fresnel lens could be used for the extraction of drinking water from industrial wastewater. The energy and exergy study of SS was carried out by Shanmugan et al. (2012) based on experimental and numerical findings. Between experimental and numerical findings, they found strong agreement. Panchal and Sadasivuni [27] examined several built-in condensers to increase the SS condensation rate. They also discussed future research on the SS and the built-in condenser.

It has been found from the above literature that many researchers have worked on SS to boost performance. The significant research works by a couple with solar collectors, condenser, Fresnel lens, air fan, blower and much more. It has also been found that working one on nanomaterials is limited to enhance the yield of SS. Therefore, the main objectives of the present research article as follows:

- Determine the SS yield improvement by adding the varying weight concentration percentage of Nanomaterial with black chrome paint.
- Compared the performance of the SS with and without adding the Nanomaterial during experimental days
- Payback analysis of SS with and without adding the nanomaterials

2. Experimental setup

Fig. 1 represents the schematic diagram of the experimental setup of Modified solar still (MSS) and SS. Both the SS used in the experimental investigations have prepared by 2 mm thick GI sheet available in the local market of Patan. They have effective basin area of 1-m square (1 m width \times 1 m length) used for research work. The high, as well as a low side of walls, have taken as 45 cm and 20 cm to maintain the latitude of patan district (23°) [28]. 2 cm depth of the water maintained in both SS. The MSS inner surface was painted black chrome paint to raise solar rays' absorptivity. MSS was painted with a mixture of paint and Nanomaterials. Silicon is also used to join the glass and a solar still and make it leak proof.

The storage tank of 100 L of tap water was used to supply the raw water in both stills. For the equal distribution of water into the SS, valves V1 and V2 are provided in Fig. 1. All the research experiments have been conducted in Government Engineering College Patan's climate conditions for four days for each nanomaterial concentration (20–50%). Average readings have been used during August 2019 to research both stills. Various measured parameters like the velocity of wind, different temperatures (Glass and water), sun rays have been measured by calibrated instruments like an anemometer, k type thermocouples, suryampai. MnO₂ has a density (200 kg/m^3), thermal conductivity (80 W/m-K), specific heat (42.3 J/mok-K) and average particle size (10–20 nm). Also, the 20% weight concentration means using 20-g nanomaterial in 1 kg of black chrome paint.

In the experimental work, the performance always depends on the parameters used in it. Here parameters such as water, glass and ambient temperature, the velocity of wind, sun rays and yield etc. used to determine both stills' performance. Various temperatures have been measured by calibrated K Type thermocouples (Accuracy $\pm 0.4 \text{ K}$). The sun radiations measured by suryamapi having a range of $0\text{--}2000 \text{ W/m}^2$ (Accuracy $\pm 1 \text{ W/m}^2$). The speed of the wind measured by vane type anemometer (Accuracy $\pm 0.11 \text{ m/s}$). The yield from both SS collected by a flask of 1 L (Accuracy 1 mL). The uncertainty of the experiments has measured by the equations available in Ref. Naveen Kumar et al. [6]. It has been found that the maximum uncertainty must not be increased by more than 2.3% during the experimentations.

3. Result and discussion

During the experimental days, the wind speed varies from the 2–4.5 m/s, and sun intensity ranged from the $50\text{--}1000 \text{ W/m}^2$. The performance of MSS tested by mixing the MnO₂ mixed with the black chrome paint. Also, the performance of the MSS with the SS assessed and also compared.

3.1. Variations of sun intensity and temperature during experimental days

Hourly variations of the sun radiation and temperatures on both stills are represented in Figs. 2 and 3, respectively. MSS shows the effect on the use of the weight concentration of MnO₂ with 2–50%. It is found that the hourly variations of temperature and sun radiation found a similar trend. It is also found that temperatures increases as the day passes to the noon and reduces to the off-sunshine hours. It is seen that the MSS temperature with nanoparticles found higher temperature compared with other experimental still. Fig. 2 shows that the temperature of MSS raises around 0–2 degree Celcius and 0–3.5 degree Celcius with 20% the weight fraction of nanomaterials compared with other experimental SS. Similarly, Fig. 3 shows the 0–3 degree Celcius and 0–5.9 degree Celcius temperature rise with 50% weight concentration in MSS than the experimental SS.

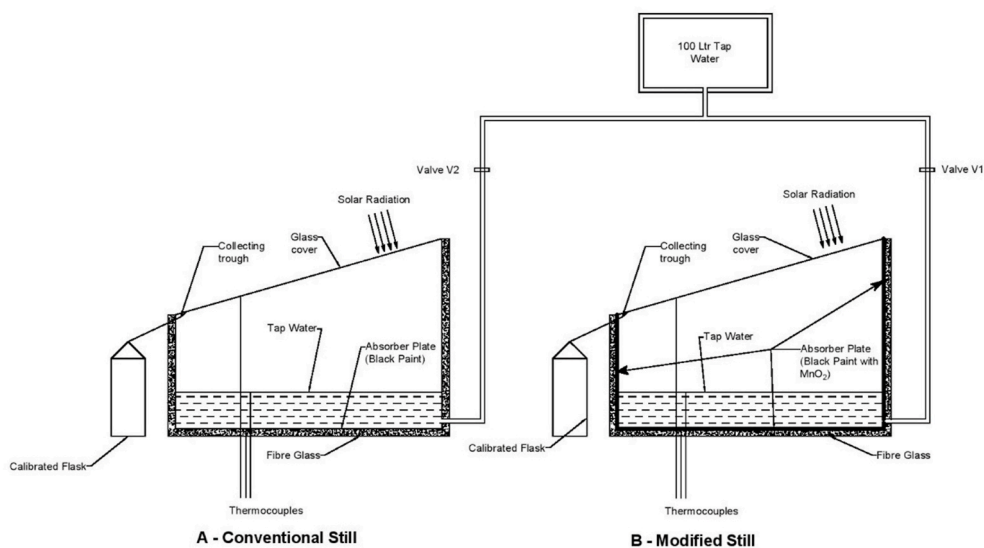


Fig. 1. Schematic diagram of SS and MSS experimental setup.

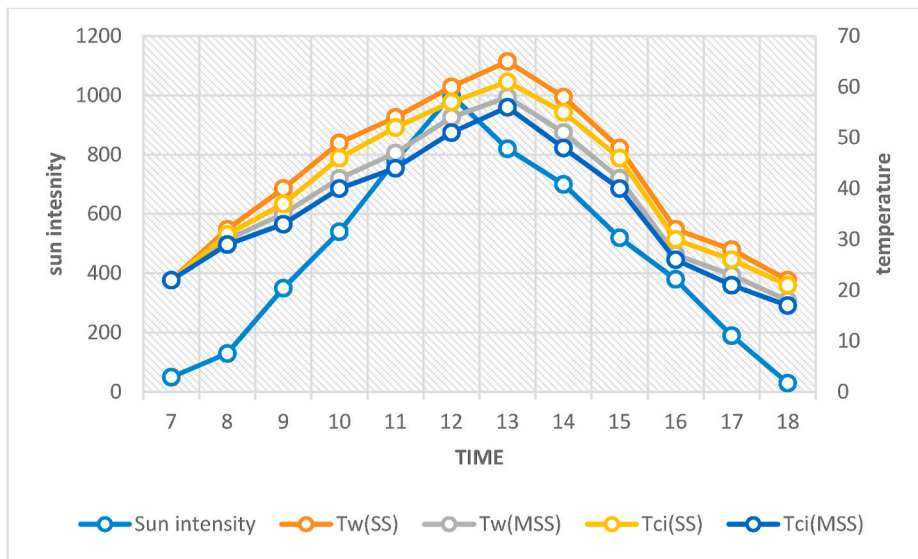


Fig. 2. Hourly variations of temperatures and sun rays on SS and MSS with 20% weight concentration of nanoparticles with black chrome paint.

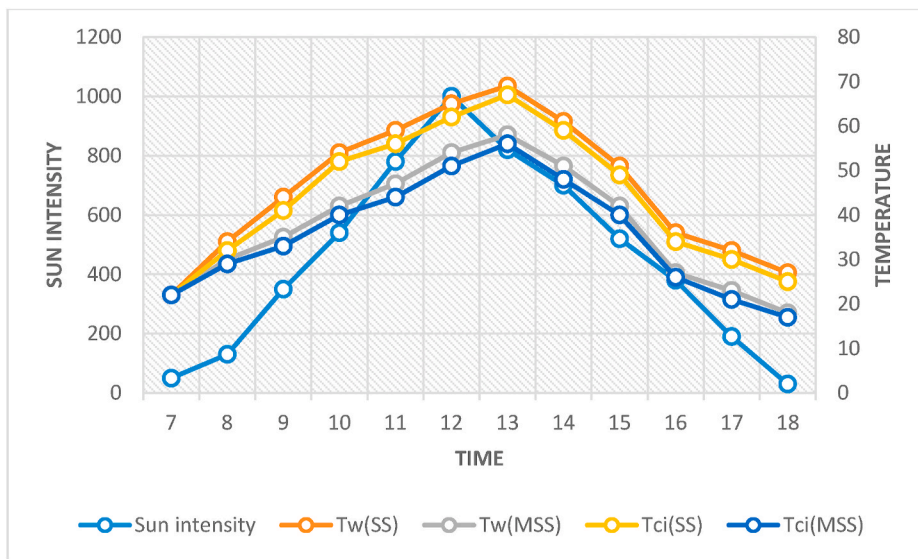


Fig. 3. Hourly variations of temperatures and sun rays on SS and MSS with 50% weight concentration of nanoparticles with black chrome paint.

It is seen that the adding of nanoparticles in the MSS absorbs the more heat energy of the sun as compared with the other experimental still. The higher absorption of sun heat is the heat transfer characteristic of either thermal conductivity of nanoparticles with black chrome paint or the SS basin walls. Higher absorption of sun radiations raises water evaporation in the MSS compared with the other experimental still and better condensation. And performance depends on the evaporation and condensation in the still; therefore, the implementation of MSS found better than the other experimental still. So the nanoparticles improved the evaporation and condensation in the MSS for the improvement of the performance of MSS.

It is also evident from Figs. 2 and 3 that the sun radiations incident on both stills same so the trends remains the same. Also, they have lower value during the early morning and then increases during the afternoon and reduces after it. Even the ambient temperature also varied but remained the same for both the stills. But the black chrome paint with the nanomaterials absorbs the higher amount of rays, so the temperature variation is shown in both the stills. Fig. 4 shows the interpretation of the velocity of wind during the experimental day. It is shown that the wind speed remains the same for both the stills and It does not remain constant throughout the day.

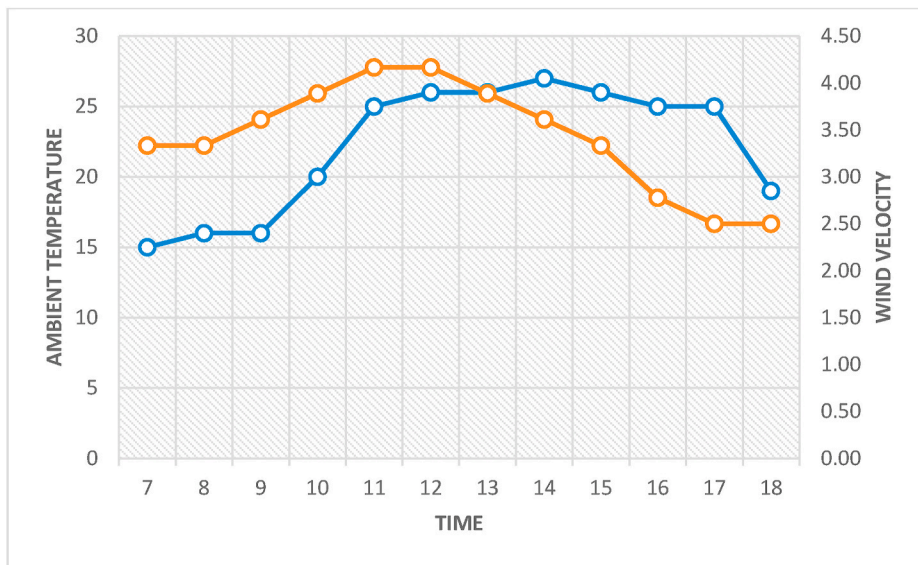


Fig. 4. Hourly variations of the velocity of wind and ambient temperature during the experimental day.

3.2. Variations of yield in MSS and SS

The potable water generation started in the morning and increased up to the afternoon and then reduces. The reason behind the Water generation is that the water and glass temperature differ in temperature. More water and less glass cover temperature enhance the generation of more yield. Fig. 5 expresses the variation of yield from the MSS and other experimental SS. It is also concluded from ref. Dumka and Mishra [24] that the yield of the SS depends on the sun radiations. Therefore, water generation increases from morning to afternoon and then reduces to zero during the off-sunshine hours.

Fig. 5 shows that the yield of the MSS more as compared with the other experimental solar still. The reason behind the higher yield is the use of the nanomaterial mixing with the black chrome paint. Generally, paint is used in every SS to absorb the sun rays and increase the water temperature. The mixing of nanomaterial with the black chrome paint increases more absorption of sun rays than the experimental still. So the heat generation was found higher in MSS than the other experimental still, so the evaporation and condensation also increase. And higher evaporation and condensation in the MSS with the help of mixing of Nanomaterial and black chrome paint found 19.5% higher yield than the other experimental SS.

3.3. Comparison between the daily yield obtained from MSS and SS

Daily yield comparisons showed in Table 1. Fig. 6 represents the cumulative yield obtained from both stills during the experimental day. As discussed earlier, that the hourly yield of the MSS found higher as compared with the experimental still, so the cumulative yield also remained higher for MSS. Fig. 6 shows that the daily yield production from the MSS and SS found 3200 and 3868 mL yield during 08/08/2019.

3.4. Effect of concentration of nanomaterials

Fig. 6 shows the effect of nanomaterials' concentration in the MSS to see its effect on the increment of yield. The concentration of nanomaterials ranging from 20 to 50% and mixed with the black chrome paint. It is clear from the figure that the higher concentration of nanomaterials increased the yield in MSS. The higher yield by higher concentration is the enhancement of heat transfer in MSS in terms of evaporation and condensation. And evaporation and condensation increased the yield in MSS. It is shown that the 50% concentration found around 22% yield.

3.5. Payback analysis

For any solar thermal or solar photovoltaic systems, the payback analysis is critical. Total fabrication cost of the MSS and SS are 110 \$ 85 \$ respectively.

Price of the available potable water is 0.270 so, For this work, the cost of the distilled water per litre is taken as twenty-seven dollars and seventy cents (0.270 \$).

Price of yield/day for SS = daily productivity \times cost of water per litre = $3.2 \times 0.270 = 0.864$ \$.

Price of yield/day for MSS with nanomaterial concentration (20%) = $3.8 \times 0.357 = 1.35$ \$.

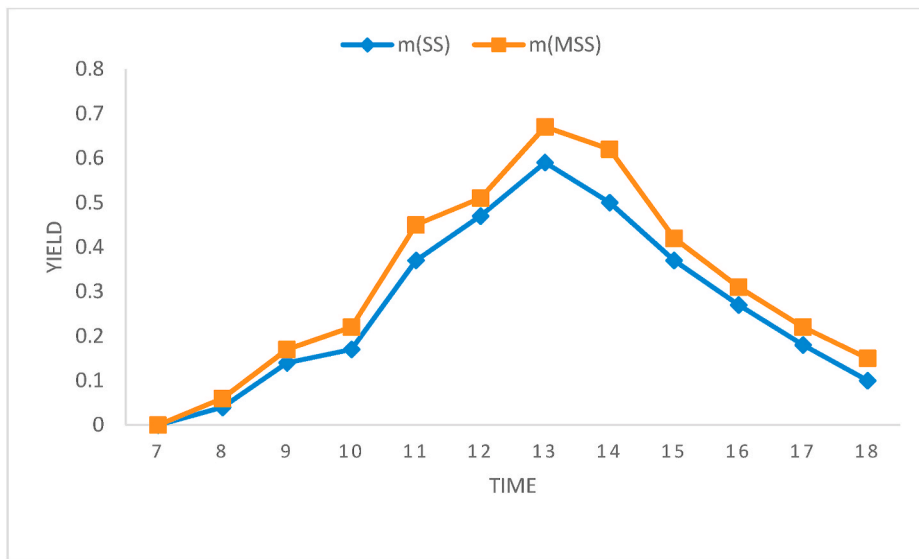


Fig. 5. variations of yield obtained from SS and MSS (with 20% nanoparticles weight concentration with black chrome paint).

Table 1

Daily yield comparisons in SS

Experiment Date (Month of August 2019)	Weather during experimental days.			Daily yield obtained		Percent rise in yield
	Sun rays (W/m ²)	Ambient Temperature (Celsius)	Speed of wind (m/s)	MSS	SS	Percentage Increment (%)
8/8/2019	620	29.7	1.4	3200	3868	20.8
9/8/2019	608	28.9	2.1	3150	3751	19.0
10/2019	601	28.1	1.1	3100	3687	18.93

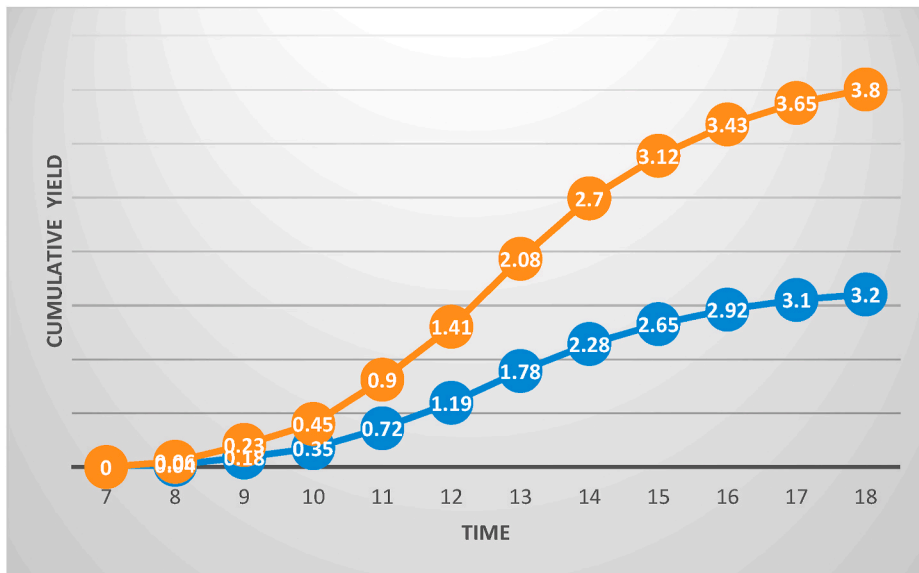


Fig. 6. Variations of cumulative yield obtained from SS and MSS (with 20% nanoparticles weight concentration with black chrome paint).

Payback time (SS) = Fabrication cost/earning = 85/0.864 = 88.7 = 98 days.

Payback time (MSS) = investment/net earning = 110/1.35 = 82 days.

4. Conclusions

Two same-sized solar stills (MSS and SS) have been tested experimentally in climate conditions of Patan during August 2019. Same water depth of 2 cm also maintained in both SS for the experimental work. Following points are obtained as a conclusion from the result and discussion sections:

- The presence of nanomaterial percent in the black chrome paint on MSS improved the heat transfer rate.
- Manganese oxide nanoparticles 50% weight concentration improved the performance of MSS.
- The presence of nanoparticles mixing with the black chrome paint improved the yield 19.5% more than the other experimental SS.
- The MSS and SS's payback time was found 98 days and 82 days during the experimental days during August 2019.

Author statement

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Analysis by Mohammad Khalid, Swapnil Dharaskar, S. Shanmugan.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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