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Research Article

Effect of different aluminium oxide based nanofluid concentrations on the efficiency of solar water desalination system

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ABSTRACT

In this study, the effect of different concentration of the Aluminium oxide-based nanofluid on the performance of Solar Desalination system was discussed. The Aluminium Oxide was used in different concentrations 1%, 2% and 6% on weight basis. The flow rate was also varied and its effect on the system efficiency was discussed. The nanofluid was compared with the water and there was improvement occurred in the efficiency during variation of incident radiation. With an increase in the concentration of Aluminium oxide nanoparticles, improvement in the efficiency was attained. More efficiency was attained at 6% nanoparticles addition with compared to 1% and 2%. With an increase in mass flow rate of the fluid, the nanofluid also showed better performance in terms of improvement in the efficiency.

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INTRODUCTION

The application of Solar Energy for the purpose of drinkable water is one of the cleanest approaches. With the exhaustion of ground water resources, the demand of fresh water escalates rapidly with the continuous rise of population, to achieve this demand there is rapid extraction of lakes or river which may become dry and briny in near future [1], [2]. To clean the saline water requires high and continuous supply of energy, with the overexploitation of fossil fuel it is necessary to supply more reliable source to provide potable water to meet the global demand. Solar desalination is in tremendous use as they can operate in the low temperature range of 800C to 120□ along with lower cost of energy [3].

There are various methods have been proposed to increase their efficiency like introduction of absorption material in the base of solar still, and application of nano additives. The nanofluids have provided better output in terms of increasing the efficiency of water due to their higher thermal conductivity properties.

Some numerical studies show the heat transfer performance of nanofluids in various applications. Kilic M et al [4] presented numerical study. Authors studied the heat

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transfer from heated surface using swirling jet and various nanofluids. Authors noticed significant increment in average Nusselt number. Kilic M and Ali HM [5] studied numerically the effect of different volume ratio, different heat flux and various nanofluids on heat transfer performance. Authors noticed that on increasing volume ratio of CuO/H2O, Cu/ H2O and TiO/ H2O nanofluids the Nusselt number increases significantly. Kilic M [6] examined the heat transfer from a porous rectangular channel using hot air and water. Author concluded that on increasing Reynold number, surface temperature increases and cooling performance decreases. Increasing mass flow rate of water, decrease in wall temperature and increase in cooling efficiency was noticed.

Abdulvahitoglu A [7] studied the application of Cu/ water, NiO/water and CuO/water nanofluids. Thermal conductivity is considered as most important thermophysical property for coolant. Author concluded that Cu/water is the most suitable coolant for radiator of vehicles.

The application of nanofluids have shown more interest due to the enhancement in the efficiency of the solar water heaters. Following are the properties of the nanofluids that are responsible for the changes in the efficiency of the solar water heaters. There are (a) nanoparticle size (b) shape (c) concentration (d) Viscosity (e) Thermal conductivity etc. Various studies were performed with respect to the efficiency of the solar desalination systems [8].

The role of nanoparticles has played a significant role to enhance the performance of solar still, recently many studies have shown the advanced absorbing materials to improve the productivity. Both single slope and double slope solar still have presented the rise in yield with different nanoparticles as absorbing materials. In a performance study of solar still while using 0.1% aluminum oxide with brine water resulted to an improvement in the yield with around 30% [9], [10] while with 1.2wt% of aluminum oxide nanoparticles in water could improve the productivity by 12% [11]. Some other experiments were done using nanoparticles with base water and the similar results has been achieved on active solar desalination system along with heat exchanger [12], [13]. In an experimental work on active solar still along with condenser while using Al2O3 nanoparticles in base water which has resulted to a yield of 116% improvement in the productivity [11],[14]. When this active system along with vacuum now compared with Cu2O and Al2O3 nanoparticles in brine water would result to a rise of 133% and 125% productivity of CuO and Al2O3 nanoparticles respectively and when the same system along with corrugated wick was analyzed, more improved result was obtained. The productivity has improved to about 285% and 255% with of CuO and Al2O3 nanoparticles respectively [15].

Many reports have focused on the use of nanofluids to improve the productivity of solar still in remote areas also which are deprived of freshwater access. It has been observed that with the utilization of nanofluid the productivity enhances by improving the thermal conductivity to some extent. Alumina is one of the most suitable one for the purpose of improvement in the productivity of water desalination due to its availability and low cost [16], [17]. Active solar still has proved to be better solution when it comes to productivity enhancement as compared to passive water desalination. Certain work has shown that solar still when coupled with solar collector system provides optimized solution to brackish water problem [18]. Moreover, active system integrated with nanoparticles have been investigated many times and it has shown much better results over former solar still for water desalination.

According to the available literature, most of the studies was concentrated on the application of nanofluids either to natural circulations or forced circulations. According to the author's best knowledge, no work has been reported while considering their comparison focussing on the performance of solar stills. In this study, Al2O3 nanoparticles were used due to their higher thermal conductivity and low density. The mixture of Al2O3/water nanofluid was inhouse prepared and nanoparticles characterization was also conducted in this analysis. The Al2O3 nanofluid was analysed with different concentration with various mass flow rate.

Governing Equation

The energy conservation equation is applied at the same time to every one of the three parts of a component, glass cover, absorber plate and saline water, taking into consideration the unsteady-state thermal performance of each part [19]. Three separate control volumes are considered in the investigation of a component of the sun based still: the glass cover, the absorber plate and part of the insulation, and the saline water with the following assumptions: (a) no vapour leakage, (b) no heat loss, (c) no temperature gradient between basin water and glass cover, (d) heat transfer coefficient are temperature dependent.

The energy balance equation for the control volume of the glass cover is:

$$q_{I,g} + q_{c,w-g} + q_{r,w-g} + q_{evap} = q_{c,g-a} + q_{r,g-a} + \frac{d_{eg}}{dt} \quad (1)$$

The energy balance equation for the absorber plate and part of the insulation is:

$$q_{I,p} = q_{c,p-w} + q_{p,loss} + \frac{d_{eg}}{dt} \quad (2)$$

The energy balance equation for the part of the element of brine water film flowing over the absorber plate is:

$$q_{I,w} + q_{c,p-w} + q_{in} = q_{c,w-g} + q_{r,w-g} + q_{evap} + q_{out} + \frac{de_w}{dt} \quad (3)$$

The performance of a solar basin still could be evaluated by calculating its efficiency as:

$$\eta(t) = \frac{q_{evap}}{I(t)A} \tag{4}$$

MATERIALS AND METHODS

During the first phase, aluminum oxide-water nanofluid was prepared and further characterized. In the second phase, comparative analysis was done between aluminum oxide- water nanofluid with water in an indirect flat plate solar desalination system.

Experimental Set-Up

Figure 1 shows the schematic experimental setup of the solar desalination system. It consists of water collector box consisting of coils made of copper, nanofluid tank, pump, piping, and measurement tools. The setup was worked on the forced convection system with an electrical pump operated to circulate the nanofluid through the system. The solar radiation was absorbed by the nanofluid and results in both natural and forced convection system.

Table 1 shows the detailed description of the solar desalination system. The experiment was performed in a set up installed at GLA University, Mathura, Uttar Pradesh, India. The average wind speed in Mathura city during the month May to July was 2.8 m/s having 27.4924oN latitude and 77.6737oE longitude. The accuracy of measuring instruments is shown in Table 2.

Figure 2 shows the experimental set up of the solar desalination system. To measure the solar irradiance, solar meter (TES-132) was used. The K-type thermocouple was installed at the inlet and outlet position of

Table 1. Detailed description of the solar desalination system

Details	Value
Size (mm)	Length = 1050
	Width = 1050
	Height = 120
Thickness of glass (mm)	3
Absorber plate area (m2)	1.0
Thickness of absorber (mm)	1.2
Tube details inside absorber (mm)	Diameter = 5.4
	Thickness = 1.0
Insulation thickness (mm)	25

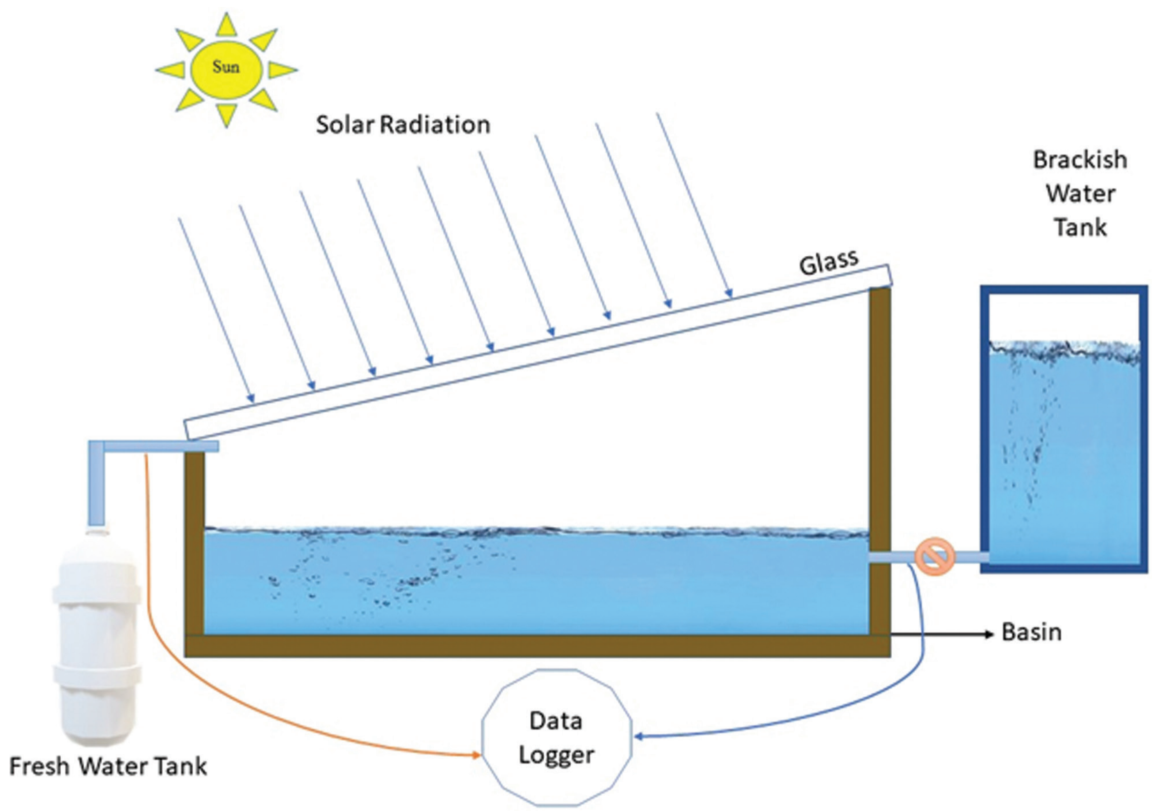

Figure 1. Schematic representation of solar desalination set up.

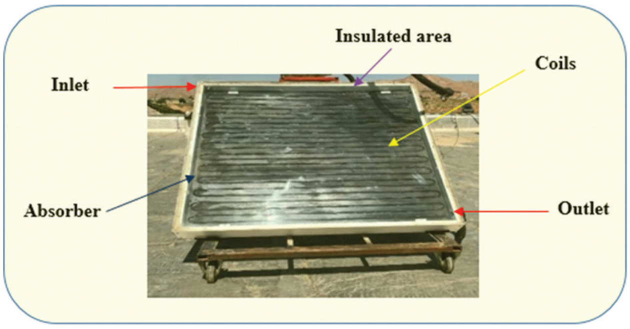

Figure 2. Solar water desalination system experimental set up.

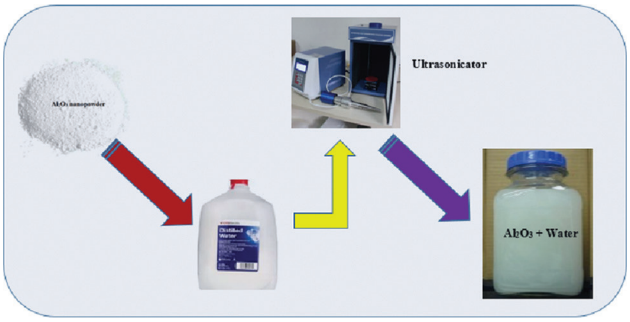

Figure 3. Schematic image of the process applied for the nanofluid preparation.

Table 2. Measuring instruments with accuracy

S. No.	Instrument	Accuracy
1	Magnetic Stirrer	±1oC
2	Solarimeter	±1W/m2
3	K-type thermocouple	±2.20C
4	Ultrasonicator	±0.5%

the system. One thermocouple was kept at the exit point of the absorber. The data was displayed in a data logger (ktt310-kimo data logger). The mass flow rate was regulated with the help of flow meter and it was maintained at a rate of 0.02 kg/s and 0.06 kg/s. The pump was electronically operated using electrical supply and could operate up to 0.5 kg/s flow rate.

Nanofluid Mixture Preparation

The aluminum oxide nanoparticles were purchased from Ultra nanotech Private Ltd., Bengaluru, India. The nanoparticles were white in color having 99.9% purity as recommended by the supplier. The size of the nanoparticles was varied from 30 nm to 50 nm. The alpha was the phase type, and it was having density of 3878 kg/m3, thermal conductivity of 38.7 W/mK and 763.1 J/kg K heat capacity. To mix with water, two step method was followed according to the details mentioned in literature. The Al2O3 was mixed to the water up to 1%, 2% and 6% by weight. Figure 3 shows the process applied for the preparation of nanofluid.

The Al2O3 nanoparticles was added to the water with sodium Do-Decyl Benzene surfactant. The surfactant was added around 10% weight of the nanoparticles. The solution was stirred using magnetic stirrer for around 30 min. For complete dissolution of the nanoparticles to the water and removal of their agglomeration in the surface, ultrasonication process was performed for around 60 min. After this process, a complete homogeneous mixture of Al2O3/water nanofluid was obtained.

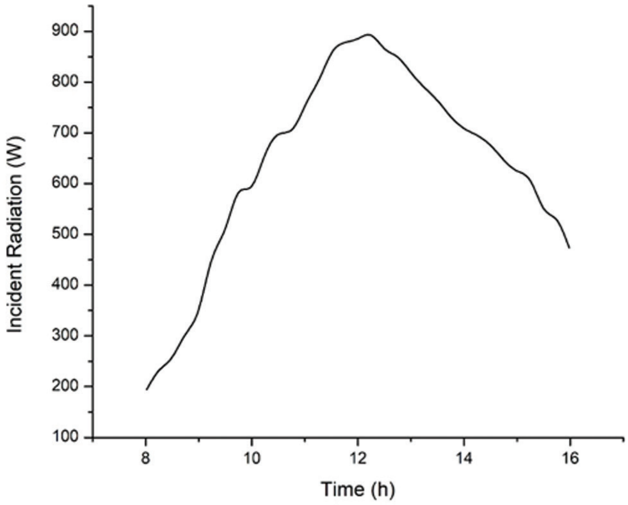

Figure 4. Incident solar radiation with time duration.

RESULTS AND DISCUSSION

To evaluate our methods, the experiments using the laboratory equipment in a clear and sunny weather conditions were performed. The data represented in the Figures is the average of the five experiments performed for each test. The reliability of data is 95%. For this study, key data were extracted from 8 hours to 16 hours at the interval of 15 minutes. The work focuses on the performance and efficiency of the solar still by considering the temperature aspects under different conditions. To ensure reproducible results the experiments were carried out in a controlled environment with no clouds in the sky and wind speed less than 1 m/s.

The trend of the figure 4 shows that radiation increases with dawn, reaches a peak around noon, and then decreases significantly thereafter as shown in figure 4. As expected, there is a small increment in the solar irradiance even after reaching the peak point. It is widely adopted that the solar irradiance has direct effect on the system efficiency as shown in figure 5. Nanofluid as heat transfer fluid on the effect of solar radiation and still efficiency was investigated

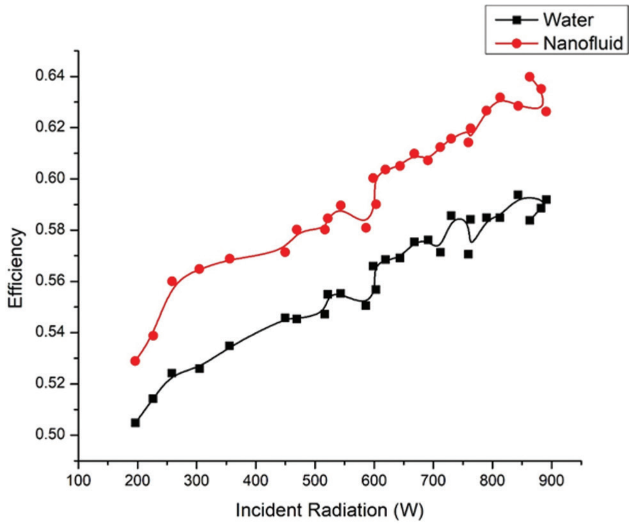

Figure 5. The efficiency of solar desalination system with incident radiation at 1% flow rate.

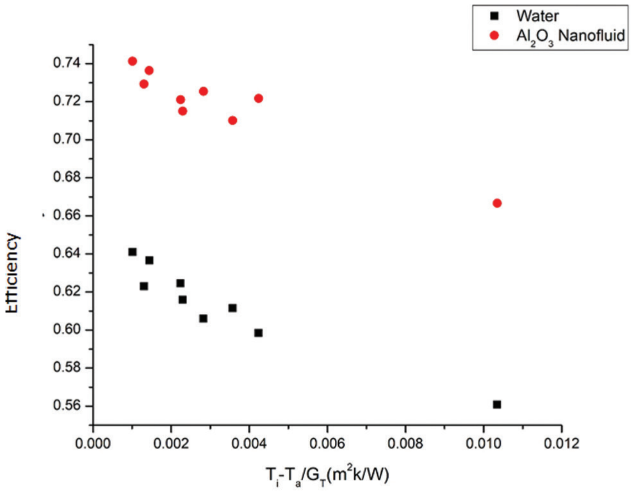

Figure 6. The effect of parameter on the desalination system efficiency with a flow rate 0.015% at 1% Al2O3 nanofluid.

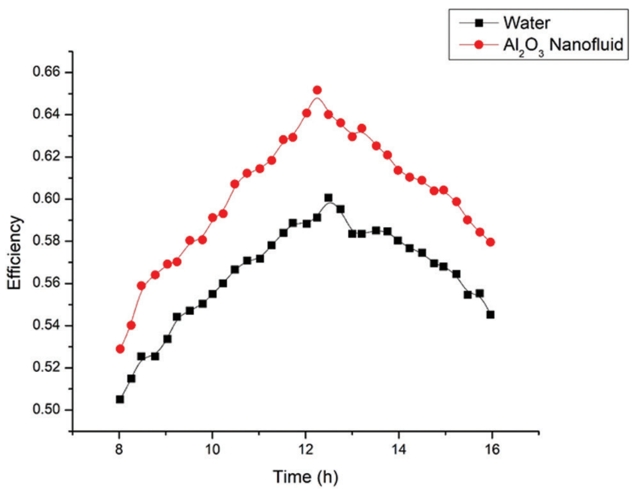

Figure 7. Efficiency of the desalination system with time duration for water and 1wt% Al2O3 nanofluid.

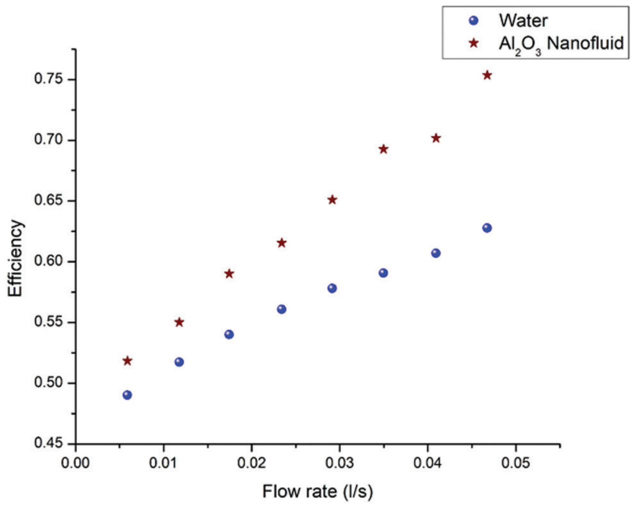

Figure 8. Variation of flow rate with respect to the efficiency of water and 1wt% Al2O3 nanofluid.

and the trend of the figure 5 illustrates that a significant increment in efficiency is observed when incident solar radiation is increased by using nanofluid as the heat transfer fluid over pure water. This is due to the fact that the nanoparticles have the potential to boost the convective heat transfer because of Brownian motion along with the conductive heat transfer [20].

Figure 6 represents the efficiency with respect to function of parameter (Ti – Ta)/GT. It has been observed from the figure 6 that the still efficiency drops substantially for both the heat transfer fluid, however, it can be seen that the efficiency is significantly higher for nanofluid. Figure 7 illustrates the performance of still at distinct times of a day. It is obtained from the figure that the aluminium oxide nanofluid based still has higher efficiency due to increased evaporation rate, it is due to increased heat transfer rate and water temperature because of existence of nanofluids. During the mid-way of the day the efficiency has reached to highest due to more incoming irradiance [8], [21]. The efficiency has reached to 74.78% with a maximum increase in 10.2% by using nanofluid as the heat transfer fluid, while the increment was averaged around 3.8% only.

Absorber efficiency is one of the key findings in relation to volumetric flow rate of Al2O3-water nanofluid as shown in Figure 8. As expected, a significant increment in Reynolds number is observed on increasing the fluid flow rate. There is a notable advantage of using nanofluid as the effectiveness improves when compared with water as the

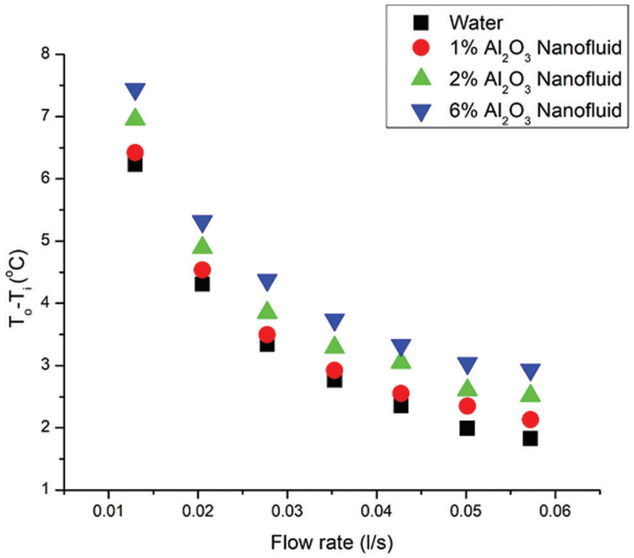

Figure 9. The effect of flow rate on the desalination system parameter for water and different wt% Al2O3 nanoparticles.

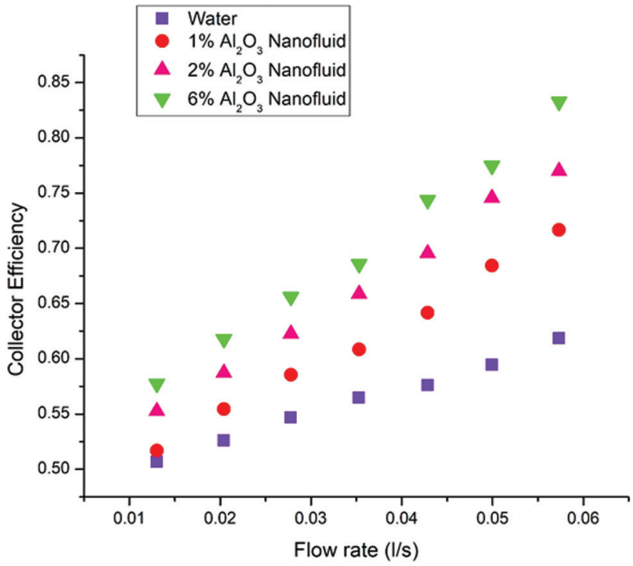

Figure 10. Variation of flow rate Solar desalination system efficiency for various wt% Al2O3 nanofluids.

heat transfer fluid. Thus, the gap of the curve is substantially higher between the nanofluid and water with rise in flow rate. This divergence trend arises due to Brownian motion that promotes collisions in the fluid flow, leading to increased heat transfer [22] After careful examination, it is observed that the system efficiency for the Al2O3-water nanofluid at a flow rate of 0.02 L/s is 74.7%.

To measure the effectiveness of nanoparticles concentration on the efficiency of nanofluid based still, several experiments were done with Al2O3-water nanofluid mixtures with a weight percentage of 1wt%, 2wt% and 6wt%. Figure 9 describes that the efficiency of the desalination system for various concentrations of nanoparticles and various flow rates of heat transfer fluid. The result obtained shows the improvement in productivity with the addition of nanoparticles and increasing heat transfer fluid flow rates. The obtained efficiency was found to be 0.532, 0.562, and 0.575 at a flow rate of 0.025 L/s for 1wt%, 2wt%, and 6wt% nanofluid mixtures, respectively. This is mainly caused by enhanced heat transfer due to the addition of nanoparticles. However, with high flow rate of heat transfer fluid, the efficiency further improved as a result of improvement in convective heat transfer [1], [23].

Figure 10 reported the input and output temperature of the Solar desalination system varies with the concentration of nanoparticles. It can be observed that with the rise wt% of nanoparticles the temperature also rises which in turn improve the overall system productivity. However, an increase in heat transfer fluid flow rate decreases the temperature difference, this is due to the fact that at high flow rates, heat transfer fluids at high temperatures do not get sufficient time to heat [8, 9].

CONCLUSIONS

Previously many studies are already being done to improve the overall efficiency of the solar desalination system which has impacted a positive effect on present level. Despite this, there is still need for further improvement as compared to conventional technologies. The present study involves the addition of nanoparticles in the heat transfer fluid to achieve the significant improvement in the Solar desalination system efficiency since nanoparticles have proved that the addition of nanoparticles to the heat transfer fluid improves the thermal efficiency. Nanomaterial in the form of Aluminum oxide is synthesized in this paper, Al2O3-water nanofluid mixtures are prepared as a heat transfer fluid to improve the efficiency of the desalination system. The result obtained are in good agreement with nanofluid and improves the efficiency of the system. There is a significant rise in efficiency for both the fluids, however, with the addition of nanofluids produced a significant higher efficiency due to enhancement in connective heat transfer while comparing with water as heat transfer fluid. According to experimental investigations, the following observations are observed.

- Nanofluid provides higher productivity as compared to conventional method.
- There is maximum 10.2% rise in efficiency by using nanofluid which is averaged around 3.8% only.
- With the utilization of nanoparticles better absorber efficiency with respect to volumetric flow rate is observed. It is around 74.7% at a flow rate of 0.02L/s for Al2O3-water nanofluid.

- Different concentrations were used to measure the effectiveness on the efficiency of nanofluid. It has been found that there is improvement in productivity with efficiency of 0.532, 0.562, an 0.575 for 1wt%, 2wt%, and 6wt% nanoparticles concentrations, respectively.

NOMENCLATURE

$q_{I,g}$	heat transfer by radiation from ambient air to glass cover
$q_{c,w-g}$	heat transfer by convection from water to glass cover
$q_{r,w-g}$	heat transfer by radiation from water to glass cover
q_{evap}	heat transfer of evaporation
$q_{c,g-a}$	heat transfer by convection from glass cover to ambient air
$q_{r,g-a}$	heat transfer by radiation from glass cover to ambient air
$\frac{de_g}{dt}$	rate of energy change of glass cover
$q_{I,p}$	heat transfer by radiation to absorber plate
$q_{c,p-w}$	heat transfer by convection from absorber plate to water
$q_{p,loss}$	heat loss from the absorber plate
$\frac{de_p}{dt}$	rate of energy change of the absorber plate
$q_{I,w}$	heat transfer by radiation to water film
$q_{c,p-w}$	heat transfer by convection from absorber to water film
q_{in}	heat in the water film element of tilted solar still
$q_{c,w-g}$	heat transfer by radiation from water to glass cover
$q_{r,w-g}$	heat transfer by radiation from water to glass cover
q_{evap}	heat transfer of evaporation
q_{out}	heat out from the water film element of the tilted solar still
$\frac{de_w}{dt}$	rate of energy change of water film
I	Irradiation (W/m2)
t	Time (s)
A	Area (m2)

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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