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Enhancing the performance of modified solar still using Al_2O_3 nanofluid by harvesting solar energy

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The present research work has been carried out to analyze and compare the enhancement in productivity of modified double slope solar still (MDSSS) using harvesting solar energy along with Al_2O_3 nanofluid in the base fluid (Gomti river water). In terms of high demand for clean water, solar distillation is known as one of the most cost-effective and prominent technique as compared to other water purification processes, especially in coastal and arid areas. This method provided comparatively low yield; therefore, its performance was improved using Al_2O_3 nanoparticle with a surfactant sodium dodecylbenzene sulphonate (SDBS). Experimental runs were carried out for the base fluid (without nanoparticles) and for nanofluid with 0.01 concentration. The effect of concentration of Al_2O_3 nanoparticle on fluid temperature and thermal conductivity of the base fluid had been considered which greatly enhanced the rate of evaporation as well as total efficiency of the system. The efficiency of nanofluid was found to be 25% higher than that of the base fluid. Moreover, the payback period was also evaluated to check the feasibility of modified solar still using Al_2O_3 nanofluid which was found more effective in terms of economic point of view.

Keywords: Solar still, solar energy, desalination, nanofluids, productivity.

Introduction

Water is the basic need for every living thing and we know that without water life cannot exist in this world. We also know that 73% of the earth's surface is covered with water bodies, even after that there is a shortage of clean potable water for basic needs for living creatures. The main reason for the shortage of water is that around 96% of the water on earth's surface is saline, 2.7% percent of water is in the form of glaciers and 1.3% of ground water is available for use1. Due to the regular increase in population and pollutions of various forms, water scarcity is becoming an internal serious agenda. Due to the scarcity of water, there are various methods i.e. as desalination, electrodialysis, filtration, and reverse osmosis etc. are used to treat this water. Among all these processes, the solar distillation is found to be more effective and more economical and efficient process for the purification of drinking water by utilization of solar energy2.

Solar distillation is a coupled heat and mass transfer process. Internal mass and heat transfer relationship is considered for designing and calculation of various parameters in the solar still. The construction of material and geometry of the covering surface are the important factors for internal heat transfer coefficient3. In this study, experimental work has been performed to monitor the efficiency of modified double slope single basin solar system. There are some benefits of the solar energy based desalination technology such as: (i) solar energy is available free of cost during sunny days and it produced 500 Watt electricity per hour of sunlight, (ii) it requires low maintenance cost, because of no moving parts. Therefore, it is considered as reliable, (iii) the quality of product water is better obtained from this technology as compared to other methods because this act as a distilled water vaporizer without boiling the water, and (iv) it is also used to neutralize pH value, which is not acceptable for the pH of steamed distilled water as WHO standard4.

Recently, multitudinous researchers investigated the effect of different nanofluids for enhancing the productivity of solar system. Some studied are also available in the literature on solar still using nanofluids like oxides of aluminum, tin, and zinc and then enhanced the performance was 29.95%, 18.63%, and 12.67%, respectively[5]. Our present research is focused on Al_2O_3 based nanofluid due to increased production of potable water.

Material and methods

The solar still system is fabricated for the conduction of experiments at top roof on the Department of Chemical Engineering, IET Lucknow, Sitapur Road, Uttar Pradesh, India (Latitude 29°60°N and longitude 113°59°E) and is studied on day time from 9:00 AM to 5:00 PM in the period of March, 2018 to May 2018.

Experimental setup

The experimental setup of the modified double slope solar still (MDSSS) is shown in Fig. 1. The body of the still is fabricated with fiber reinforced plastic (FRP). The surface area (inner side) of the still is design with 2.0 m×1.0 m. The upper part of bottom surface of basin is painted by black dye with resin for better absorption of solar radiation. For enhancement of the productivity of our system, it has been fabricated in the orientation of East-West direction to acquire high solar radiation for the achievable absorption which gradually increases the temperature of the system. The width of the wall of this modified system (still) is 0.12 m at the East-West corner's location and 0.48 m at the center. FRP sheet with 0.005 m thickness is used instead of acrylic sheet with 0.003 m thickness for base and North surface wall. The top side of this system is made up of two transparent sheets with glass material (thickness = 0.004 m) and for increasing the productivity, two ordinary window glasses are also used ($1.03 \times 1.06 \times 0.004$ m^3) which is designed over the surface of the walls of the still at 15° angle in inclined position using FRP material on both sides[6].

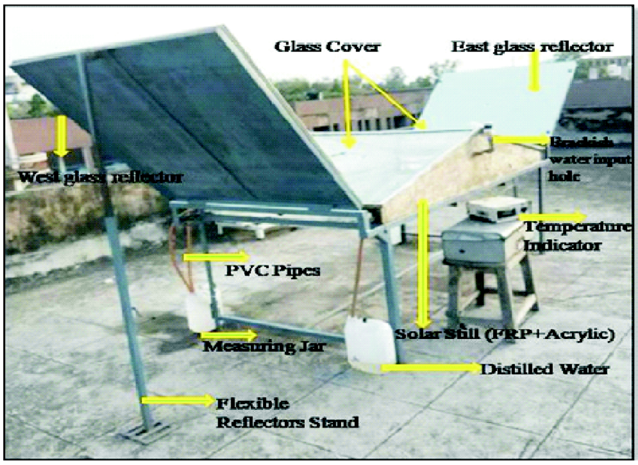

Fig. 1. Pictorial diagram of a modified double slope solar distillation system with reflectors.

Preparation of nanofluid:

Nanoparticles aluminum oxide (Al_2O_3) is insoluble in water. Thus, the two-step method is used to dissolve the nanoparticles in the base fluid, i.e. water. First, we take 4 liters of water as base fluid and we add Al_2O_3 nanoparticles and sodium dodecyl benzene sulphonate (SDBS) as the dispersant. Alumina and SDBS are mixed in the ratio of 10:2. After that, the magnetic stirrer and vibrator are used to suspend the nanoparticles for 1 h[7]. Finally, we will get the nanofluid. This nanofluid has affected the performance of solar still due to its various physical properties like thermal conductivity (129 W/mK), morphology (nearly spherical shape), purity (99.9%), density (3.95 g/cm^3), particle size (average 20 nm), specific heat capacity (860 J/kg.K) and color (white)[8].

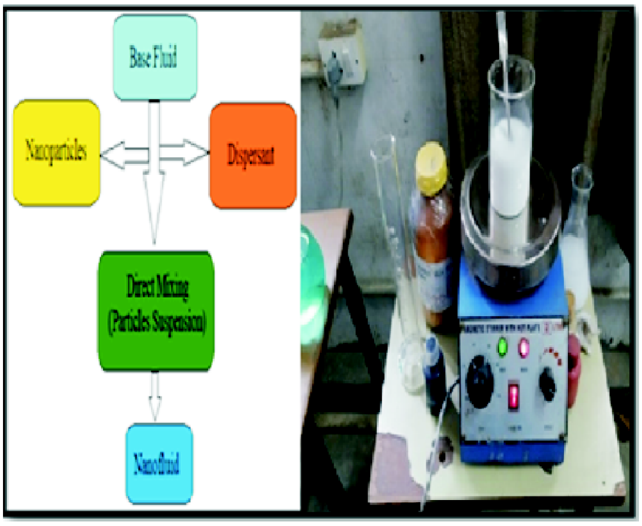

Fig. 2. Procedure to prepare Al_2O_3 nanofluid by the two-step method.

Instruments used for present study:

During the experimental work, many types of instruments were used for the evaluation of solar still performance. The depending parameters for the analysis of solar still performance are various temperature values at a different location on the still i.e. water phase region, vapor phase region, glass surfaces (inner and outer) and ambient temperature of the atmosphere. These various temperature values have been measured by using thermocouple (k-type) with least count 1°C and these were coupled with a temperature indicator device. The output (distillate) was collected in a measuring cylinder which has maximum capacity of 1 liter and its least count is 0.001 liters. The magnetic stirrer with hot plate and its speed range 0–2200 rpm. The total solar radiation measured by using solari-meter which having a range from 0 to 2000 W/m^2 and its least count is 0.1 W/m^2[29].

Working principle of passive MDSSS with nanofluid:

A solar still system works on principles of evaporation (water vapour) and condensation (water droplets) phenomena as shown in Fig. 3. The impure brackish feed water enters into the solar still and the solar radiation penetrates a cover glass surface causing the water to heat up through the nanofluid and consequently, evaporate. Nanoparticle arises the temperature of the solar still due to plasmon adsorption band and IR spectrum properties. Then, these nanoparticles mixed as a nanofluid (Al_2O_3) with base fluid (water) which directly adsorbs the sun's rays due to optical adsorption spectrum. Due to the absorption of solar intensity from the condensing glass cover surface, every nanoparticle's temperature arises which increases the thermal conductivity[10]. The black basin liner surface also transfers thermal conductivity to the water[12]. Consequently, the effect of nanoparticles and black basin liner surface also increases the water surface temperature of MDSSS.

Results and discussion

The experimental setup was designed and directed to get more solar radiation because the bottom surface of solar still was insulated with the insulating material as thermocol and covered with a tin sheet to prevent heat loss. This increases the evaporation of water by 25%. The black painted bottom surface has also increases the evaporation rate by up to 5%[11].

When the experiment was conducted and the observation of the distilled normal water and the distilled nanofluid was observed. The results showed that the nanofluid increased the thermal efficiency of the system in experiment by the value of 5% with distillation process as compared to normal water[12].

Fig. 4 shows the effect of temperature with respect to time (with and without nanofluid). It can be seen clearly from the figure that the maximum value of temperature was ob-

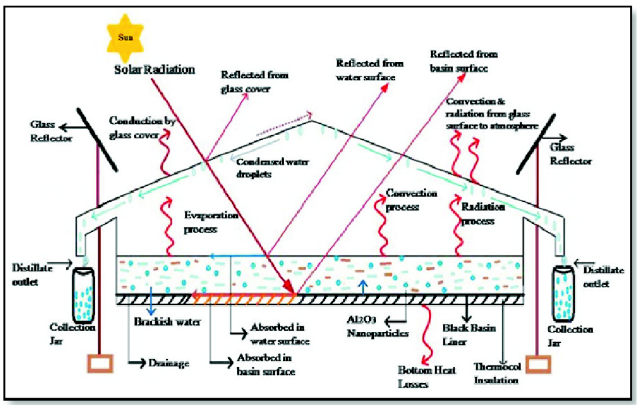

Fig. 3. Systematic diagram or principle of Modified Double Slope Solar Still (MDSSS).

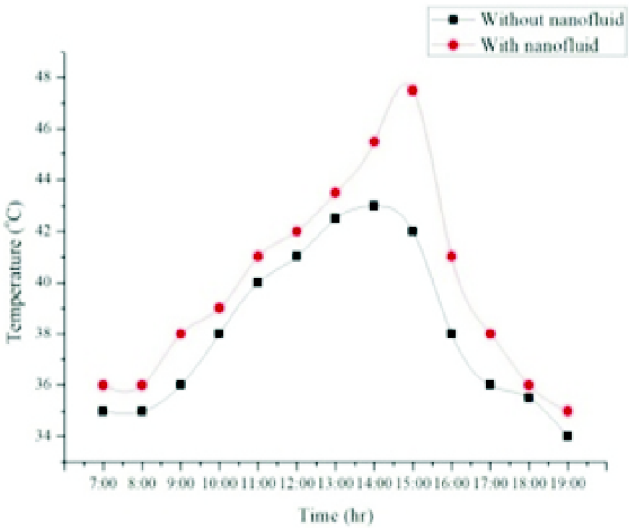

Fig. 4. Variation of solar still temperature (with and without nanofluid) against time.

served between time 01:00 PM to 03:00 PM which means at this time higher evaporation rate in the still and hence, maximum output collected as distillate. The nanofluid was added with base fluid (water) in the solar still to see the effect on the different parameters of solar still system like water temperature (reached up to 47.5°C), change of thermal conductivity and rate of heat transfer coefficient (convective). Due to increasing the heat transfer rate, the evaporation rate was found higher which improved the performance of the solar still[13].

Fig. 5 depicts that the productivity curves with the effect of nanofluid in base fluid (water) against hourly time on the variation of modified solar still performance. It is observed that without using nanofluid the maximum yield was found more than 2.7 liters during highest temperature between 12:00 noon to 03:00 PM but in case of with nanofluid, the yield was found more than 4.85 liters during highest temperature between 12:00 noon to 03:00 PM. It is clear from this observation that nanofluid provides higher yield[14].

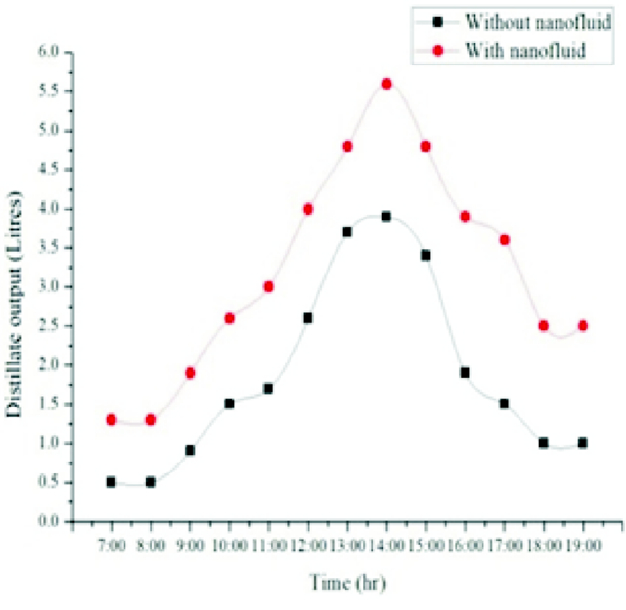

Fig. 5. Variation of distillate output (with and without nanofluid) against time.

Thermal efficiency analysis:

The obtained results show a significant raise in the thermal conductivity of the Al_2O_3 based nanofluid water as compared to normal water[15].

The total yield for this solar system is calculated by:

$$\eta = \frac{\Sigma M_w . L}{\Sigma A_s . I_{rad} . 3600} \quad (1)$$

Our experimental investigation observed that the total yield of the solar still with nanofluid is found higher as 62% whereas the total yield of the solar still without nanofluid is around 55%.

Error analysis:

The error analysis with % uncertainity regarding experimental data as both internal and external errors for the most important product such as distillate water. % uncertainty (U) for this obtained data is calculated by using below equation[16]:

$$U = \frac{\sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \cdots + \sigma_n^2}}{N} \quad (2)$$

where, σ = standard deviation which can be calculated as:

$$\sigma = \frac{\sqrt{\Sigma (X_i - \bar{X})^2}}{N_0} \quad (3)$$

where, $(X_i - \bar{X})$ = difference between mean and initial observation value, N = number of sets and N_0 = number of observations in each set.

$$\text{Internal uncertainity (\%)} = \frac{U_i}{\text{Mean of total observation}} \quad (4)$$

During the experiments, we observed the productivity of output (distilled water) was achieved 11.08% uncertainty and 12.04% for MDSSS with and without nanofluid, respectively.

Calculation of the various heat losses:

If the system is adiabatic then there is no transfer of heat and mass between the system and surrounding. But through the practical point of view, no system can be adiabatic; hence there is loss of heat and mass in the solar still during the experiment work. The amount of heat loss can be calculated by various means[17].

Heat energy used in water evaporation:

$$Q = m.L \quad (5)$$

Q = amount of heat (kJ), m = mass of water (kg), L = latent heat of evaporation (kJ), L = [7.4935×10^6(1 –

$9.4779\times10^{-4} T_V + 1.3132\times10^{-7} T_V^2 - 4.7974\times10^{-9} T_V^3)]$ for $T_V < 70°$, the average amount of heat loss = 826 kJ.

The heat used in heating water:

$$Q = m \,.\, C_P \,.\, \Delta T \quad (6)$$

The average amount of heat used for water heating = 580 kJ.

Heat losses from the all side walls of the solar still:

$$Q = U \,.\, A \,.\, \Delta T \quad (7)$$

The overall heat losses from the all side walls of the solar still = 483.84 kJ.

Heat loss from the glasses:

$$Q = U \,.\, A \,.\, \Delta T \quad (8)$$

The overall heat loss from the glasses = 962.97 kJ

The total heat losses during the experimental work (Q_T) = 826 + 580 + 483.84 + 962.97 = 2,852.81 kJ.

Analytical analysis:

The analytical analysis was done with Gomti river water used as a solar still feed water for the experimental work, the change of TDS values such as 682 ppm (without nanofluid) and 510 ppm (with nanofluid). While the change of pH values such as 7.8 (without nanofluid) and 7.2 (with nanofluid) were recorded. These most effective water quality parameters are acceptable as per WHO[17].

Economical analysis:

To check feasibility of any process, the economical analysis is an essential part. For present process, the evaluation of payback period has been done including maintenance, capital, and operating cost of whole system.

For MDSSS, the payback time is dependent on cost analysis:

The total cost for fabrication is taken as Rs. 12,350. The feed water, maintenance, operating costs is considered none due to very low quantity. Production yield on daily basis is 0.36 and the produced water cost is Rs. 1 per liter. Then, total produced cost in per day = yield on daily basis × produced water cost in per liter i.e. 0.36 × Rs. 1 = 0.36 Rs.

The description of total expenditure is: - Capital expenditure (FRP sheet and iron stand = Rs. 2650, tin sheet = Rs. 1100, still glass = Rs. 500, collection jar = Rs. 250, fabrication charges = Rs. 1200), thermocouples = Rs. 500, and running expenditure (thermocol = Rs. 150, nanoparticles = Rs. 4500). installation and labor charges = Rs. 1500.

Conclusion

The experiment was conducted with and without nanofluid. It is concluded that the nanofluid increases the thermal conductivity of the water up to 25% and the distillation process was also 25% faster as compared to the experiment conducted with the normal water. Even insulting the bottom surface of the solar still with the thermacol and aluminum sheet also increases the evaporation rate. The black painting inside the solar still also increases efficiency by 5%[19]. When the total efficiency of the MDSSS was calculated between the normal water and nanofluid, there was a 5% increment in the nanofluid efficiency as compared to normal water.

Acknowledgments

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Abbreviations

WHO	World Health Organization
MDSSS	Modified Double Slope Solar Still
η	Solar efficiency
M_w	Mass of condensate (kg)
m	Water mass (kg)
A_s	Glass cover surface area (m^2)
I_{rad}	Intensity of solar radiation (W/m^2)
L	Latent heat of vaporization (kJ/kg)
U	Total uncertainty
σ	Standard deviation
$(X_i - \overline{X})$	Mean from deviation
N_0	No. of examination in each set
N	Number of sets
U_i	% Internal uncertainty
C_P	Specific heat of evaporation (kJ/kg.K)
Q	Amount of heat (kJ)
ΔT	Temperature difference from final to the initial (°C)
A	Overall basin surface area of solar still (m^2)

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