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Performance improvement of a solar desalination system assisted with solar air heater: An experimental approach

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In the solar distillation unit, the primary issue is the less productivity of distillate output from solar stills. The foremost objective of this experiment is to improve the distillation rate of the conventional solar still system. The present research examined the additional effect of coupling solar air heater (SAH) to conventional single slope solar still. The experimentation was performed on the climatic state of Ranchi (India) in the south-facing single slope solar still having an inclination angle 23°. The warm air coming from the solar air heater is permitted to the base of solar still to heat the basin water. It has been compared to the distillate output of modified solar still to the conventional type passive solar still due to additional supply of thermal energy as hot air. Results show that the volume of distilled water collected has been increased from 0.8815 liter/m^2/day with conventional single slope solar still to 1.30 liter/m^2/day with single slope solar still assisted with Solar Air Heater with PCM, respectively. The thermal efficiency of solar still with passive solar still is reported as 41.03%, and when solar still is coupled with Solar Air Heater, it reaches up to 57.06%. Moreover, the experimental results obtained at optimized conditions were in close agreement with the predicted responses of theoretical aspects.

Keywords: Desalination, Solar Air Heater (SAH), thermal efficiency, heat transfer coefficients, distillate output.

Introduction

Water is the entity that allowed our planet to carry life; emboldening Earth as witnessed today, savoring it; is not merely a resource for satisfying the thirst for our human-centric pursuits but an element that roots the planet with approximately 8.7 million distinct life forms. Mankind has always been dependent upon various forms of water resources as rivers, ponds, lakes, etc. Though water bodies almost three-fourth cover the earth's area, natural and drinkable water is a mere 1% percentage. The demand for clean water has seen tremendous growth in the last decade and has also witnessed a water crisis in many parts of the world. Scientists and researchers have predicted that by the year 2025, the available drinking/potable water will be reduced to half of what is present today in most countries, and there will be a severe water crisis. The quest for looking at ways to produce safe drinking water has seen tremendous growth in recent years, many of which are non-environment friendly. However, the production of safe drinking water should be formed using technologies with the least ecological disturbances, commercial resources, and have long term sustainability. The foremost challenge is to fill the gap by keeping a balance between the supply source and demand of potable or freshwater. There are many technologies available for the purification of briny water, contaminated water. However, most of the technologies consume high graded energy, which is generated through the sources of non-conventional energies. Solar is the most suitable renewable energy source for the distillation process, having no pollution.

Desalination is one such process to produce drinkable water for human consumption and various other purposes utilizing solar energy[1,2]. In general, enormous work has been performed theoretically as well as experimentally based on single slope solar still. An effort is being given for increasing the effectiveness and yalso productivity of conventional type solar still. It depends upon constructing the system and ambient conditions of the solar still. The salinity of water disturbs distillate production even at low concentrations. It decreases with collective saltiness. The thermal efficiency generally lies between 25 to 60%, and hence productivity of this device is relatively low. Various factors such as water depth, solar input, wind velocity and ambient temperature are responsible for the yield of solar still. Numerous researchers have carried out experiments to raise freshwater productivity. The effect of radiation heat transfer is knowingly fewer as compared to the convective heat transfer in the solar still[3,4]. Hence, it is considered that the effect of radiation heat transfer is negligible. However, in the schematic diagram, it should be shown.

Senthilrajan did his experimental exertion for a still-active system, which was attached with the biomass water heater equipment to raise the temperature of basin water for a higher evaporation rate. From the analysis, it can be stated that biomass heater increases yield output during sunlight and night[6]. Various researchers worked for energy analysis and thermal efficiency for the active still system under forced convection mode of operation[7]. Panchal *et al.* have estimated the additional effect of vacuum tubes coupled with a solar still. It can be inferred that the additional supply of thermal energy by vacuum tubes increases the distillate output[5]. Tiwari *et al.,* worked to assess the coefficients of various heat transfer for both the solar still active and passive mode of single slope solar still (SSSS)[8]. Researchers worked for an active system in which solar still is attached to a flat plated collector. An experimentation was carried out without using a temporary thermal storage material on solar air heating system to increase and evaluate its thermal performance[2,3].

Research gap

First after having many literature surveys, it has been found that the conventional type single inclined solar distillation system has some drawbacks. Hence, the evaporation process can be achieved to a higher rate than the convention still installation set-up by assisting some external heat source giving its heat input to the solar still basin. Moreover, the distillate water efficiency can be improved by coupling additional heat sources to the basin water. The core objective of the present article is advancement in the thermal performance of the conventional single inclined solar still (SSSS). To increase the thermal performance and distillate outcomes of the conventional solar still.

(a) Studying the effect of adding an external heat source to the still basin.

(b) Comparison of the profitability by the addition of heat source with the conventional still.

Experimental set-up and procedures

The experimentation was completed from 9:00 AM to 6:00 PM at the climatic condition of Ranchi having latitude angle 23° in the month of June 2018 in Ranchi, Jharkhand. Two experimental set-ups have been designed and manufactured to inspect the effect of the solar air heater with paraffin wax density of 790, melting point (°C) – 50, specific heat of (kJ/kg °K) – 2.95, latent heat of fusion (kJ/kg) – 173.6, *k* of (W/m °K)

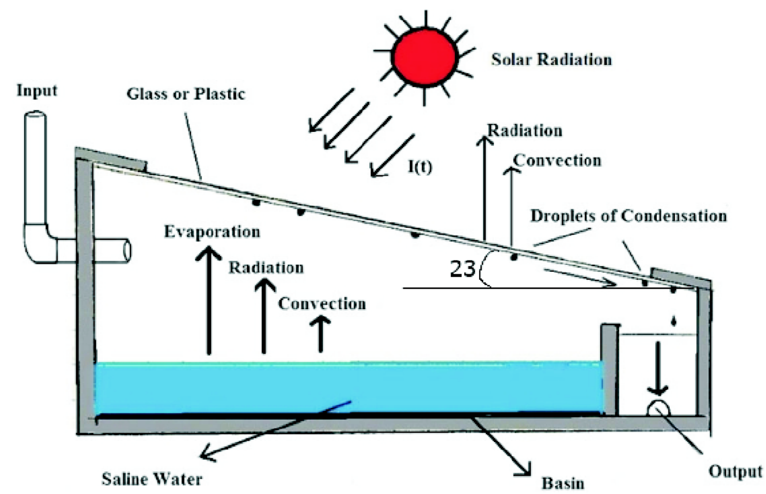

Fig. 1. Working on the conventional single slope solar still.

– 0.167 (liquid) on the thermal efficiency. The detailed schematic of the conventional solar still is mentioned in Fig. 1.

The still solar basin and its inner walls are made up of fiber-reinforced plastics (FRP) sheet material of 4 mm thickness. The bottom area of the still basin is coated with dark black paint (absorptivity 0.88) for more excellent absorptivity. The distillate volume is accumulated in a channel attached to the subordinate vertical height of the basin and sent to a measuring jar with the assistance of a connecting pipe. For the protection of leakage problem into the still system use of silicone rubber and putty has been used for that purpose. The distillate output is being collected in the plastic beaker for the measurement of its volume. Parameters for passive type solar still system is being recorded per hour of the experimentation.

Vapor temperature is a crucial concept for the determination of thermophysical properties of solar stills. A critical observation while doing experimentation, it is followed that after taking readings and the still is being kept in idle condition for one day, this is only because of to attain steady-state condition. The diagram of the modified solar distillation unit is given in Fig. 2. Experimentations were successfully conducted from 9:00 AM to 6:00 PM in the climatic condition of Jharkhand having latitude angle 23°. All the considered parameters were recorded solar radiation, vapor, water, glass, and basin temperature. The accumulated water volume has also been measured in the beaker. The depth of the water basin is being kept at 3 cm. Since the lower depth of the water basin gives higher productivity. It has been observed that the maximum productivity of the solar still with solar air heater has an average value of the whole day is 1.30 liter/m^2/day, and it is of conventional solar still is noted as 0.8815 liters/m^2/day.

Results and discussion

It has also been concluded that the distillation of set up with the solar air heater having PCM improves the still productivity to a greater extent compared to the conventional solar still. However, it also has been considered the charging and discharging of the solar air heater due to phase change material. During the sun shine-off periods, the solar still gives it productivity due to the presence of PCM.

The result analysis of the experimental results is being carried out. In this research work, the single slope solar still is being coupled with the solar air heater for the enhancement of the yield rater of the conventional solar still. This experimentation is conducted for 10 h.

From Figs. 3 and 4, it can be concluded that the conformist solar still has less temperature scale of all the parameters like water, basin, and glass temperature. This in-

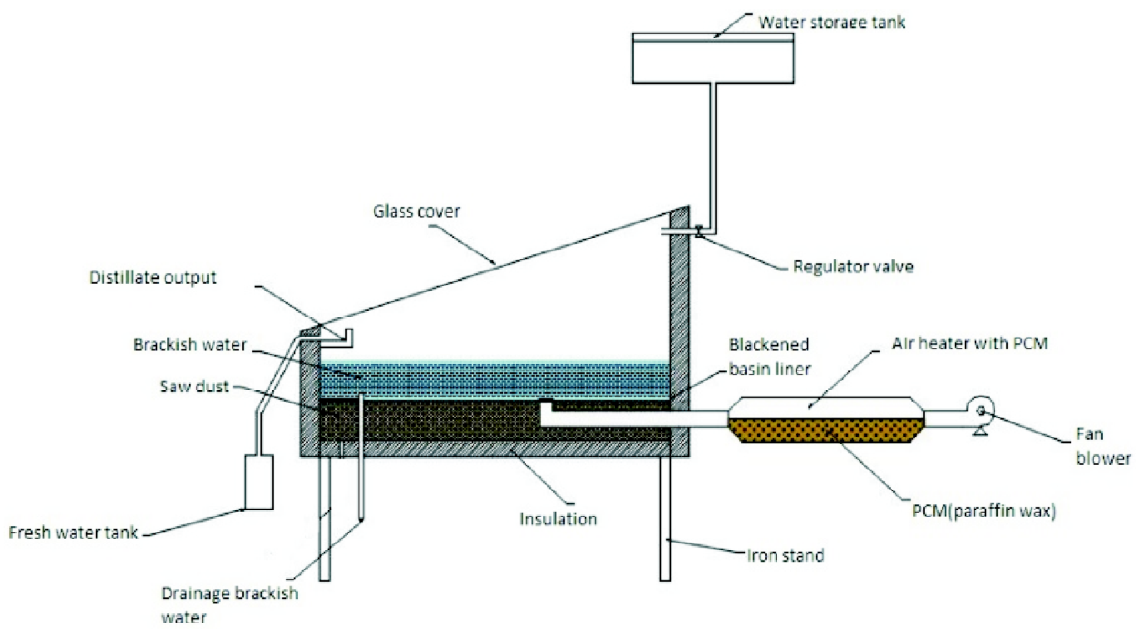

Fig. 2. Labeled diagram of the modified single slope solar still with solar air heater with PCM.

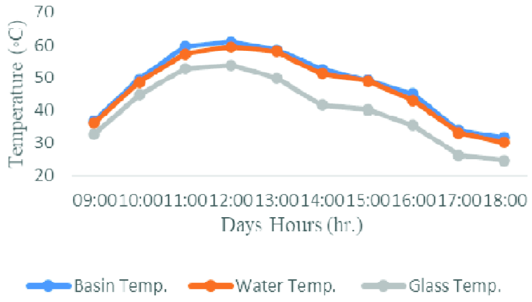

Fig. 3. Variation of the basin, water and inner glass temperature of the conventional solar still.

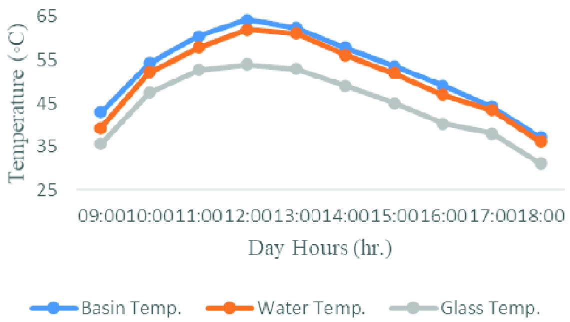

Fig. 4. Temperature variation of the basin, water, and inner glass of the modified solar still.

crement in temperature leads to enhanced productivity of the solar still. The only reason for this increment in differences in temperature of the water and the glass due to the presence of external heat sources of solar air heater. From the Fig. 5, it is clear that the basin temperature is much advanced than the temperature of the water and the inner glass superficial. Since the temperature of the water is lesser at the beginning of the morning time because water particles take time to warm up. As it receives the amount of energy from the solar still basin. The still basin releases its heat energy to the water particle up to the evaporation point. In the afternoon time, the curve has maximum values are 61°C, 59.49°C, 53.85°C of basin, water and glass temperature respectively of the conventional solar still. After the addition of the external agencies of heat source to the basin material, the temperature values get higher in case of modified solar still. They are as follows 64.34°C basin and 62.06°C, 54.03°C of water, inner glass temperature of modified solar still respectively. Its temperature values go diminishing in the evening time as the solar intensity get reduces.

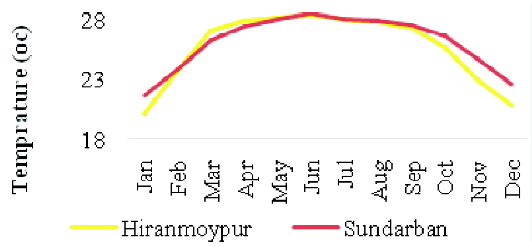

Fig. 5. Vapor temperature for the modified and conventional solar still.

From Fig. 5, it has been observed that vapor temperature is higher in the case of the modified type of solar still than the passive type of solar. Due to additional heat input to the basin plate from the solar air heater. This leads to an increment in the more evaporation rate and higher vapor temperature than the conventional type of solar still.

Figs. 6 and 7 shows the hourly discrepancy of the convective and evaporative heat transfer coefficient respectively for both the conventional and modified solar distillation set-

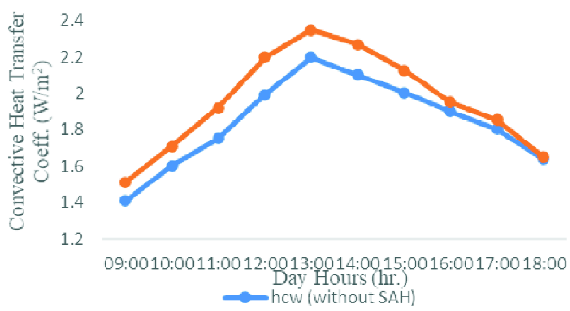

Fig. 6. Convective heat transfer for conventional and modified solar still.

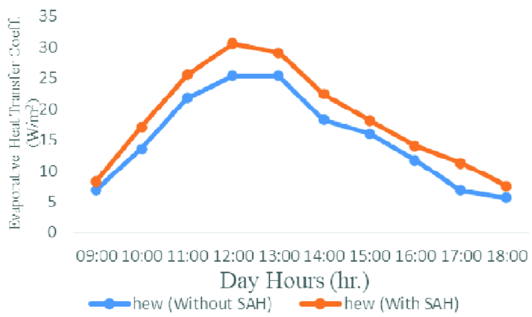

Fig. 7. Evaporative heat transfer for conventional and modified solar still.

up. It has been observed that hourly production of the freshwater through the distiller for the modified unit higher as compared to conventional set-up. The maximum value of the coefficient of evaporative heat transfer was 25.39 W/m^2 for the conventional still set-up and 30.64 W/m^2 for the modified solar still coupled with the solar air heater. While the value of the convective heat transfer coefficient having slight variation as compared to the modified set-up, its averaged values are 1.88 W/m^2 (conventional set-up without external heat source) and 2.20 W/m^2 (with solar air heater).

Conventional solar distillation: Thermal efficiency = (Yield output×Latent heat of vaporization)/Incident energy on solar still×100%

Modified solar distillation: Thermal efficiency = (Yield output×Latent heat of vaporization)/Energy supplied by PCM + Incident energy on solar still×100%.

Experimental results are compared with the help of Fig. 8, that the daily averaged thermal efficiency for the conventional type solar distillation still and improved solar distillation coupled with PCM is approximately recorded as 41.03% and 57.06%, respectively. In comparison, its variation during the mid-hours was fluctuating 57.20% afternoon and decreasing in the evening time as 23.63% for the conventional still. Moreover, it has been seen 67.63% in the afternoon time, it again slightly decreases to 45.32% in the evening time.

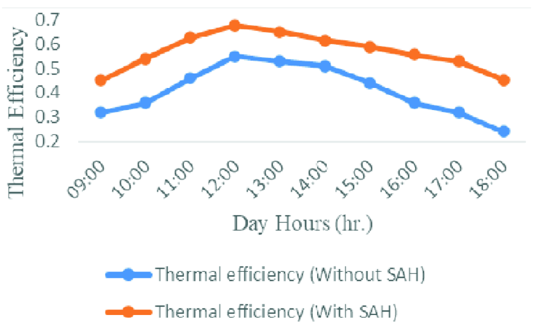

Fig. 8. Hourly variation of thermal efficiencies of the conventional and modified solar stills.

Fig. 9 shows the hourly variation of the distillate output of the freshwater of the conventional solar still and the modified solar distillation equipped with the air heater with PCM. It can also be concluded that the volume of the collector channel filled with freshwater productivity increases from the morning time and reached the maximum in the afternoon time. The reason behind the lesser productivity in the morning time is that water takes some more time to warm up for the evaporation process as the expectations were seen from experience that the maximum productivity lies in between the peak day time of noon. From the Fig. 9, it is also clear that productivity is much more generous of the modified solar distillation than the conventional solar distillation. The productivity in the evening time is almost the same since the temperature of the saline water is almost equal.

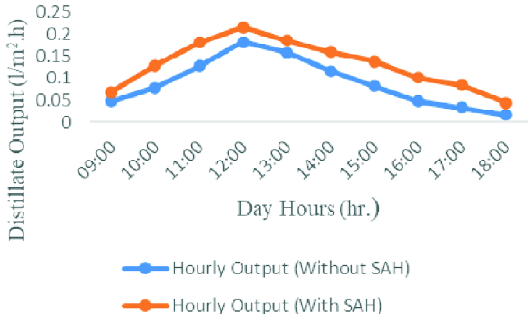

Fig. 9. Freshwater yield of the conventional and modified solar still.

Conclusions

The present experimental study comes to the important conclusion that the coefficients of evaporative and convective heat transfer are the major governing factors that determine the volume of the distillate output. The still productivity of the conventional single slope solar is improved to a certain extent by adding a solar air heater to the external heat input to the basin material. Storage of energy and enhancement in the efficiency has enhanced the research effort in the field of PCMs. The maximum distillate has been obtained using paraffin wax as compared to the other research work in which lauric acid and stearic acid was used as PCM. The findings have been highlighted in conclusion section. From the rigorous, extensive study and experimental results of conventional/traditional solar still and the modified set-up of solar still assisted with solar air heater, the following conclusion can be drawn:

(i) Adding the external heat source (Solar air heater) increases the temperature of the basin water, vapor temperature as compared to the conventional set-up of solar still by 3–5°C.

(ii) As the temperature difference between the water and the condensing surface increases, the evaporative heat transfer coefficients of the changed set-up rise to 30.64 W/m^2.

(iii) There is a marked difference in water productivity of 0.88 liters/m^2/day and 1.30 liters/m^2/day, respectively found for traditional/conventional and modified experimental set-up.

(iv) The average thermal efficiency of conventional solar still is 41.03%, and it reaches 57.06% for the still assisted with solar air heater.

(v) In this modified case, productivity has been increased (approximately 47% more than a conventional design of the solar still).

Nomenclature

A_g	Area of toughened glass cover (m^2)
C_p	Heat capacity of working fluid (J/kg °C)
C	Convective correlation constant
h_{cw}	Coefficient of convective heat transfer (W/m^2 °C)
h_{ew}	Coefficient of evaporative heat transfer (W/m^2 °C)
I_g	Global radiation on the inclined surface (W/m^2)
k	Conductivity of the fluid (W/m °C)
L	Characteristics length (m)
L_v	Latent heat of vaporization (J/kg)
M_{ew}	Distillate output (yield) (kg/day)
Nu	Nusselt number
n	Convective correlation constant in Nusselt number
Pr	Prandtl number
q_{ew}	Evaporative heat transfer (W/m^2)
Ra	Rayleigh number
ΔT	The effective temperature difference between toughened glass and water (°C)
T_v	Vapor temperature (°C)
T_{gi}	Inside glass temperature (°C)
T_w	Water temperature (°C)
N	Total number of samples

Greek symbols

ρ	Density (kg/m^3)
η	Efficiency

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