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Performance Evaluation of A Stepped Solar Still with Thermal Storage System

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ABSTRACT

The ampleness of solar radiation available to earth is an opportunity to extract it as much as possible. The solar radiation received on the earth surface on a bright sunny day is approximately 1kW/m^2. This energy is freely available and most importantly it is eco-friendly. In the present work, the performance of modified solar still (MSS) with modified steps and thermal storage material has been investigated and compared experimentally. It was found that the maximum glass temperature of CSS was 56^{o}C at 12:30 pm whereas the maximum glass temperature for MSS was recorded to be 68^{o}C at 1:30 pm. The maximum CSS vapour temperature was found to be 63^{o}C whereas the highest temperature achieved by MSS vapor was 65^{o}C. The maximum hourly distillate was 135 ml and 325 ml for CSS and MSS, respectively. Thus, the maximum hourly productivity of MSS was about 2.4 times that of CSS. The accumulated productivity of CSS and MSS for 8 hour duration was found to be 517 and 1359, respectively, i.e. MSS has 162.86% higher productivity as compared to CSS.

Keywords-- Solar still, solar energy, reflecting mirrors, desalination system, saline water, thermal storage material, distillate

I. INTRODUCTION

Solar energy is a renewable form of energy. The ampleness of solar radiation available to earth is an opportunity to extract it as much as possible. The solar radiation received on the earth surface on a bright sunny day is approximately 1kW/m^2. Solar energy can be used utilized directly in two ways namely: 1) collecting the radiant heat and using in thermal system 2) collecting and converting it directly to electrical energy using a photovoltaic system. This energy is freely available and most importantly it is eco-friendly. Solar distillation is one of the thermal techniques to utilize solar energy. During the process radiant heat which is allowed to pass through a transparent glass is trapped inside. The black coated basin absorbs the heat and helps in evaporation of water. The vapour produced condenses on inside surface of the glass and drips down. Distillation process leaves behind impurities such as salts, minute metal particles etc. Distilled water is the final output of this system. It finds its application in domestic, industrial and academic sectors.

II. LITERATURE REVIEW

Hiroshi Tanaka [1] compared a basin type solar still having flat plate external bottom reflector with internal reflector (two sides and back wall). A geometrical model was proposed to analyze the amount of solar radiation reflected by the external bottom reflector and absorbed into the basin. A numerical analysis was made to observe the variations in heat and mass transfer. The daily productivity with internal and external bottom reflector was predicted to be 41% and 25%. It was concluded that modified solar still had productivity 62% higher than that of conventional solar still.

Tabrizi et al. [2] designed a cascade solar still (CSS) for water purification with a view of enhancing the daily productivity. The influence of water flow rate on the internal heat and mass transfer and daily productivity of CSS was studied. Dunkle's relations were employed to predict the still behavior because of its wide application in the literature. However Dunkle's relation could not display the satisfactory results for CSS behavior due to special geometry and operational conditions. They calculated the internal heat and mass transfer coefficients using the experimental data obtained from modified cascade solar still. It was noted that there was a decrease in the internal heat and mass transfer rates as well as daily productivity with an increase in water flow rate. The daily productivity

was found to be 7.4 and 4.3 kg/m^{2}day, for minimum and maximum flow rates respectively.

Omara et al. [3] presented a hybrid desalination process which consisted of evacuated solar water heater and jute geotextile. An evacuated solar water heater was integrated with desalination system to get the continuous production of distillate. Identical portable solar wick still and one basin conventional solar stills were designed to evaluate the system performance. The jute linen woven fabrics were stitched to the plane wick (lengthwise and crosswise) and integrated with solar still. The aim of adding jute fabrics was to reduce the rate of water flow to the appropriate rate. Single and double layers wick, plane wick, lengthwise and crosswise linen, feeding hot water during night and two base slope angles of wick still (20° and 30°) were studied. Theoretical analysis was verified through experiments. Distillate productivity was increased by 114% over conventional still for double layer square wick (DLSW) solar still at 30° base slope angle. The daily average efficiency of DLSW was 71.5%. Distillate productivity was increased by 215% when hot brackish water was feed during night time.

Kabeel et al. [4] performed an experimental as well as theoretical investigation on a conventional single slope solar still and a modified stepped solar still simultaneously. The effect of depth and width of trays on the performance of the stepped solar still was analyzed. A vacuum tube solar collector was used to vary the feed water temperature to the stepped still. To enhance the productivity, a wick on the vertical sides of the stepped still was added. A good coordination between the experimental and theoretical results was witnessed. The results revealed that the depth and width of tray affect the yield of the stepped solar still to a considerable amount. A tray having depth 5 mm and width 120 mm was giving the maximum productivity for stepped solar still, which was approx. 57.3% higher than that of the conventional still. The daily efficiency was 53% and 33.5% for stepped and conventional solar still respectively.

Kumar and Tiwari [5] investigated two solar stills namely: (1) single slope passive photovoltaic/ thermal, (2) single slope active photovoltaic/ thermal. Photovoltaic operated DC water pump was used between solar still and photovoltaic (PV) integrated flat plate collector to re-circulate the water through the collectors and transfer it to the solar still. The designed hybrid (PV/T) active solar still was self-sustainable and can be made available to remote areas where sources of distilled water is a myth. The experiments were conducted for 0.05, 0.01 and 0.15 m water depth for both the stills. It was noticed that maximum productivity of 2.26 kg and 7.22 kg were obtained for passive and hybrid active solar still respectively at 0.05 m water depth. The daily productivity for hybrid active solar still is 3.2 and 5.5 times higher than passive solar still in winter and summer months respectively. It was concluded that hybrid active solar still had higher electrical and overall thermal efficiency which is about 20% higher than the passive solar still.

Halima et al. [6] were engaged in a theoretical study of a simple solar still coupled to a compression heat pump. A mathematical model was developed with the help of mass and heat balance. It was thorough comparison of conventional solar still with proposed solar still under same climatic conditions. The simulation results disclosed that proposed solar still had efficiency 75% higher than that of conventional solar still. The daily production of still reached 13.5 kg/m^{2}day in month of june and the average annual production was 9.9 kg/m^{2}day.

Dehghan et al. [7] presented an extensive thermodynamic modeling of a novel portable solar still using first and second law analysis. A thermoelectric module was employed to calculate the temperature difference between evaporating and condensing zones. Energy and exergy balance were written for all the components of solar still including the glass cover, thermoelectric module, saline water and basin liner. It is important to consider the exergy stored within the saline water which was neglected in previous studies. The daily average energy and exergy efficiencies of the stills were 19.8% and 0.95% respectively. It was noted that the exergy efficiency was much lower than the energy efficiency. The rate of exergy destructions in solar still components is proportional to the solar intensity. The largest exergy destruction belongs to thermoelectric module which was 643.4% of the total energy destruction while the glass cover had the smallest share of it. Finally it was concluded that thermoelectrically assisted solar still had efficiency higher than simple passive solar still. However, its exergy efficiency was found to be lower.

El-zahaby et al. [8] explored the performances of solar stills which are greatly affected by the water depth. This was done by feeding the saline water into still through a controlled transverse reciprocating spraying system in the form of fine droplets to spread on the top surface of a corrugated stepped shape absorber of solar still. A significant advantage on the still performance was gained by the application of thin film of saline water with very low warming up period. An accumulated yield of 6.355 kg/m^2 over 10 working hours with an efficiency of 77.35% was obtained.

Ziabari et al. [9] described a detailed analysis of a prototype designed to remove the site's problems related to solar still. The average fresh water productivity for modified cascade solar still was found to be 6.7 kg/m^2/day which 26% higher as compare to initial sites. Weirs were used to keep the water film as shallow as possible and improve the water distribution upon evaporating surface. The modified prototype was modeled mathematically. The proposed procedure, instead of constant intensity was implemented in the model. The model results were similar to 1 month daily basis recorded experimental data.

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Dashtban and Tabrizi [10] performed an experiment on a weir-type cascade solar still, integrated with latent heat thermal energy storage system. This was designed to enhance the productivity of distillate. They used 18 kg mass of paraffin wax (2 cm thickness) beneath the absorber plate which keeps the operating temperature of still high enough to produce the distillated water in the absence of sunlight, especially at night. Theoretical models were developed for still with and without PCM and results obtained were compared with the experimental data. Moreover the important parameters affecting the performance of the still such as water level on the absorber plate and the distance between water and the glass surfaces etc. were theoretically investigated. The performance was still with and without PCM was studied on a typical day in Iran. The daily productivity was found to be 6.7 and 5.1 kg/m^2 day for still and without PCM respectively. The results showed that the productivity of the still with PCM was theoretically 31% higher than that of without PCM.

Kumar et al. [11] analyzed the concentrated-coupled hemispherical basin solar still. They added a phase change Material (PCM) in order to increase the efficiency and productivity of the distillate. The two modes of operation namely (1) single-slope solar still without the PCM effect, and (2) single-slope solar still with PCM effect were studied. The temperature of water, temperature of PCM, air temperature, inner cover temperature and outer cover temperature were measured. Experimental results indicated that the effect of thermal storage in concentrator-coupled hemispherical basin solar still increases the productivity by 26%.

III. EXPERIMENTAL SET UP

Figure 1 shows the experimental set up. The experiment was performed at college campus, Radharaman Institute of Research and Technology, Bhopal, India. The coordinate was set up at 23.25^o N, 77.41^o E. Both the stills were facing south direction to receive maximum radiation. The experiment continued for 9 hrs from 9:00 a.m. to 6:00 p.m. for 5 days. The galvanized iron sheet of 0.5 mm was used for construction of the stills. Toughened glass (100 cm X 90 cm X 5cm) was used to cover the stills. Insulating materials were glass wool and thermocol. Reflecting mirrors were attached to the vertical wall of the steps in modified solar still. All the steps were black coated to enhance the absorptivity. There was provision to store heat absorbing material (refined soya oil) in the design of the modified solar still. A reflecting mirror was used in the modified still to increase the intensity of radiation on toughened glass. In the presence of solar radiation, radiant heat trapped inside the still was helping in the evaporation of water and some part of it was heating the oil stored under the steps. Saline water tank was placed behind for feeding the water in the stills. A proper passage was provided to remove excess of saline water from the steps. Temperatures such as ambient air temperature, glass temperature, vapor temperature, and oil temperature were measured using thermocouple wire and temperature indicator. Hygrometer was used for measuring the humidity and digital pyranometer for solar radiation.

Fig. 1. Experimental set up

IV. RESULTS AND DISCUSSIONS

The variation of ambient temperature, glass temperature, vapor temperature and radiation with time for CSS has been shown in figure 2. CSS glass temperature first increases and then reached to maximum temperature of 56°C at 12:30 pm, afterwards it shows a gradual decrease in temperature. The CSS vapour temperature at 2:00 pm. was found to be maximum i.e. 63°C. The minimum and the maximum atmospheric temperature during the experimentation were 31°C and 42°C, respectively.

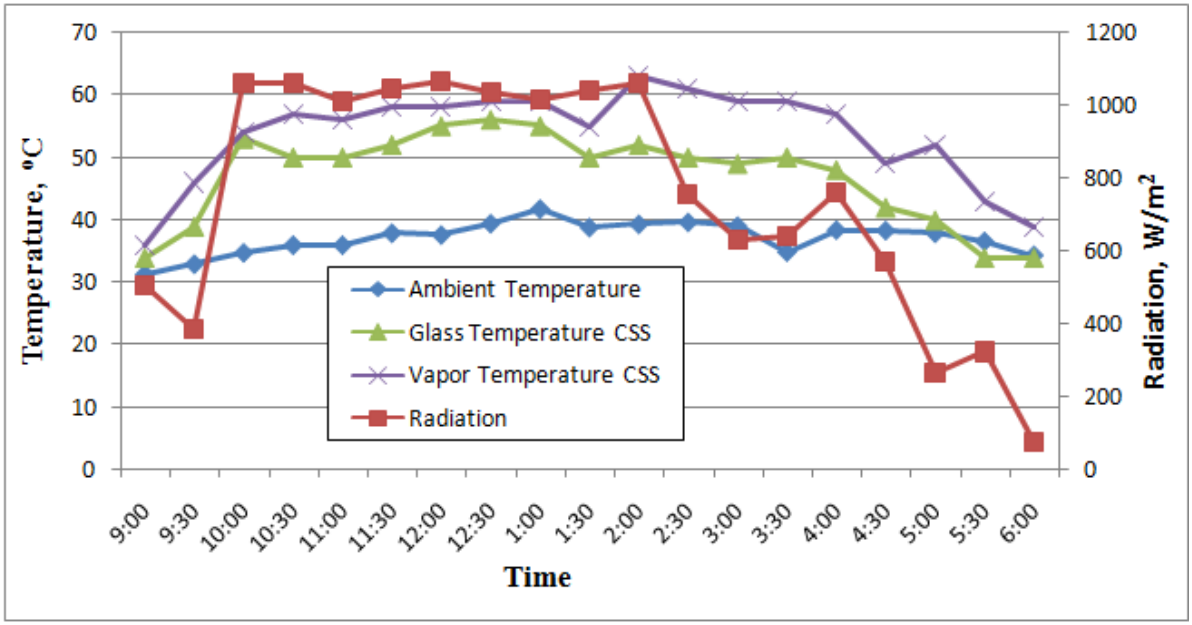

Fig. 2. Variation of CSS temperatures with time

Figure 3 exhibits that MSS glass temperature was higher than MSS vapour temperature up to 2:00 pm, after that MSS vapor temperature was higher till the end of the experiment i.e. 6:00 pm. The maximum glass temperature for MSS was recorded to be 68°C at 1:30 pm. whereas the highest temperature achieved by MSS vapor was 65°C. Solar radiation during the experimentation varied between 74 and 1066 W/m^2. It was observed that there was very low fluctuation in the radiation from 10:00 am to 2:00 pm.

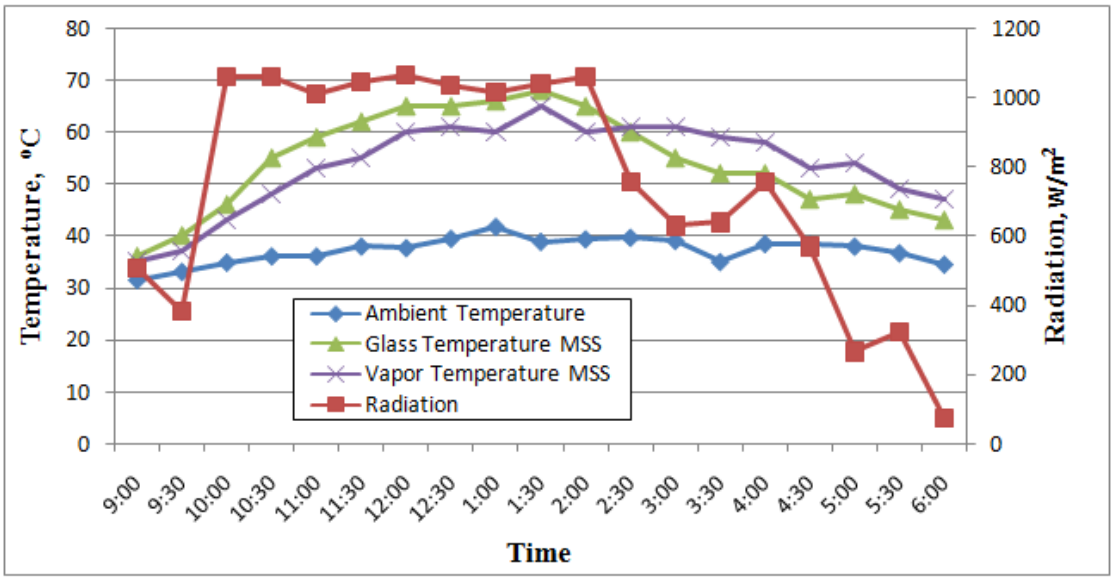

Fig. 3. Variation of MSS temperatures with time

The comparison of hourly productivity of CSS and MSS with time has been shown in figure 4. The maximum distillate for both the stills was collected at 2:00 pm which were 135 ml and 325 ml for CSS and MSS, respectively. Thus, the maximum hourly productivity of MSS was about 2.4 times that of CSS. At the time of maximum distillate production, ambient temperature, and radiation were 39.2°C and 1059 W/m^2, respectively. The accumulated productivity of CSS and MSS for 8 hour duration was found to be 517 and 1359, respectively, i.e. MSS has 162.86% higher productivity as compared to CSS.

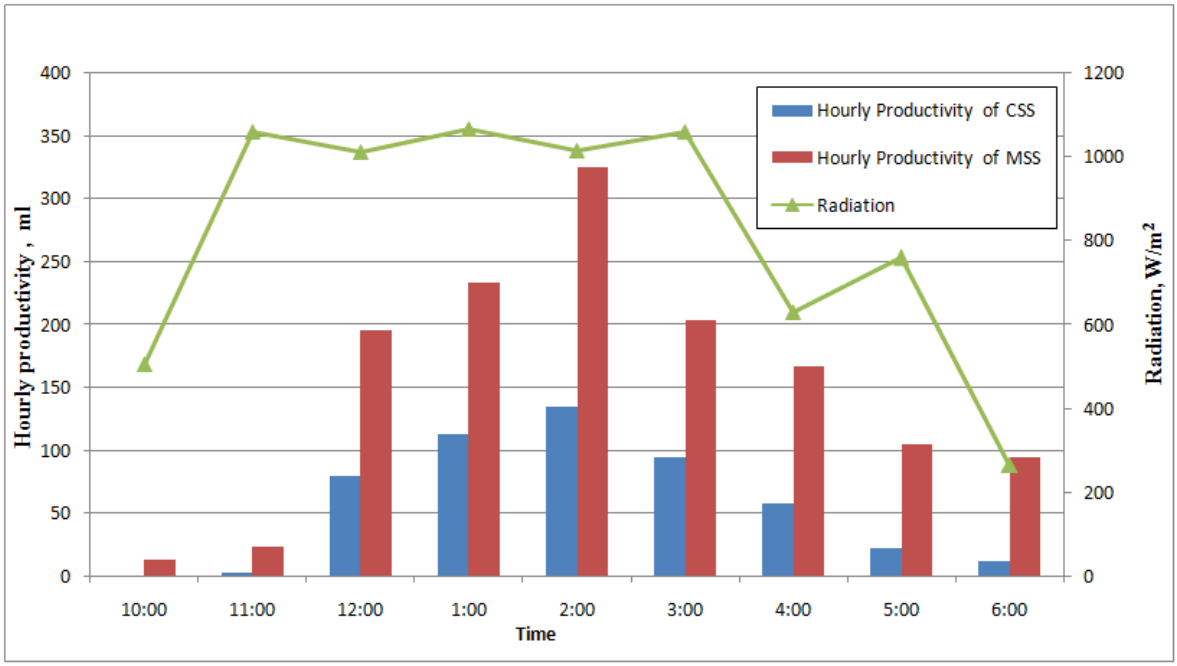

Fig.4. Comparison of hourly productivity of MSS and CSS with time

V. CONCLUSIONS

In the present work, the performance of modified solar still (MSS) with modified steps and thermal storage material has been investigated experimentally. The performance of this MSS was compared with the conventional solar still (CSS). The following conclusions were withdrawn.

1. Maximum glass temperature of CSS was 56°C at 12:30 pm whereas the maximum glass temperature for MSS was recorded to be 68°C at 1:30 pm.
2. The CSS vapour temperature at 2:00 pm was found to be maximum i.e. 63°C whereas the highest temperature achieved by MSS vapor was 65°C.
3. The maximum hourly distillate was 135 ml and 325 ml for CSS and MSS, respectively. Thus, the maximum hourly productivity of MSS was about 2.4 times that of CSS. The accumulated productivity of CSS and MSS for 8 hour duration was found to be 517 and 1359, respectively, i.e. MSS has 162.86% higher productivity as compared to CSS.

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