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Experimental Investigation on A Modified Solar Still with Thermal Storage System

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ABSTRACT

The efficiency of conventional solar still is quite low and applications are only limited to sun shine hours. In this research a modified solar still with steps, external reflector and thermal storage system has been designed. The conventional and modified solar stills were designed and fabricated and their performance was compared. After performing experiments it was found that the maximum temperature of water in the steps of modified solar still (MSS) and in the basin of conventional solar still (CSS) was recorded as 65oC and 59oC, respectively. The CSS basin water temperature was found to be higher than MSS step water temperature up to 11:00 am. Afterwards, the trend shows the higher temperature range of MSS step water as compared to CSS basin water temperature till the end of experiment i.e. 06:00 pm. The hourly production of distillate for MSS is higher than that of CSS during the entire time period of experimentation. The maximum hourly distillate collected from MSS and CSS was 325 ml and 135 ml at 2:00 pm. The maximum increase in the hourly productivity of MSS was found to be 692% higher than that of CSS i.e. about 8 times.

Keywords : Solar Still, Desalination System, Reflectors, Saline Water, Thermal Energy Storage, Steps

I. INTRODUCTION

Sun radiates energy in the form of electromagnetic waves, simply referred as solar radiation. Solar energy is a renewable energy which is clean and inexhaustible. Solar energy can be used for space heating, water heating, and to generate electricity through PV cells. Solar distillation is one of the promising applications of solar energy. It is a method of converting saline water into distilled water. In this process solar radiations are allowed to pass through a transparent air tight glass cover into a black paint coated basin which contains water. The absorbed solar radiations are converted into heat which causes evaporation of water. The vapor produced gets condensed under the glass cover to give purified water. The condensed water flows down the sloping roof and collected in trough placed at the bottom. This can be used to supply distilled water in colleges, science school laboratories, defense lab, petrol pump, hospitals and pharmaceuticals industries etc.

II. LITERATURE REVIEW

Kabeel et al. [1] investigated a double passes solar air collector-coupled modified solar still with phase change material (PCM) to enhance the productivity of freshwater during June-July 2015 under the Egyptian climatic conditions. They studied the influence of injected hot air on the performance of modified still with PCM and conventional still to evaluate the freshwater productivity. The experimental results revealed that freshwater productivity reached 9.36 (L/m^2day) for double passes solar air collector-coupled modified solar still with PCM, while its value was recorded 4.5 (L/m^2day) for the conventional still. The freshwater productivity of double passes solar air collector-coupled modified solar still with PCM was 108% higher than that of the conventional still on average.

Sathyamurthy et al. [2] studied a solar still with phase change material in between evaporating and condensing chamber. The performance of the solar still was evaluated during the summer conditions in Chennai, TN, India. The results showed a maximum of 9% efficiency of the solar still during sunset. The accumulated yield with PCM was 52% more than the accumulated yield for still without PCM.

Omara et al. [3] worked out an experimental investigation on stepped solar still with internal reflectors. A comparative study between modified stepped solar still with trays (5mm depth × 120 mm width) and conventional solar still under same climatic conditions. The results showed that the productivity of modified stepped solar still with and without internal reflector was higher than that for conventional still approximately by 75% and 57% respectively. It was also noted that the daily efficiency for modified stepped still with and without internal reflectors and conventional solar still is approximately 56%, 53% and 34%, respectively.

Kumar et al. [4] studied a single solar still integrated with an evacuated tube collector (ETC) which operated in forced mode. Thermal model of integrated system was developed to predict the performance of solar still under New Delhi (India) climatic conditions. The daily yield was recorded as 3.47 kg for basin water depth 0.01 m and at mass flow rate of 0.0006 kg/s. The optimum performance was found at mass flow rate of 0.06 kg/s for water basin depth 0.03 m. The optimum yield was recorded as 3.9 kg with energy and exergy efficiencies as 33.8% and 2.6% respectively.

Sathyamurthy et al. [5] performed an analysis on a semi-circular absorber solar still with baffles to enhance the freshwater productivity by increasing the contact time of water in the basin. The results revealed that the daily yield of still was higher than the conventional still approximately by 16.66 %. The outlet of water temperature of solar still was high enough that it can be coupled with multi-state of solar stills to increase the productivity. Thus, it can be sufficiently extended for other continuous solar desalination system.

Rajaseenivasan et al. [6] gave a report on a flat plate collector basin (FPCB) still and conventional basin still tested under local climatic conditions with different modifications in the basin. They used cloth and black gravels in the basin to improve the evaporation rate and heat capacity of the still. The results indicated that FPCB still had higher evaporation rate than conventional basin still. The effect of extended surface and preheated water supply increases the distillate of the FPCB still about 60% than that of the conventional still for the same basin conditions. Stills with jute cloth enhanced the productivity in sunshine hours and the black gravels had a significant effect at afternoon hours. The maximum productivity values obtained for conventional and FPCB stills were 3.62 and 5.82 kg/m^2day respectively.

El-Agouz [7] presented a modification in stepped solar still with continuous water circulation using a storage tank. Total dissolved solids (TDS) of sea water and salt water before desalination was found to be 57100 and 2370 mg/l. The effect of installing a storage tank and cotton black absorber in modified stepped solar still on the distillate productivity was investigated. The results displayed that the productivity of the modified stepped still is higher than that for conventional still approximately by 43% and 48% for sea and salt water respectively with black absorber respectively , while 53% and 47% for sea water and salt water respectively with cotton absorber. The daily efficiency for modified stepped still is higher than that for conventional still approximately by 20%. The maximum efficiency of modified stepped still was found at a feed water flow of 1 LPM for sea water and 3 LPM for salt water. 41 and 27 mg/l TDS was recorded for sea water and salt water, respectively, after desalination.

Dashtban and Tabrizi [8] 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 the still with PCM 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. [9] 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 experiments were held at the college premises of Radharaman Institute of Research and Technology, Bhopal (23.25° N, 77.41° E). The experiment started at 9:00 a.m. and ended at 6:00 p.m. The conventional and modified solar stills were designed and constructed. The galvanized iron sheet of 0.5 mm was used for fabrication work. The conventional stills covered with toughened glass having thickness 5 mm (100 cm × 90 cm) framed with G.I sheet. Stills were insulated with glass wool and thermocol from bottom to the side walls to reduce the heat loss. Both the set up faced south direction to receive maximum solar radiation. The modified solar still (MSS) had similar construction and geometrical size as that of conventional solar still, besides the steps and thermal storage system. A part of solar radiation during the day time was utilized for heating the thermal storage (oil). The heat of the oil helped in continuing the evaporation of water in the absence of sunlight. The total volume of box for heat storage material including the space underneath steps was 45.5 L (0.0455 m^3). All the steps were coated with black paint to increase the absorptivity. Reflecting mirrors were used on the vertical side of the steps. Another reflecting mirror (105 cm × 90 cm) was placed to direct the solar radiation on the desired area which would have been wasted otherwise. Various temperatures like ambient air temperature, steps water temperature, glass temperature, surface temperature, heat storage material temperature were measured with thermocouple wires and temperature indicator. Digital pyranometer was used for measuring the solar radiation and hygrometer for measuring the humidity.

Figure 1. Experimental set up

IV. RESULTS AND DISCUSSIONS

The performance of MSS was estimated and compared with the CSS under the same climatic conditions. The variation of ambient temperature, MSS water temperature, CSS water temperature, and radiations with time are shown in figure 2.

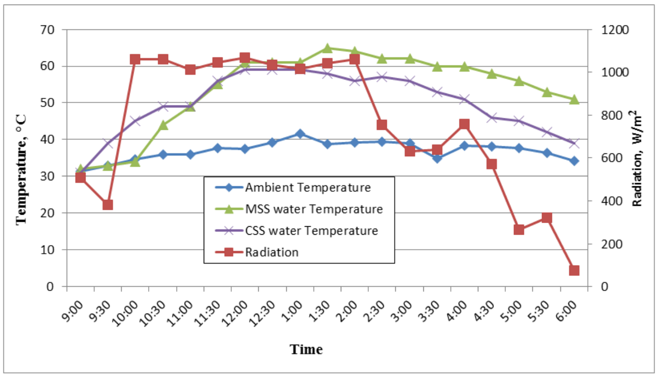

Figure 2. Variation of temperatures with time

The maximum temperature of water on steps in the MSS and in the basin of CSS was recorded as 65°C and 59°C respectively. The ambient temperature during the process varied between 31°C and 42°C. The maximum radiation was received at 12:00 noon which was 1066 W/m^2. The CSS basin water temperature was found to be higher than MSS step water temperature up to 11:00 am. Afterwards, the trend shows the higher temperature range of MSS step water as compared to CSS basin water temperature till the end of experiment i.e. 06:00 pm.

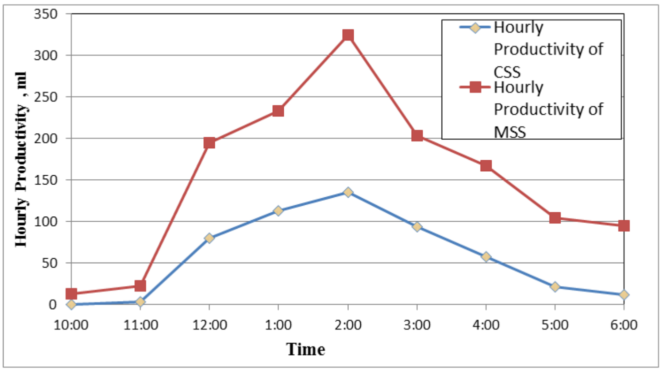

Figure 3. Variation of hourly productivity of MSS and CSS with time

Fig. 3 shows the variation of distillate of MSS and CSS with time. The hourly production of distillate for MSS is higher than that of CSS during the entire time period of experimentation. The maximum hourly distillate collected from MSS and CSS was 325 ml and 135 ml at 2:00 pm. The maximum increase in the hourly productivity of MSS was found to be 692% higher than that of CSS i.e. about 8 times.

V. CONCLUSIONS

Solar distillation is one of the promising applications of solar energy. This can be used to supply distilled water in colleges, science school laboratories, defense lab, petrol pump, hospitals and pharmaceuticals industries etc. Since, the efficiency of conventional solar still is quite low and applications is only limited to sun shine hours, in this research a modified solar still has been designed which has a higher efficiency as well as can be used for extra few hours even in the absence of solar radiation. The conventional and modified solar stills were designed and fabricated. The experiments started at 9:00 a.m. and ended at 6:00 pm and leads to following conclusions.

1. The maximum temperature of water on steps in the MSS and in the basin of CSS was recorded as 65°C and 59°C respectively. The ambient temperature during the process varied between 31°C and 42°C. The maximum radiation was received at 12:00 noon which was 1066 W/m^2. The CSS basin water temperature was found to be higher than MSS step water temperature up to 11:00 am. Afterwards, the trend shows the higher temperature range of MSS step water as compared to CSS basin water temperature till the end of experiment i.e. 06:00 pm.

2. The hourly production of distillate for MSS is higher than that of CSS during the entire time period of experimentation. The maximum hourly distillate collected from MSS and CSS was 325 ml and 135 ml at 2:00 pm. The maximum increase in the hourly productivity of MSS was found to be 692% higher than that of CSS i.e. about 8 times.

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