Experimental investigations on performance enhancement of a heat pump assisted regenerative solar still with heat storage materials

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Introduction

The access to clean water becomes the basic need for humans. The demand of fresh water is increase due to increase in human population and industrialization all over the world. In recent decades many researchers have been conducted that aims at improving the distillate of the solar still. Many research works has been developed on Heat Pump Solar Still (HPSS) by the authors. In a related work, the performance of a HPSS was numerically simulated for the climate conditions of the kazakhstan[1]. It was reported that, the daily productivity of HPSS was improved by 12.5 kg/m^2 which was 80% higher than the Conventional Solar Still (CSS). In a related work, Hidouri K and Mohanraj M [2] made an experimental investigation on various configurations of the HPSS. It was reported that, the HPSS with various glass position has achieved the maximum system efficiency of about 84.5% when compared to the CSS. In a recent work, Dhivagar et al[3] improved the energy and exergy efficiency of the single slope solar still using gravel coarse aggregate sensible heat storage material by 32% and 4.7%, respectively. They found that that cost per litre of distillate was about 0.0618$ with a payback period of 4.3 months and the results confirmed that, the proposed system has 8.27 tons of reduced CO_2 emission.

These experiments found the importance of the HPSS to enhance the daily distillate and performance efficiency for different climate conditions. However, there is no specific research work reported on second law of thermodynamics analysis of HPSS with PCM. Furthermore, the economical and environmental aspects are not carried out to investigate the effectiveness of the existing system configurations. This research work aims to improve the performance ratio and COP of the heat pump, reduce the payback period and compared the net CO_2 emission of the existing HPSS with a CSS.

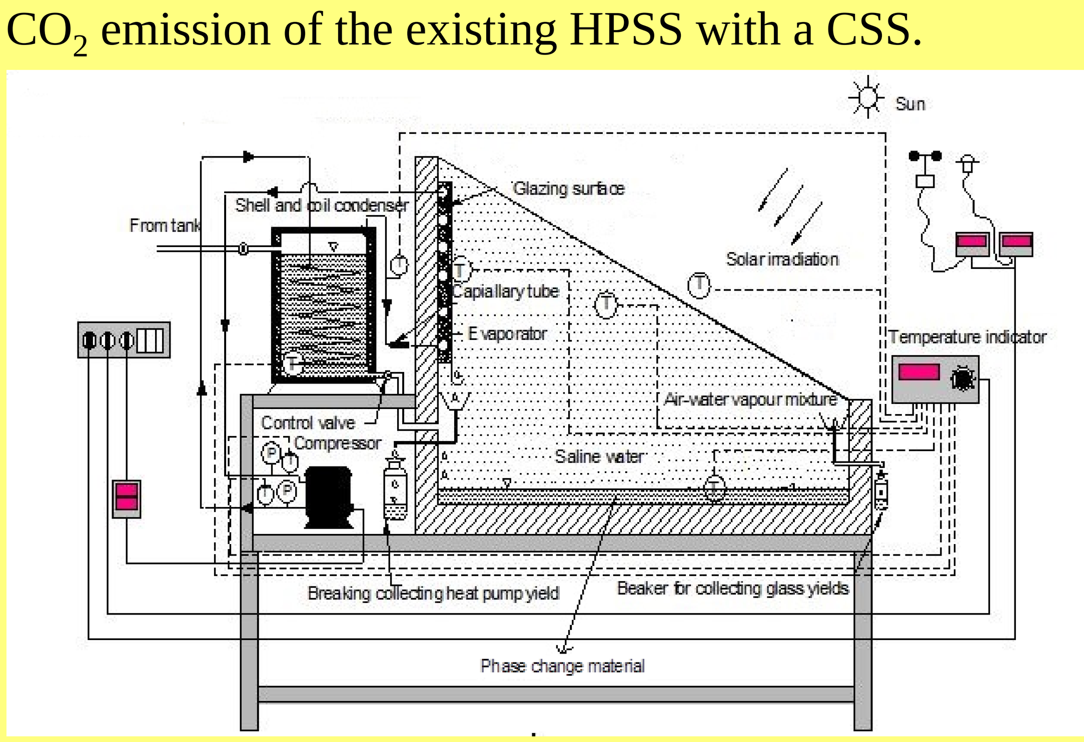

Fig. 1. Schematic view of HPSS

System Description

The schematic view of HPSS is depicted in Fig. 1. The walls and basin of a solar still are made up of mild steel sheet of 1.2 mm thick. The basin of a solar still was coated with back paint to maximize the heat absorption coefficient and placed with paraffin wax PCM material which retains the heat during off sunshine hours. The top portion of the solar still was covered with 3 mm thick glass plate with maximum transmission coefficient of more than 0.9 and minimum absorption coefficient of less than 0.1. The glass cover was titled at an angle of 12^o according to the latitude of Coimbatore. The rubber seals were used for fixing the glass plate and to check the leak of water vapour from the solar still. The sides of solar still were insulated with 25 mm thick glass wool to reduce the heat loss. The system consists of 1 m^2 basin area with the provision for holding PCM heat storage and R134a based compression heat pump system which has capable of delivering 0.5 kW of condenser heat output. The compression heat pump consists of a hermetically sealed reciprocating compressor, a shell and coil type condenser, a liquid receiver, a sealed-type refrigerant drier, a capillary tube expansion device and the plate type evaporator. Two separate provisions have been made for collecting the condensate produced through the glass and also through the evaporator. The solar still was located along east-west direction by facing south direction to maximize the absorption of solar irradiation. The flow control valves are used to control the water flow rate passing through the condenser to solar still.

System Procedure

Before experimental observations, the basin was filled with required quantity of water and allowed the solar still to warm up and attain steady state with ambient conditions. The glass surface was cleaned using a soft cloth to remove the dust accumulation, which may influence the performance of the solar stills. The latent heat released during condensation of water vapour generated inside the solar still was regenerated for preheating the saline water before entering the basin of a solar still. Furthermore, the solar irradiation transmitted through the glazing surface is also used to heat the basin water and stored the excess energy in PCM. The evaporated vapor starts to condensate at the bottom of the glass cover, which is collected separately as glass yield. The evaporator placed inside the solar still used to dehumidify the air-vapor mixture and collected separately as an evaporator yield. The heat emitted from the condenser is used to maintain the basin water temperature warmly during the fluctuation of solar irradiation and off sunshine hours. During the experimental observation, the solar irradiation, ambient temperature, ambient wind velocity and temperature at all typical locations in the solar still were measured at every one hour interval form 9:00 to 21:00 hours. The water level in the basin of the solar still was monitored every one hour interval and maintained at minimum level. The productivity of the solar still at every one hour was monitored using a calibrated jar and the salt deposition in the basin was removed periodically. The experimental observation made on 10.05.2019 (CSS and HPSS) and are used for thermodynamic performance comparison. Before the calculation of observations, ten experimental trails have been made to check the consistency of the final results. Finally, experimental observation have been tabulated and the performance was evaluated.

Results

The cumulative yield of the both solar still is depicted in Fig. 2. The maximum cumulative yield of about 16.1 kg/m^2 per day was observed for HPSS which is 82.8% higher than the yield of CSS and also 73.3% higher than the earlier experimental work reported using solar still with coarse aggregate as sensible heat storage medium[4].

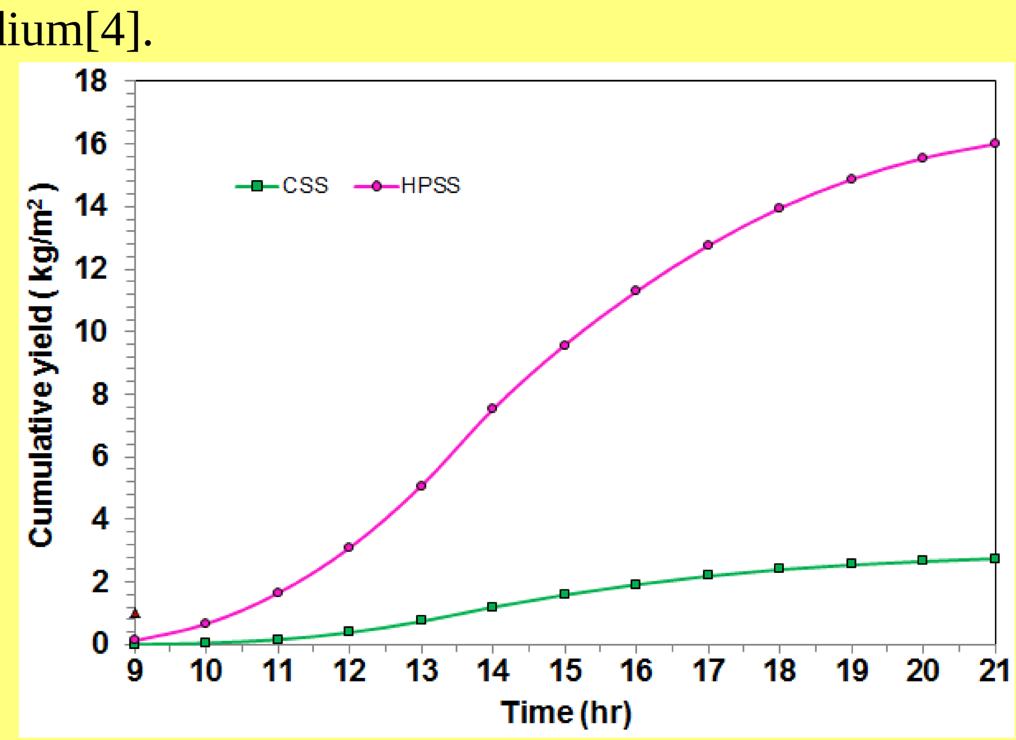

Fig. 2. Cumulative yield of the both stills

The variations of Gross Performance Ratio (GPR) with a Coefficient of Performance (COP) of HPSS is depicted in Fig.3. The maximum GPR of HPSS was observed to be about 0.78 which was determined using actual and predicted solar irradiation with energy efficiency of the system. It was observed that, the system has the overall GPR of about 78% with the productivity of about 16.1 kg/m^2 . The maximum COP of the heat pump was observed to be about 3.4 during the noon hours and reduced during evening hours as sunshine reduced. Because the COP of the heat pump was determined using preheated feed water temperature and the temperature difference between saline water and evaporator[5].

Fig.4 shows the exergy performance of both solar still. It is observed that, the proposed system (HPSS) has the maximum exergy efficiency of about 18.8% which is 75% higher than the previous work reported using coarse aggregate sensible heat storage materials [3]. The maximum exergy efficiency for CSS is observed to be about 2.5% which is 86.7% lower than the HPSS.

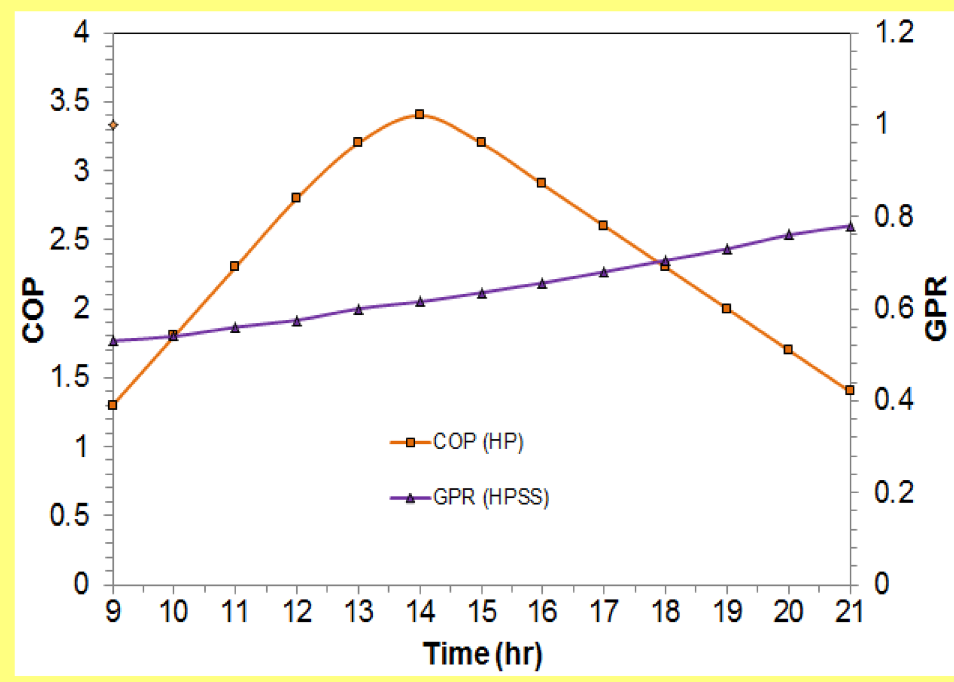

Fig. 3. GPR and COP of HPSS

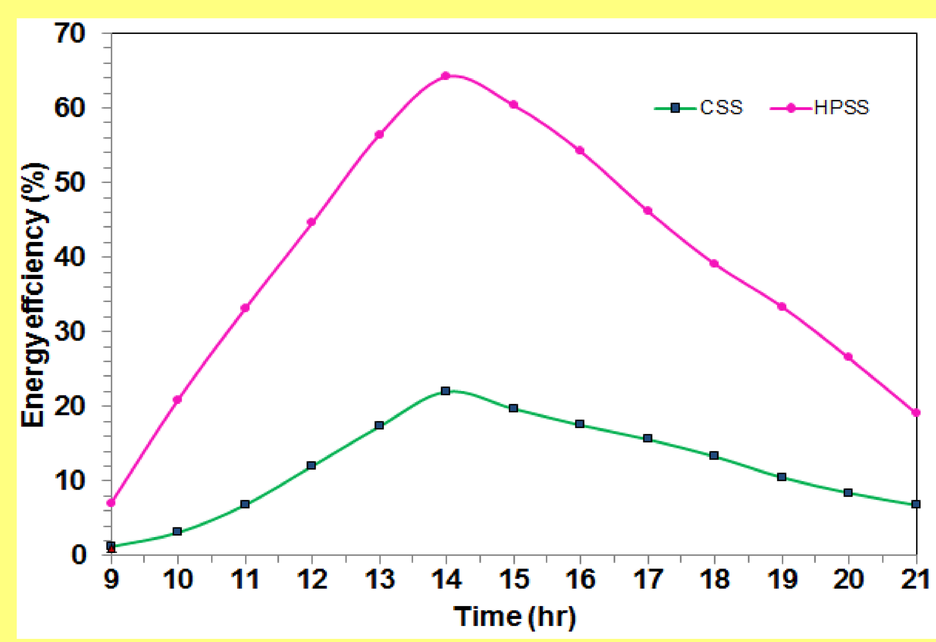

Fig. 4. Exergy efficiency of the both stills

Conclusions

The main conclusions drawn from all these work are:

(i) The maximum energy and exergy effciency of HPSS were found to be about 64.2% and 18.8%, respectively;

(ii) The cost per litre of distillate was observed about 0.0171$ with the payback period of about 2.7;

(iii) The proposed system has reduced 12.98 tons of CO_2 emission during its 10 years of lifetime;

References

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