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A Development in Solar Desalination system with Flashing of Solar Heated Water

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ABSTRACT

Solar still was successfully used for the desalination of saline water in many arid and oceanic regions of the world. But the yield of solar still was found very low and fluctuating. The new develop system with the flashing of solar-heated water is found possible during the study of flashing of hot water in many thermal processes used during the chemical and pharmaceutical processes. A compact and effective desalination system using solar energy had designed during the research work from the design reviews collected from flashing hot water devices used in many thermal processes. The compact flash chamber and flash steam condenser are critical components developed for the novel desalination system using locally available materials during the research work. In present experimental work a flash chamber is designed for flashing of solar heated water. Experimental work shows that by increasing the mass flow rate of water from 0.01 kg/sec to 0.02 kg/sec the distillate output of water could be increased with higher temperature of water. It shows that around 38% of higher distillate output in water could be achieved with development of new system.

Key Words: Solar still (SS), Flat Plate Collector (FPC), Evacuated Tube Collector (ETC), Flash Chamber, Flash Steam Condenser, Vacuum Pump

INTRODUCTION

Solar energy is an effective non-conventional energy source, which can be used for many thermal applications like air heating, air drying, water heating and desalination. Solar still is an example of the effective use of solar energy in the field of desalination. However, it is found possible to design many other modified devices from solar still for better output. Solar stills with different configurations were studied during the literature review. The performances of the solar still were compared for the designing of the modified system. To increase the distillate productivity the design of solar still has been changed. There are different modifications were done to solar still to increase its productivity like attachment of flat plate collector, fins, nanomaterials, evacuated tubes etc.

The inclination angle of the glass, depth of water in the basin and basin materials are the main parameters that affect the out of single basin still. (Dev & Tiwari 2009) suggested that at a 45° inclination angle the best optimum performance could be achieved. The single slope solar still with 0.04m depth of water higher efficiency could be achieved. (Elango & Kalidasa Murugavel 2015) found that with a lower depth of basin water higher distillate could be achieved. (H. N. Panchal & Shah 2016) found that with lower depth of water (0.03 m) the performance of solar still could be higher, also with the addition of energy storage materials higher night distillate output could be achieved. (Singh et al. 2013) suggested that with the integration of evacuated tube in SS the temperature of basin increased. Also with ten number of evacuated tubes and 0.03 m depth of water the performance of solar still could be increased. The respective daily energy and exergy efficiencies have been obtained as 33.0%and 2.5% and maximum among with daily yield of 3.8 kg/m^2. (Omara & Eltawil 2013) used still with solar disk concentrator (SDS) and compared its output conventional solar still (CSS). Air humidification and dehumidification, multi-effect humidification and multi-flash desalination are different techniques to use solar energy in desalination like. Solar-powered air humidification and dehumidification is the very emerging solar desalination technology effectively used in many oceanic regions for producing pure water. The cost and maintenance of the HDH system were found very high during the review of such systems. The size of the HDH system was found large and not suitable for domestic uses. In contrast to the natural hydrological cycle, the HDH process simulates it in a box where evaporation occurs when hot water mixes with dry air in the humidification chamber before being transferred to the dehumidification chamber, where a condenser is utilized to produce fresh water. (Garg et al. 2003) prepared a multi-effect humidification system as shown in fig.1 to heat the water for desalination system.

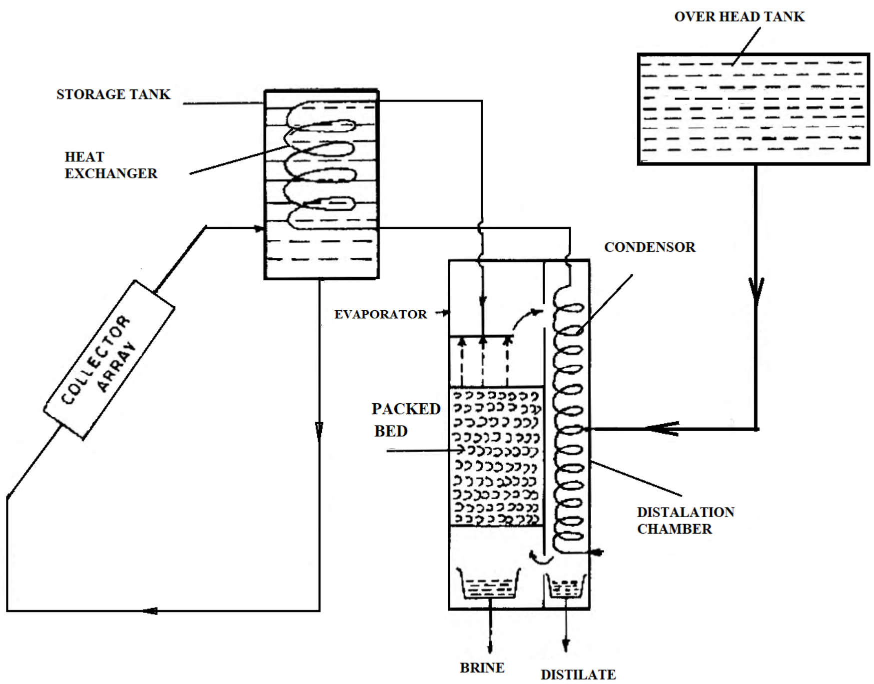

FIGURE 1. Humidification (HDH) dehumidification desalination system

In the distillation plant to increase the output and optimization of various components humidification and dehumidification system is used viz. solar water heater, humidification chamber, and condensation chamber.

A pad humidifier was used by Amara et al. 2004 in a humidification dehumidification pilot plant so, the output could be increased. The investigation was carried out with different operating parameters in terms of temperature, relative and absolute humidity and quantity of evaporating water during the experiment. The numerical study shows good agreement with experiment performance. The different factors are considered during the design of the bed of the humidifier for better humidification. (Orfi et al. 2007) presented on the theoretical study of a solar desalination system with humidification–dehumidification using solar collectors for heating water and air. A general mathematical model expressing the heat and mass transfers in each component of the systems is presented. A numerical model has been developed and validated. The present system produces fresh water at a higher rate. In order to evaluate the performance of a humidification and dehumidification system with an integrated parabolic trough solar collector, (Al-Sulaiman et al. 2015) presented a thorough thermodynamic analysis. Because of its consistent performance and efficient heating nearly throughout the entire year, PTSC is therefore favored for use in such systems. As shown in Figure 2 (Sharshir et al. 2016) investigated a solar desalination system integrated with humidification and dehumidification. An evacuated solar water collector is utilized in the humidification and dehumidification. The daily water productions of the conventional solar still, solar still with humidification and dehumidification, humidification and dehumidification exit and continuous solar desalination unit are 3.9 L/day, 13 L/day, 24 L/day and 37 L/day, respectively.

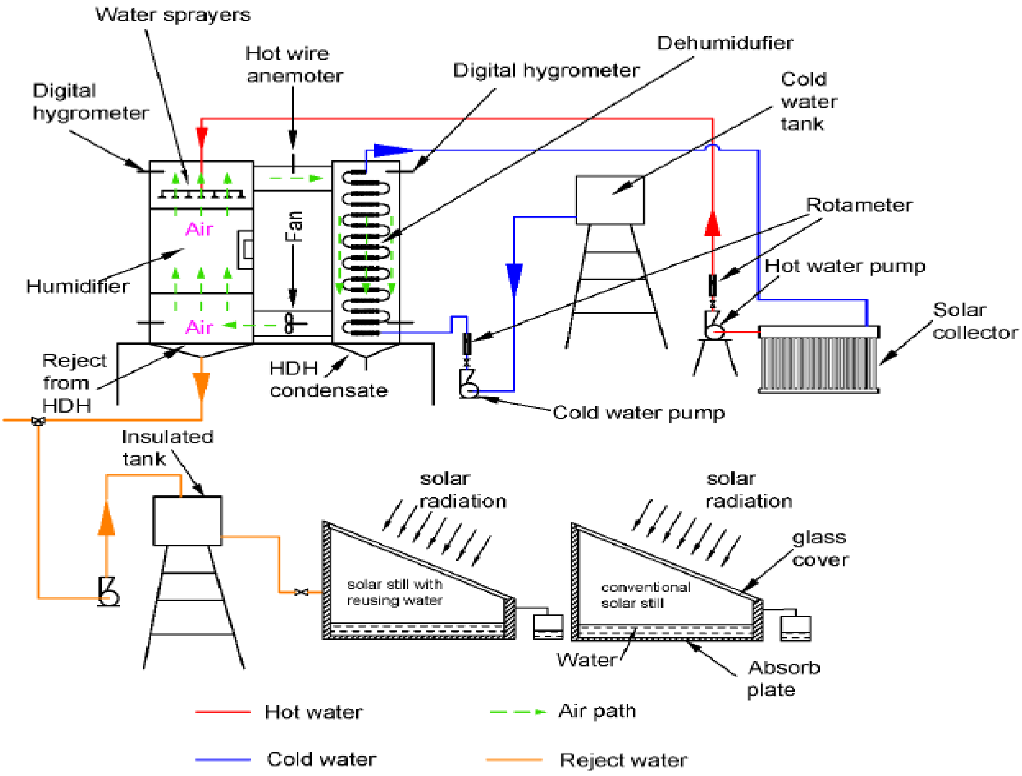

FIGURE 2. A schematic of new developed system

The literature survey was carried out by (Thakkar et al. 2018) who developed the design of the humidification and dehumidification system with flat plate collector type solar air collector and recorded output of more than 40 L/ day. Al-Nimr et al. 2023 developed a hybrid RO and flash desalination system operated by solar thermal collectors to get pure water in remote areas. The novel system gave better results in performance than the existing system. Kaheal et al. 2022 developed a multi-stage flash desalination system for large-scale operation of the desalination plant. With the newly developed system they reduced the price of water by 15%. Yadav et al. 2023 developed a green desalination system for geothermal water. They used a multi-stage flash desalination system with evacuated tubes to increase the temperature of water. The salt concentration of water was reduced by this system

The novel solar desalination system which is compact like a solar still and efficient like the humidification and dehumidification system can be designed using flashing of solar-heated water in the flash chamber. The Single Stage Flash is the modified design of the solar still which will give better output by improving the processes of the solar still by using flashing hot water in an evacuated chamber.

DESIGN OF A COMPACT DESALINATION SYSTEM USING FLASHING SOLAR-HEATED WATER

It is found possible from the study of different designs of solar still and humidification and dehumidification systems to develop a compact desalination system by adding flashing of solar-heated hot water in an evacuated flash chamber and flash steam condenser. The different attempts for designing solar-powered water flashing systems are studied and found following useful inputs in designing compact desalination systems using flashing solar-heated water.

A compact solar-heated water flash desalination was designed and its mathematical model was developed by (Nafey et al. 2007). In that a water heater is attached as a flat plate solar collector) which works as a brine heater and a vertical flash unit that is attached to a condenser/preheater unit as shown in Figure 3. In this work, the system is investigated theoretically and experimentally. The emblematic summer productivity varied from 4.2 to 5 kg/day/m^2 in June to 5.44 to 7 kg/day/m^2 in July and August.

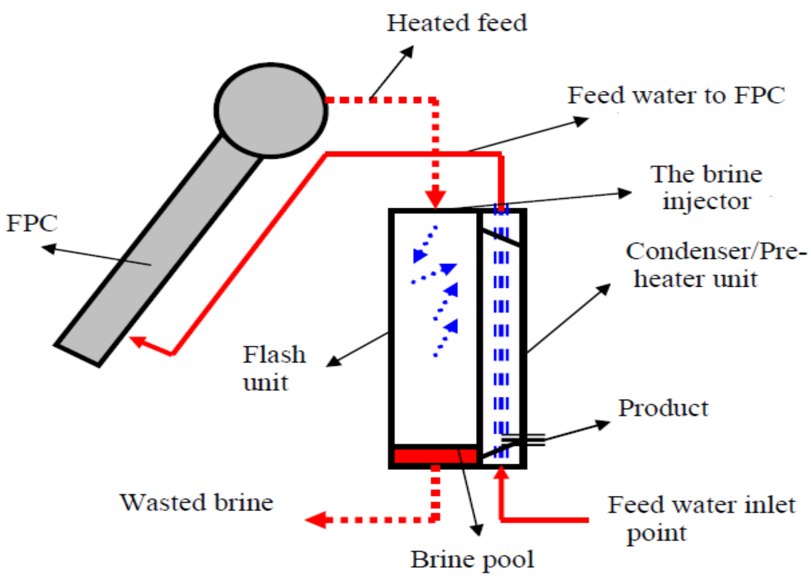

FIGURE 3. Water flashing system with FPC collector

According to an analysis by (Maroo & Goswami 2009), a single-stage system using SS and a solar collector with a 1 m^2 area produced 5.54 kg of water in 7.83 hours, whereas a two-stage system produced 8.66 kg in 7.7 hours. El-Zahaby et al. (2010) created an innovative design for a stepwise solar desalination system with a flashing chamber through practical testing. The investigation's major goal was to evaluate how well a step-wise water basin and spray water system worked together by increasing desalination productivity with two air heaters. (Kabeel & El-Said 2013) presented a paper on a hybrid solar desalination system consisting of a humidification–dehumidification unit and a single-stage flashing evaporation unit. The results show that the studied hybrid desalination system gives significant operational compatibility between the air humidification–dehumidification method and flash evaporation desalination with daily water production up to 11.14 kg/m^2/day. The efficiency of the system is measured by the gained output ratio (GOR) with daytime. The gained output ratio (GOR) of the system reaches 4.5. The main components of the desalination system using flashing of solar-heated water were designed and fabricated from locally available materials. The layout of the compact desalination system using flashing of solar-heated water is shown in Figure 4.

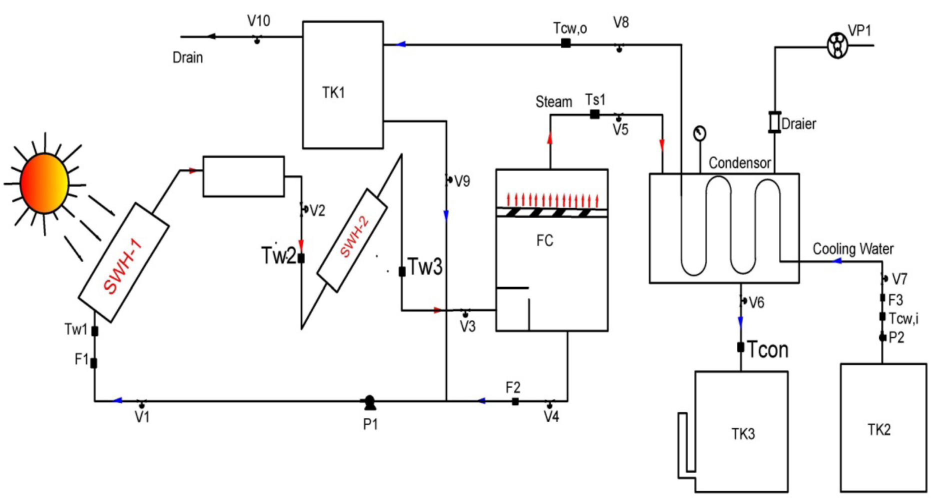

FIGURE 4. A compact desalination system with flashing of solar-heated water

In this experimental work, the equipments used are a water pump (P_1), cooling water pump (P_2) and vacuum pump (VP_1). Flow meter F_1 & F_2 with different valves V_1 to V_{10}. TK_1, TK_2 and TK_3 are used to supply water, cooling water, and collect pure water.

DESIGN OF TWO-STAGE SOLAR WATER HEATER

Solar still with ETC gave higher basin water temperature to increase the distillate output. The flash operation with FPC is also possible and gives good results, as (Morrison et al. 2004) suggested. Wannagosit et al., 2018 found that ETCs with SS increase basin water temperature maximum at 4:00 p.m.

Thermally isolated horizontal tank with an outer stainless-steel cylinder measuring 165 cm in length and 40 cm in diameter and an inner stainless steel cylinder measuring 145 cm in length and 30 cm in diameter (total volume 100 liters) with 50 mm-thick polyurethane foam thermal insulation. The compact desalination system using flashing of solar-heated water used a two-stage water heater for better output which enhances the temperature of water up to 95 °C.

FIGURE 5. ETCs in solar water heater

DESIGN OF FLASH CHAMBER

As shown in below Figure 6, a flash chamber having an area of 0.05 m^3 was prepared from a GI sheet and to reduce corrosion it was powder coated. A flash plate and demister are used to make the water flash more frequently. Stainless steel is used to create a demister to lessen corrosion.

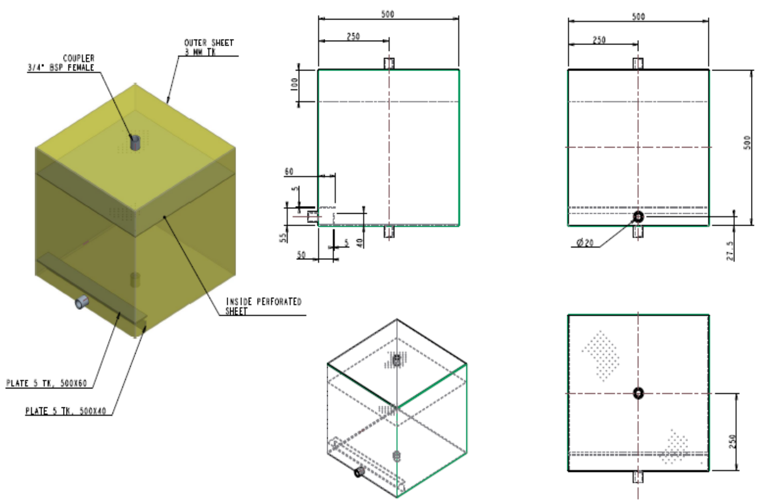

FIGURE 6. Solid model of the flash chamber

EXPERIMENTAL RESULTS AND DISCUSSION

In Figure 7 an experimental setup is shown. For two different flow rates of 0.01 kg/sec and 0.02 kg/sec, experimental readings were taken. The experimental readings were taken in the climatic conditions of Ahmedabad, Gujarat, India. In Figure 8 the experimental setup is shown for a flow rate of 0.01 kg/sec. It was found that during noon time the maximum temperature was achieved, which gives the higher distillate output. Compared to the winter season, in summer months higher solar intensity and water temperature could be achieved, which gives higher distillate output. It was also found that with a 0.02 kg/sec water flow rate higher distillate productivity could be achieved. So it was observed that distillate productivity could be improved with higher value of solar intensity and flow rate.

FIGURE 7. Experimental setup of compact desalination system using flashing of solar-heated water

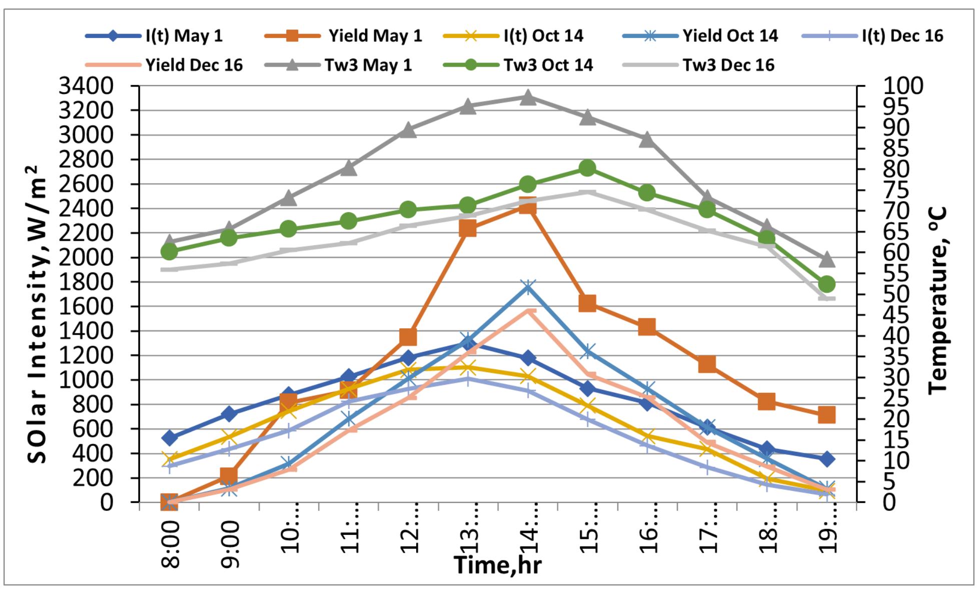

FIGURE 8. Experimental results with water flow rate of 0.01 kg/sec (May 1st, October 14th and December 16th, 2019)

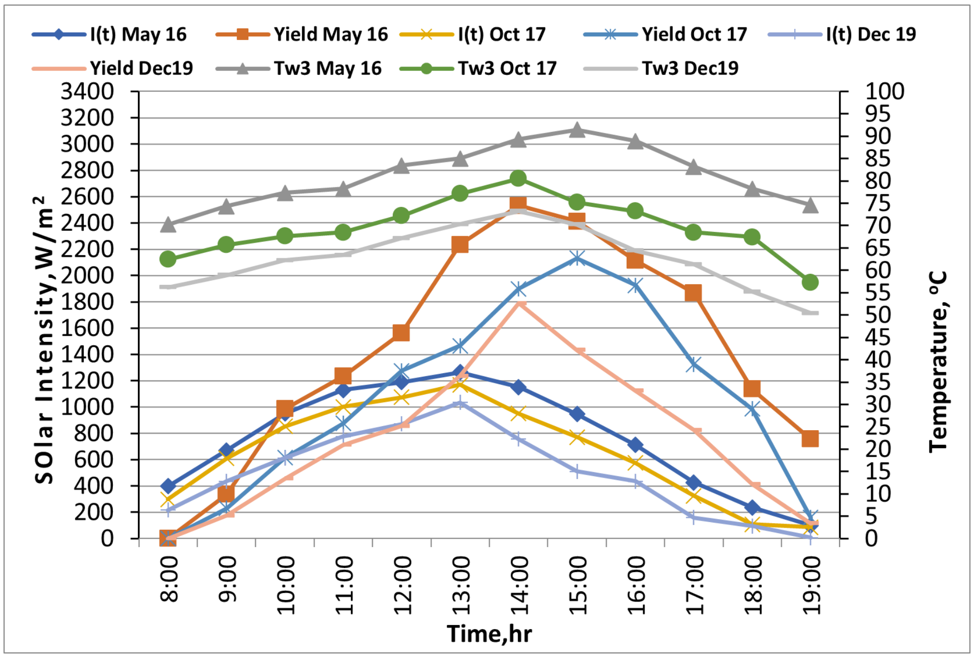

FIGURE 9. Experimental results with water flow rate of 0.02 kg/sec (May 16th, October 17th and December 19th, 2019)

From Figure 9 it was found that water with a flow rate of 0.02 kg/sec gives higher value of water temperature and lower cooling temperature. It also gives a higher value of distillate output.

Figure 10 shows the comparison in distillate output between single and multi-stage solar desalination systems with flow rates of 0.01 kg/sec and 0.02 kg/sec. It was found that a solar still with a 0.02 flow rate of water gives higher distillate productivity than a 0.01 kg/sec flow rate solar still. This condition was generated due to the higher value of water temperature and lower cooling temperature.

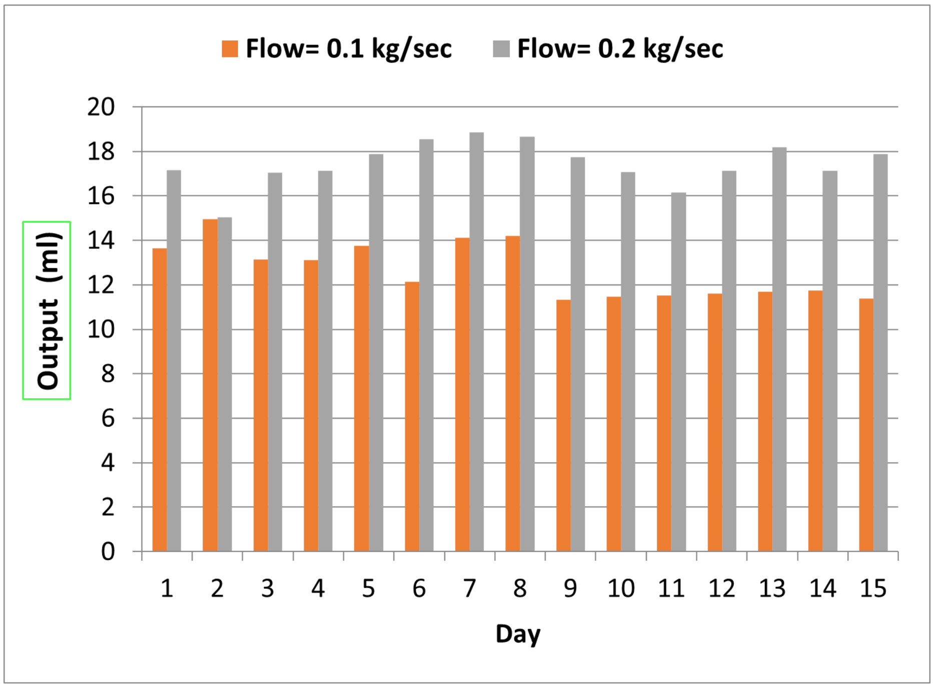

FIGURE 10. Comparison of distillate output with different flow rate (1st May 2019 to May 30th 2019)

CONCLUSION

The present experimental work shows the development of a solar desalination system with flashing of solar-heated water. After conducting the experimental work, the following points are summarized:

1. The solar desalination system with flashing solar heated water gives distillate productivity of 11-13 liter per day with a flow rate of 0.01 kg/sec.
2. Using a water flow rate of 0.02 kg/sec, the yield of a desalination system using flashing solar- heated water can be increased by up to 16–18 liters per day.
3. From experimental readings it was found that during noon time maximum temperature could be achieved.
4. With higher values of flow rate higher distillate productivity could be achieved.
5. Increasing the flow rate of water gives the maximum value of water temperature and lower cooling temperature.
6. The compact design of the flash chamber with a condenser makes it suitable for domestic and commercial utilization with an effective look.
7. The solar intensity and water flow rate have a higher impact on the performance of solar still.

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DECLARATION OF COMPETING INTEREST

None

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