IJCTA, 9(37) 2016, pp. 545-553

A Novel Method of Enhancing the Productivity and Efficiency of Solar Still – An Experimental Study

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Abstract: The aim of this work is to enhance the performance of a single slope solar still using finned-PCM heat recovery unit. The important parameters affecting the performance of still such as depth of water, temperature of inlet water and water-glass cover temperature difference are investigated experimentally. The experimental results indicate that the still using waste heat recovery unit ensures low thermal losses, better heat preservation and improved rate of water evaporation. The results reveal that depth of water in the solar still is inversely proportional to the productivity of the still. The addition of finned-PCM heat recovery unit increased the inlet temperature of saline water closer to its saturated temperature which in turn reduces the amount of heat required to evaporate the water in the still and leads to a still with higher productivity and efficiency.

Index Terms: Solar energy, Solar desalination, waste heat recovery, distillate water production.

1. INTRODUCTION

There is an urgent need of clean and safe drinking water in many countries. Often, water sources are brackish and containing harmful bacteria and therefore cannot be used for drinking. Fresh water supply by trucks and laying long pipelines carrying potable water from far off region is usually not economically feasible. In addition, pollution of the rivers and lakes by industrial wastes and large amount of sewages results in contamination of water quality. Further, in coastal areas and deserts, potable water is the main problem. So, there is a need for desalination of brackish water to meet the requirement economically. One of the options used to obtain potable water from saline water is to use solar distillation process. Solar still seems to be better and simple compared to other desalination techniques. The disadvantages of the solar desalination systems are their low efficiency and daily distillate water production. However, solar stills are suitable for low capacity freshwater demand [1]. Theoretical and experimental investigations were performed for single slope solar still [2-6] under different climatic conditions. The more water surface in the solar still enhanced the rate of evaporation. As a result, the influence of using jute cloth or wick materials on the performance of still was investigated [7-8]. It was found that provision of wick, porous or energy storage material in the basin increases the distillate output. The depth of basin water is an important factor affecting fresh water productivity of the still. Solar desalination process can be significantly enhanced using active mode operations. Therefore, many attempts have been made to improve the solar still by coupling the stills with parabolic trough, solar ponds and solar thermal collectors [9-11] Another method that can be used to enhance the productivity of still is by using thermal energy storage systems (sensible and latent heat storage). The latent heat storage system has a significant advantage over sensible heat system, including high energy storage capacity and isothermal operating characteristics. Arun kumar et al. [12] investigated the effect of phase change material on the productivity of the concentrator-coupled hemispherical basin still. To the author's best knowledge, this is the first experimental study investigating the effect of finned-PCM on the performance of solar still. The objective of this work is to analyze and compare the performance of

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a solar still using finned-PCM heat recovery unit with conventional solar still and to enhance the freshwater productivity of the single basin solar still using finned PCM heat recovery unit.

2. EXPERIMENTAL SETUP AND PROCEDURE

Air conditioning systems are designed to remove heat from the interior space and reject it to the atmosphere. In split or window air conditioner, the heat is rejected directly to the atmosphere. Forced convection air condenser rejects heat from air conditioner to atmosphere. The finned-PCM waste heat recovery system utilizes the rejected heat from air condenser to preheat the saline water. The inclusion of waste heat recovery system increases the temperature of saline water before it is sent to the still. Solar radiation is transmitted through top glass cover to the preheated saline water in the basin of still. Thus, basin water gets more heated and evaporated. Incorporation of waste heat recovery unit in the single slope solar still reduced the time required to evaporate the saline water. Thus the freshwater production of still can be increased. The solar still is made up of galvanized iron of 0.6 m × 0.4 m with maximum height of 50 mm and 3 mm thick. The basin of still is painted black to improve its absorptivity. The basin is made waterproof using M-seal. The condensing cover uses a glass of 4 mm thickness. Rubber sealant is used to ensure vapor tightness of system. The still is insulated well to reduce bottom and side heat losses. An outlet is also provided to drain out purified water from still. The waste heat recovery unit is placed in front of the hot side of the air condenser. The hot air from the air condenser passes through the waste heat recovery unit. The automobile radiator is used as waste heat recovery unit which preheats the saline water before entering the solar still. The preheated water is stored in an insulated storage tank. The capacity of insulated storage tank is 60 litres. The heated saline water is then supplied to the still at constant flow rate. The mass flow rate of hot water injected to the solar still is controlled by valves. The constant depth of water was maintained throughout the experiment with the help of float valve.

Table. 1
Accuracy and Range for Various Measuring Instruments

S.No.	*Instrument*	*Accuracy*	*Range*
1.	Thermometer	±1°C	0 – 100°C
2.	Thermocouple	±0.1°C	0 – 100°C
3.	Pyranometer	±30 W/m^2	0 – 1750 W/m^2
4.	Digital anemometer	±0.4 m/s	0.4 –30 m/s
5.	Measuring jar	±10 ml	0 – 1000 ml

Thermocouples with five channel digital display system are used to measure basin water temperature, glass cover temperature, inlet saline water temperature, initial water temperature and water temperature at storage tank. Digital anemometer and mercury thermometer are used to measure the wind velocity and ambient temperature. The produced freshwater is collected in the measuring jar to determine the quantity of the water. The performances of still with heat recovery unit and conventional still have been studied. The readings are taken from 8 a.m. to 5 p.m. for every half an hour.

3. RESULTS AND DISCUSSION

To enhance the distillate output of the single slope solar still, finned – PCM heat recovery unit is incorporated in the solar still. Use of finned- PCM heat recovery unit increases the inlet temperature of basin water and makes the water susceptible for evaporation. Figure 2 shows the solar radiation and ambient temperature with respect to local time during the experimental period. The variation of different temperatures and freshwater production for both solar still with heat recovery unit and conventional still are shown in Figure 3-6.

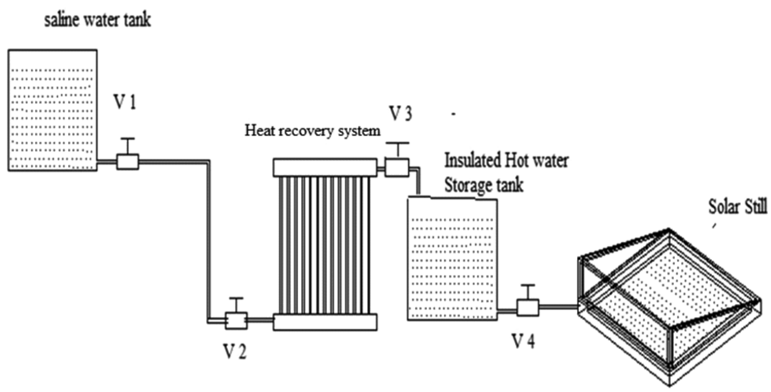

Figure 1: Schematic of the experimental setup

For the given radiation conditions, the basin water temperature, basin liner temperature and glass cover temperature and the time taken to reach their maximum value depends upon the basin water level. The production rate of still mainly depends on the basin water temperature. Around 1 p.m solar still with heat recovery unit reached the maximum temperature and production rate point. Figure 6 shows the variation of freshwater production of solar still with heat recovery unit and conventional solar still for different depths of water in the basin. For both stills, the freshwater production varies inversely with depth. Various parameters affecting the performance of solar still with heat recovery unit are studied.

A. Effect of Intensity of Solar Radiation and Ambient Temperature

Solar still freshwater production depends on climatic conditions of the particular location like intensity of solar radiation, ambient temperature, wind speed etc. Figure 2 shows the variation of solar radiation and ambient temperature on 11/2/2016.

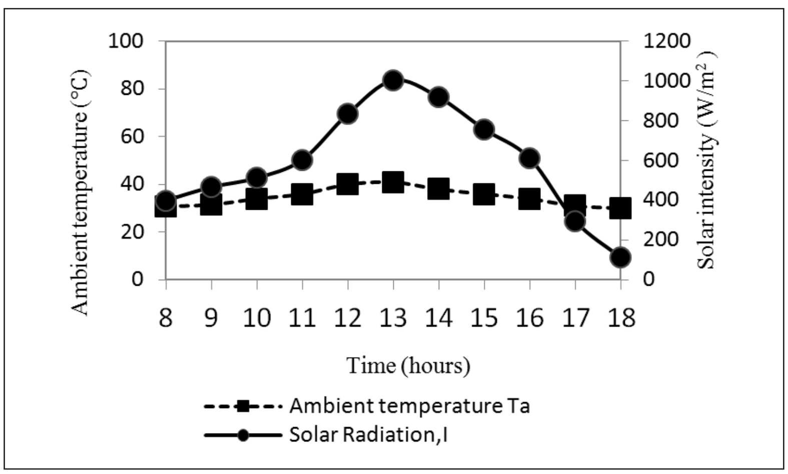

Figure 2: Hourly variations of solar intensity and ambient temperature

The intensity of solar radiation attained the maximum value of 1002 W/m^2. The ambient temperature was minimum (30.8°C) at 8 am and it reached the maximum value (41°C at 1 pm. The above parameters are based on climatic conditions of the particular day.

B. Effect of heat recovery unit on the performance of solar still

Figure 3 shows the variation of ΔT throughout the day for different water depths in the both stills. It is clear that, during the morning hours, glass encounters the radiation first and its temperature increases rapidly in comparison to water temperature and as a result, ΔT becomes negative till temperature of water attains glass cover temperature. This duration is called as zero yield period. As the water temperature exceeds the glass cover temperature, the yield commences and ΔT becomes positive. Also it is noted that once ΔT attains positive, it remains positive till the end of the operation. As the depth of water increases, the commencement of productivity is delayed as well as the productivity decreases due to large amount of water available in the still. However during the later period, the productivity increases steeply with lower depth of water.

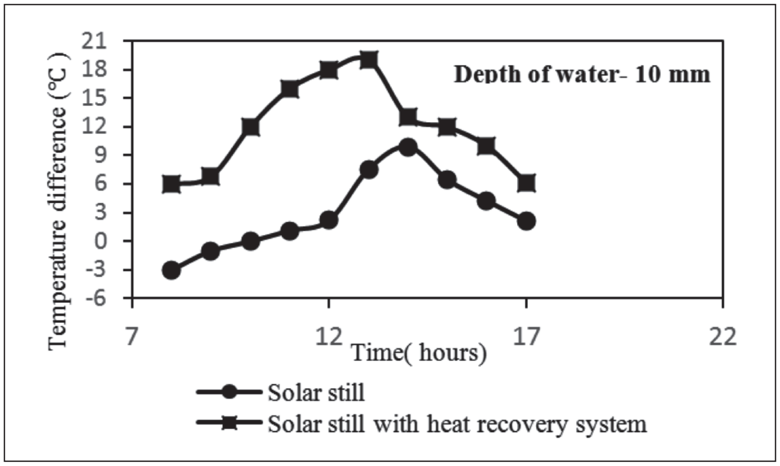

Figure 3: (a) Hourly variations of temperature difference between basin water and glass cover for 10 mm depth of water

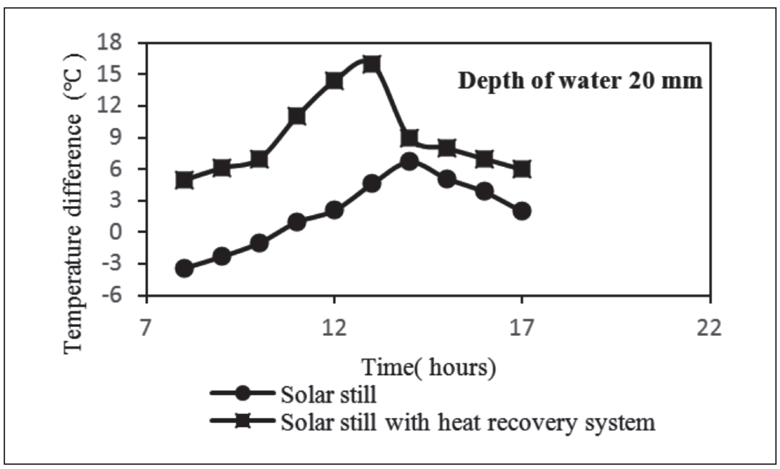

Figure 3: (b) Hourly variations of temperature difference between basin water and glass cover for 20 mm depth of water

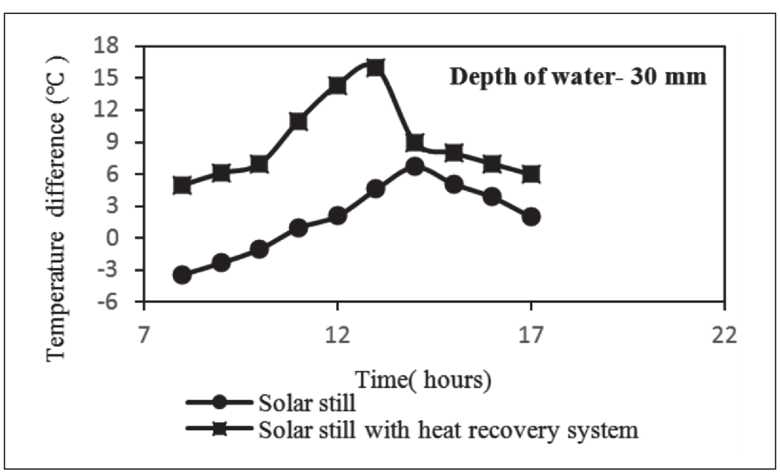

Figure 3: (c) Hourly variations of temperature difference between basin water and glass cover for 30 mm depth of water

The productivity of still depends on the temperature difference between basin water and glass cover. The use of heat recovery unit increases the inlet temperature of basin water and ΔT remains positive till the end of operation. It can be concluded that incorporating heat recovery system in the solar still eliminates the zero yield period and enhanced the productivity of the still.

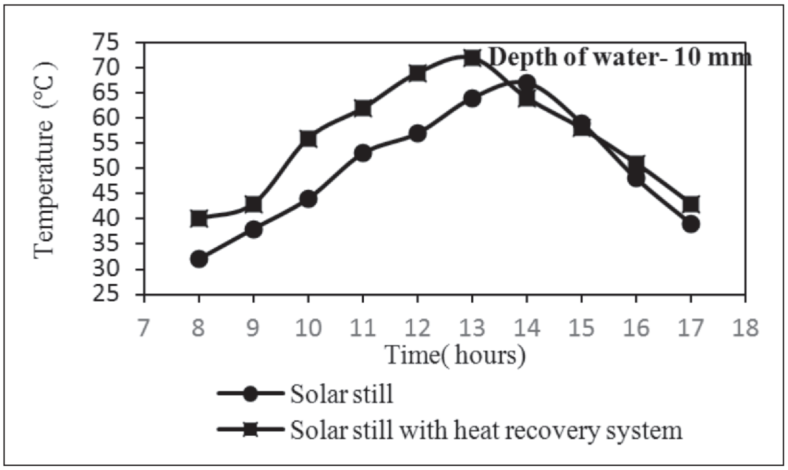

Figure 4: (a) Hourly variations of basin water temperature for 10 mm depth of water

The variation of basin water temperatures for solar still with heat recovery unit and conventional still are shown in Figure 4 The temperature of basin water gradually increases from 8 a.m. to 1 p.m. due to bright sunshine and reduced during the evening. The maximum temperature of basin water in the still is 64°C at 10 mm water depth in the conventional solar still. The maximum basin water temperature at 10 mm, 20 mm and 30 mm depth of water in the still with heat recovery unit are 72°C, 67°C and 64°C. The maximum basin water temperature at 10mm, 20mm and 30 mm depth of water in the conventional still are 63°C, 60°C and 55°C. From the Figures 7-9, it was observed that increase of depth of water decreases the basin temperature in both stills.

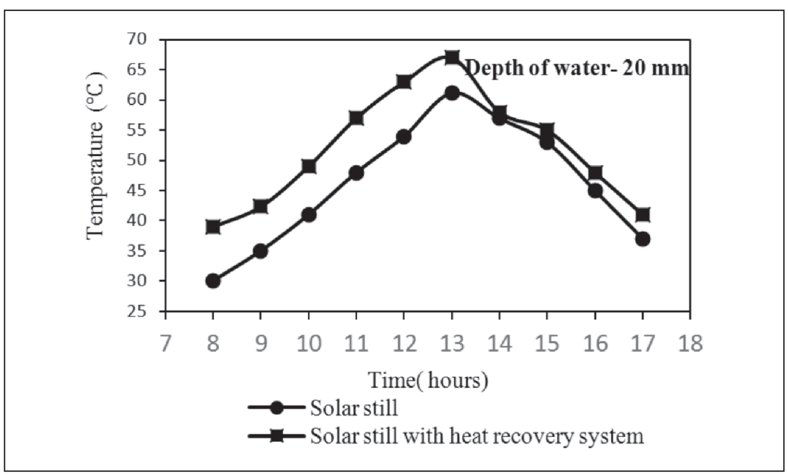

Figure 4: (b) Hourly variations of basin water temperature for 20 mm depth of water

The variation of basin liner temperatures for both solar still with heat recovery unit and conventional still are shown in Figure 4. The maximum basin water temperature at 10 mm, 20 mm and 30 mm depth of water in the still with heat recovery unit are 76°C, 68°C and 67°C. The maximum basin water temperature at 10 mm, 20 mm and 30 mm depth of water in the conventional still are 69°C, 65°C and 58°C. From the Figures 10-12, the increase of depth of water decreases the basin liner temperature in both solar still with heat recovery unit and conventional still.

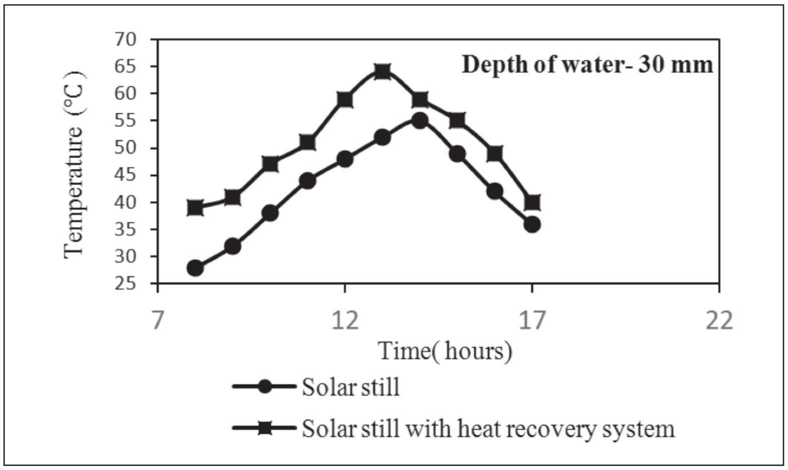

Figure 4: (c) Hourly variations of basin water temperature for 30 mm depth of water

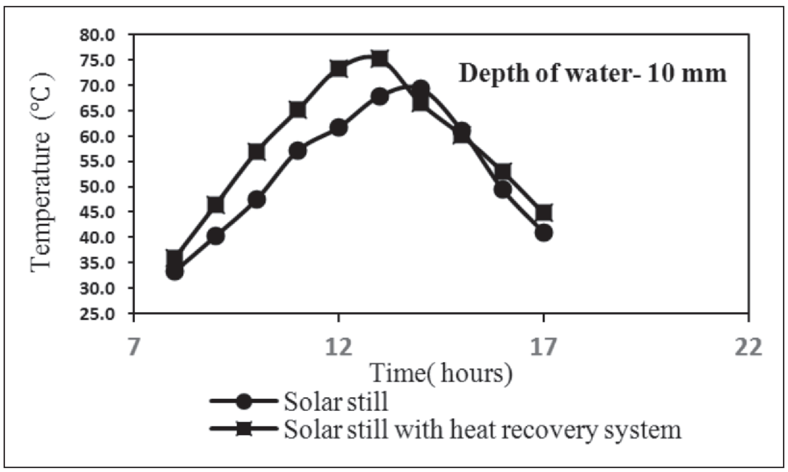

Figure 5: (a) Hourly variations of basin liner temperature for 10 mm depth of water

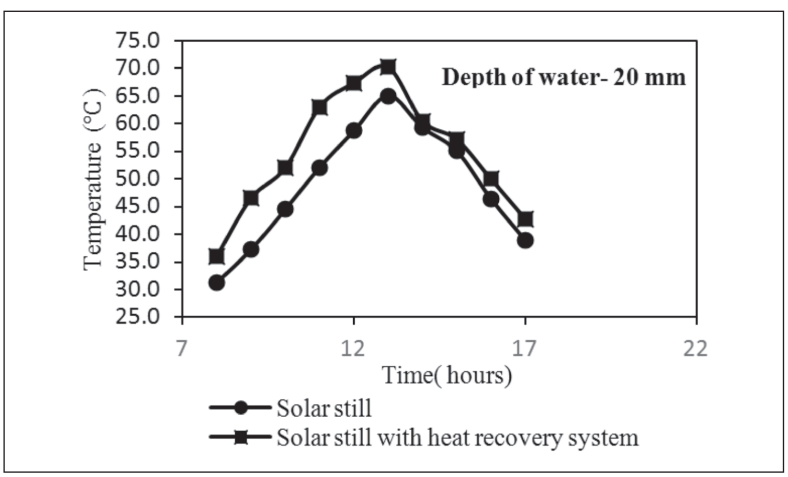

Figure 5: (b) Hourly variations of basin liner temperature for 20 mm depth of water

The hourly variation of productivity of both solar still with heat recovery unit and conventional still are shown in Figure 6. The highest yield at 10 mm, 20 mm and 30 mm depth of water in the still with heat recovery unit are 213 ml, 202 ml and 197 ml. The highest yield at 10 mm, 20 mm and

30 mm depth of water in the conventional still are 198 ml, 174 ml and 143 ml. The increase in depth of water decreases the freshwater productivity in both solar still with heat recovery unit and conventional still.

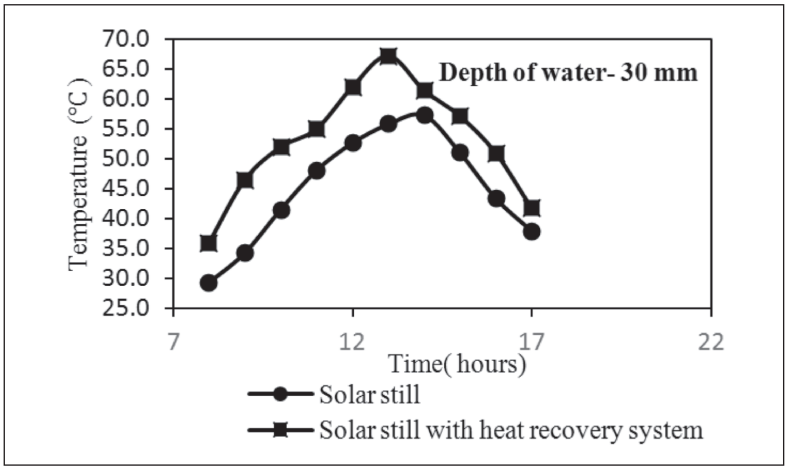

Figure 5: (c) Hourly variations of basin liner temperature for 30 mm depth of water

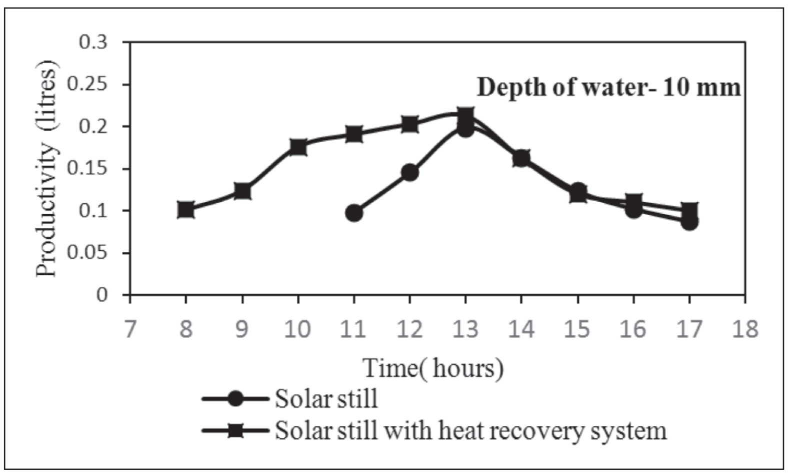

Figure 6: (a) Hourly variations of productivity for 10 mm depth of water

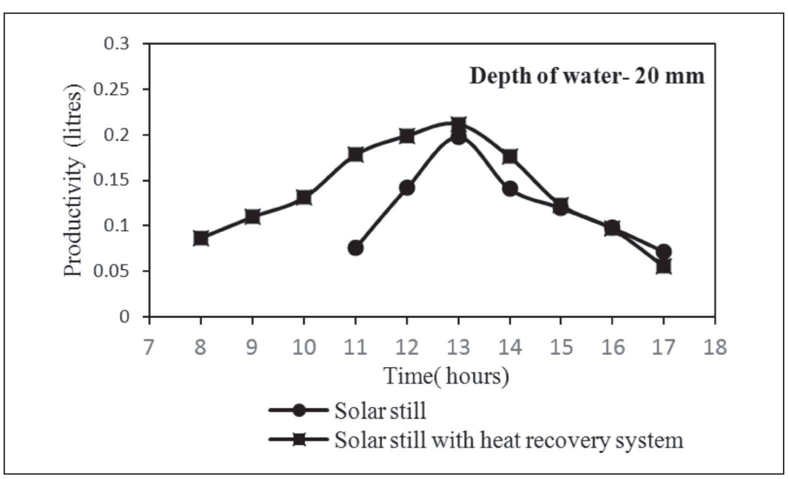

Figure 6: (b) Hourly variations of productivity for 20 mm depth of water

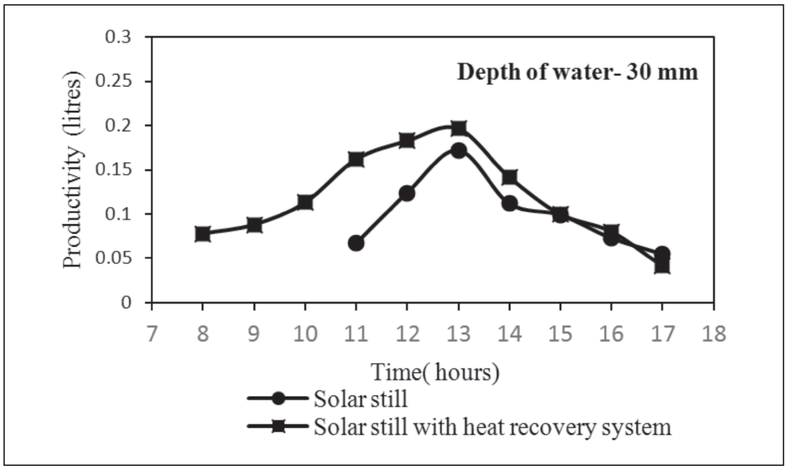

Figure 6: (c) Hourly variations of productivity for 30 mm depth of water

The daily productivity is increased by 56 % using heat recovery system. The maximum accumulated yield per day of both solar still with heat recovery unit and conventional still at 10 mm depth of water are 1.49 kg and 0.95 kg respectively.

4. CONCLUSIONS

The solar still integrated with heat recovery unit and conventional still have been fabricated and tested with different depth of water. As the depth of water increases, the output of the still decreases. The operating temperature of the basin water and basin liner decreases when the water depth is increased. The accumulated yield of still is highly dependent on inlet temperature of saline water. The addition of heat recovery unit to the solar still has increased the inlet temperature of basin water closer to its saturated temperature which needs a lesser amount of heat for evaporation that in turn leads to higher productivity with higher efficiency. The daily accumulated productivity is increased by 56 % using heat recovery system

References

1. Amumul Ahsan, Arunkumar. T and Sanjay Kumar (2012), "*An experimental study on hemispherical solar still*," Desalination, Vol. 286, pp. 342-348.
2. Amumul Ahsan and Jayaprakash (2012), "*Experimental study on various solar still designs*," Renewable energy, Vol. 23, pp. 1-10.
3. Ashkhan Zolfaghari Sharak, Farshad Farshchi Tabrizi and Hamid Moghdam (2013), "*Theoretical and experimental study of cascade solar stills*," Solar Energy, Vol. 90, pp. 205-211.
4. Kabeel. A.E, Omara. Z.M and Essa. F.A (2014) , "*Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach*," Energy Conversion and Management, Vol. 78, pp. 493-498.
5. Bhardwaj. R, Mudde. R.F and Kortenaar. M.V (2013), "*Influence of condensation surface on solar desalination*," Desalination, Vol. 326, pp. 37-45.
6. Elango. T, Kalidasa Murugavel. K and Rajaseenivasan (2013), "*Comparative study of double basin and single basin solar stills*," Desalination, Vol. 309, pp. 27-31.
7. El-Sebaii. A.A, Aboul-Enein. S, Ramadan M.R.I and El-Bialy. E (2009), "*Year- round performance of a modified single basin solar still with mica plate as a suspended absorber*," Renewable Energy, Vol. 25, Issue 1, pp. 35-39.
8. Ganapathy Sundaram. E, Sivakumar. V (2013), "*Improvement techniques of solar still efficiency*," Renewable and Sustainable Energy Reviews, Vol. 28, pp. 246-264.
9. Hitesh. N and Panchal (2013), "*Enhancement of distillate output of double basin solar still with vacuum tubes*," Engineering Sciences, Vol.29, pp. 123-128.
10. Malik. M.A.S, Tiwari. G.N and Kumar. A (1982), "*Solar Distillation*," Pergamon Press, Vol. 10, pp. 33-38.

11. Naga Sarada Somanchi, Sri Lalitha Swathi Sagi, Thotakura Ashish Kumar and Ajay Parik (2015), "*Modelling and analysis of single slope solar still at different water depth*," Aquatic Prodedia, Vol. 4, pp. 1477-1482.

12. Arunkumar. T, Amimul Ahsan, Denkenberger. R and Jayaprakash (2013), "*The augmentation of distillate yield using concentrator coupled solar still with phase change material*," Desalination, Vol. 314, pp. 189-192.

13. Rai. S.N and Tiwari. G.N (1983), "*Single basin solar still coupled with flat plate collector*," Energy Conversion and Management, Vol. 23, pp. 145-149.

14. Sakthivel. M and Shanmugasundram. S (2008), "*Effect of energy storage medium (black granite gravel) on the performance of a solar still*," International Journal of Energy Research, Vol. 32, pp. 68-82.

15. Saurabh Yadav and Sudhakar. K (2015), "*Different domestic designs of solar stills: A review*," Renewable and Sustainable Energy Reviews, Vol.47, pp. 718-731.

16. Tayab .A. M (1992), "*Performance study of some designs of solar stills*," Energy Conversion and Management, Vol. 33, pp. 889-898.

17. Tiwari. A.K and Tiwari. G.N (2006), "*Effect of water depths on heat and mass transfer in a passive solar still: in summer climatic condition*," Desalination, Vol. 195, pp.78-94.

18. Tiwari. G.N and Bapeshwara Rao. V.S.V (1984), "*Transient performance of a single basin solar still with water flowing over the glass cover*," Desalination, Vol. 49, pp. 231-241.

19. Velmurugana. V and Srithar. K (2007), "*Solar stills integrated with a mini solar pond- analytical simulation and experimental validation*," Desalination, Vol. 216, pp. 232-241.

20. Yadav. Y.P (1991), "*Analytical performance of a still integrated with a flat plate solar collector*," Energy Conversion and Managaement, Vol. 31, pp. 255-263.