Performance Analysis of Modified Basin Type Double Slope Multi-Wick Solar Still

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Abstract: In this paper, effect of brackish water depth and wick material on the performance of modified basin type double slope multi-wick solar still (MBDSMS) has been studied at MNNIT, Allahabad, U.P., India. Modifications made in the conventional Multi-wick solar still leads to significant increase in the heat input, yield obtained and overall efficiency of the modified design. Total yield obtained shows increase with decrease in the depth of brackish water and black cotton as wick material is found to be more effective in comparison to jute wick.

Keywords: Double slope multi-wick solar still, Desalination, overall Efficiency.

1. Introduction

Fresh drinking water crisis is one of the major challenges that most of the countries of the world is facing now a days. There are many factors responsible for this crisis but human actions that include unplanned use of non-renewable energy resources, deforestation etc. are mainly responsible for this crisis of pure water. All these factors affect the availability of pure water which leads to its scarcity in the world. Drinking impure water is hazardous to health of all living beings. Thus, various researches are going on in the field of distillation of water to provide pure water cheaply and easily to all living beings. Solar distillation is one of the area in which many researchers are working to solve the problem of pure water.

In 1982 Tanaka et al. [1] performs an experimental study on a tilted-wick type solar still and found that there was an increase of 20-50% in distillate output in comparison to simple basin type solar still. In 1986 Yeh and Chen [2] analyzed the effects of various parameters like climatic parameters etc. on the output of wick type solar still. In 1992 Singh and Tiwari [3] presented a thermal analysis of a double effect multi-wick solar still. It was concluded that double effect distillation is more efficient at low flow velocity and overall thermal efficiency decreases with an increase in mass flow rate. In 2002 Naim et al. [4] used charcoal particles as absorber medium inside a basin-type solar still.

In 2005 Shukla and Sorayan [5] presented and validated a model for a tilted wick-type solar still. In 2010 Mahdi et al. [6] designed and constructed a tilted wick-type solar still and presented its performance and practical aspects. In 2013 Rajaseenivasan et al. [7] presented a new approach by adding an additional basin in the double slope solar still. Experiments were performed by varying water depths, wick materials, and various energy storing materials. It was found that production rate decreases with increase in the depth of water. Also, it was concluded that production in double basin solar still is 85% more than that of single basin solar still.

In 2015 Hansen et al. [8] investigated the performance of inclined solar still by performing experiments using different wick materials on different absorber plate configurations. It was concluded that, water coral fleece material with porosity (69.67%), absorbency (2s) and capillary rise (10 mm/h) is the most suitable wicking material for higher productive solar still. Also, maximum output of the still was 4.28 litre/day when water coral fleece with wire mesh-stepped absorber plate was used.

Hence, many researchers tried to enhance the productivity of the multi wick solar still by varying different parameters related to the solar still. The above analysis shows that the main problem of a simple solar still is –

1- Its productivity is low.
2- It is not efficient in utilizing the solar energy.

In this paper, analysis of a modified design of basin type double slope multi-wick solar still is performed and the effect of brackish water depth and wick material on MBDSMS has been studied. Experiments are performed on MBDSMS in the climatic conditions of Allahabad, U.P. (Latitude and Longitude is 25°27’ N and 81°44’ E respectively).

2. Solar Distillation

Solar distillation is a technique that utilizes solar energy to produce pure water as its output from
brackish/saline water. Brackish water absorbs the solar radiation falling on the surface of solar still and gets heated. Water vapours are formed when it reaches to its boiling point and this water vapour is condensed and cooled on the cooler transparent, inclined glass surface. This condensate is collected by providing troughs to collect pure water. Solar still is used as an apparatus for solar distillation process. It consists of basin tray which contains impure water, a surface above basin where water vapour gets condensed (glazing cover) and a trough is provided to collect the distilled water and to drain it to the storage tank.

3. Multi-wick solar still

In this type of solar still, a water reservoir is introduced at the top of the absorber and a number of porous fibers like jute cloth pieces are dipped into the water reservoir while the other ends of the porous fiber are spread over the absorber. Water reaches to the top of the absorber through capillary action, thus a thin layer of water is always available for evaporation. Thus, less amount of heat input is required for evaporation in multi-wick solar still as a result of which output yield is more in multi-wick solar still in comparison to simple solar still.

4. Working principle of MBDSMS

In this type, brackish water is collected in the basin through the inlet provided. There are 19 steel rods which support the wick system installed as latest modification to the conventional still as shown in the Fig.1. Water moves to the top of the wick due to capillary action and a layer of water is formed on the wick layer of black cotton 12 cm below the glazing cover. The incident solar radiation has dual advantage of heating the water in the basin as well as evaporating the thin film of water from the wick layer. The water evaporated gets condensed on the inner surface of toughened glass by losing its latent heat of vaporization and is collected in flask after it passes through well designed troughs. The sun’s energy heats water to the point of evaporation. As the water evaporates, water vapour rises and condenses on the inner glass surface and collected. This process removes impurities such as salts and heavy metals and eliminates microbiological organisms leading to the production of pure drinking water.

5. Modifications in conventional multi-wick solar still

Modifications done in the conventional multi-wick solar still to develop MBDSMS are as follows-
1. Condensation takes place on the ceiling of two glasses as well as the south wall, thus, by providing trough on south wall to collect the condensate, increases the net yield from the solar still.
2. There are 19 steel rods which support the wick system installed as latest modification to the conventional still.
3. East, west and south wall are transparent to allow maximum hours of sunshine on the MBDSMS.

6. Experimental Setup

Experimental set up of this study is installed on the terrace of Heat and Mass Transfer and Solar Energy lab (Mechanical Engineering Department), MNNIT Allahabad, U.P., India as shown in fig. 1 and 2. The orientation of the MBDSMS has been kept in east-west direction to receive solar radiation for maximum hours of sunshine. The glass cover dimensions are 1.03×1.03×0.004 m. Basin area of solar still is 2 m². Height of walls of the solar still is 0.12 m at the ends and 0.38 m at the center. Troughs are kept at a height of 7 cm from the base at east, west and south wall for collection of distillate output. 4 outlet pipes are provided (one pipe each at east and west trough and two pipe at south trough) to collect distillate output.
The basin and the north wall are made of Fibre-Reinforced Plastic (FRP) sheet of 5 mm thickness which is blackened from the inside. The south, east and west side walls are made of transparent acrylic sheet of 3 mm thickness (which is equivalent thickness of acrylic sheet with respect to thickness of FRP on the basis of same heat transfer rate). The north wall and basin surfaces are painted black from inside to absorb more solar radiations and prevent it from escaping and use it to heat the basin water. The angle of cover has been chosen as 15° to allow easy collection of condensed water by the action of cohesion, adhesion and gravity. It allows the height of the double slope solar still to be optimum at the center since more height will cause problem in capillary action and the water will not be fed properly for effective evaporation in case of multi-wick solar still.

7. Measurements of various parameters

- **Temperature measurements**

Temperatures are measured by using calibrated T type thermocouples. Water temperature is measured by using mercury-in-glass thermometer having a range of 0-120°C with the least count of 1°C.

- **Radiation measurements**

Solar radiation was measured by solarimeter. Its range is 0 - 1200 W/m² and least count is 1 W/m².

- **Yield measurements**

Graduated cylinders are used to measure the yield obtained from the solar still. Its range is 0 – 250 mL and least count is 10 mL.

8. Results and discussions

8.1 Effect of variation of brackish water depth on MBDSMS

Experiment was performed on MBDSMS by varying brackish water depth on September 10, 2015 and September 16, 2015. Depth of brackish water is 1 cm on September 10, 2015 and 2 cm on September 16, 2015.

Fig. 3 shows that there was a small variation in global solar radiation on September 10, 2015 and September 16, 2015. Hence, comparison can be made by varying depth of brackish water in MBDSMS by assuming same heat input to MBDSMS on both days. From Fig.3, it can be seen that global solar radiation is maximum at 12 noon and is minimum in the morning and evening. Jute is used as wick material in MBDSMS.

Fig. 4 shows that as the global solar radiation increases from 7:00 am to 12 noon (as shown in Fig.3), total yield produced also increases as heat input to the brackish water increases.
Fig. 4 Variation of hourly yield of MBDSMS with time on September 10, 2015 and September 16, 2015

Total yield obtained in MBDSMS at 1 cm and 2 cm depth of brackish water is 3.415 litre/m² and 3.171 litre/m². This is due to the fact that, 1 cm depth of brackish water evaporated early in comparison to the 2 cm depth of brackish water as 1 cm depth has less mass of water in comparison to the 2 cm depth of brackish water. So, more heat is absorbed by 2 cm depth of brackish water before evaporating in comparison to the 1 cm depth of brackish water. And, due to more heat storage capacity of 2 cm depth of brackish water, yield produced by MBDSMS at 2 cm depth of brackish water increases in the night in comparison to that at 1 cm depth of brackish water.

Overall thermal efficiency of MBDSMS at 1 cm and 2 cm water depth is 23.36% and 22.19% respectively. Thus, there is an increase of 7.73% in yield when depth of brackish water decreases from 2 cm to 1 cm in MBDSMS.

8.2 Effect of wick material on performance of MBDSMS

Experiment was performed on MBDSMS with 2 cm depth of brackish water by using jute and black cotton as wick material on March 17, 2016 and March 25, 2016 respectively.

Fig. 5 shows that there was a negligible variation in the global radiation on March 17, 2016 and March 25, 2016. Hence, comparison can be made by assuming same input of global solar radiation on MBDSMS.

Fig. 6 shows that yield obtained with black cotton as wick material is greater than yield obtained with jute as wick material in MBDSMS. This is due to more solar radiation absorbing power of black cotton wick in comparison to jute wick. Due to which, thin layer of water formed due to capillary action at the top of black cotton wick gets evaporated at much faster rate than that in jute wick.

Fig. 6 Variation of hourly yield with time on March 17, 2016 and March 25, 2016

Thus, yield is obtained in case of black cotton wick is more in comparison to jute wick. Total yield obtained in case of black cotton wick is 3.86 litre/m² and in case of jute wick is 3.52 litre/m². There is an increase of 9.94% in yield produced from MBDSMS when black cotton is used as wick material in place of jute wick. Overall thermal efficiency of MBDSMS with jute as wick material is 21.98% and with black cotton as wick material is 24.73%. Rajaseenivasan et al. [8] performed experiments at National Engineering College, Kovilpatti, Tamil Nadu, India on single basin, double basin and double slope solar still of same
basin size 0.9×0.7×0.008 m$^3$ from March to May, 2012. It was concluded that with increasing depth of impure water there was a decrease in the total output yield produced by the solar stills. It was also concluded that of different wick materials (like black cotton, jute pieces, waste cotton cloth) used in the multi wick solar still, black cotton wick was found more effective than the other wick materials. In this research, it is concluded that total yield produced from MBDSMS decreases with increase in depth of brackish water in the solar still. And, black cotton wick is found to be a better wick material in comparison to jute wick. Thus, the results obtained from the experiments performed on MBDSMS shows similar trend as it was in the result of Rajaseenivasan’s experiments.

9. Conclusions

- The study of effect of brackish water depth on the performance of MBDSMS shows that as the brackish water depth increases, yield produced from MBDSMS decreases.
- Total yield obtained in MBDSMS in the month of September at 1 cm and 2 cm depth of brackish water is 3.415 litre/m$^2$ and 3.171 litre/m$^2$ respectively. Thus, there is an increase of 7.73% when depth of brackish water decreases from 2 cm to 1cm in MBDSMS.
- The study of effect of wick material on the performance of MBDSMS shows that black cotton is better wick material in comparison of jute. Thus, there is an increase of 9.94% in yield produced from MBDSMS when black cotton is used as wick material in place of jute wick. Overall thermal efficiency of MBDSMS with jute as wick material is 21.98% and with black cotton as wick material is 24.73% in March, 2016.

10. References