Experimental performance analysis of single slope single basin solar still with extended pin fins basin liner in summer and winter climatic conditions

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Abstract. In this work, the conventional single slope, single basin solar still and modified single slope, single basin solar still with extended pin fins basin liner was fabricated and experimentally investigated in summer and winter climate at Rewa (Lat. 24°33' 20.81'' N). The modified basin liner was prepared by 2.5 cm long and 0.18 cm diameter mild steel pins which were vertically inserted in the basin liner sheet of mild steel. Each pin was kept at a distance of 1.5 cm from the adjacent pin. The basin liner with pin fins was painted black so that more and more solar energy could be absorbed. The daily productivity values of modified pin fins basin liner solar still during summer and winter were obtained as 4.375 Kg/m² and 2.565 Kg/m² respectively. It has been observed that in the modified solar still, 13.2 % more distillate output is obtained than conventional solar still in both summer and winter climate. The increase in the productivity of modified solar still is due to increase in the surface area of basin liner.

Keywords. Solar still; Basin liner; Pin fins; Summer climate; Winter climate

1. Introduction

The idea of life on earth is impossible without water. Even today, scientists are searching for such planets where water is present like on the earth so that that life can be started even there. It shows how much precious the water is for us. Due to the growth of population, industrialization, and urbanization throughout the world, the demand for water is increasing day by day. Only 3% clean water is found on the earth, in which less than 1% of water is available for human beings, and the rest of the water is in the oceans as saline water. Therefore, to meet human water requirements, this saline water must be converted into clean water through available technologies. The technique of solar distillation is a better option for purifying the saline water, in which water is converted into vapor due to the heat of solar radiation, then condensed and impurities get separated from the water in this process. This water is collected for drinking purpose. Solar still is a device which is used for purification of water. The drawback of this technique is that the amount of distillate output is very low. Therefore, scientists from all over the world are working on improving the technology to increase its distillate output.

A thermal model was developed by Kumar and Tiwari [1] for coefficient of convective mass transfer for various values of Grashof Number. Lof et al. [2] observed the effect of various climatic parameters on the yield of the solar still. Cooper [3] developed a simulation technique to analyze the
effect of different parameters of the solar still. Garg and Mann [4] investigated the performance of solar stills (single and double slope) for different parameters in Indian arid zone conditions. Nafey et al. [5] modified the conventional still with the applications of different absorber materials like mat of black rubber (with thickness 2 mm, 6 mm and 10 mm) and black gravel (sizes 7 to 12 mm, 12 to 20 mm and 20 to 30 mm). For 60 liter/m² brine volume and 15° condensing cover inclination, the distillate output increased by 20% with 10 mm thick black rubber mat. Similar results were obtained with black gravel with sizes 20 to 30 mm for 20 l/m² brine volume and 15° condensing cover inclination.

An important research, the effects of different absorbing materials on performance characteristics of conventional solar still were investigated by Abdallah et al. [6]. Three absorbing materials, namely, uncoated and coated metallic wiry sponges, and black volcanic rocks were used. Productivity enhancements for wiry metallic sponge were 28% (coated) and 43% (uncoated). For black volcanic rocks, the productivity enhancement was 60%. A comprehensive study conducted by Rajvanshi [7] on the suitability of dyes at various concentrations for deep basin stills, recommends black naphthylamine for high distillate output. Riahi et al. [8] conducted experiments on three similar sizes, triangular solar stills with different heat storage materials. It was found from the experiments that daily productivity was considerably increased in the case of black painted basin solar still as compared to conventional solar still.

Velmurugan et al. [9] conducted the experimental and theoretical study to enhance the rate of production by using sponge, wicks and fins in the conventional solar still. It was observed that the rate of production increases by 45.5%, 29.6% and 15.3% by using fins, wicks and sponges respectively. Alaudeen et al. [10] carried out experiments on stepped solar still with flat plate collector using heat storage material, namely rocks, pebbles and wicks for enhancing the rate of evaporation resulting in higher productivity as compared to conventional solar still. Theoretical and experimental study on pin fins absorber plate solar still were presented by Aliab et al. [11]. The experiment was conducted during the winter season and basin area was 0.52 m². It was found that the daily distillate output of pin fins absorber plate solar still (modified) is 12% higher than that of conventional still.

Alaian et al. [12] fabricated two identical solar stills. Out of two, one was conventional and other one was modified by incorporating the pin-finned wick surface in basin. It was noticed that the productivity of modified solar still increased by 23% as compared to conventional still. Rabhi et al. [13] carried out the experimental study on pin fins absorber modified solar still with condenser under the climatic conditions of Gafsa-Tunisia. The performance of pin fins absorber plate still with condenser and without condenser and still with condenser only was compared to the conventional still. An important observation was that, the productivity gain for pin fins absorber plate still with condenser, pin fins absorber plate still without condenser and still with condenser only was 41.95%, 23.39% and 11% respectively. Arun Kumar et al. [14] enhanced the thermal performance by using the carbon impregnated foam (CIF) as a floating absorber and bubble-wrap (BW) sheet as insulation of solar still. It was found that productivity of single slope single basin solar still was increased by 24% with CIF and BW whereas productivity of still with BW only was 22%.

The main objective of this work is to improve the productivity of conventional single basin solar still. In this work, conventional basin liner is replaced by vertically extended pin fins basin liner to improve the performance of modified still. The experiment was conducted during summer and winter days. The experimental performance analysis of modified and conventional solar stills in summer and winter climatic conditions was compared and presented.

2. Experimental setup and procedure
Figure 1, 2 (a) and 2 (b) show the schematic view, and a photograph of pin fins basin liner modified solar still experimental setup. The experiment was conducted at Rewa, India (Latitude: 24°33’ 20.81” N).
Figure 1. Schematic view of extended pin fins basin liner modified solar still.

For the experiment, two single slope, single basin solar stills of similar shape and size are fabricated. Out of two, one solar still is used as conventional still in which, the basin liner of 0.1 cm thickness is made of mild steel. This basin liner is painted black to enhance the rate of absorption of solar radiation. In the second solar still which is used as modified still, the traditional basin liner is modified by inserting the vertically extended pin fins. These pin fins are made of mild steel having dimensions as 2.5 cm length and 0.18 cm diameter. Each pin fin is kept at a distance of 1.5 cm from the adjacent pin fin. The surface of the basin liner with pin fins is painted black. Both solar stills are placed along the east-west direction. The plain window glass (4 mm thickness) is used as inclined condensing cover for both solar stills. The glass cover is fitted to the solar still at 24° angle [15]. The gaps between the glass cover and solar still are packed by glass putty and silicone tape in order to make a leak proof system. A distillate channel made from aluminum sheet is used to collect the condensate, which passes through the inner surface of glass cover. This condensate is measured and collected in measuring jar.

Figure 2(a). Photograph of extended pin fins basin liner modified solar still.
This work was conducted during clear days of typical summer and winter, the days in which clear sky conditions and maximum solar radiation was received. During summer, May 20, 2018 and during winter, January 05, 2018 was selected to collect the respective data for experimentation. Global solar radiation, ambient temperature, and wind velocity readings are collected from the solar station situated at Rewa Engineering College, Rewa, India. Calibrated Ni-Cr thermocouples are used with digital thermometer to measure the temperature of various components of solar stills namely glass cover, basin water, basin liner, and modified basin liner. The calibrated measuring jar is used to measure the amount of condensate. The basin of both solar stills is filled by 3 cm water depth. The filled water (groundwater) in the basin was obtained from Rewa Engineering College, Rewa, whose TDS (Total dissolved solids) is 1025 mg/ml. The experimental performance of single slope, single basin solar still is investigated during the summer and winter days for constant basin water depth (3 cm) which is maintained throughout the experimentation. All the readings are taken from 8:00 AM to 8:00 PM with a one-hour interval except nocturnal condensate. It is collected from 7:00 PM to 8:00 AM on the next day.

3. Calculation of distillate output and efficiency

The daily distillate output of modified basin liner solar still per unit basin area is given by the relation [16],

\[ M_{dms} = \sum M_{ms} \]  

Where \( \sum M_{ms} \) represents the sum of hourly distillate output for 24 hours. Of modified still.

The daily efficiency of modified basin liner solar still per unit basin area can be calculated as [16],

\[ \eta_{dms} = \left( M_{dms} \times L_{ev}\right) / \left( \sum I \times 3600 \right) \]  

Where \( L_{ev} \) is the latent heat of evaporation of water in Joule per Kg and \( \sum I \) is the sum of solar intensity for 24 hours.

4. Results and discussion

Figure 3 shows the hourly variations of solar intensity and ambient temperature on one of the typical summer (20/05/2018) and winter (05/01/2018) days in Indian climatic conditions. The maximum solar intensity received during the summer and winter days is 840.6 and 658.4 W/m² respectively at noon while the maximum values of the ambient temperature are obtained as 41.7 °C (at 2:00 PM) during summer and 23.5 °C (at 3:00 PM) during winter respectively. It can be observed that the maximum
value of solar intensity is achieved before the maximum value of the ambient temperature because the mass of air inside the still is higher so that it gradually heats up and the temperature gradually increases up to the maximum level.

Figure 3. Hourly variation of solar intensity and ambient temperature on typical summer and winter days.

Figure 4 depicts the variations of temperature of basin water and glass cover on a one-hour interval of modified and conventional solar still during summer and winter days. It can be seen that the value of basin water temperature of modified solar still is always higher than the conventional solar still during each hour interval of summer and winter days. The maximum temperature values of basin water are found to be 72.4 and 53.1°C (modified still in summer and winter) and 69.7 and 49.7°C (conventional still in summer and winter) respectively. It can be understood that the basin area of modified still increases due to use of the pin fins on the basin liner. Also from figure 4, variations of glass cover temperature of modified and conventional still for summer and winter is presented.

Figure 4. Hourly variations of temperature of basin water and glass cover of solar stills during summer and winter days.

It has been observed that the values of glass cover temperature of modified still are throughout above than conventional still from morning to evening hours. It is because of an increase in the heat transfer area of basin liner of modified still due to vertically extended pin fins. It is illustrated in figure 5, the hourly variations of solar intensity and basin liner temperature of modified and conventional solar stills are plotted during summer and winter.
It can be seen that the pin fins basin liner (modified) temperature is higher than that of the without pin fins (conventional) basin liner for each sunshine hour of the day. As seen in figure 5, solar intensity increases from 8:00 AM to 12:00 noon. The temperature of the basin liner also increases and reaches a maximum value at 2 PM and after that, gradually decreases till evening. A similar trend is observed in both modified and conventional stills during summer and winter. The maximum values of basin liner temperature for summer are found to be 73.8 °C (modified), 71.0 °C (conventional), and for winter 54.7 °C (modified), and 51.1 °C (conventional), respectively. Figure 6 reveals the variation of productivity of modified and conventional solar stills for each hour of the time interval during summer and winter. It is indicated that the higher productivities are obtained during each hour of sunshine time in case of pin fins basin liner still (modified) than without pin fins basin liner still (conventional). This is happening due to the addition of extra surface area (pin fins) in the basin liner. The maximum productivity of each still has been obtained at 3:00 PM in both seasons. The values of maximum productivity are 0.66 Kg/m² (modified) and 0.58 Kg/m² (conventional) for summer and 0.44 Kg/m² (modified) and 0.39 Kg/m² (conventional) for winter respectively.
It has been observed that cumulative productivity for 24 hours (daily productivity) of pin fins basin liner still (modified) is 13.2% higher than that of without fin basin liner still (conventional) for summer and winter days. This corresponds to the fact that the vertically extended pin fins on the basin liner increase the rate of evaporation resulting in higher productivity of modified still than conventional still. The values of daily productivity obtained are 4.37 Kg/m² (modified still) and 3.86 Kg/m² (conventional still) during summer and 2.56 Kg/m² (modified still) and 2.26 Kg/m² (conventional still) respectively during winter. In figure 8, daily efficiency of modified and conventional solar stills during summer and winter is shown. In summer and winter, the values of daily efficiency of modified still in both the seasons are more than the conventional still. The values of daily efficiency in summer are 43.79% (modified still) and 38.64% (conventional still), whereas in winter, the corresponding values are 39.96% (modified still) and 35.24% (conventional still) respectively.
5. Conclusions
Based on the present work the following conclusions can be drawn:

- The main purpose of this work is to use the vertically extended fins in the conventional basin liner of conventional solar still to increase productivity.
- The work is conducted for one of the typical summer (20/05/2018) and winter (05/01/2018) days in Indian climatic conditions.
- The daily productivity obtained during summer is 70% higher than the winter season for both modified and conventional stills.
- The maximum values of basin liner temperature for summer are found to be 73.8 °C (modified) and 71.0 °C (conventional). For winter, the corresponding values are 54.7 °C (modified) and 51.1 °C (conventional) respectively.
- The rate of heating of basin water in modified still is higher as compared to the conventional still.
- The daily productivity is obtained as 4.37 Kg/m² (modified still) and 3.86 Kg/m² (conventional still) during summer and 2.56 Kg/m² (modified still) and 2.26 Kg/m² (conventional still) respectively during winter.
- The daily productivity of modified still is 13.2% more than that of conventional still in both summer and winter seasons.
- The daily efficiency of modified still is higher in comparison to conventional still in summer and winter.
- It is a very cheap and easy method to convert the saline/groundwater into potable water in the backward and remote areas.

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