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Experimental study on a single-slope single-basin solar still with air at different velocities

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ABSTRACT

A single-slope single-basin solar still has been experimentally investigated with hot atmospheric air injected through the copper pipe placed in the still at different velocities. The experiments were conducted in the months of August and September 2016 under the Indian climatic conditions. Experiments were done for different velocities of air such as 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5 m/s. The freshwater productivity with 3.5 m/s of air was higher than the other velocities of air. The productivity of 3.5 m/s of air flowing was 10.78% more than the conventional still. The variations of Reynold's number, Nusselt number and friction factor with the air velocity have also been obtained.

Keywords: Solar still; Productivity; Air; Velocity

1. Introduction

The supply of freshwater is the greatest challenge to the mankind in today's world. The demand for freshwater is increasing day by day due to the increase in the population, development of industries, and so on. Nearly 97.5% of the available water on land is in the form of seas and oceans, which contain dissolved salts and hence unfit for human consumption. Hence, there is a need for seawater desalination. There are several methods and technologies for seawater desalination, for example, distillation, reverse osmosis, and so on. One such method is a solar desalination using solar stills. This method is simple and cost-effective when compared with the other methods.

The only drawback of solar stills is its low productivity. Hence, many researches are done to increase the productivity of solar stills. The influence of hot air injected in a modified still with phase change materials (PCM) was investigated by Kabeel et al. [1]. The productivity of the modified still with PCM was 108% more than the conventional still. Castillo-Tellez et al. [2] performed experiments in a solar still at different average velocities such as 2.5, 3.5, 5.5 and 6.9 m/s and found that the velocity of 3.5 m/s was optimum. Kabeel et al. [3] conducted experiments using trays in a solar still and found that the optimum depth was 5 mm. The productivity was 30.4% higher than that of the conventional still. Omara et al. [4] conducted experiments in a stepped still with internal reflectors and found that the productivity was 75% higher than that of the conventional still. Velmurugan et al. [5] added pebbles in the solar still and found that the productivity was 20% higher than the conventional still. Bapeshwararao et al. [6] studied the effect of the water flowing on the upper glass cover of a double-basin still and found that there is an increase in productivity. Murugavel et al. [7] conducted experiments in a solar still with minimum water depth and also with different storage materials in the basin such as quartzite rock, washed stone, cement block pieces, red brick pieces and iron scraps. Arun Kumar et al. [8] conducted experiments in a single-basin single-slope solar still using agitation effect and external condenser. It was found that the productivity was 39.49% more than the conventional

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still. Rajaseenivasan et al. [9] performed experiments in a flat plate collector basin still and found that the productivity was 60% higher than the conventional still. Alaian et al. [10] investigated the performance of a solar still with pin-finned wick and the enhancement in the productivity was more than 23% than the conventional still. Al-Karaghoulia et al. [11] conducted experiments in a single-basin and double-basin solar stills and found that the productivity of double-basin still was 40% more than the single-basin still. Sakthivel et al. [12] conducted experiments in a solar still with jute cloth as an energy storing material. The productivity of the modified still was 20% higher than the conventional still. Bassam et al. [13] used sponge cubes in a solar still and the productivity increased by 273% compared with the conventional still. Pandey et al. [14] studied the effect of air bubbling and glass cover cooling and found that there is an increase in the productivity compared with the conventional still. Feilizadeh et al. [15] studied the effects of water and basin depths in single-basin solar stills and found that different basin depths can affect the productivity up to 26%. Rajaseenivasan et al. [16] conducted experiments in a glass basin solar still with integrated preheated water supply and used energy storing materials to improve the productivity. Elango et al. [17] studied the effect of water depth on the productivity of single- and double-basin double-slope glass solar stills and found that for the same basin area, the insulated double-basin still was more efficient. Ali et al. [18] compared the productivity of solar stills with conventional absorber plate and pin-fin absorber plate and found that the productivity of pin-fin absorber plate is 12% more than the conventional plate. Abdullah [19] performed experiments with a stepped solar still coupled with a solar air heater and found that the productivity increased by 112% than the conventional still.

In this work, hot air is passed through copper pipe placed in the still at different velocities such as 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5 m/s. The productivity for the air velocity of 3.5 m/s was higher compared with the other velocities of air.

2. Experimentation

2.1. Solar still

Single-slope single-basin solar still was fabricated using 0.01 m thick GI sheet. The glass cover inclination was 25° and the area of the absorber of the basin was 0.5 m × 0.5 m. The schematic diagram of the solar still is shown in Fig. 1. The inner sides of the still basin were painted black to get the maximum amount of incoming solar radiation. The sides and the bottom of the basin were insulated with thermocole of 10 mm thickness. Ordinary window glass was used as the top glass cover of the solar still with a thickness of 3 mm.

The experimental setup was kept facing south to receive the maximum amount of solar radiation. Silicon rubber sealants were used to seal between the glass cover and the body of the still to prevent leakages, if any, of the evaporated vapour. The distillate was collected in a distillation trough that was fitted on the lower side of the still. An inlet pipe was provided to supply the saline water and drain tubes were provided to remove the impurities. Fig. 2 shows the photographic view of the copper pipe placed in the still. Fig. 3 shows the photographic view of the still with air blower.

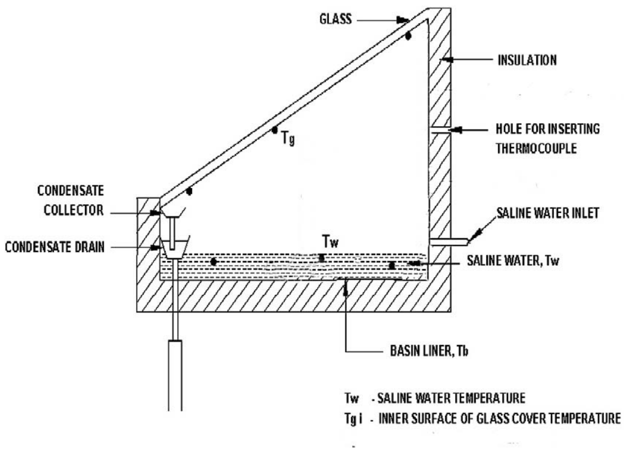

Fig. 1. Schematic diagram of the single-slope single-basin solar still.

Fig. 2. Photographic view of the copper pipe placed in the still.

2.2. Experimental procedure

Experiments were conducted in a still at the University College of Engineering, Villupuram (11.9547°N, 79.5277°E), Tamil Nadu, India. The experiments were conducted during the months of June and July, 2016. The depth of water used was 3 cm for all the experiments. For each velocity of air, the readings were taken for 3 days. The maximum sunshine day values of solar radiation, wind velocity and productivity (Figs. 4–6) were considered for the analysis.

Fig. 3. Photographic view of the still with air blower.

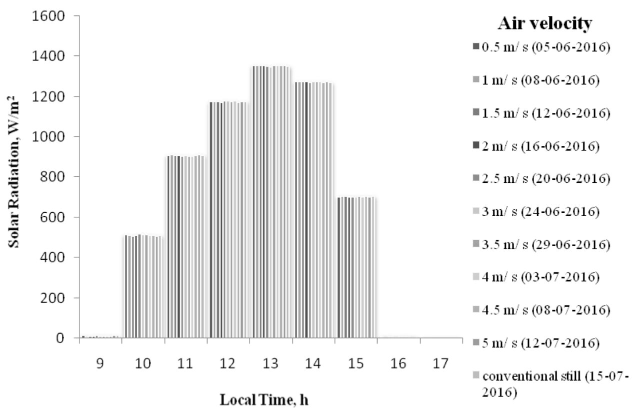

Fig. 4. Variation of solar radiation.

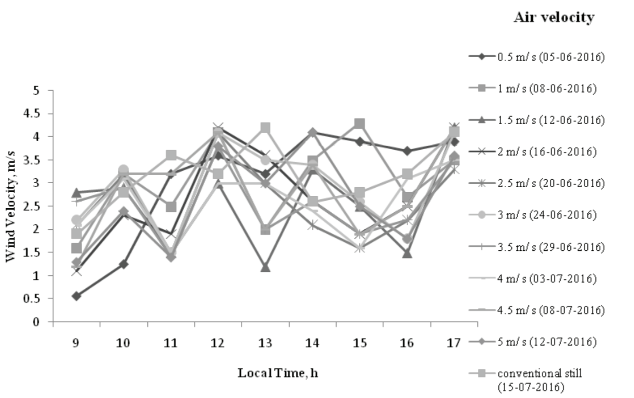

Fig. 5. Variation of wind velocity.

The readings were taken for every 1 h interval from morning 9 am until the evening 5 pm. The incident radiation was measured by the PV type sun meter. The wind velocity was measured by digital anemometer and the ambient temperature was measured by mercury thermometer. The temperatures of the saline water, absorber plate and the inner glass cover were measured using the K-type thermocouples with multi-channel digital display unit. The basin and the glass cover must be cleaned at regular intervals to prevent the salt deposition and the dust. The error analyses are shown in Table 1.

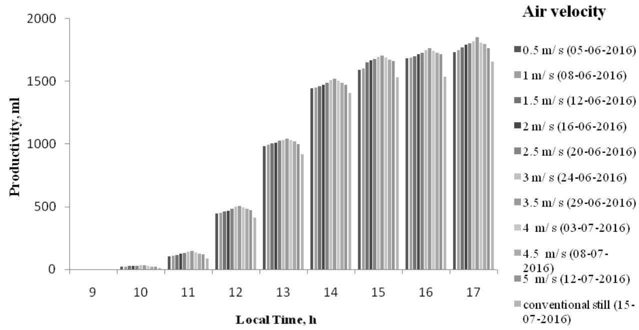

Fig. 6. Variation of productivity.

Table 1
Accuracies and error for various measuring instruments

S. no.	Instrument	Accuracy	Range	% Error
1	Thermocouple	±1°C	0–100°C	0.25
2	Solarimeter	±1 W/m²	0–5,000 W/m²	0.25
3	Anemometer	±0.1 m/s	0–15 m/s	10.00
4	Measuring jar	±10 mL	0–1,000 mL	10.00
5	Thermometer	±1°C	0–100°C	0.25

3. Theoretical analysis

- Heat transfer coefficient 'h' is calculated as:

$$h = \frac{Q}{A(T_s - T_f)} \tag{1}$$

where Q is the heat transferred in W; A is the area of the tube in m²; T_s is the surface temperature of the tube in °C; T_f is the average air temperature in the tube $(T_i + T_o/2)$ in °C.

- Heat transfer:

$$Q = mC_p\,(T_o - T_i) \tag{2}$$

where m is the mass flow rate of the fluid in kg/s; C_p is the specific heat capacity of the fluid in kJ/kg K; T_o is the temperature of the fluid at the exit in °C; T_i is the temperature of the fluid at the inlet in °C.

- Nusselt number: Nu

$$Nu = \frac{hD}{k} \tag{3}$$

where h is the heat transfer co-efficient in W/m²K; k is the thermal conductivity of the fluid in W/m K.

- Friction factor 'f_D': The friction factor was determined using the Darcy–Weisbach equation:

$$f_D = \frac{2\Delta pD}{\rho LV^2} \tag{4}$$

where V is the flow velocity in m/s; Δp is the pressure drop in N m²; ρ is the density of the fluid in kg/m³; D is the inner diameter of the pipe in m; L is the length of the pipe in m.

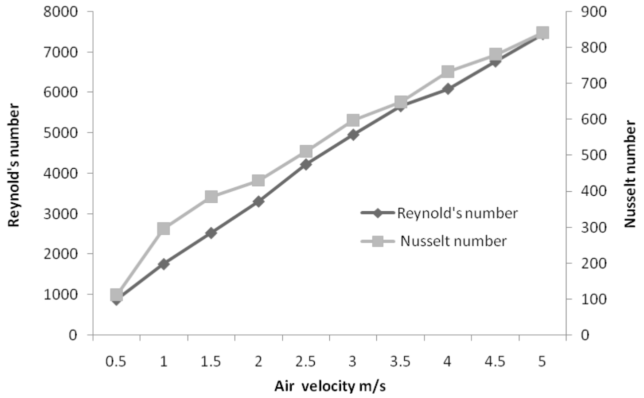

Fig. 7. Variation of Reynold's number and Nusselt number with air velocity.

- Reynold's number 'Re': The Reynold's number of the air flow in the tube is calculated from the relation:

$$\mathrm{Re} = \frac{VD}{\gamma} \tag{5}$$

where γ is the kinematic viscosity of the fluid in m^2/s.

4. Results and discussion

The graphs show the changes of climatic conditions on the days of experiment even though the experimental days were different. Figs. 4, 5 and 6 show the variation of solar radiation, wind velocity and the productivity, respectively, of the solar stills. Fig. 7 shows the variation of Reynold's number and Nusselt number with the air velocity. It is found that the Reynold's number and Nusselt number increase with the increase in the air velocity. Fig. 8 shows the variation of friction factor with the Reynold's number. It shows that increase in the Reynold's number decreases the friction factor.

5. Economic analysis

The payback period of the experimental setup depends on the overall cost of fabrication, maintenance cost, operating cost and cost of feed water. The cost of feed water is negligible.

The cost of fabrication of the conventional still is Rs. 4,000 and the fabrication cost for the still with 3.5 m/s of air passing through the pipe is Rs. 6,000 (includes the cost of still and the copper pipe used for the air supply). The economic analysis of the system is shown in Table 2. The system with 3.5 m/s of air yields 10.78% more productivity than the conventional still. The payback period of the still with 3.5 m/s of air is 5.40 years, which is greater than the payback period of 4.04 years for the conventional still.

6. Conclusions

The studies on the performance of the still with different velocities of air were done. It showed that the still with 3.5 m/s of air gave more productivity than the other stills. The use of 3.5 m/s of air in the still increase the productivity by 10.78% more than the conventional still. The Reynold's number, Nusselt number, friction factor and the climatic conditions play a vital role in improving the performance of the solar stills. The cost analysis shows that the payback period of the still with 3.5 m/s of air is 5.40 years, which is greater than the payback period of 4.04 years for the conventional still.

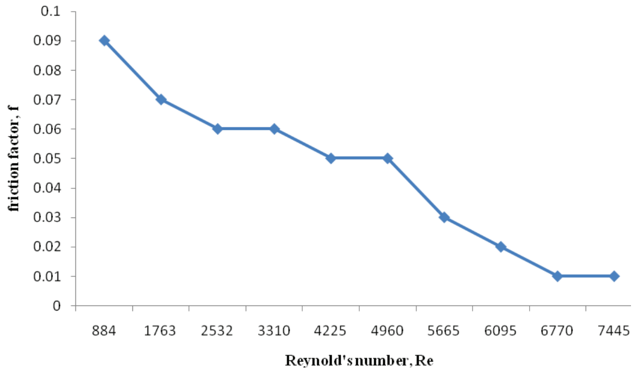

Fig. 8. Variation of friction factor.

Table 2
Economic analysis

Factors	Conventional still	Still with 3.5 m/s velocity of air
Fabrication set up	Rs. 4,000	Rs. 6,000 (includes energy spent on air)
Yearly usage	300 d	300 d
Productivity/day	1.65 $L/m^2/d$	1.85 $L/m^2/d$
Total production	300 × 1.65 = 495 L/year	300 × 1.85 = 555 L/year
Total cost saved	495 L × Rs. 2 L^{-1} = Rs. 990	555 L × Rs. 2 L^{-1} = Rs. 1110
Payback period	4.04 years	5.40 years

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