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Desalination of Water Using Double Slope Double Basin Solar Still Coupled With Evacuated Tubes

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Abstract: Water temperature and glass temperature are the quantities which give productivity of a solar-still. This paper deals with a study done on a double-slop, double -basin solar-still directly connected with evacuated tubes, where in productivity is increased upon reduction of heat loss. Eight double-walled hard borosilicate glass tubes have been used. The experiments were conducted on the still only during sunlight hours from 9 am to 5 pm; and by using tap water as feed. Results obtained were plotted and laboratory results of chemical composition of water given as input and collected from the basin were found out.

Index Terms: Desalination, double basin, double slope, evacuated tubes, solar still.

I. INTRODUCTION

We all know the Earth is covered mostly with water bodies, but availability of water for edible purposes are limited. Day by day there is an increase in demand for fresh water; it's because of various reasons – population increase, agriculture now is more intensified, and of course the improved living standards. The limited potable water is not uniformly distributed across the globe. Apart from cities and developing regions, what can be done in arid regions? It's down to the option of desalination of seawater and sometimes brackish water to satisfy the current and future demands. There arises a need for purification of water, not just any method but of economically viable and simplicity in technology- one such method is Solar distillation.

Similar to the hydrological cycle in nature, a solar still works in cycle of evaporation and condensation. There are two types of solar still – Active and Passive. Passive solar still is single basin type. This cost-effective type of solar still has simplicity in construction but has a low yield. Active solar still is fed with extra thermal energy to the water inside basin to enhance the temperature of water through the concentrated solar collectors.

The main objective of this work involves fabrication of a double slope double basin solar still coupled with evacuated tubes. The inclination of these pipes is 20° with horizontal axis; and were attached to lower basin of still having area of 1 m^2. Polystyrene was used as insulation material to prevent heat loss. Outer tubes of evacuated tubes were transparent; inner tubes were coated with a selective coating of Al-Ni/Al compound for better solar radiation absorption and minimum emittance. These tubes were used to give extra thermal energy to the system and thereby increasing the water temperature. When the water temperature increases, the evaporation rate increases which also increases the productivity rate of distillate water[1].

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II. EXPERIMENT SETUP

The setup was designed and installed at Amrita School of Engineering, Amritapuri (latitude**:** 9.09°N, longitude**:** 76.49°E and an altitude of 26m above sea level), Kerala, India. The experiments were carried out during the month of January 2019 from 9:00am to 5:00pm. Figure 2.1 and Table 2.1 shows diagram and specification of setup.

The solar still setup is mainly divided into two parts – basin and evacuated tubes. The basin here used is double slope double basin. This 1 m^2 area basin is made using Galvanized Iron (GI) sheets. Apart from top surface, all the sides are insulated to reduce the heat loss to atmosphere. Borosilicate glass is used to restrict the water vapor and condense the same. It is fixed at 15° with respect to horizontal axis. Tap water used to fill the basin. There are 2 inlets, 4 outlets and a drain pipe which is fixed at the bottom of the basin. Portions for both inlet and outlets are given at the rear face. Outlets at the left and right sides of the rear face to collect the condensed water which is coming through the U-shaped folded GI sheet at the interior side of walls of basin. Water is collected using a measuring jar. In order to hold the glass structure intact with basin surface sealant used was silicon rubber, also to prevent vapor leakage. Holes are provided at the upper and side of basin to fix thermo couples inside.

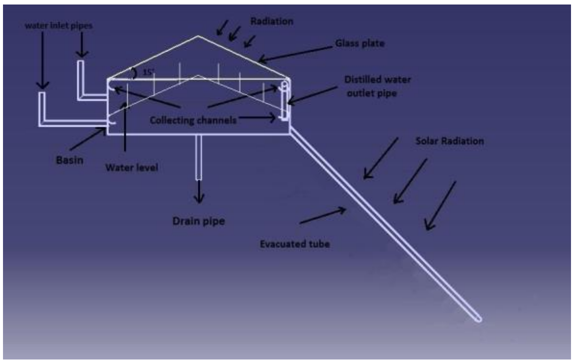

Fig. 1 Diagram of setup.

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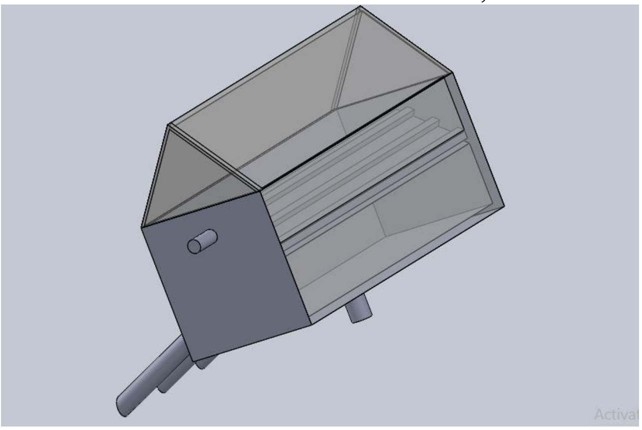

Fig. 2 Arrangement of setup

outlets and a drain pipe which is fixed at the bottom of the second is the evacuated tubes (the arrangement is shown in figure). These tubes are connected through 5 cm diameter hole on lower side of still. 20° inclination is provided for tubes which are placed on wooden stand. This inclination is maintained to receive maximum solar radiation. Reflected plates made of aluminum are used to increase the radiation by reflecting the rays that fall on them back to the tubes. They are placed below the tubes. CPVC pipes are used to fix the tube to the inner side of basin. Heat energy is transferred to water in the tube by a selective surface absorber present in inner glass after receiving solar radiation. The vacuum between the inner glass and outer glass is to reduce heat loss. The flow of water to these tubes take place naturally through the single ended opening. [2]

Table 1. Specification of setup

Basin Material	Galvanized iron sheet (0.002m)
Basin area	1m*1m
Basin height	0.3m
Transparent cover	Glass material (0.004m)
Glass plate inclination	15^0 with horizontal
Insulation material	Solid Polystyrene
No. of tubes	8
Length of tube	1.5m
Inner and outer diameter of Evacuated tube	0.047m and 0.058m
Centre distance of two adjacent tubes	0.100m
Tube material	Borosilicate glass
Tube inclination	20^0 with horizontal

III. OPERATING PRINCIPLE AND PROCEDURE

This system works similar to nature's hydrological cycle. The solar radiation penetrates through the glass surface heats up the water which is on the basin. This heated water evaporates due to difference on volatility, salt and chemical substances are left back after the condensation which take place on inner surface of the glass. The water after condensation drips down the inner surface and carried away by the channel provided and measuring jar collects it. The collected water is free from further chemical contamination. [3]

The basin is initially filled with water sample (who's chemical composition is tested) from feed tank through the provided inlet at the rear face. There are two concentric borosilicate tubes in this evacuated tube set up. The space in between the tubes is vacuum. Water is filled in inner tube; the selective coating absorbs heat from radiation. Due to the heat transfer from the coating water present in inner tube is heated and it moves up the basin and cold water enters the tube. The water in basin is heated by this thermosiphon process. Moreover, the convection losses in evacuated tube is null. The experiments were carried out between 9.00 hrs. and 17.00 hrs. and The variables measured in this experiment are water temperature, T_w, basin temperature T_b, vapor temperature, T_v, inner glass temperature, T_{gi}, outer glass temperature, T_{go}, evacuated tube inlet temperature, T_{ei}, evacuated tube outlet temperature, T_{eo}, ambient temperature, T_a, solar radiation on still, $I_s(t)$, solar radiation on evacuated tube, $I_e(t)$, wind speed, V and productivity (hourly distillate yield) P, will be measured on hourly basis. [4][5]

IV. MEASURING INSTRUMENT

During the experiment period, the wind speed was found to be in the range of 2.5 m/s in Kollam. "K" type thermocouples were used to find out the temperatures at various locations in the still, which was in the range of 0-700 K. Pyrometer in the range of 0-1200 W/m^2 was used to find out the intensity of radiation. Concluded that the average solar intensity radiation at Kollam was 4.62 kWh/m^2 /day. 1000ml measuring jar is used for collecting the water.

V. THEORETICAL ANALYSIS OF SOLAR STILL

A. Energy balance of still

$$\alpha_g I(t) + h_{1w}(T_w - T_g) = h_{1g}(T_g - T_a) \quad (1)$$

$$\alpha_w I(t) + h_1(T_b - T_w) = M_w C_w \frac{dT_w}{dT} + h_{1w}(T_w - T_g) \quad (2)$$

$$\alpha_b I(t) = h_{1w}(T_b - T_w) + h_b(T_b - T_a) \quad (3)$$

h_{1w} : Total internal heat transfer coefficient between water surface and glass cover. [6]

B. Bottom and side loss coefficient

Heat loss also take place from water in the basin to the ambient through insulation also,

$$q_b = h_b(T_b - T_a) \quad (4)$$

Overall thermal efficiency of the still,

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$$\eta_{Active} = \frac{m_{ew} * L}{((I(t)_c * A_c * 3600) + (I(t)_s * A_s * 3600))} \quad (5)$$

where,

$$m_{ew} = \frac{h_{ew}(T_w - T_g)}{L} * A_s * 3600 \quad (6)$$

L is the latent heat of vaporization, and is calculated using the following expression.

For Tv < 70°C:
$2.2935*10^6*[1- 9.4779*10^{-4}Tv +1.3132*10^{-7}Tv^2-4.7974*10^{-9} Tv^3]$
For Tv >70°C:
$3.1615*10^6*[1- (7.616*10^{-4}*Tv)]$ (7)
where,
T_v, vapor temperature $T_v = (T_w+T_g)/2$ (8)

VI. RESULTS

Various temperatures (°C), solar intensity (W/m^2), Production (ml/m^2) were found out and were plotted against local standard time (hr). Also, the chemical composition of water given as input and output produced were tabulated. [4]

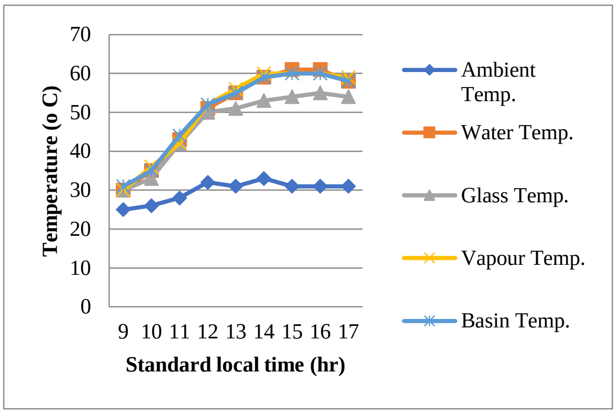

Fig. 3 Temperature plot

Figure 3 shows the temperature of the setup at various points. The temperature of water reaches its maximum after the peak hours of the surrounding (that is 1200hrs).

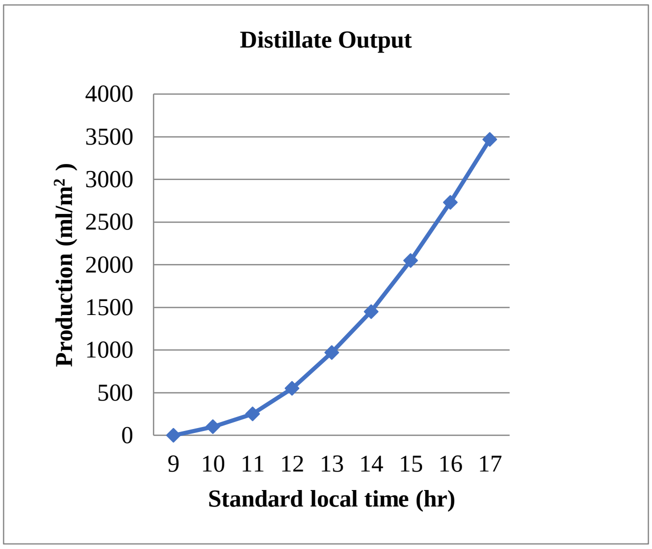

Fig. 4 Distillate Output

Table 2. Test report of water inlet

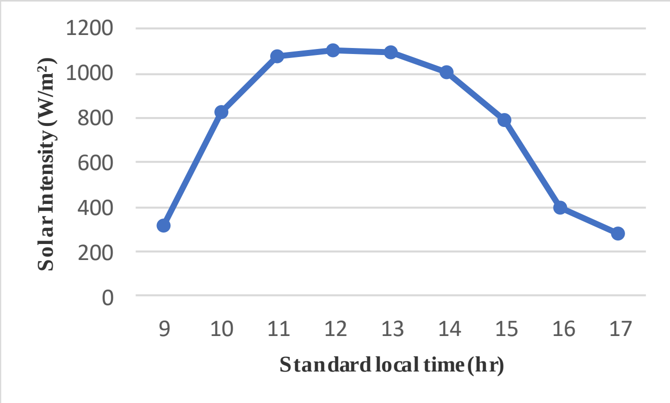

Fig. 5 Solar intensity

From Fig.5, the maximum solar intensity the solar still can get is during mid-day. After this point the graph declines to a lower point.

Test Parameter	Test method	Units	Result
Colour	IS 3025 Part 4: 1983 RA 2017	Hazen	1.00
Taste	IS 3025 Part 8: 1984 RA 2017	-	Agreeable
Turbidity	IS 3025 Part 5: 1984 RA 2017	NTU	1.40
pH	IS 3025 Part 11: 1983 RA 2017	-	6.40
Total dissolved salts	IS 3025 Part 16: 1984 RA 2017	mg/L	23.0
Total hardness ($CaCO_3$)	IS 3025 Part 21: 2009 RA 2014	mg/L	<1.00
Total alkalinity ($CaCO_3$)	IS 3025 Part 23: 1986 RA 2014	mg/L	3.94

Table 3. Test report of water outlet

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The tables 2 and 3 shows the chemical property values of water sample given as input and water sample got back as output. These properties can be compared with the standard data of drinking water.

Test parameter	Test method	Units	Result
Color	IS 3025 Part 4: 1983 RA 2017	Hazen	1.00
Taste	IS 3025 Part 8: 1984 RA 2017	-	Agreeable
Turbidity	IS 3025 Part 5: 1984 RA 2017	NTU	3.40
pH	IS 3025 Part 11: 1983 RA 2017	-	6.83
Total dissolved salts	IS 3025 Part 16: 1984 RA 2017	mg/L	253
Total hardness ($CaCO_3$)	IS 3025 Part 21: 2009 RA 2014	mg/L	56.6
Total alkalinity ($CaCO_3$)	IS 3025 Part 23: 1986 RA 2014	mg/L	47.3

VII. CONCLUSION

Solar distillation is one of the methods for removing dissolved salts in water. This process can be achieved by the double slope double basin solar still coupled with evacuated tubes. Use of polystyrene as insulation helped to reduce heat loss from basin, thus increasing the productivity of still. Another advantage of double basin is that it prevents the heat loss from lower basin to atmosphere. Water quality analysis which was carried out show significant decrease of number of dissolved salts.

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