COMPARATIVE STUDY OF STEPPED AND WEIR TYPE CASCADE SOLAR STILL

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ABSTRACT

In this communication comparison of stepped and weir type cascade solar still have been made under the hot and humid climatic conditions of Hisar, India. Two solar stills of similar dimensions have been designed, fabricated and tested. Thermal performance of both the still has been analyzed using Dunkle's correlation and various heat transfer coefficients were evaluated. Productivity of weir-type cascade solar still was observed to be 2.1 l/m^2 which were nearly 20% higher than stepped solar still. Average values of heat transfer coefficients (convective, evaporative and radiative) for stepped solar still were found as 1.25, 11.4 and 7.06 W/m^2 ^{o}C respectively and for weir type cascade solar still they were observed as 1.43, 12.8 and 7.0 W/m^2 ^{o}C respectively. Efficiency of weir type cascade still was found 22% higher than stepped solar still.

Keywords: Dunkle's Correlation, Heat Transfer Coefficients, Productivity, Stepped Solar Still, Weir Type Cascade Solar Still

I. INTRODUCTION

Water scarcity and environment degradation are the major concern of today globally. From the last decade, main focus in the world is to save environment and using renewable energy for different activities of life. Solar distillation is one of the thermal technique in which contaminated water is evaporated and condensed to collect potable water. It is a free, clean, simple, and low cost water purification method. Main disadvantage of this technique is its lower distillate output. To meet the water demand different designs of solar stills along with different parameters are studied and tested all over the world [1-3].

Basic principle of solar distillation is similar to natural hydrological cycle. Simple conventional type solar still is schematically shown in Figure 1. It consists of an air tight basin made up of concrete/cement, galvanized iron sheet, or fibre reinforced plastic in which impure/contaminated water is placed. Inner surface of the basin is black painted to absorb maximum solar radiation. The base and side walls of the still are well insulated to minimize heat losses. Whole assembly is covered with a transparent cover of glass to allow free entry of sunlight. Solar radiations after passing through the transparent cover entrapped into the closed enclosure and absorbed by the water and blackened surface. Thermal energy from the basin surface is convected to water mass and raises its temperature which causes evaporation of brackish/impure water. The evaporated water vapor gets condensed in the inclined transparent glass/plastic cover and gets collected in the collection chamber. Solar distillation process easily removes the salt and other impurities such as water borne pathogens, heavy metals, microbiological organism etc. from the contaminated water [4].

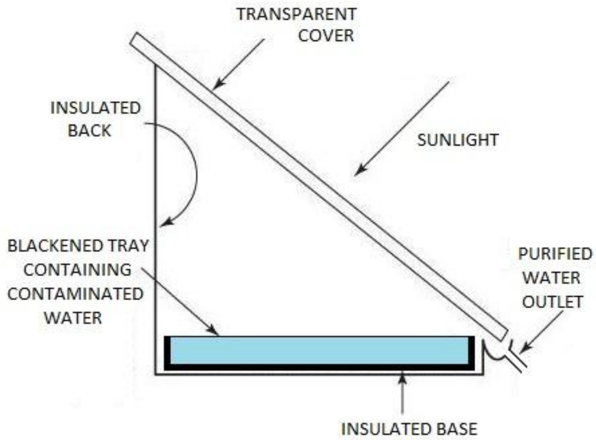

Figure 1. Schematic view of conventional solar still

There are three important parameters which affect the performance of solar still viz., design, operational and meteorological parameters respectively. Numbers of solar still designs like hemispherical, conical, wick type, inclined, double basin double slope, spherical, stepped type, weir type cascade solar still etc. gives the distillate higher than the conventional solar still. Water depth, salinity, internal and external reflector, condensing cover material and its inclination angle, energy storage materials etc. are some operational parameters which improves the distillate output. Meteorological parameters include wind speed, ambient temperature, solar intensity, latitude of the place etc. [2, 4]

Stepped and weir type cascade solar stills are improved designs of conventional still. Efficiency and distillate output of these designs of solar stills were found comparative with other designs. Some of the research work carried out on stepped and weir type solar stills with different parameters are discussed below.

Kabeel et al., [5] studied and compared the performance of stepped solar still with conventional solar still. Productivity of stepped solar still was investigated at different depth and width of trays, using wicks on vertical side of still and by supplying preheated water from vacuum tube solar collector to solar still. Productivity of stepped solar still was found inversely related with water depth and dependent on absorber tray depth and width. Omara et al., [6] investigated the performance of stepped solar still with and without internal reflectors. An increase of 75% and 57% in distillate was observed in stepped still with and without internal reflectors over conventional still. In the next study, Omara et al., [7] tested the performance of stepped solar still with internal and external reflectors. Distillate was observed to be increased upto 75% with the use of internal reflector and by 125% with the use of both internal and external reflectors. Abdullah [8] studied the effect of various parameters viz., hot air, heat storage and glass cover cooling on the performance of stepped solar still. Productivity of stepped solar still was observed to increased by 85%, 53%, and 65% with the use of hot air, heat storage and glass cover cooling on it. Experiments were carried out with industrial effluent water as feed in stepped and single basin solar still coupled with solar pond by Velmurugan et al., [9]. Proposed system has been tested using Pebble, baffle plate, fins and sponges for improvement in distillate output. An increase of 78% in productivity was observed with fin and sponges in stepped solar still. Velmurugan et al., [10] tested the performance of stepped solar still integrated with settling tank for effluent desalination. Effect of sponges, fins, pebbles and their combinations were also studied with stepped solar still. An overall increase of 98% in productivity was observed when fins, sponges and pebbles were used in stepped solar still. Saravanan and Manikandan [11] studied the effect of flow rate and phase change material on the performance of single slope stepped solar still. Productivity of the stepped solar still was observed to increase with low flow rate and using phase change material. A weir type cascade solar still with and without phase change material (PCM) was studied by Tabrizi et al., [12]. Performance of designed still was highly increased using PCM in cloudy days. Maximum distillate output of 4.85 and 5.14 kg/m^2 was observed at minimum flow rate of 0.055 kg/min for still with and without PCM in sunny days. Further, effect of water level on the absorber plate and air gap between water surface and glass plate on the performance of weir type cascade solar still was studied by Dashtban and Tabrizi [13]. It was concluded that productivity of the still was increased by reducing the water level and air gap in the still. With the use of PCM, still shows 31% higher yield than the still without PCM. Effect of water flow rate on thermal performance of weir type cascade solar still was investigated by Tabrizi et al., [14]. Distillate output of 7.4 kg/m^2 day was collected at minimum flow rate of 0.065 kg/min. In further investigation, Ziabari et al., [15] modeled a cascade type solar still system. Various characteristic and drawbacks of initial systems was studied and the performance of modified system was investigated. Average distillate of the proposed still was found to be around 6.7 l/m^2. Zoori et al., [16] studied the effect of various parameters on energy and exergy efficiency of cascade weir type solar still. Efficiency of the system was reduced by increasing brine flow rate and with increase of water thickness over absorber plate. Maximum energy and exergy efficiency of 83.3% and 10.5% were observed at 0.065 kg/min of brine flow rate. Hansen et al. [17] investigated the performance of inclined solar still with different wick materials. 4.28 l/day distillate was collected with water coral fleece wick with wire-mesh stepped absorber plate. Recently, Kabeel et al., [18] reviewed various performance improvement techniques for stepped solar still.

In this paper, comparative study of stepped and weir type solar still have been made under the climatic condition of Hisar, India. Two solar stills of same basin area have been fabricated and tested and their performance has been thermally evaluated using Dunkle's correlation.

II. EXPERIMENTAL SET-UP DETAIL AND THERMAL ANALYSIS

Stepped and weir type solar still have been fabricated using 6 mm wooden box with an area of 0.25 m^2. Box is completely insulated with 10 mm thermocol sheet for prevention of heat losses from side walls. Absorber plate of stepped type solar still have been made of aluminium sheet having ten steps of equal size 50 cm × 5cm × 3 cm. Plate is black painted for maximum absorption of incident solar radiation. Whole assembly is covered with 4 mm glass cover inclined to 30^o angle. Basin/absorber plate of weir type solar still is in stepped form and each stepped has some section through which water will flow. Schematic view of stepped solar still and absorber plate of weir type solar still has been shown in Figure 2 (a, b).

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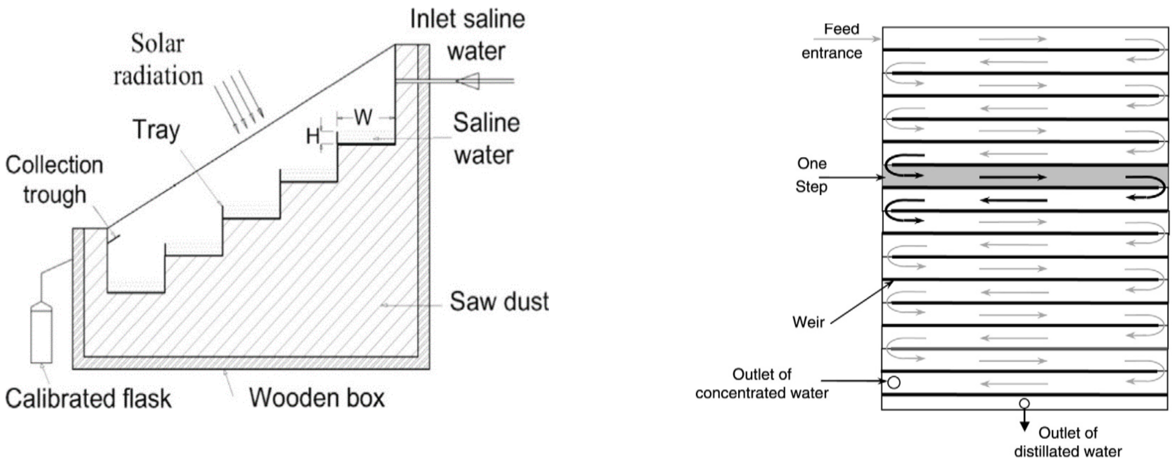

(a) (b)

Figure 2 (A, B): Schematic View Of Stepped Solar Still and Absorber Plate of Weir Type Solar Still

The various temperatures at different location of solar still were measured using calibrated Pt-100 thermocouples with a digital temperature indicator of 0.1 ^{o}C least count. The solar intensity was measured by using solar power meter (MECO). The mass of distilled water collected was measured with an electronic weighing balance (Capacity of 6 kg; Smartech) having a least count of 0.1 kg. The essential data of temperatures, sun radiations and distilled output was recorded at 7 a.m. to 6 p.m. The experimental data was recorded after every 1 hour time interval. The amount of distilled water collected for each hour reading was obtained by subtracting two consecutive reading in a given time interval. Dunkle's correlation was used to evaluate the thermal performance of stepped and weir type solar still using experimental data. Tiwari and Tiwari [19] gives the Dunkle's correlation as

$$h_{cg} = 0.884\left[T_w - T_g + \frac{(P_w - P_g)(T_w + 273)}{268.9\times10^3 - P_w}\right]^{1/3} \quad (1)$$

Evaporative and radiative heat transfer coefficient is evaluated using Eq. (2) and Eq. (3)

$$h_{eg} = 0.01623\times h_{cwg.}\left[\frac{P_w - P_g}{T_w - T_g}\right] \quad (2)$$

$$h_{rg} = \varepsilon_{eff} \times \sigma\,[(T_w + 273)^2 + (T_g + 273)^2](T_w + T_g + 546) \quad (3)$$

where,

$\varepsilon_{eff} = 1/(1/\varepsilon_w + 1/\varepsilon_g - 1)$

The efficiency of solar still is given by

$$\eta_{passive} = \frac{\sum m'_{ew} \cdot L_w}{A_p \int I(t)\,dt} \times 100 \quad (4)$$

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III. RESULTS AND DISCUSSION

Various heat transfer coefficient were evaluated using measured temperature at different location of solar stills. Basin area, solar intensity and distillate output were used to calculate efficiency of solar stills. Cumulative distillate output for stepped and weir type solar still was observed to be 1.65 l/m^2 and 2.1 l/m^2 respectively. Higher basin water temperature and distillate output was observed at higher solar intensity period i.e. during afternoon hours (12 noon to 3:00 p.m.). Solar intensity, basin water temperature and distillate output of stepped and weir type solar still is shown in Figure 3 to 5.

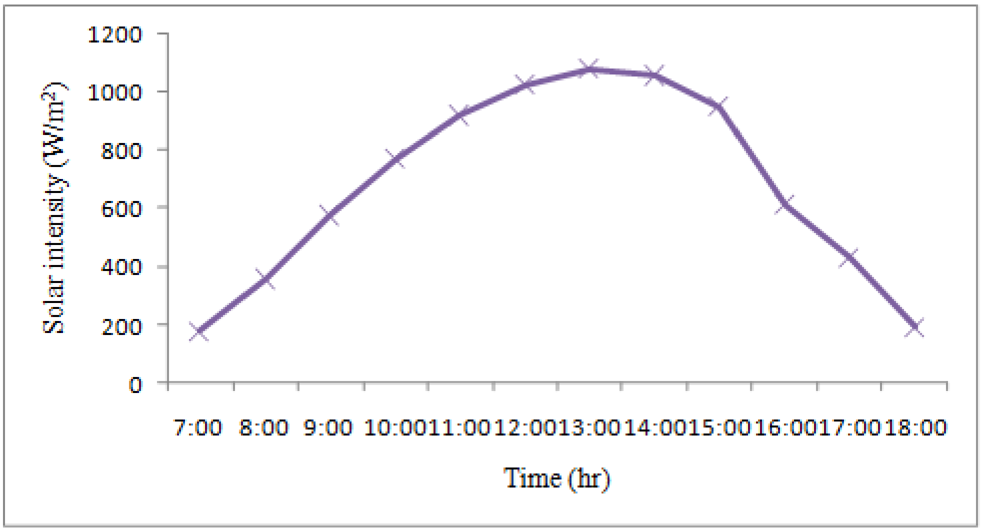

Figure3. Solar Intensity during day of experiment

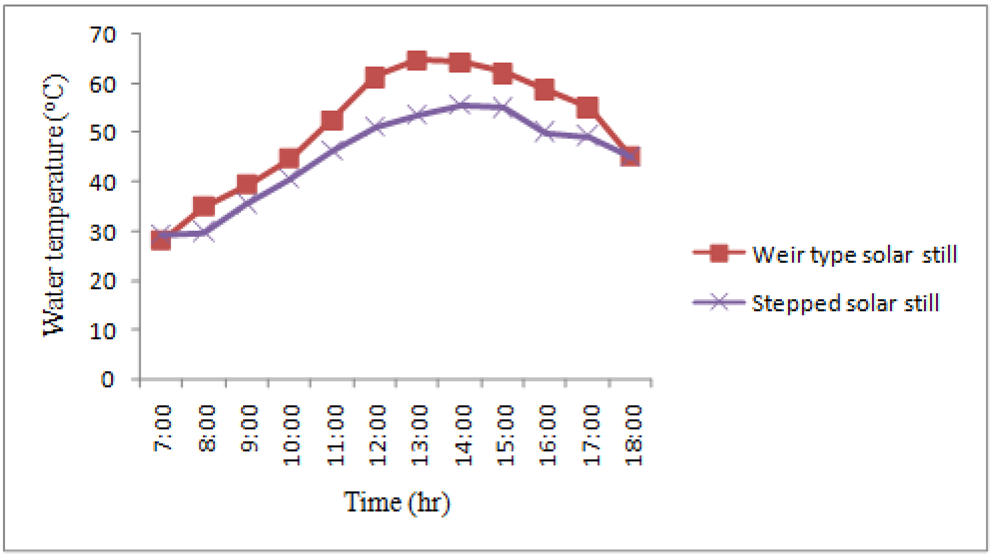

Figure4. Basin water temperature of stepped and weir type solar still

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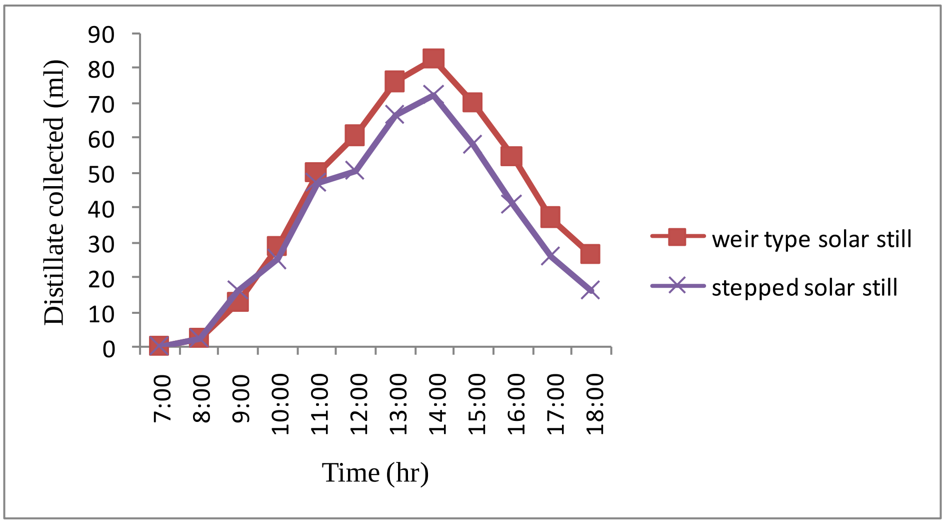

Figure5. Distillate output of stepped and weir type solar still

Average values of various heat transfer coefficients (convective, evaporative and radiative) for stepped solar still were found as 1.25, 11.4 and 7.06 $W/m^2 \, ^oC$ respectively and for weir type cascade solar still they were observed as 1.43, 12.8 and 7.0 $W/m^2 \, ^oC$ respectively. Values of evaporative heat transfer coefficient were observed to increase with increase of solar radiation and it decreases in late hours. Thermal efficiency of stepped and weir type solar still was observed as 16.7 and 21.4% respectively. Figure 6 and Figure 7 shows the variation of convective, evaporative and radiative heat transfer coefficients for stepped and weir type solar stills.

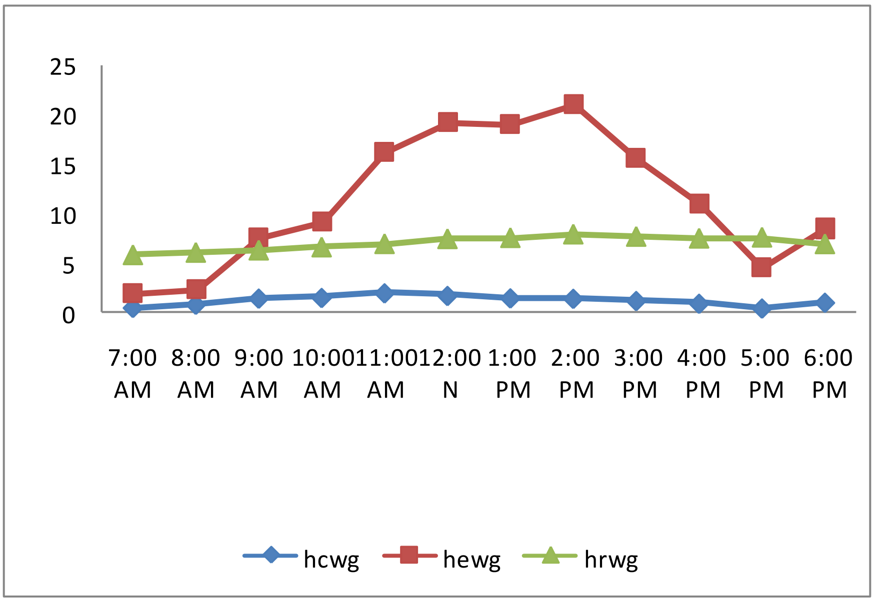

Figure 6: Variation of Various Heat Transfer Coefficients For Stepped Solar Still

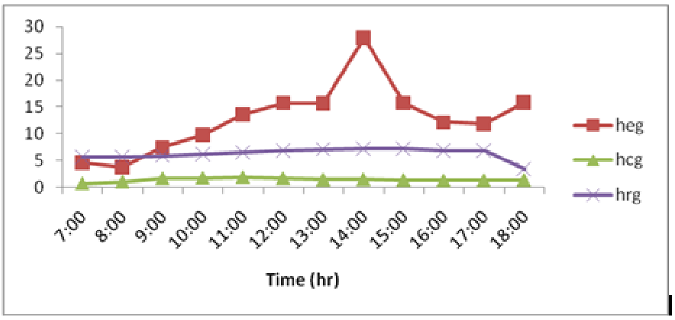

Figure 7: Variation of Various Heat Transfer Coefficients For Weir Type Stepped Solar Still

IV. CONCLUSION

Stepped and weir type cascade solar still is one of the simplest design modification of conventional solar still. The steps on still basin increase evaporative area which helps in more heat absorption and better efficiency. In this paper comparison of both the still has been made under the hot and humid climatic conditions. The following conclusions have been made from the present study:

- Distillate output of the weir type cascade solar still was observed 20% higher than stepped solar still.
- Productivity of both the still increase with increase of solar radiation and ambient temperature.
- Average values of heat transfer coefficients (convective, evaporative and radiative) for stepped solar still were found as 1.25, 11.4 and 7.06 $W/m^2\ ^oC$ respectively and for weir type cascade solar still they were observed as 1.43, 12.8 and 7.0 $W/m^2\ ^oC$ respectively.
- Thermal efficiency of stepped and weir type solar still was observed as 16.7 and 21.4% respectively.

Nomenclature

A_p	basin area (m^2)
h_{cg}	convective heat transfer coefficient ($W/m^2\ ^oC$)
h_{eg}	evaporative heat transfer coefficient ($W/m^2\ ^oC$)
h_{rg}	radiative heat transfer coefficient ($W/m^2\ ^oC$)
I(t)	solar intensity (W/m^2)
L	latent heat (J/kg)
m′	hourly productivity (kg/h)
p	partial vapor pressure (N/m^2)
t	passed time from starting
T_w	Water temperature (^oC)
T_g	inner glass cover temperature (^oC)
ε_{eff}	effective emissivity, dimensionless
ε_g	emissivity of glass cover, dimensionless
ε_w	emissivity of water, dimensionless
σ	Stefan–Boltzmann's constant ($5.6697\times10^{-8}\ W/m^2\ K^4$)
η	thermal efficiency (%)

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