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Design and Development of Single Basin Double Slope Acrylic Solar Still

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ABSTRACT: With increasing energy demand, environmental concerns, and the rapid depletion of nonrenewable energy sources, it has become vital to use renewable energy sources for a variety of uses. Solar energy is one of the renewable energy sources that must be used for a country's socioeconomic growth. Solar still is one of the efficient way to convert saline water into drinkable water. In this research paper, we have used acrylic material for the construction of the solar still because this material reduces the heat loss which lead to increase in the rate of evaporation of water. The maximum distilled output is 2.41 l/m²/day at 1cm depth of basin water. The unit cost of desalination of basin water was estimated Rs10.63/litre and the payback period was found to be 2.43 years.

KEYWORDS: Acrylic, Solar still, heat transfer coefficient, techno-economic evaluation, payback period

I. INTRODUCTION

Solar energy is the cleanest, most environmentally friendly, inexhaustible, and abundant source of renewable energy. The sun emits energy in the form of electromagnetic waves in all directions. The earth and atmosphere absorb around 3.8×10^{24} J of solar energy per year. On a bright sunny day, the energy radiated by the sun varies from 4 to 7 kWh/m² in different places (Arjunan *et al.* 2009). The use of renewable solar energy significantly reduces reliance on nonrenewable sources. Solar energy use is critical in nations where sunshine is abundant for the majority of the year. Along with electricity, one of today's primary problems is clean water. Water covers more than 70 percent of the Earth's surface. Only 2.5 percent of the water on Earth is fresh water, leaving 97.5 percent as salt water. Almost 70% of that fresh water is frozen as polar icebergs, with the remainder present as soil moisture or in deep underground aquifers as groundwater inaccessible to humans. Only 1% of the world's fresh water is accessible for direct human use, is replenished on a regular basis by rain and snowfall, and is thus available on a sustainable basis (Postelet *al.* 1996). Water purification is accomplished using a variety of technologies and processes, the majority of which are costly and energy intensive. Along with environmental concerns, new methods of purifying water at a cheaper cost and with less energy use are required.

II. REALTED WORK

Agrawalet *al.* (2017) conducted a theoretical and experimental study at the central Indian location of Rewa, M.P., India. The theoretical and experimental results for a single sloped basin type solar still are compared in depth in this research. For basin water depths ranging from 2 cm to 10 cm, results for various parameters such as basin water temperature, glass cover temperature, distillate production, evaporative, convective, and radiative heat transfer coefficients, and attenuation factor were obtained. The daily distillate yield of the solar still dropped as the basin water depth increased. The theoretical daily efficiency for 2 cm and 10 cm basin water depths was approximately 52.83 percent and 41.75 percent, respectively, while experimental daily efficiency for the same basin water depth was around 41.49 percent and 32.42 percent.

Alwanet *al.* (2021) studied the heat transfer coefficient and daily cumulative production of a single-slope solar distiller at various water depths. In the climatic circumstances of Iraq, three separate days were evaluated with three different water depths of 1, 2, and 3 cm. The results show that the overall heat transfer coefficients inside the solar distiller rise as the depth of the basin water drops. The maximum total coefficient of heat transmission was obtained around 1:00

p.m. with the shallowest basin water depth (1cm). Furthermore, the solar distiller became productive earlier at 1cm water depth than at the other two levels.

III. METHODOLOGY

The acrylic solar still was developed at Department of Renewable Energy Engineering, College of Technology and Engineering, Udaipur. The research region is located at 24° 39' North latitude, 73° 43' East longitude, and 582.5 m above mean sea level.



Plate 1: Developed Acrylic Solar Still

The heat transfer process in a solar still can be classified into two processes. One is internal heat transfer and other is external heat transfer.

Internal heat transfer process:(Cooper, 1973).

(a) Convection loss coefficient:

$$q_1 = h_1(T_1 - T_2)$$

The convection heat transfer coefficient is given as,

$$h_1 = 0.884[(T_1 - T_2) + \frac{(P_1 - P_2)}{(268.9 \times 10^3 - P_1)} T_1]^{\frac{1}{3}}$$

$$P_1 = \exp(25.317 - \frac{5144}{T_1})$$

$$P_2 = \exp(25.317 - \frac{5144}{T_2})$$

(b) Radiation loss coefficient:

$$q_2 = h_2(T_1 - T_2)$$

The radiation heat transfer coefficient is given by

$$h_2 = \epsilon_{\text{eff}} \times \sigma [(T_1^2 + T_2^2) + (T_1 - T_2)]$$

$$\epsilon_{\text{eff}} = \frac{1}{(\frac{1}{\epsilon_w} + \frac{1}{\epsilon_g} - 1)}$$

(c) Evaporation loss coefficient:

$$q_3 = h_3(T_1 - T_2)$$

The evaporation heat transfer coefficient is given by

$$h_3 = (16.273 \times 10^{-3})h_1 \frac{(P_1 - P_2)}{(T_1 - T_2)}$$

(d) Top loss heat transfer coefficient

The total top loss heat transfer is the sum of radiation and convective heat transfer which is given as

$$q_t = q_4 + q_5$$

The radiation heat transfer from the glass cover to the external atmosphere is

$$q_4 = h_4(T_2 - T_a)$$

The glass cover radiation heat transfer coefficient is given by

$$h_4 = \epsilon_g \times \sigma \left(\frac{T_2^4 - T_{sky}^4}{T_2 - T_a} \right)$$

The sky temperature is calculated as

$$T_{sky} = T_a - 6$$

(e) Bottom heat loss coefficient:

The heat loss equation for the bottom is

$$q_b = h_b(T_b - T_1)$$

The heat loss coefficient from the basin liner and the water mass is

$$h_b = \frac{K_w}{d_w} \times C(G_r \times P_r)^n$$

(f) Hourly theoretical distilled output : (Panchalet *al.* 2016)

$$m = \frac{h_3(T_1 - T_2)}{L} \times 3600A_s$$

Where,

L = Latent heat of vaporization (kJ/kg)

A_s = area of the still (m²)

(g) Efficiency of solar still:

The efficiency of solar still is calculated as (Badranet *al.* 2007)

$$\eta = \frac{L \times \Sigma M}{A_s \times \Sigma I}$$

(h) Economic evaluation of the solar still:

The economic evaluation of the developed unit will be carried out in terms of unit cost of desalination of saline water and payback period.

Payback period(PP):

The payback period is refers to the amount of time it takes to recover the cost of an investment.

IV. EXPERIMENTAL RESULTS

The unit cost of desalination of saline water (UC)

The unit cost of desalination of water is given as (Tiwari *et al.* 1984)

$$UC = \frac{TAC}{A_y}$$

TAC = total annualized cost



A_y =annual average productivity (L)

The total annualized cost of the acrylic solar still was Rs.5400/-. The maximum productivity of the distilled water was 434 ml and total operating days for distillation assumed to 365 days. So, the annual productivity of the distilled water was 158.41 litre.

The unit cost of desalination of saline water = $1381.5/130.2$
 = Rs. 10.63/litre.

Payback period (PP)

$$PP = \frac{\ln\left[\frac{CF}{CF-(C \times i)}\right]}{\ln[1 + i]}$$

$$CF = A_y \times SP$$

$$CF = 130.2 \times 20$$

$$= \text{Rs. } 2608.2/-$$

$$\text{payback period} = \frac{\ln\left[\frac{2608.2}{2608.2-(5400 \times 0.1)}\right]}{\ln[1 + 0.1]}$$

$$PP = 2.43 \text{ years}$$

Table 1: TDS of raw water and solar distilled water in ppm

Sample No.	Raw Water TDS (ppm)	Solar Distilled Water TDS (ppm)
Sample – 1	550	40
Sample – 2	590	50
Sample – 3	540	30
Sample - 4	550	50

Hourly relation between temperatures

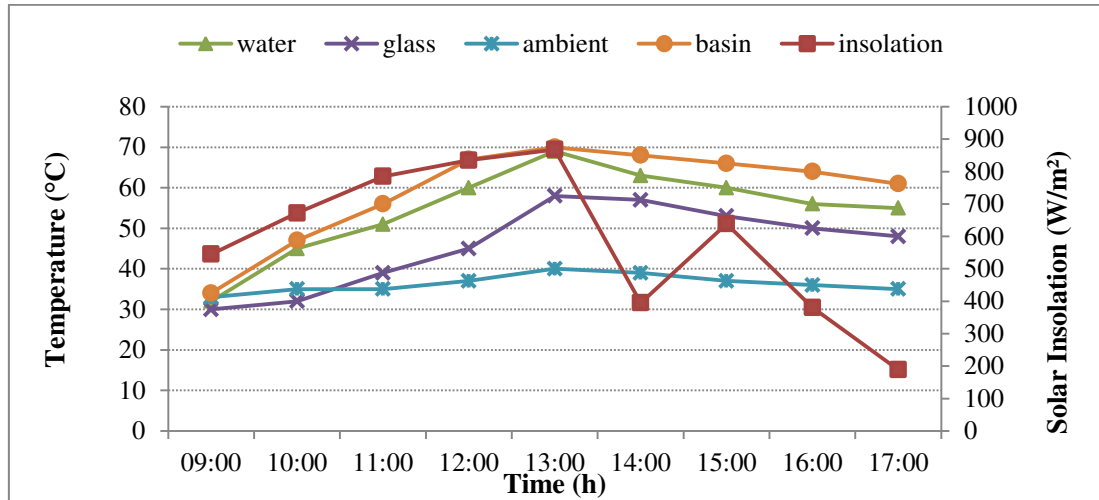


Figure 1: Hourly variation of temperature and solar radiation with time

During the first test, solar insolation was measured in the range of 381 W/m² to 868W/m² between the hours of 9:00 AM and 5:00 PM. The air temperature was discovered to be in the range of 33 °C to 40 °C, with an average temperature of 36.33 °C. The average temperature of the basin, basin water and glass was determined to be 59.22 °C, 54.55 °C, and 45.77 °C respectively. The temperature of the basin, basin water and the glass were found in the range of 34 °C to 70 °C, 32 °C to 69 °C, 30 °C to 58 °C respectively. Figure 1 depicts the hourly change in the temperatures of the solar still component.

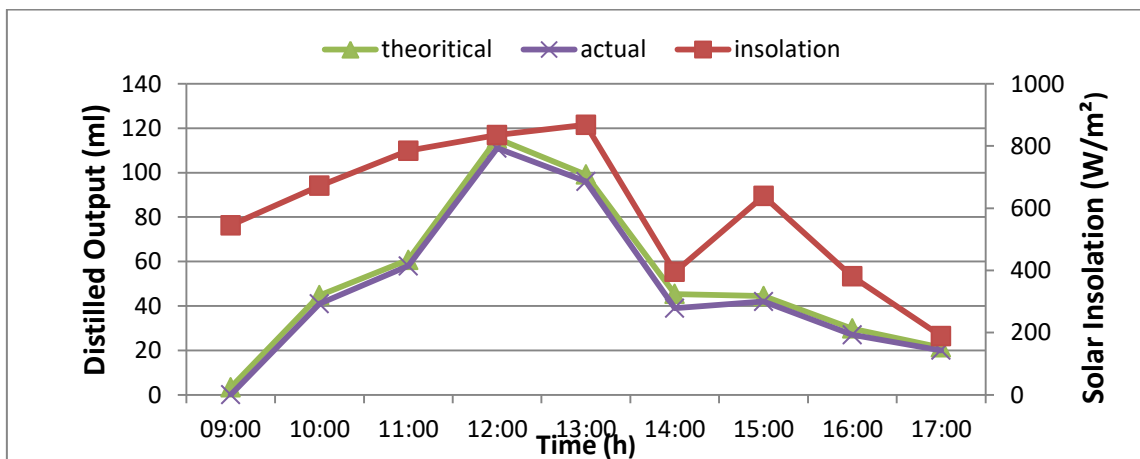


Figure 2: Hourly variation between theoretical and actual distilled output

Figure 2 depict the change in distillation production and solar radiation over time at a water depth of 0.01 m in the water basin. The first test reveals that during the testing hours, the distillation unit produced an average of 0.434 l of distilled water. Similar to this, the theoretical output was estimated using the experiment's recorded data and was discovered to be 0.464 l for the first experiment. This demonstrated that the still's theoretical output and real output are rather close.

Hourly relation between internal heat transfer coefficient

At 0.01 m, the range convective, radiative, and evaporative heat transfer coefficient were found to be 1.22 W/m²K to 2.46 W/m²K, 5.41 W/m²K to 7.34 W/m²K, 5.71W/m²K to 31.43 W/m²K respectively. The average convective, radiative, and evaporative heat transfer coefficient were found to be 1.98 W/m²K, 6.47 W/m²K and 19.32 W/m²K.

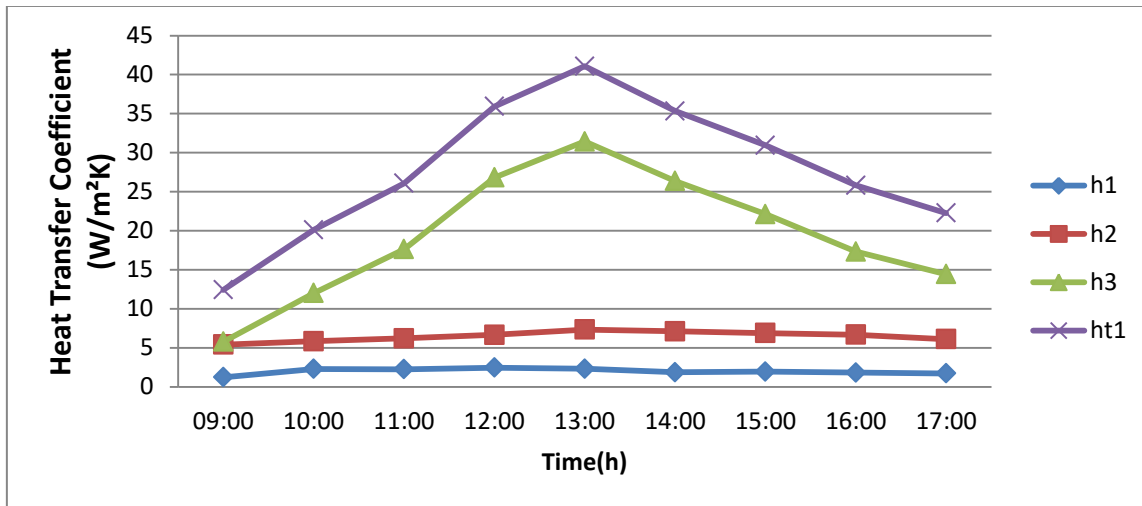


Figure 3: Hourly variation between internal heat transfer coefficients

V. CONCLUSIONS

1. The internal heat transfer coefficient i.e. the average evaporative heat transfer coefficient at 1cm, 2cm, 3cm and 4cm depth was found to be 19.32 W/m²K , 19.23 W/m²K, 15.36 W/m²K and 15.13 W/m²K. The average radiative heat transfer coefficient at 1cm, 2cm, 3cm and 4cm depth 6.47 W/m²K , 6.41 W/m²K , 6.33 W/m²K and 6.39 W/m²K. The average convective heat transfer coefficient at 1cm, 2cm, 3cm and 4cm depth was found to be 1.98 W/m²K, 1.8 W/m²K, 1.61 W/m²K and 1.6 W/m²K.
2. The external heat transfer coefficient i.e. the average top loss coefficient was found to be 15.63 W/m²K whereas the average bottom loss coefficient was found to be 64.78 W/m²K.
3. The distilled water output at different depth were find out i.e. at 1cm depth of basin water, the output was 2.41 l/m²/day, at 2cm depth of basin water, the output was 1.94 l/m²/day, at 3cm depth of basin water, the output was 1.24 l/m²/day and at 4cm depth of basin water, the output was 1.15 l/m²/day.
4. The maximum efficiency of the acrylic solar still was found to be 32.12% at 1cm depth of water. It was found that the efficiency was much higher at 1cm depth of basin water than at 4cm depth of basin water.
5. The unit cost of desalination of basin water was estimated Rs10.63/litre and the payback period was found to be 2.43 years.
6. The TDS of the normal water and distilled was measured and was found to be 550-600 ppm and 30-50 ppm respectively.

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