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Effect of Water Depths on the Distillate Productivity of Single Slope Solar Still: An Experimental and Theoretical Study

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Abstract: The most important thing that is responsible for preserving life is the water on this planet. In agriculture, population, and commerce, the need for potable water is growing exponentially. It is essential to manage the demand volume and availability of freshwater by emerging water distillation techniques. Solar distillation is the leading innovative and inexpensive technique for using solar energy to make use of freshwater. Various surveys have been carried out in this field of clean energy resources. The current correspondence has attempted to identify the optimum depth of water suitable for maximum distillation performance and thermal efficiency. Outdoor experimentation was carried out to evaluate the impact of various depths of the basin's water on water production and thermal efficiency. The distillate yield and the average thermal performance are recorded as 0.727, 0.628, 0.617, 0.634 l/day, and 45.11, 41.29, 36.67, and 39.02 percent respectively for all four water depths (3, 6, 9, 12cm). In addition, the experimental results obtained under optimum circumstances were in solid harmony with the forecasted reactions of the conceptual factor. Therefore, it seems to be known that the heat flow parameters are in the solar system are also primarily determined by the depth of the water.

Author Keywords: Heat Measurement, Coefficients of Heat Transfer, Thermal Efficiency, Single Slope Solar Still (SSSS).

1. Introduction

Human beings are suffering from a freshwater shortage for drinking purposes in the current situation. This water problem inflation can be regulated through efficient recycling, maintenance, and proper allocation of the available fresh water on the planet. The primary challenge is to fill the void by ensuring a balance between the source of supply and the demand for drinking or freshwater. Several technologies for the purification of brine water, polluted water [1], are available. Most technologies, however, consume high-grade energy produced by non-conventional energy sources. The most suitable source of renewable energy for the distillation process is thermal, without any emissions.

Solar is used to distill water from brine water for drinking purposes in the solar distillation process, for purposes such as battery charging and equipment used in the medical industry. The Solar still system operates on the singularities of evaporation and condensation, rendering liquid water available for human drinking purposes [2]. Solar rays heat the still water in the basin to evaporate and to produce vapors. Vapors such as these are allowed for the condensation phenomenon to enter the inclined glass mask. Freshwater is the distillate production obtained at the collection channel. This approach's biggest drawback is that solar energy is used instead of fossil fuels, causing environmental concerns such as global warming and the greenhouse effect [3].

In general, based on a single solar slope, enormous analysis has been carried out technically and experimentally. Efforts are being made to improve both the efficiency and competitiveness of traditional solar types. It depends on the construction of the structure and the Solar still atmospheric conditions. In general, the thermal efficiency lies between 25 and 50 percent. The definition of payback time and cost calculation decreases the probability of project failure, so awareness of its methodology is essential[4]. Studies on the economic scrutiny of various structures for the solar system have been carried out [5]. For the single slope and the pyramidal solar even, Fath et al. carried out thermo-economic research and comparison. The pyramidal-shaped Solar has also been observed to expense than a single slope significantly[6].

2. Research Gap

The literature review stated that more experimental work had been conducted in order to strengthen the relationship between the internal heat transfer coefficients. Much of the research work was carried out to find suitable criteria for the single sloped solar still, such as inclination angle, glass cover thickness, and basin content. This research paper focuses on discovering that process parameters (water depths) significantly influence distillate processing's accuracy characteristics and overall experimental efficiency. For the convective heat transfer coefficient, which is focused on the preliminary findings obtained from studies, thermal research has also been performed. The work is performed in four different water depths on a set inclined toughened glass cover (3 cm, 6 cm, 9 cm, 12 cm). The evaporative and convective heat transfer coefficients were calculated for each depth and compared to the best depth of water for the solar system's passive mode.

3. Experimental configuration summary

A detailed view of the domestic SSSS system is given in Fig.1. The experimentation is being performed in India's hot and dry climate setting for sunlight hours on south-facing, single slope solar stills cover. (from 11:00 to 17:00). The structure is inclined at the Latitude of Bhopal at 23º of the transparent toughened glass case (India). The residual solar container and Its interior surfaces are composed of walls that are 4 mm plastic panel fiber-reinforced (FRP). The lower surface of the still basin (50.80*50.80) cm is coated dark black to enhance absorption (absorptivity 0.87). The heat storage results were analyzed by meeting the still tank with basin water from 3cm to 12cm at various depths. The distillate is collected via a tube added to the bottom's Vertically lower height and sent to a pot with an attached pipe. For that purpose, to protect against the problem of leakage into the still system, silicone rubber and putty were used. The distillation production for the measurement of its duration is gained in the plastic beaker. The schematics and photographs of the passive solar distillation system are given in Fig.1 and Fig.2. In table 1, a detailed design specification of the configuration is given. Distillate output is being collected in the plastic beaker for the measurement of its volume. The schematic and photograph of the passive solar distillation unit are given in Fig.1 and Fig.2. A detailed design specification of setup is given in table 1.

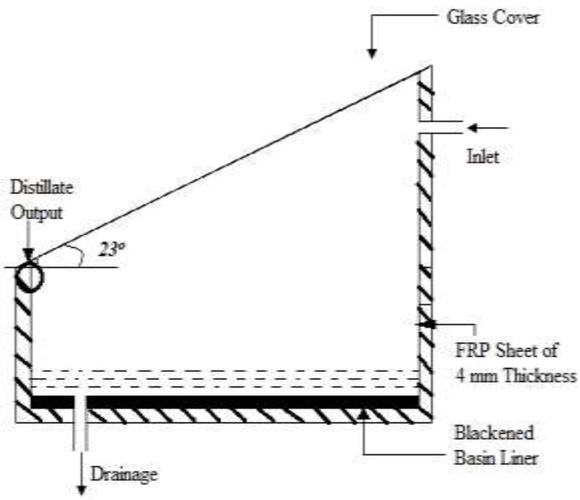

Fig.1. The cross-section of the SSSS domestic form

Table 1: A rigorous architecture specification for solar also exists in effect

S.No.	Toughened Glass Cover Dimensions	Solar Still Basin Dimensions
1.	Thickness -5 mm	Basin area = 50.80 cm ×50.80 cm
2.	Length – 58.42 cm	Length-base = 50.8 cm Breadth-base = 50.8 cm
3.	Breadth – 50.8 cm	Lower-Height = 20.32 cm Higher-height = 48.26 cm
4.	Inclination –23^0	Material-Basin: FRP FRP-4 mm thickness

3.1 Method and findings for experimentation

The experiment was carried out from 11.00 am in Bhopal's climatic condition with a latitude angle of 23º. Till 5.00 pm, Parameters for different water depths and water temperature for 6 hours for 1 hour are recorded for the Passive form of the solar device. The leading theory is vapor temperature for the assessment of thermophysical properties of solar stills. A fundamental discovery found during testing is that after taking readings for one water depth and one water temperature for all six hours, the still is held in idle condition for one day. This is only attributable to the steady-state condition to be obtained and then begins the same for the next water depth, the hourly variance of modified water depth parameters and usage of water temperature.

- Basin temperatures of the water
- The temperature of the toughened inclined glass
- The temperature of the water vapor inside
- Total radiation incident on the cover of the glass
- Temperatures of the ambient air
- Productiveness of distillate
- In the still, relative humidity inside
- Velocity of the storm

3.2 Assumptions

When doing experimentation, the following conventions are well-thought-out. The findings are reported by the following assumptions being assumed. They are like the following:

- Vapor evidence of leakage.
- Static, quasi-steady state.
- There is no internal heat generation still taking place inside the solar
- There are marginal lateral heat losses within the distiller system

Fig.2. Photograph of the SSSS configuration

4. Thermal Analysis

The thermal study of the heat transfer process inside the Solar still system provides the concept of the equation governance.

Under steady-state conditions, these tests are carried out. The proportion of evaporation and condensation was believed to be equal at steady conditions. Then, through steam and air mixture to the condensing glass sheet, the process of evaporation starts. The thermal analysis offers details on the heat flow and its coefficients for evaporation and heat transfer still within the solar [7][8].

4.1. Governing Equation

Thermal analysis is being conducted for the heat allocation inside the Solar still box, as can be seen for the solar system's various components with energy balance equivalences. The still system's heat conversion through convective and evaporative is included in the equation established by this study. It is possible to write a relationship between the heat transfer rate by convection between basin water and inclined toughened glass [9].

$$\dot{Q} = h_{cw}.A.(T_w - T_g) = h_{cw}.A.\Delta T \quad (1)$$

Where hcw, which depends on the Nusselt number, is the coefficient of convection heat transfer. The dimensionless Nusselt number parameter associated with the coefficient of convected heat transfers is seen as follows,

$$Nu = \frac{h_{cw} L_v}{K_v} = C(Gr.\mathrm{Pr})^n \quad (2)$$

Or,

$$h_{cw} = \frac{K_v}{L_v} C(Gr.\mathrm{Pr})^n \quad (3)$$

The number of Grashof (Gr) and the number of Prandtl (Pr) are related to thermo-physical properties, which are expressed as (eq. 4 and 5),

$$Gr = \frac{\beta g L_v^{\,3} \rho^2 \Delta T}{\mu^2} \quad (4)$$

$$\mathrm{Pr} = \frac{\mu C_p}{K} \quad (5)$$

The constants that are undefined in Eq. (2), are based on (Gr) and (Pr). These unspecified constants are monitored by regression methods using preliminary experiment statistics.

The determined coefficient from Eq. (3) illustrates the importance of C and n. The Dunkle relationship is demonstrated in Eq. (6)[10].

$$h_{cw} = 0.884[(T_w - T_g) + [\frac{(P_w - P_g)(T_w + 273)}{268.9 \times 10^3 - P_w}]^{\frac{1}{3}} \quad (6)$$

It is believed that water vapors conform the ideal gas equivalence. Between warm basin water and inner toughened inclined glass shell, the rate of evaporation (Qew) is represented as:

$$\dot{q}_{ew} = h_{ew}(T_w - T_g) = 0.01623 h_{cw}(P_w - P_g) \quad (7)$$

A typical relationship is built from a simple formulation, the Chilton-Colburn analogy [11], often widely referred to as the Lewis relationship [12]. Uh. (Eq.8). Upon replacement of the value hcw;

$$h_{ew} = 16.273 \times 10^{-3} h_{cw} (\frac{P_w - P_g}{T_w - T_g}) \quad (8)$$

$$h_{ew} = 16.273 \times 10^{-3} \frac{K_v}{L_v} C(Gr.\mathrm{Pr})^n (\frac{P_w - P_g}{T_w - T_g}) \quad (9)$$

The distillate production per hour (in l/hr.) from the distiller unit can be obtained from the partnership, from the distiller unit[13],

$$\dot{m}_{ew} = \frac{\dot{q}_{ew}}{L} \times 3600 \quad (10)$$

It can be easily evaluated from the relationship obtained in detailed form using the above equation, and defined as,

$$m_{ew} = \frac{0.01623}{L} \frac{K_v}{L_v} 3600(P_w - P_g) C(Gr.\mathrm{Pr})^n \quad (11)$$

And re-composed as

$$\frac{\dot{m}_{ew}}{R} = C(Gr.\mathrm{Pr})^n \quad (12)$$

Where R is shown as

$$R = \frac{0.01623}{L} \frac{K_v}{L_v} A_w t (P_w - P_g) \quad (13)$$

If the log value is taken from both sides of the equation (12), it shifts to the straight line[14]:

$$\ln(\frac{m_{ew}}{R}) = \ln \mathrm{C} + n \ln(Gr.\mathrm{Pr}) \quad (14)$$

Eq. (14) represents the similarity of a straight line;

$$\mathrm{y=ax+b}$$

$$\mathrm{y} = \ln\left(\frac{\mathrm{m}_{ew}}{R}\right), \mathrm{b} = \ln \mathrm{C}; \mathrm{X} = \ln(\mathrm{Gr.Pr}); \mathbf{a = n} \quad (15)$$

$$\mathrm{a} = \frac{\mathrm{N}\left(\sum \mathrm{xy}\right) - \left(\sum \mathrm{x}\right)\left(\sum \mathrm{y}\right)}{\mathrm{N} - \left(\sum \mathrm{x}^2\right) - \left(\sum \mathrm{x}\right)^2} \quad (16)$$

$$\mathrm{b} = \frac{\left(\sum \mathrm{y}\right)\left(\sum \mathrm{x}^2\right) - \left(\sum \mathrm{x}\right)\left(\sum \mathrm{xy}\right)}{\mathrm{N}\left(\sum \mathrm{x}^2\right) - \left(\sum \mathrm{x}\right)^2} \quad (17)$$

N=number of studies measurements made

After collecting missing parameters, which can be analyzed with experimental evidence from various parameters, 'a' and 'b' from equation 15 can be used for achieving unknown C and n (16) and (17), respectively. Thus, convective heat transfer coefficients resulting from the experiments were inferred are comparatively lower relative to the values of Coefficients of evaporative heat flow achieved.

5. Result and Discussion

The experiment was carried out in Bhopal's Indian environment conditions for the different water depths (3, 6, 9,12 cm) of the SSSS basin, as mentioned above. During the preliminary reading, substantial precautions for the consistency and precision of outcomes were perceived. It was observed that the yield production for the minimum water depth of the basin, i.e., 3cm, was higher after the findings were collected and contrasted with the experimental evidence. For reference, the reasons behind numerous graphs that have been produced by plotting based on the preliminary data reported and approximate results are described below.

5.1 Convective heat transfer coefficients

The inference can be taken from Fig. 3 that the convection heat transfer coefficients are larger for a water depth of 3 cm. It has a growing existence from the beginning hour of the tests until 1-2 pm; then after 2 pm, it decreases nature. For passive types, the maximum potentially high value of the hcw is 3 cm, which equals 0.92 W/m^{2,} and for the influential Solar, which FPC already supports, it is 1,67 W/m^2. The present average value of the 9 and 12cm water deepness is 0.608 W/m^2, 0.616 W/m^2, which is evenly inactive. Its importance reduces as the water density increases.

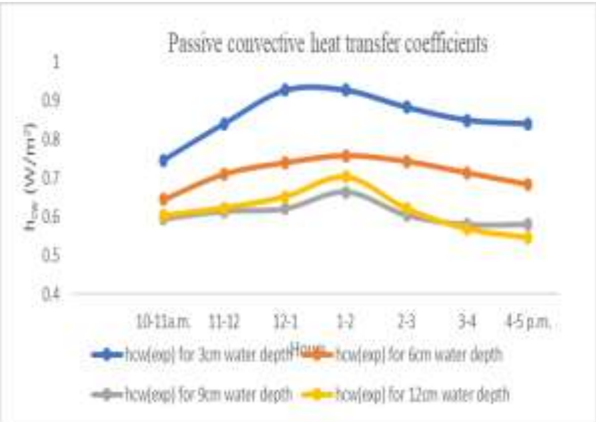

Fig.3. Convective coefficients of heat transfer for all four depths of basin water in passive mode.

5.2 Evaporative heat transfer coefficients

Fig.4 indicates that evaporative heat transfer coefficients are optimum for 1 to 2 pm, and when the time arrives, they decline after near night time. Furthermore, as the water level of the pond grows, the evaporative heat transfer coefficient often decreases. It is just because of the conditions that the thermal entropy of water increases with increasing water, leading to a decrease in evaporation intensity. Therefore, the perfect chance for the most intense respect of hew moved towards the right, i.e., 2-3 pm, for 12 cm of water depth. From the above-stated figure, it can also be observed that the hcw value is comparatively smaller than the hew value. The highest value obtained for hew for passive solar still is 13.85 W/m^2, and rises up to 27.90 W/m^2 for 1-2 pm. The depth of water of 12 cm at 2 to 3 pm has a meaning of 7.13 W/m^2. The graph is identical to another analysis study, which was previously carried out in this area.

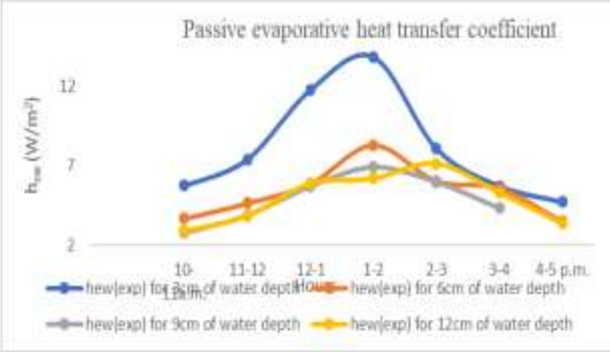

Fig.4. Evaporative coefficients of heat transfer for all four depths of basin water in passive mode.

Table 2. Various values attained for all four depth intervals

Value obtained	Water depths			
	Three	Six	Nine	Twelve
C	1.037	1.009	1.046	1.045
n	0.077	0.086	0.068	0.065
Avg. h_{cw} W/m^2	0.857	0.712	0.608	0.615
Avg. h_{ew} W/m^2	13.853	5.363	4.596	7.131

***5.3**. Productivity of distillation for different depths of water*

Fig.5 demonstrates the difference of distillate production for all four depths of basin water, namely 3cm, 6cm, 9cm, 12cm for all-day hours beginning from 10 am to 5 pm. For the lower height of the basin water level, the accompanying chart indicates that the result is highest and starts to decline as the depth of water rises across. One interesting thing is that it indicates an improvement in water depth of 12 cm, defining the average distillate production for all three water depths as 0.72, 0.68, and 0.61 l/hr. Respectively, and respectively. The average distillation output value is also 0.63 l/h for the 12 cm water depth. This is greater than the depth of the distilled amount of 9 cm of vapor. The only night impact that is typically seen in a more considerable depth of water is this heightened behavior.. If the water depth progresses continually, the quantity of distillate development reduces, i.e., these are inversely related to each other. The evaporation rate is a little healthy for the lower water level relative to the higher water depth. It may also be inferred that nocturnal production is seen with a larger depth of water, as a consequence of which the extension of the thermal gradient across the water rises, and therefore the rate of evaporation contributes to increased output.

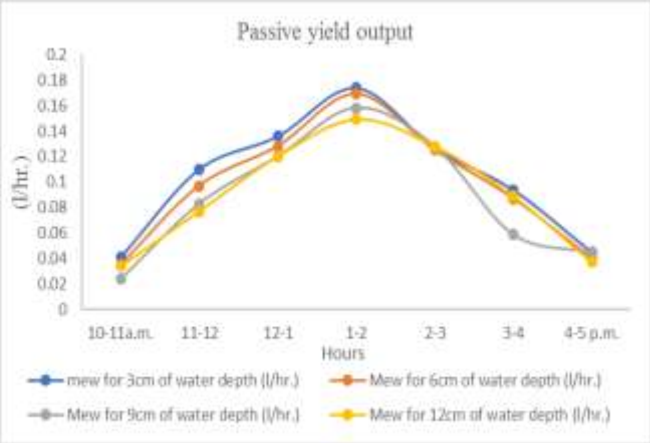

Fig.5. Hourly differences with the four depths of basin water of the distillates' outputs

5.4. Thermal effectiveness for all four depths of water

In Fig.6, the everyday efficiency of the domestic SSSS sort for various depths of water is clarified. The importance of everyday thermal production reduces as the volume of the water basin rises. This impact is pronounced since the current water level is very limited for a tiny still basin depth and as a consequence, the water temperature increase for this particular amount reaches rather quickly compared to the greater water body volume. This results in a higher evaporation rate, which improves the output of distillates. For daily efficiency, the experimental values were 45.11, 41.29, 36.67, and 39.02 percent, respectively, for 3 cm, 6 cm, 9 cm, and 12 cm water depths.

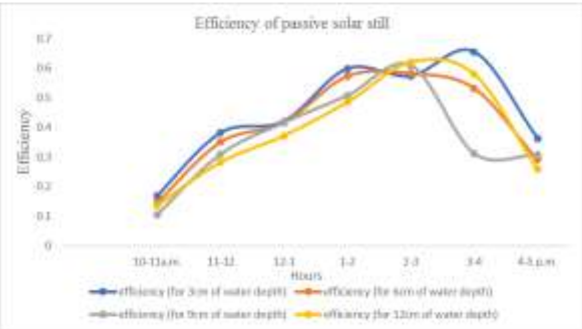

Fig.6. For all four depths of water, thermal efficiency.

However, graphs of various modes of all three coefficients of heat flow, distillate yield result, and thermal performance have been used for the new domestic style SSSS. C and n obtained value is the crucial element for controlling the present model's heat transfer coefficients' values. Several variations in the coefficients of heat transfer are determined using the standard formula and the values of the coefficients estimated from the experimental results, as per the Dunkle model. This is attributed to the shortcomings in the spectrum of temperatures of Dunkle and its presumptions. For passive solar, the values of C and n and hew and hcw are still seen in table 2.

6. Conclusion

Experiments have been performed to find the optimized outcome for the optimum performance of purified water. It was also carried out for all four water depths, namely 3, 6, 9, and 12 cm, respectively, of the depth of the water in the basin. Various parameters (i.e., water depth, atmospheric temperature, solar radiation, and glass temperature) were tested. After obtaining the optimized result, it can be concluded that the distillation performance and thermal efficiency are primarily heavily dependent on the depth of the water in the basin. Furthermore, for both the distillate output and the thermal efficiency, the highest value was found. 45.11, 41.29, 36.67, and even 39.02%, as well. One thing that can also be found is improved distillate production and thermal performance due to the conservation impact of heat energy for the greater depth of basin water. Besides, it is also seen that at greater water depths, the nocturnal influence controlled the responses.

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Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

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