EXPERIMENTAL AND THEORETICAL INVESTIGATION OF SINGLE SLOPE SOLAR STILL COUPLED WITH ETC WITH STAINLESS-STEEL REFLECTOR WITH CENTRAL V-GROOVE

Bhushan L. Patil
Department of Mechanical Engineering, JSPM'S Rajarshi Shahu College of Engineering, S. P. Pune University, Pune,
patilb6982@gmail.com - https://orcid.org/0000-0003-4810-0708

Jitendra. A. Hole
Department of Mechanical Engineering, JSPM'S Rajarshi Shahu College of Engineering, S. P. Pune University, Pune,
jahole1974@gmail.com - https://orcid.org/0000-0002-0158-6221

Sagar V. Wankhede
School of Mechatronics Engineering, Symbiosis Skills and Professional University, Kiwle, Pune
sagarwankhede8890@gmail.com - https://orcid.org/0000-0002-2341-3110

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ABSTRACT

Due to population, industrial, and agricultural growth as well as the rising demand for potable water, there is currently shortage of water in many region of the world. Desalination of brackish and salty water is one of the simplest and economical processes to convert it into potable or drinkable water. But solar still has a low productivity device as its main flaw. Mechanisms for heat exchange play a significant part in increasing the daily yield. The output of any solar desalination system is influenced by the water temperature. The productivity rises as the basin's water temperature rises. A series of experiments were conducted for four different cases in the current study, and it was discovered that the still combined with a parabolic concentrator and stepped basin is the most productive and efficient. The results were verified using mathematical modeling, and it was discovered that in all of these instances, the percentage RMS values range from 10% to 40% and the coefficient of correlation is varies in between 0.8 to 0.99. The overall thermal efficiency of 16.54% is obtained for the integrated system when coupled with evacuated tube collector.

KEYWORDS

Solar stills, Thermal modeling, ETC, Parabolic Reflector, V-groove, stepped basin solar still

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1. INTRODUCTION

Numerous authors have studied solar stills to enhance their performance. Some of the most important elements to get noticeable system improvements are heat exchange mechanisms [1]. (TES) and PCM materials further increase the internal energy of the solar distillation system (PCM). Creating temperature gradient between the surface of glass and the temperature of the top cover is another effective way to encourage evaporative heat transfer. Manokar et al. [2] provided basic principle of working evaporation and condensation in solar still. They claimed that the wind speed and glass cover configuration have a significant impact on the condensation process. The rate of condensation and yield are significantly influenced by the variation in wind velocity. A few other factors were also discovered to affect the evaporation rate. Similar findings that an increase in ambient air velocity has a significant impact on convective heat transfer were reported by Dimriet al. [3]. A study by Murugavel et al. [4] presented a connection of solar still's output with the tilt of the glass cover. Based on the location's latitude and known seasonal variations in productivity, Khalifa[5] proposed a correlation for the best inclination and concluded that the ideal inclination of glass cover should be closer to the location's latitude. The solar still's cover material has an impact on heat transfer rate as well. Cover materials like plain glass, plexiglass, and polyethylene sheet were tested by Jones et al. [6] they claimed that glass-covered solar stills have higher water temperatures and distilled water yield. The effect of water depth in a basin has been the subject of numerous studies, and it has been concluded that the yield and efficiency decreases with increase in the water depths [7, 8]. According to Taghvaei et al. [9], the yield is inversely proportional to the water depth. Water depth optimization is therefore a cost-effective method because it can achieve acceptable performance without additional investment. Similar findings were also reported by Ahmed et al. [10], who showed a strong dependence between distillate yield and water depth. Similar studies [11–12] have been conducted in great numbers to find variation of productivity with water depth of solar still. Solar still with additional reflector and stepped basin can improve the productivity by 34% [13]. External and internal reflector with stepped basin improves the efficiency by 125% the the reference case [14]. As an alternative to adding more energy to the still, Xie et al. [15] suggested using energy recovered from condensed vapour. Estahbanati et al. [16] showed how adding more stages can significantly increase the productivity of the system. Additionally, it was stated that by using this technique, the desalination yield and performance ratio could increase to 0.91 and 1.81, respectively [17]. Matrawy et al methods of using dark-colored (black) clothing works on the principle of capillary effect resulted in a 75% increase in overall productivity. Black rubber and gravel rocks were used by Nafey et al. [7] as practical heat storage mediums, increasing the still's yield. Other researchers have proposed new, inventive designs for solar stills, including those with pulsating heat pipe-type solar stills [21], stepped solar stills [19], conical solar stills [20], and solar stills with semicircular trough-absorber and baffles [18]. These modern systems have higher efficiencies and show a significant increase in distillate output. However, the system's overall cost as well as its installation and operation complexity both rises concurrently. These solutions necessitate the attachment of devices and a greater input of energy; consequently, additional capital or operating costs must be incurred.

2. EXPERIMENTAL SETUP AND PROCEDURE

A solar still is fabricated to perform experimental work. The figure.5 shows a stepped basin solar still, compound parabolic concentrator with ETC and storage tank. The experimental work is carried out at Indrayaninagar, Bhosari Pune (latitude 18.63o, longitude 73.84o) facing towards south.

Solar still made up of 0.7mm thick galvanized steel sheet with dimensions 1.41m x 0.70m also secondary stepped basin made up of 0.7mm thick galvanized steel sheet. Black paint is applied to improve absorptivity of solar still and secondary stepped basin. Cover glass is made up of toughened glass 4mm thickness.

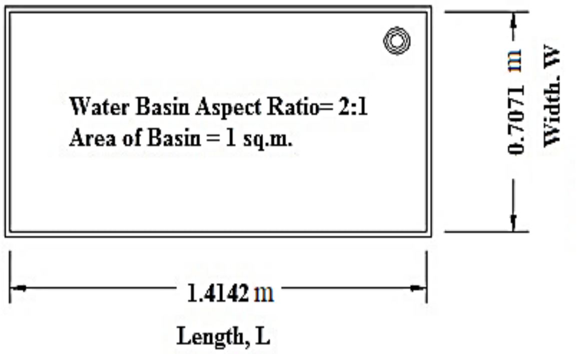

Figure 1. Basin area of solar still with aspect ratio 2:1

Figure 2. Stepped absorber plate

To build the solar still, gauge 22 galvanized iron sheet is used. The basin area is maintained at 1 m2, with a 2:1 aspect ratio. This is consistent with the findings of El-Swify and Metias[43], who found aspect ratio of 2:1 results in the solar still's best ability to capture solar energy. It is necessary to paint the interior of the basin black in order to effectively absorb solar energy. A condensing cover made of plain glass and inclined at an 18° angle (approximately equal to latitude location) is used to cover the basin. The solar still is facing towards the south to ensure maximum amount of solar energy incident on the still.

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Figure 3. Steel parabolic concentrator

3. INSTRUMENTATION AND OBSERVATION

The different measurements were taken to calculate the hourly yield such as temperature of water, glass cover temperature, inside and outside glass temperatures, atmospheric temperature and solar intensity. The temperatures were recorded using a probe type digital thermometer with L.C of 0.10C and the hourly productivity is calculated by using a measuring jar of L.C 10ml. the experiment were conducted from 8 A.M to 7 P.M. A computer program using Microsoft Excel was made to find inner glass, outer temperature of glass, temperature of water from basin and yield.

4. RESULTS AND DISCUSSIONS

In this study four cases are examined.

1. Single slope solar still with constant flow rate.
2. Single slope solar still with secondary stepped basin.
3. Single slope solar still coupled with compound parabolic concentrator.
4. Single slope solar still with secondary stepped basin coupled with compound parabolic concentrator.

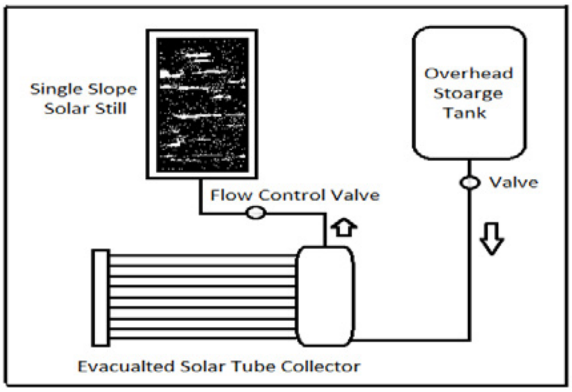

Figure 4. Schematic diagram of solar still coupled with evacuated tube solar collector.

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Figure 5: Experimental setup

CASE 1. SINGLE SLOPE SOLAR STILL WITH CONSTANT FLOW RATE (REFERENCE CASE)

Figure 6 shows variation of temperatures of various parts of the solar still such as temperature at outer, inner side of the glass temperature of basin, temperature of water and vapor with respect to the time of the day and found that the maximum temperature of 49.30C is obtained at the basin at around 3:00P.M. The figure 7 shows the relationship between hourly productivity and found that the maximum yield of 200ml is obtained at 3:00P.M.

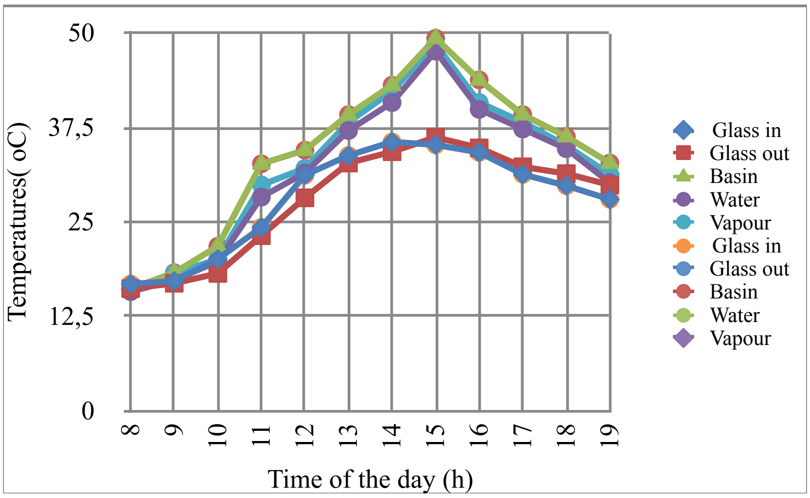

Figure 6. Relationship between various temperatures of solar stills with time.

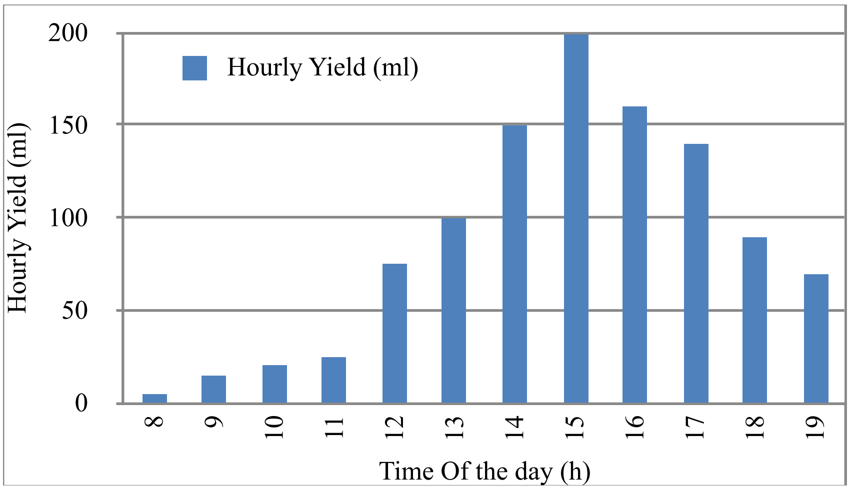

Figure 7. Relationship between hourly productivity with time.

CASE 2. SOLAR STILL WITH A SINGLE SLOPE WITH A SECONDARY STEPPED BASIN

Figure 8 and figure 9 shows change of temperatures and hourly yield respectively when the secondary stepped basin is used with solar still and found that the maximum temperature of 59.150C and maximum yield of 250ml is obtained at around 3:00P.M.

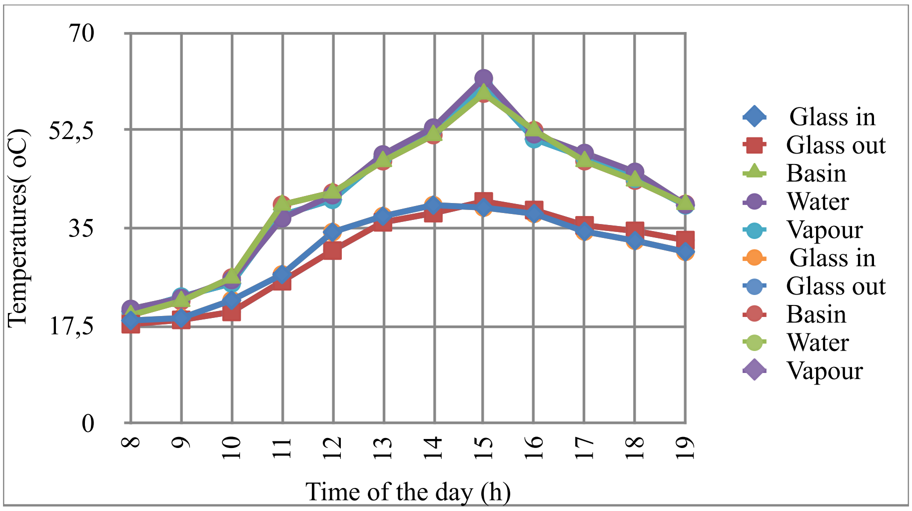

Figure 8. Relationship between solar still temperatures with time.

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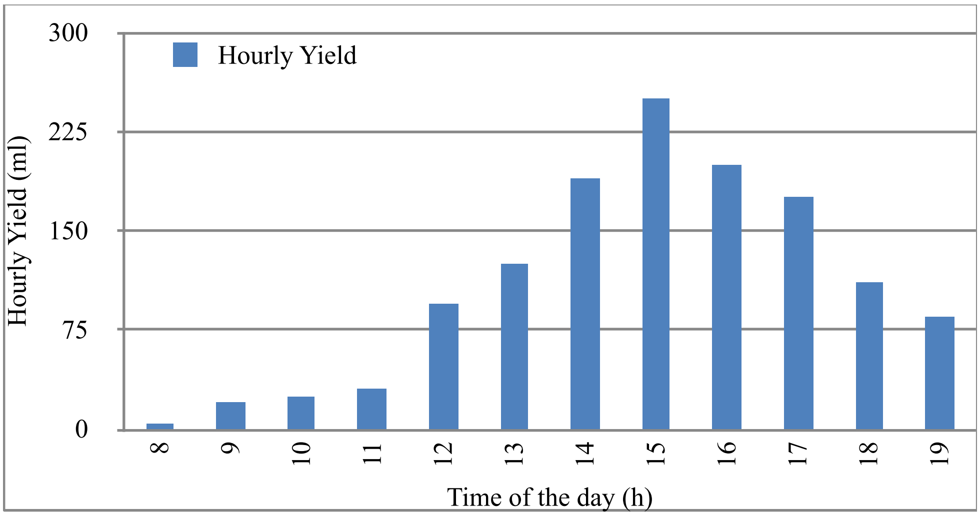

Figure 9. Relationship between hourly productivity with time.

CASE 3. SOLAR STILL WITH A SINGLE SLOPE AND A COMPOUND PARABOLIC CONCENTRATOR

Figure 10 and figure 11 shows variation of temperatures and hourly yield respectively when the still is coupled with ETC and found that the maximum temperature of 62.50C and maximum yield of 280ml is obtained at around 3:00P.M.

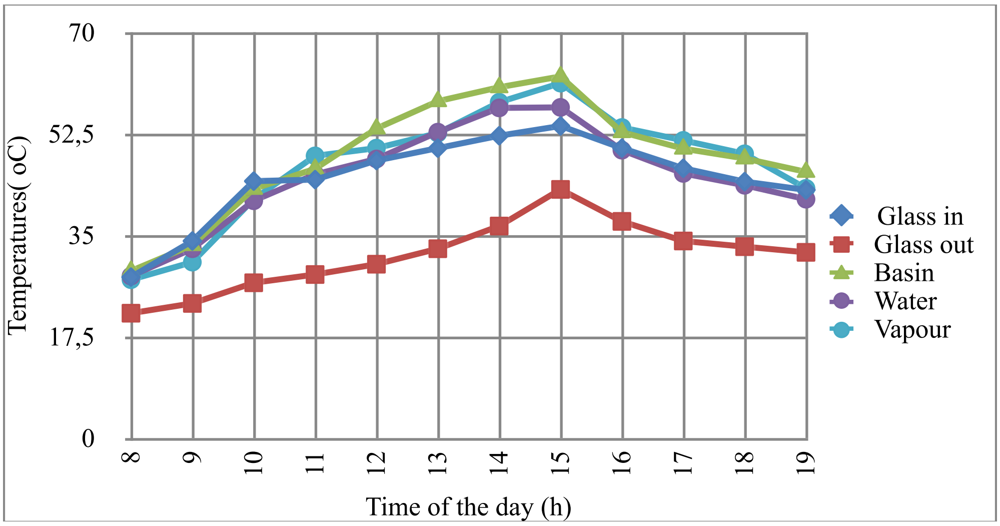

Figure 10. Relationship between solar still temperatures with time.

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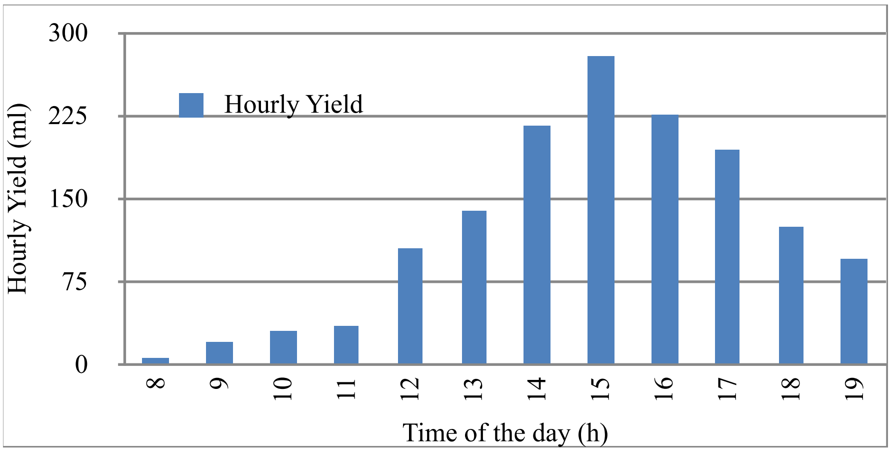

Figure 11. Relationship between hourly productivity with time.

CASE 4: SOLAR STILL WITH SECONDARY STEPPED BASIN AND COMPOUND PARABOLIC CONCENTRATOR

Figure 12 and figure 13 shows change of temperatures and yield respectively when the solar still is equipped with secondary stepped basin and coupled with parabolic concentrator with V-groove and found that the maximum temperature of 70.20C and maximum yield of 320ml is obtained at around 3:00P.M. Figure 14 shows the variation of atmospheric temperature with respect to the time of day on various days of experimentation.

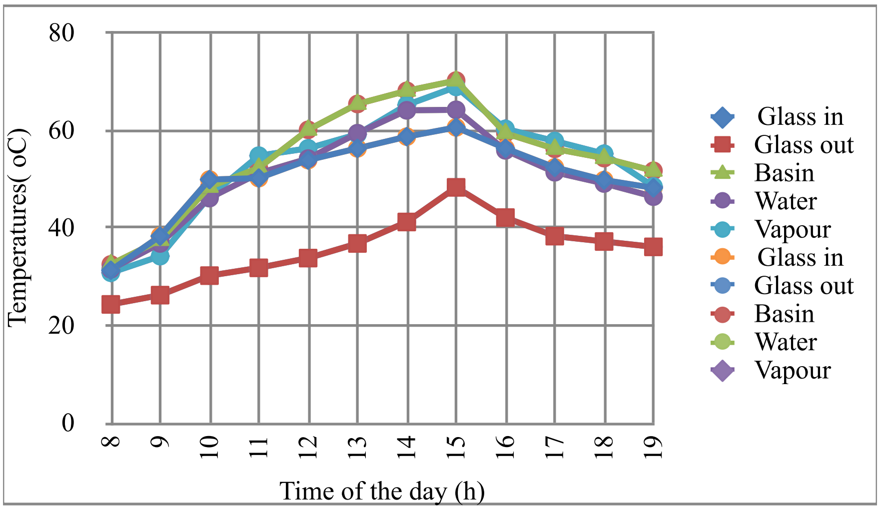

Figure 12. Relationship between solar still temperatures with time.

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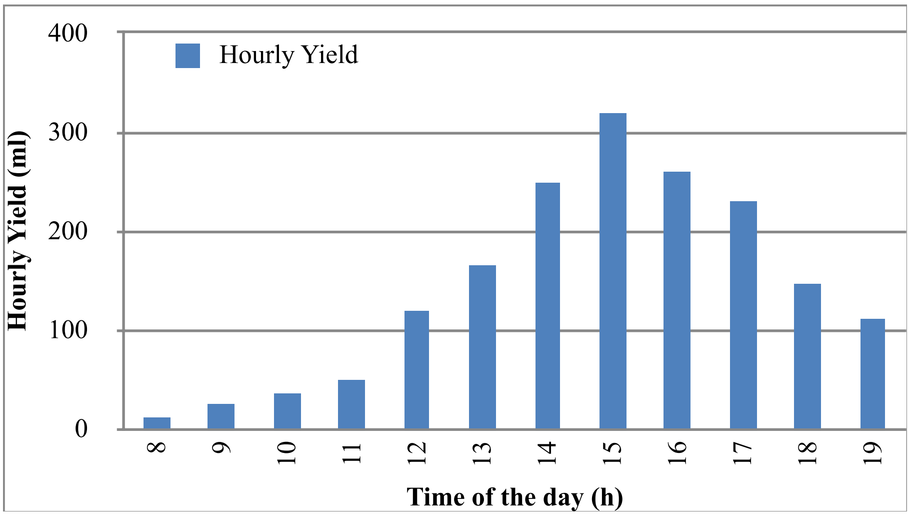

Figure 13. Relationship between hourly productivity with time.

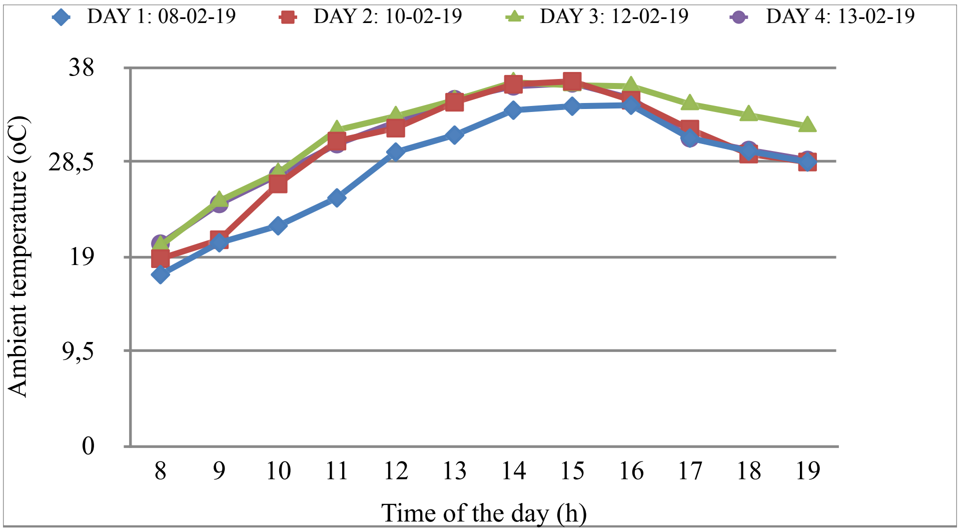

Figure 14. Relationship between ambient temperatures with time on the different days of experimentation.

5. THERMAL MODELING

Mathematical modeling of various parameters of still is performed by using the concept of validation of temperature of inner, outer glass, temperature of basin and yield of the solar still.

For inner glass

$$\propto'_g I_{effs} + h_{1w}(T_w - T_{gi}) = \frac{K_g}{L_g}(T_{gi} - T_{go}) \qquad (1)$$

For outer glass

$$\frac{K_g}{L_g}(T_{gi} - T_{go}) = h_{1g}(T_{go} - T_a) \tag{2}$$

Temperature inside the glass is given by

$$T_{gi} = \frac{\propto'_g I_{effs} + h_{1w}T_w + \frac{K_g}{L_g}T_{go}}{h_{1w} + \frac{K_g}{L_g}} \tag{3}$$

Temperature at outside of the glass is given by

$$T_{go} = \frac{\propto'_g I_{effs} h_k + U_{wo}T_w + h_{1g}T_a}{h_{1g} + U_{wo}} \tag{4}$$

For basin liner

$$\propto'_b (1 - \propto'_g)(1 - \propto'_w)I_{effs} = h_w(T_b - T_w) + h_b(T_b - T_a) \tag{5}$$

Temperature at the bottom of the basin liner is given by

$$T_b = \frac{\propto'_{-b} I_{effs} + h_wT_w + h_bT_a}{h_w + h_b} \tag{6}$$

For water mass

$$\dot{Q}_u + \propto'_w (1 - \propto'_g)I_{effs} + h_w(T_b - T_w) = (MC)_w\frac{dT_w}{dt} + h_{1w}(T_w - T_{go}) \tag{7}$$

Where,

$$\dot{Q}_u = A_cF_R\left[(\propto\tau)_c\right]I_c - U_{LC}(T_w - T_a) \tag{8}$$

Rate of evaporation is given by

$$\dot{q}_{ew} = h_{ew}(T_w - T_g)$$

And the hourly output is given by

$$\dot{m}_{ew} = \frac{h_{ew}(T_w - T_g)\ X\ 3600}{L} \quad (kg/m^2h)$$

6. RESULTS AND DISCUSSION

Various parameters from table 1 are used to find the values of basin, water, inner and outer glass temperature the figure 14 shows variation of atmospheric temperature on different days of experimentation. The atmospheric temperature, glass and water temperature are used as input parameters to calculate convective, evaporative and total heat transfer coefficient of the system. These heat transfer coefficient with initial basin and glass temperature are further used to calculate inner and outer glass temperature and also the temperature of basin The hourly yield in kg/m2h is also

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calculated theoretically and experimentally and we found that the coefficient of correlation varies in between 0.9 to 0.99 and RMS values lies between 10% to 40%.

Table 1. Various parameters for design of single slope solar still.

Parameter	**Values**
A_b	1m^2
C	0.54
C_w	4190J/kg^{0}C
G	9.81 m/sec
K_g	0.78W/m^{0}C
$L_c/L_g/L_p$	0.003m
$\propto'_g$	0.05
$\propto'_b$	0.8
$\propto'_w$	0.05
$\propto'_p$	0.05
h_w	135
μ	17.8Ns/m^2
ρ	995.8kg/m^3
σ	5.67x10^{-8}W/m^{2}K^4

Case 1. Experimental v/s Theoretical variation of different temperatures of solar stills with time of day. Figure 15, 16 and 17 shows the experimental and theoretical values of the temperature at inner, outer side of the glass and temperature of basin respectively for the single basin solar still.

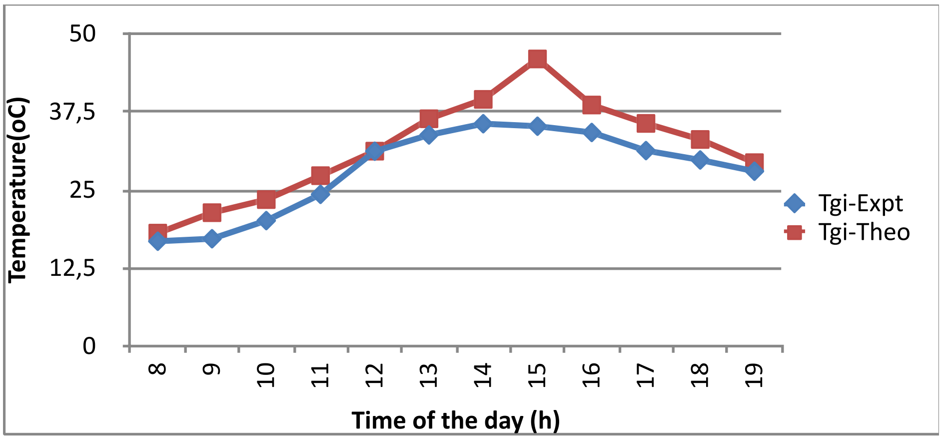

Figure 15. Experimental v/s Theoretical variation of glass inside temperatures.

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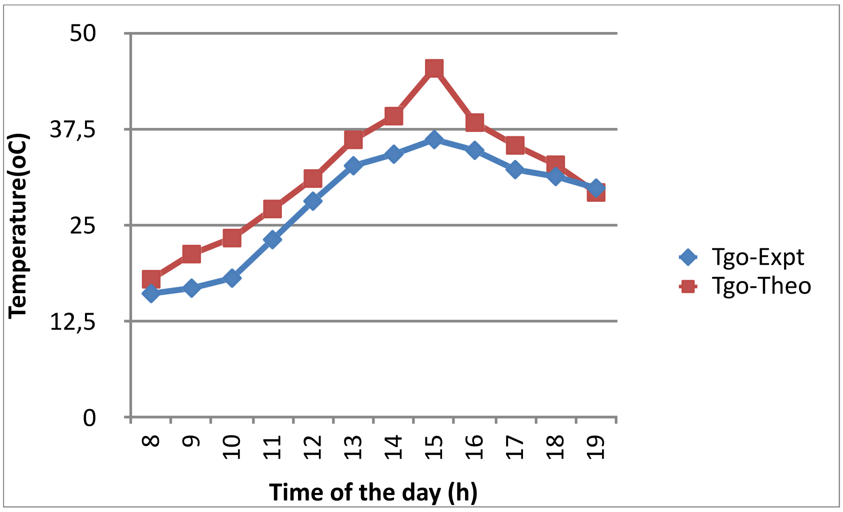

Figure 16. Experimental v/s Theoretical variation of glass outside temperatures.

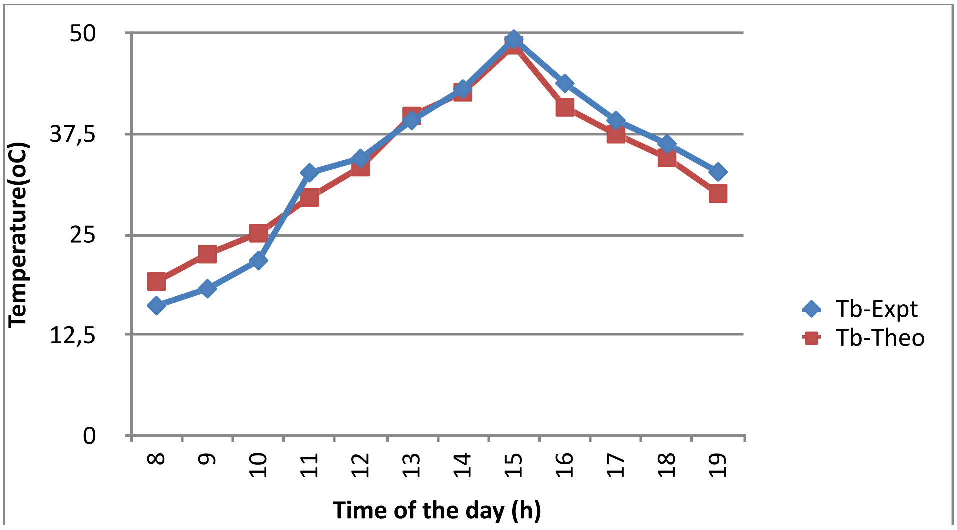

Figure 17. Experimental v/s Theoretical variation of basin temperatures.

Case2. Experimental v/s Theoretical variation of temperatures of the elements of still. Figure 18, 19 and 20 shows the experimental and theoretical values of the temperature at inner, outer side of the glass and basin respectively for the single basin solar still equipped with secondary basin.

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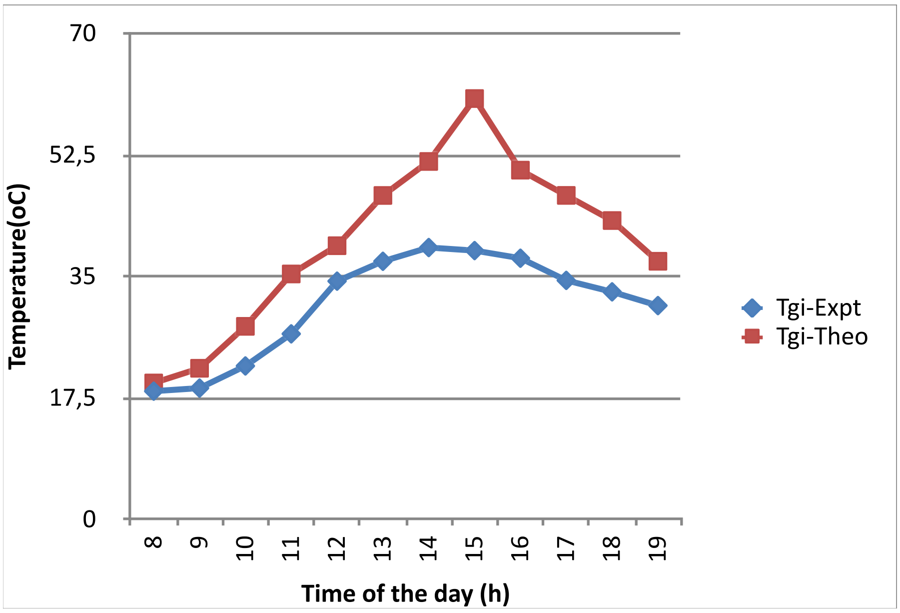

Figure 18. Experimental v/s Theoretical variation of glass inside temperatures.

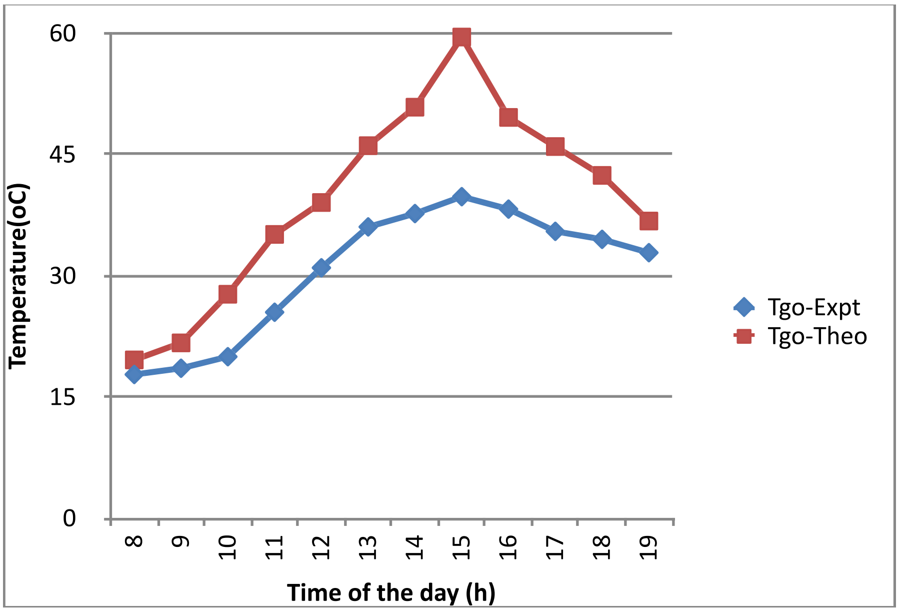

Figure 19. Experimental v/s Theoretical variation of glass outside temperatures.

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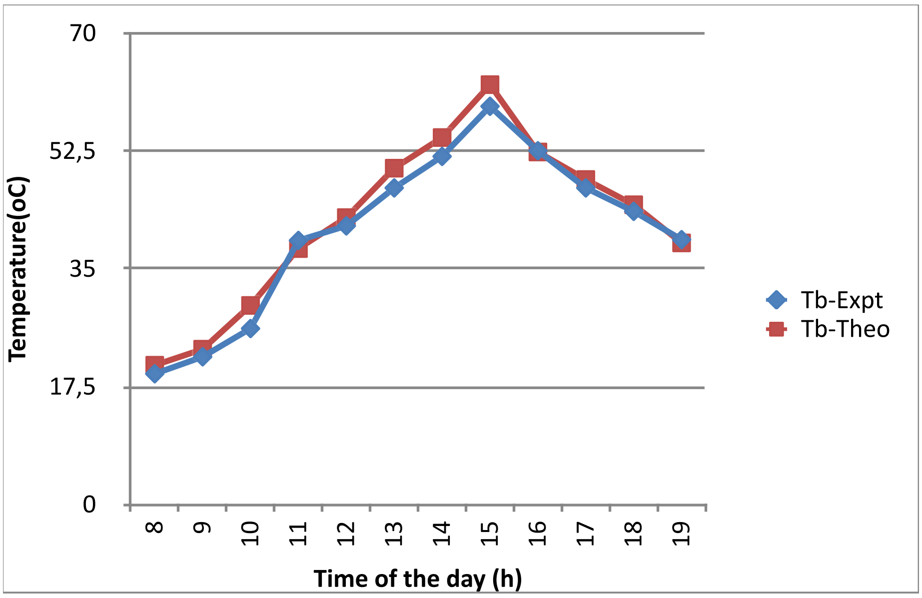

Figure 20. Experimental v/s Theoretical variation of basin temperatures.

Case 3. Experimental v/s Theoretical variation of temperatures of the elements of still. Figure 21, 22 and 23 shows the experimental and theoretical values of the temperature at inner, outer side of the glass and temperature of basin respectively for the single basin solar still coupled with parabolic collector.

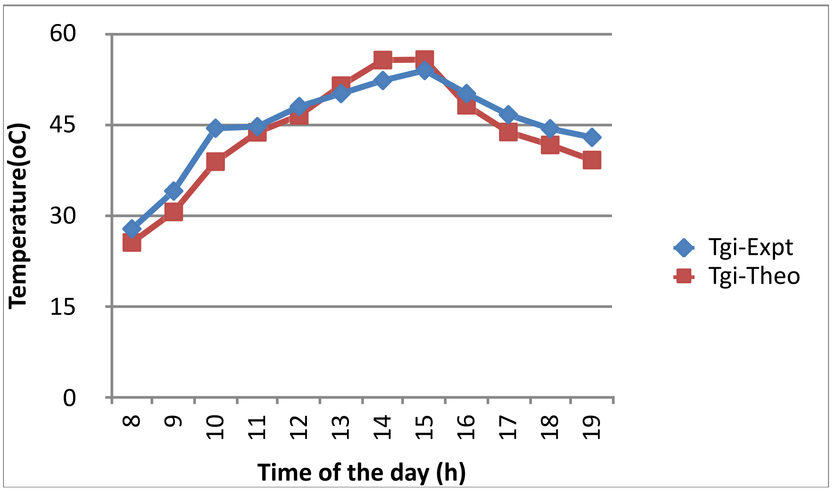

Figure 21. Experimental v/s Theoretical variation of glass inside temperatures.

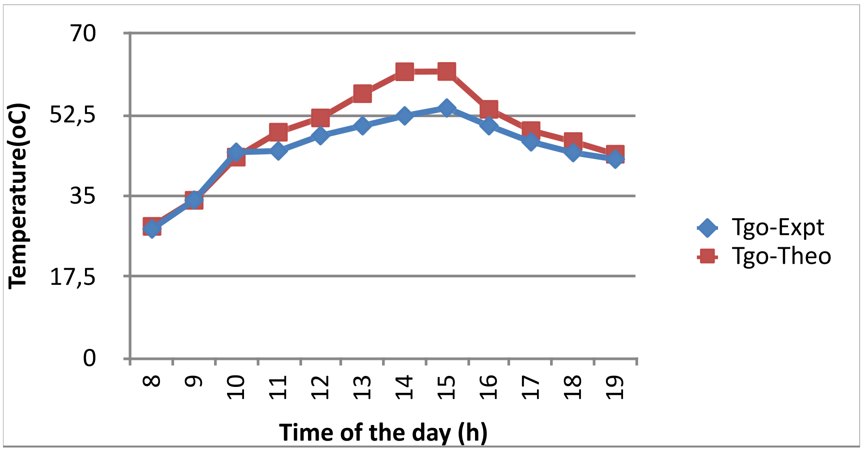

Figure 22. Experimental v/s Theoretical variation of glass outside temperatures.

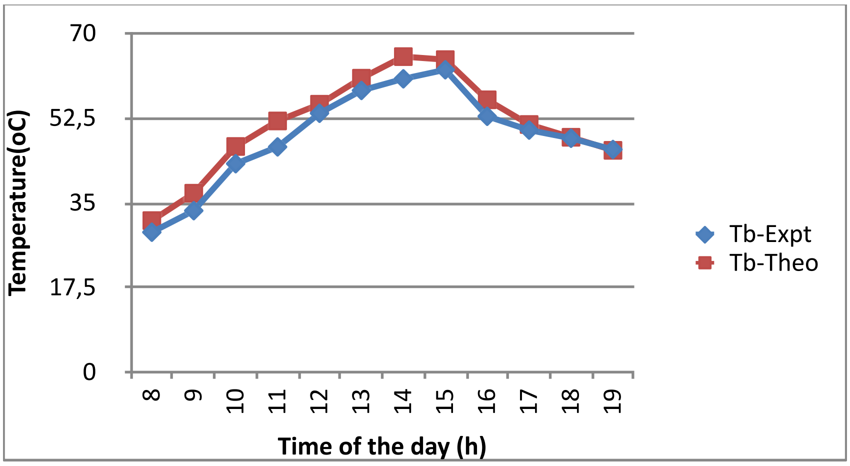

Figure 23. Experimental v/s Theoretical variation of basin temperatures.

Case 4. Experimental v/s Theoretical variation of temperatures of elements of still. Figure 24, 25 and 26 shows the experimental and theoretical values of the temperature at inner, outer side of the glass and temperature of basin respectively for the single basin solar still equipped with secondary basin and coupled with parabolic collector.

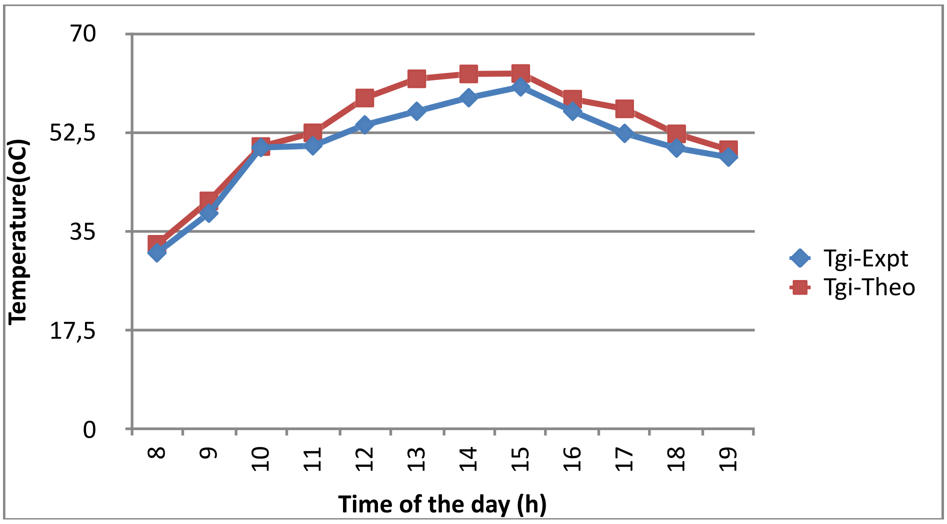

Figure 24. Experimental v/s Theoretical variation of glass inside temperatures.

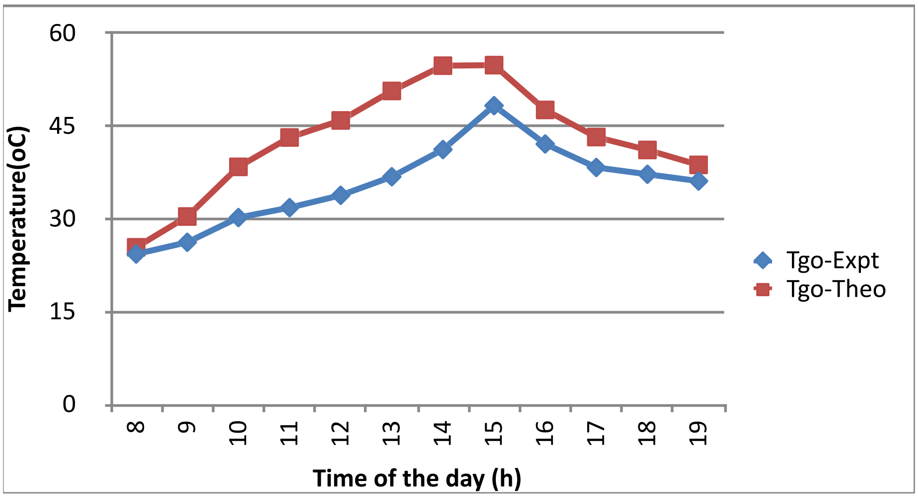

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Figure 25. Experimental v/s Theoretical variation of glass outside temperatures.

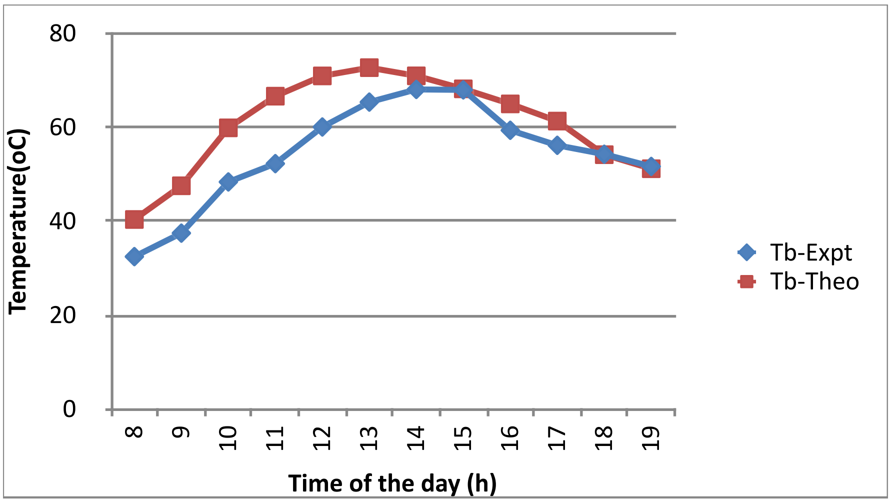

Figure 26. Experimental v/s Theoretical variation of basin temperatures.

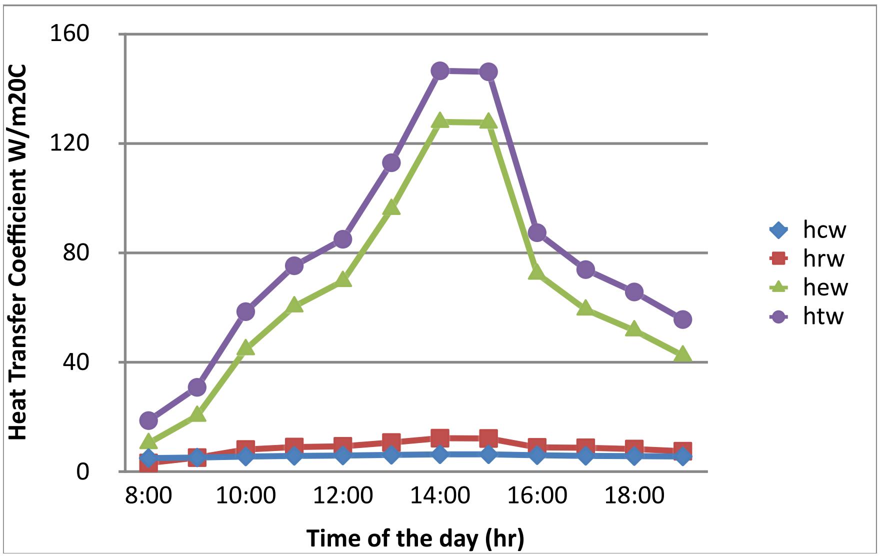

Figure 27. Heat transfer coefficient for solar still coupled with evacuated tube collector.

Figure 27 shows the variation of (h_{cw}), (h_{rw}), (h_{ew}), and (h_{tw}) heat transfer coefficient for the system when equipped with secondary stepped basin and coupled with evacuated tube collector with parabolic concentrator. The values of convective and radiative heat transfer coefficients are nearly identical. Figure 28 shows the comparison between theoretical and experimental hourly variation of yield for the integrated system when equipped with secondary stepped basin and coupled with evacuated tube collector with parabolic concentrator.

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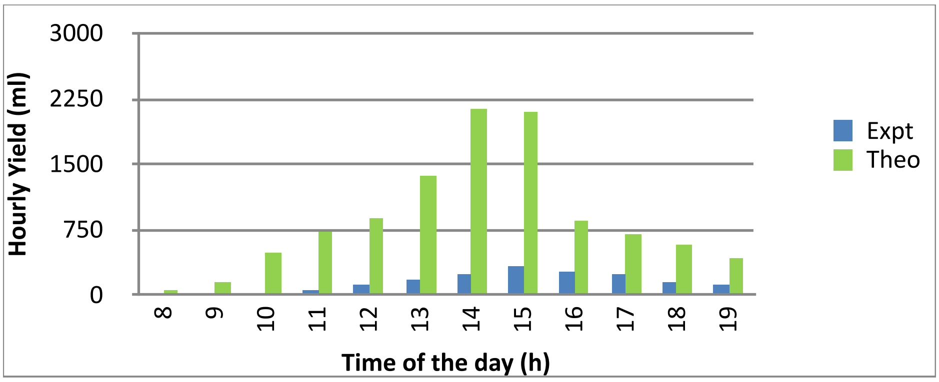

Figure 28. Hourly variation of theoretical and experimental yield for solar still coupled with evacuated tube collector.

7. CONCLUSION

The modeling of solar still with secondary basin and coupled with Tubular Parabolic concentrator using the concept of comparison of inner, outer glass temperature and temperature of basin has been validated experimentally. The experiments were carried out for four cases and found that the still coupled with parabolic concentrator and stepped basin is having maximum efficiency and productivity. Overall thermal efficiency of 16.54% is obtained for the integrated system when coupled with evacuated tube collector. The results were validated using mathematical modeling and found that the coefficient of correlation varies in between 0.9 to 0.99 and percentage RMS values lies in the range of 10% to 40%.

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