# Experimental and numerical evaluation on performance of potable water productivity with rectangular fins basin triangular solar still

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**ABSTRACT**

Demand and conservation for potable water has become a foremost concern world-wide. Many technologies were adapted for converting the saline water to potable water to meet the required demand on water conservation. In the current research work triangular solar still with rectangular-fins attached to the basin is proposed to enhance the output of potable water from the solar still setup. Solar still with and without rectangular-fins on the basin are fabricated for experimental comparison and evaluation in addition to numerical investigations. Thermal Performance, instantaneous efficiency and potable water output of the proposed solar still & base solar still are investigated during March month for the location of Sathyamangalam. Investigation shows enhancement of water production in the proposed solar still by 41% higher compared to the base still. The maximum distillate output from modified still and base still for a typical day is 3.1 liter and 2.2 liter respectively.

**Keywords:** Triangular solar still; Productivity; Energy; Exergy; Rectangular-Fins

## 1. INTRODUCTION

Water scarcity is a major problem world-wide, due to rapid industrial growth and development of chemicals lead to water contamination and pollution has drastically reduced the percentage level of potable water and ground water level. Conversion of saline water into fresh water is known as desalination. Desalination can be done by utilization of thermal, electrical and mechanical pressure for the conversion process of getting potable water. Solar desalination is the sustainable and passive desalination process done by utilizing the solar radiation and also it is well-thought-out to be more cost efficient than other methods. Several types of solar still has been designed and constructed by experimentalists for increasing the yield of the solar still. (Jubran et al., 2000) designed a multistage solar still for increasing the yield per day with cost analysis which gives 87% efficiency and yield of 9kg/m$^2$. (Abu-Hijleh et al., 2003) achieved the enhancement of solar still with various size sponge by 273% contrast to the conventional solar still. (Badran et al., 2005) suggested a still system coupled with two flat-plate solar heater which forms a closed loop of water passage through it they proved that 100% more pure water can be produced than the conventional basin type solar still. (Velmurugan et al., 2009) improved the performance of solar still by optimizing the feed depth & width of the water trays of 5mm and 120mm correspondingly. (Kabeel et al., 2012) proposed an enhancement technique for increasing the performance of the stepped solar still adapting the combination of fin, sponge and pebble. (Abdullah, 2013) integrated the solar air preheater with solar still for rising the efficiency and the yield of the still is increases by 112%. The significance of having the reflecting mirror on stepped still were also examined by (Omara et al., 2013, 2014) and the maximized enhancement on yield of the still is achieved as 125%. (Kabeel et al., 2014) incorporated the Aluminum-oxide nanoparticles in the solar still for increasing the yield due to the greater evaporation rate compared with conventional basin by 116% with an external condenser. (Elashmawy, 2017) introduced a tubular type solar still assisted with rectangular trough, half cylindrical trough and parabolic concentrator. (Manokar et al., 2018) done an experimental examination on the performance solar still assisted with PV panel for cogeneration. The performance evaluation on a solar still experimental setup was done with the rotating drum assisted with copper-oxide nanoparticles (Abdullah, Essa, et al., 2019) to improve the yield by 350%. (Xiao et al., 2019) designed a PV/T stepped bottom channel solar still for analyzing the exergy and energy of novel solar still through which the yield is enhanced by 51.7%. An investigation on performance of the novel rotating wick still was done on the experimental setup with nanofluids was done by (Abdullah, Alarjani, et al., 2019) and they noted the 300% enhancement on the yield output. Experimental investigation were also been done by (Amarloo et al., 2019) in a novel designed solar still with PCM cooling setup for increasing the condensing effect by 45%. Many research (Sarhaddi et al., 2017; Sharshir et al., 2017; Sakthivel et al., 2018; Vigneswaran et al., 2019; Patel et al., 2020) has been carried on solar still using thermal energy storage for increasing the output of the system. (Dumka et al., 2019) done an investigational analysis on the efficiency of solar still with sand filled cotton bags for better efficiency by 12%. (Velmurugan, Gopalakrishnan, et al., 2008) investigated the solar still using fins on single basin through experimental and numerical study and they found the output is increased by 45%. (Rabhi et al., 2017) experimentally studied the effect of pin fins in the absorber with an external condenser on thermal performance of solar still and they found the efficiency is improved by 15%. (Alaian et al., 2016) prepared an experimental setup of solar still using pin finned wick and shows the output to increases by 23%. (Rajaseenivasan et al., 2016) experimentally investigated the solar still with circular fins and square fins; from the result they found that there is a significant improvement on its output. (El-Naggar et al., 2015) done an experimental and numerical investigation on finned basin modified solar still and they found the improvement in the output of the still is achieved by 0.6 liter/day. (Ali et al., 2014) also investigated the solar still output with pin fins, the experimental & numerical results reveals the efficiency of the still can be enhanced by 12%. (Appadurai et al., 2015) proposed a solar still operating with fin type mini solar pond for numerical and experimental study on analyzing performance enhancement of still which gives higher output of about 3% than the base solar still. (Velmurugan, Deenadayalan, et al., 2008) found that there is a noteworthy improvement on enhancement of modified solar still with fins using a theoretical model. (Panchal et al., 2020) investigated a comparative analysis through as experimental investigation on solar stills with inclined and vertical fins and they found the improvement in the average yield is about 26% and 25% respectively.

Numerous studies had been carried out on improving the output of freshwater in solar stills by altering the design and operating parameters, but none of the investigation has been done on improving the yield of the triangular solar still using rectangular fins on the basin plate material. This study focuses on improving the thermal performance of triangular solar still using Aluminum rectangular fins on the copper basin plate material. The dynamic performance of the still with output and energy efficiency is discussed in this paper. The paper further deliberates the possessions of the ambient situations on the operating characteristic and performance of the solar desalination system through a simplified mathematical model and an experimental setup.

## 2. EXPERIMENTATION

The objective of current experimental work is to investigate and compare the performance between conventional triangular still and the rectangular-fins attached still. Thus two solar stills with similar dimensions are designed and fabricated; Figure 1 shows the layout of the design of conventional triangular solar still. Experimental setup of triangular solar still comprises of a basin plate, glass cover, water collecting jar, temperature measuring sensors and weather station. Water from tank enters to the still through a control valve and flexible hosing pipe to keep the water at steady level in the basin plate. For better thermal performance of the basin plate, 3mm thickness copper plate of aperture area of 1m$^2$ (1m x 1m)and basin depth of 40mm with black powder selective coating. The basin is rested on the wooden support which is hinged on the both ends with the supporting legs.

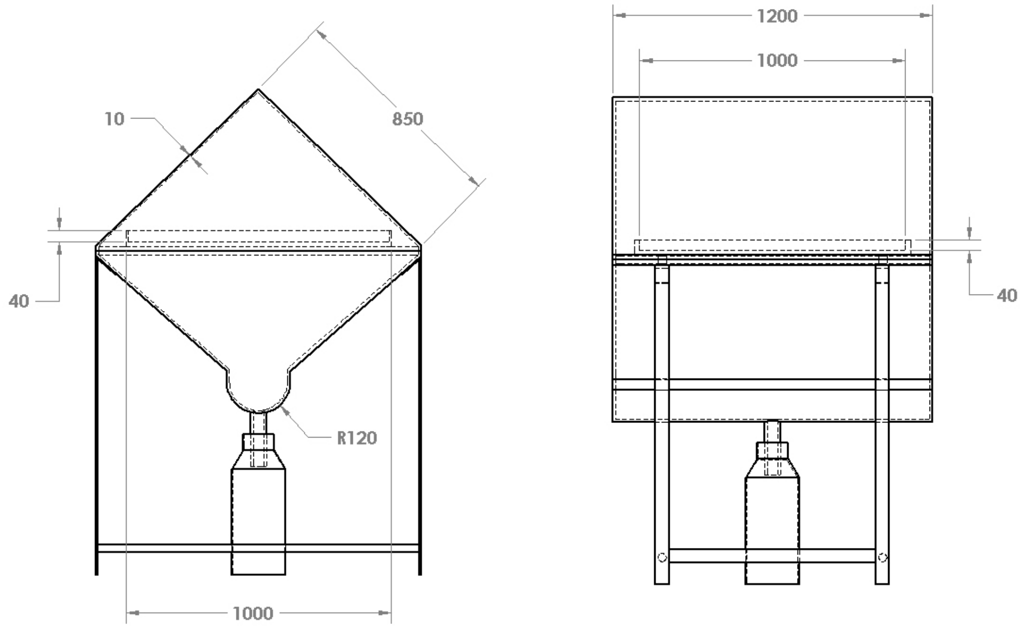


**Figure 1.** Cross sectional and design layout of the base still.

To enhance the condensation rate, double slope of borosilicate glass of 0.85m x 1m with the thickness of 3mm is fixed at top and bottom of the basin for condensation and gliding of fresh water. Condensed fresh water gets collected at bottom of the still, through the pipe which is at bottom. In modified still, 100 aluminum fins of 10 rows and 10 columns with the dimensions of (50mm x 10mm x 10mm) at 40mm fin pitch is attached at the basin absorber plate to raise the heat transfer region & to decrease the preheating time of saline water which is shown in Figure 2. The proposed experimental setup was designed, installed and tested for the ambient conditions of Sathyamangalam, Tamilnadu, India for the period of 7 days in the month of march (summer) from 06.00 AM to 06.00 PM and it is shown in Figure 3. A calibrated data logger setup was arranged to measure the temperatures of different nodes (glass inner and outer, basin plate, saline water, vapor, fins, ambient temperature) and volume of water, instantaneous global radiation, wind speed and other ambient properties of air with time step of 150 seconds. The design specifications, optical and thermal properties of basin absorber plate, transparent glass and fins in the proposed experimental setup are shown in Table 1.

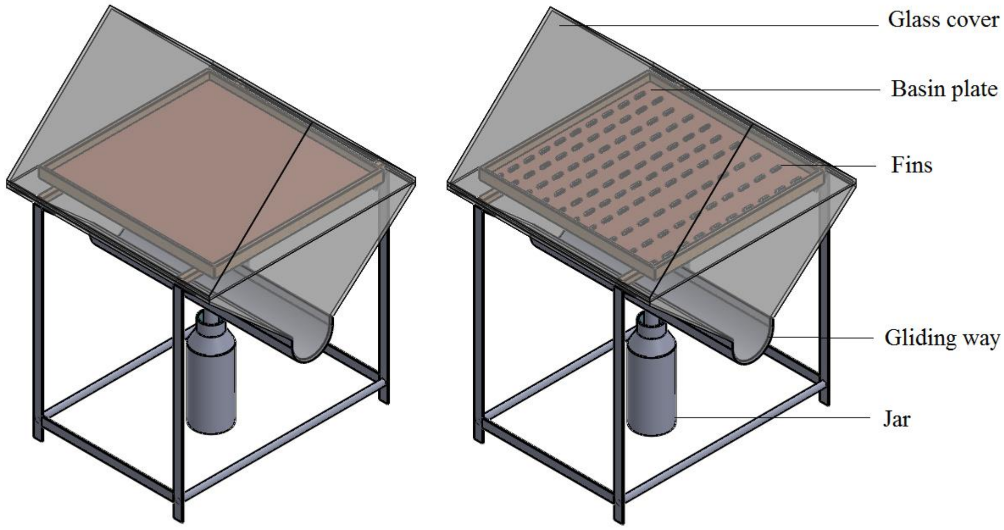


**Figure 2.** Schematic diagram of the still with and without rectangular fins.

**Figure 3.** Experimental setup of triangular solar still with fins.

The transparent cover has to allow the maximum radiation also it has to act as insulation for the shot range of thermal waves. Borosilicate glass material shows it extreme properties when compared with acrylic material as a transparent cover material. The copper absorber plate has to allow the maximum conduction of heat within the plate material and to maximize the convection heat transfer rate between the plate and water for effective heating. The aluminum fins act as the extended surface for improving the heat transfer with its higher specific heat and higher thermal conductivity.

**Table 1.** Design specifications and properties of the materials in modified solar still

| Description | Basin | Fins | Glass | Saline water |
|---|---|---|---|---|
| Length (m) | 1 | 0.05 | 1 | 1 |
| Breadth (m) | 1 | 0.01 | 0.85 | 1 |
| Thickness (m) | 0.003 | 0.01 | 0.003 | 0.015 |
| Thermal conductivity (W/mK) | 386 | 240 | 2 | 0.6 |
| Specific heat (kJ/kgK) | 379 | 880 | 0.83 | 4.178 |
| Density (kg/m$^3$) | 8960 | 2710 | 2230 | 1000 |
| Absorptivity | 0.9 | 0.9 | 0.05 | 0.05 |
| Surface area (m$^2$) | 1 | 0.12 | 1.7 | 1.95 |
| Transmissivity | - | - | 0.9 | 0.9 |

## 3. NUMERICAL MODEL

The thermal performance of base solar still and finned solar still can be numerically found by analyzing the energy balance of basin, glass material, water and water vapor. The mathematical modeling of the energy balance equations as follows (Nafey et al., 2000; Voropoulos et al., 2003; Zurigat et al., 2004; Shukla et al., 2005; Ben Bacha et al., 2007; Pal et al., 2019; Boopalan et al., 2021).The heat loss from the still, radiation energy gained by the still, sensible heat gain of the basin plate and convective heat transfer rate between the basin and saline water were computed by solving Equation(1) using MATLAB simulation.

$$\mathrm{I_g A_b \alpha_b \tau_g \tau_w} - \mathrm{m_b C_{P,b}(dT_b/dt)} - \mathrm{A_b} h_{c,b-w}(\mathrm{T_b} - \mathrm{T_w}) - \mathrm{A_b U_b}(\mathrm{T_b} - \mathrm{T_a}) = 0 \qquad (1)$$

The radiation energy gained by the saline water, convective heat transfer rate between the saline water and glass cover, radiation heat transfer rate between the saline water and glass cover, evaporation heat transfer rate between the saline water and glass cover and sensible heat gain of the saline water were computed by solving Equation(2) using MATLAB simulation.

$$I_g A_w \alpha_g \alpha_w \tau_g \tau_w + Q_{h,b-w} - m_w C_{P,w}(dT_w/dt) - A_w h_{c,w-g}(T_w - T_g) - A_w h_{r,w-g}(T_w - T_g) - A_g h_{e,w-g}(T_w - T_g) = 0 \quad (2)$$

$$h_{c,w-g} = 0.884\left\{\frac{T_w(P_w - P_g)}{268.9X10^3 - P_w} + (T_w - T_g)\right\}^{0.333} \quad (3)$$

$$h_{r,w-g} = \bar{\varepsilon}\sigma(T_w + T_g)(T_w{}^2 + T_g{}^2) \quad (4)$$

$$\bar{\varepsilon} = \frac{1}{\left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)} \quad (5)$$

$$h_{e,w-g} = \frac{0.016.173(P_w - P_g)h_{c,w-g}}{(T_w - T_g)} \quad (6)$$

The radiation energy gained by the glass, convective heat transfer rate between the glass cover and ambient air, radiation heat transfer rate between the glass cover and ambient air were computed by solving Equation(7) using MATLAB simulation.

$$I_g A_g \alpha_g + A_w h_{c,w-g}(T_w - T_g) + A_w h_{r,w-g}(T_w - T_g) + A_g h_{e,w-g}(T_w - T_g) - m_g C_{P,g}(dT_g/dt) - A_g h_{r,g-sky}(T_g - T_{sky}) - A_g h_{h,g-a}(T_w - T_g) = 0 \quad (7)$$

$$T_{sky} = 0.0552 T_a{}^{1.5} \quad (8)$$

$$h_{r,g-sky} = \varepsilon_g \sigma\left[\frac{(T_g{}^4 + T_{sky}{}^4)}{(T_g - T_{sky})}\right] \quad (9)$$

$$h_{h,g-a} = \begin{cases} 2.8 + 3u_0; u_0 \leq 5m/s \\ 6.15u_0{}^{0.8}; u_0 > 5m/s \end{cases} \quad (10)$$

The hourly output and instantaneous efficiency of the still were computed by solving Equation(11) to Equation(12) using MATLAB simulation.

$$\frac{dm_d}{dt} = \frac{Q_{h,w-g}}{h_{fg}} = \frac{h_{c,w-g}A_w(T_w - T_g)}{h_{fg}} \quad (11)$$

$$\eta_{still} = \sum \frac{m_d h_{fg}}{I_g A_b} \tag{12}$$

Based on the above mentioned energy balance model Equation(1) to Equation(20), the output and the instantaneous still efficiency can be found using the MATLAB software with the time step of 150 seconds and it is shown in Figure 4. Basin absorber surface area, water surface area and heat transfer coefficients is significantly varying with respect to the fin properties which is to be evaluated and the corresponding performance is also to be numerically investigated.

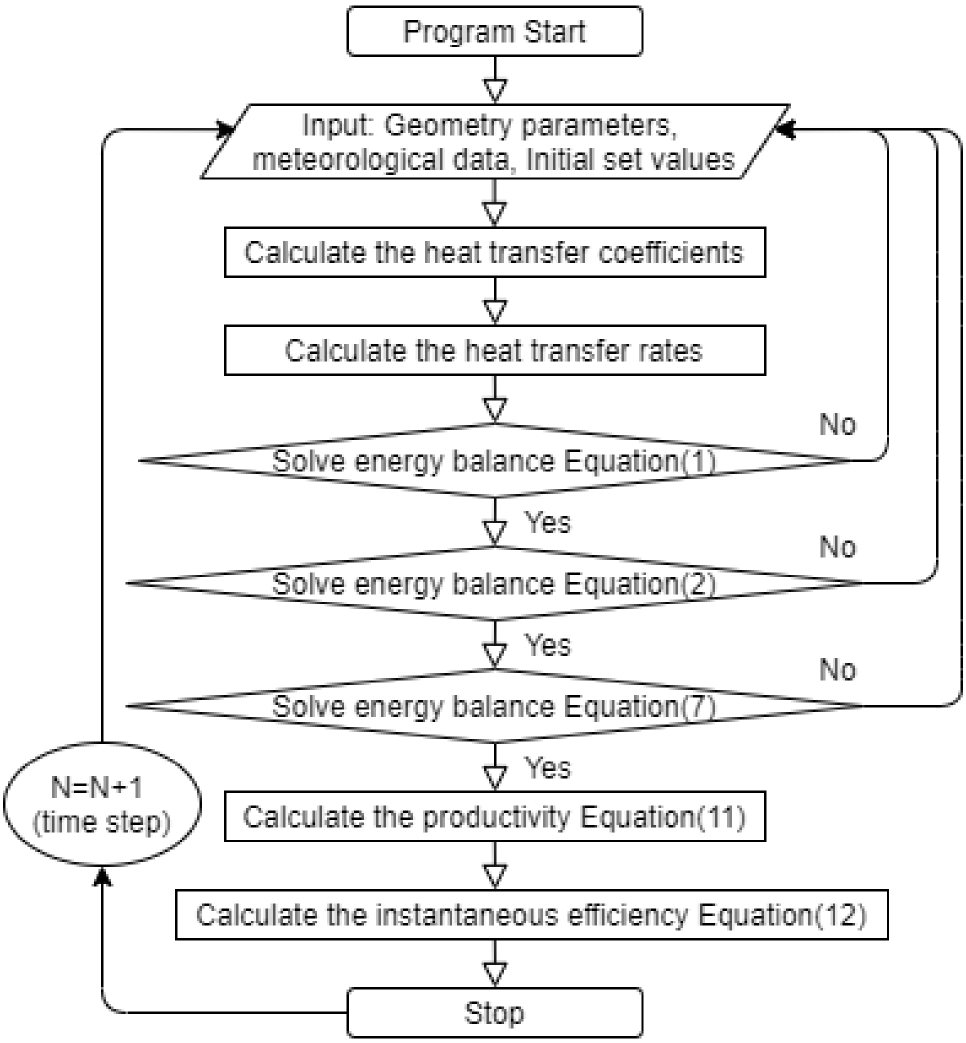


**Figure 4.** Flow chart of the simulation program.

## 4. RESULTS AND DISCUSSION

The ambient parameters such as global radiation, ambient air temperature and wind velocity are measured using weather station which is shown in Figure 5, Figure 6 and Figure 7respectively for the corresponding 7 summer days in Sathyamangalam, Tamilnadu, location11.4963° N, 77.2769° E.

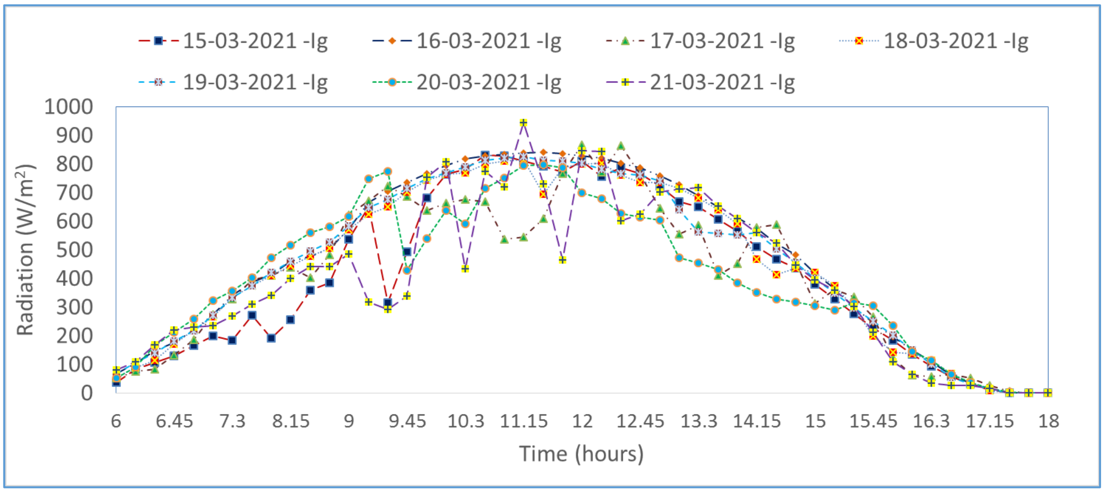


**Figure 5.** Solar radiation.

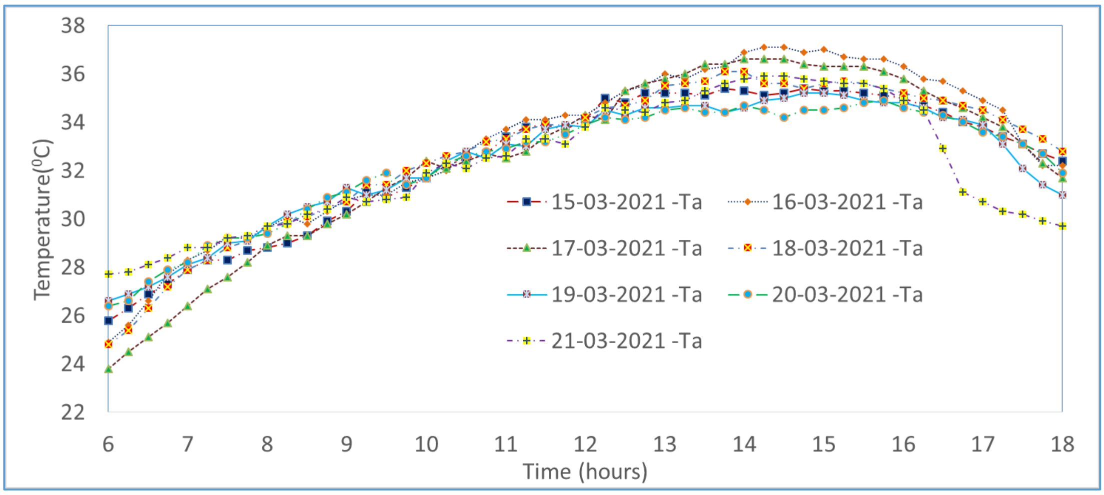


**Figure 6.** Ambient air temperature.

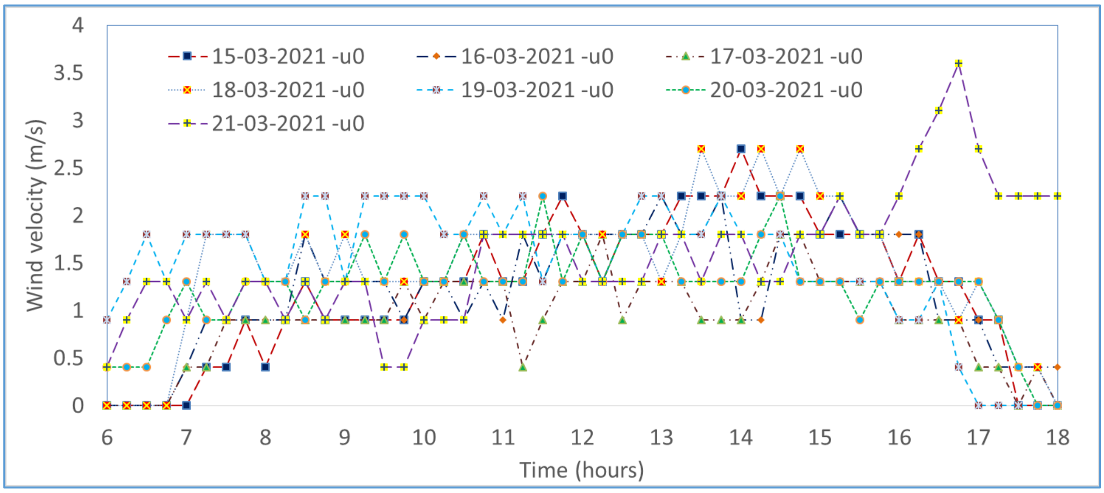


**Figure 7.** Wind velocity.

The thermal performance of the base still and modified still with rectangular-fins for a typical day on 15-03-2021 are evaluated from the experimental data's and numerical simulations which is shown in Figure 8.For a typical day 15-03-2021, the maximum hourly output of the base still is ranges from 514 and 543ml/m2/hour and in modified still it is ranges from 720 to 746ml/m2/hour. Also the instantaneous efficiency of the base still is ranges from 39 and 41% and in modified still it is ranges from 54 and 56%. The deviations on the simulation results with the experimental results were found to be 8% and the results shows that the modified solar still shows the better performance than the base still.From the experimental investigations on the modified solar still, it was found that the maximum instantaneous efficiency and hourly output is achieved on 16-03-2021, about 60.4% and 770ml/m2/hour which is shown in Figure 9 and Figure 10 respectively.

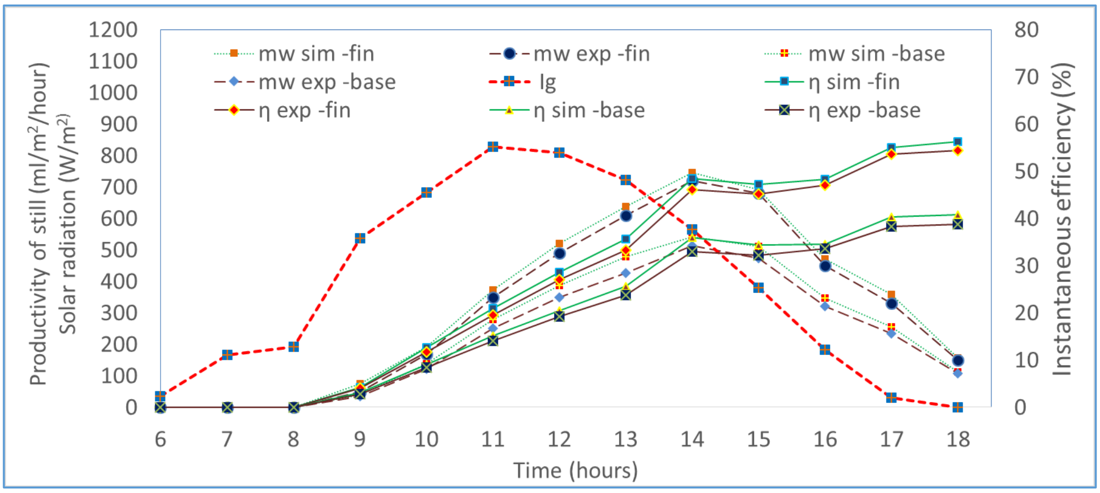


**Figure 8.** Productivity and instantaneous efficiency of stills on 15-03-2021.

The significance of the ambient constraints on the thermal performance of the still is evaluated by experimental and numerical investigations. It was found the performance of the still is maximum for the greater solar radiation and the heat loss from the still is smaller for the highest ambient temperature. The wind speed is also have significant impact on the performance of the still, the heat loss and the condensation rate of vapor on glass cover is higher for the maximum wind speed. The daily output of the base still ranges from 2.78 to 3.25 liter/m$^2$/day and for modified still ranges from 3.87 to 4.58 liter/m$^2$/day for the 7 summer days 15/03/2021 to 21/03/2021 which is shown in Figure 11.

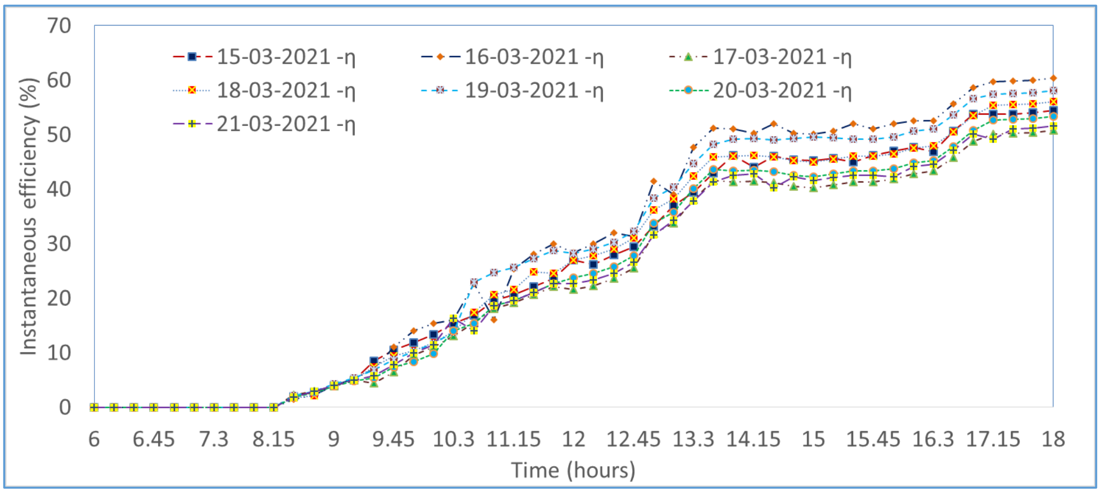


**Figure 9.** Instantaneous efficiency of still with fins.

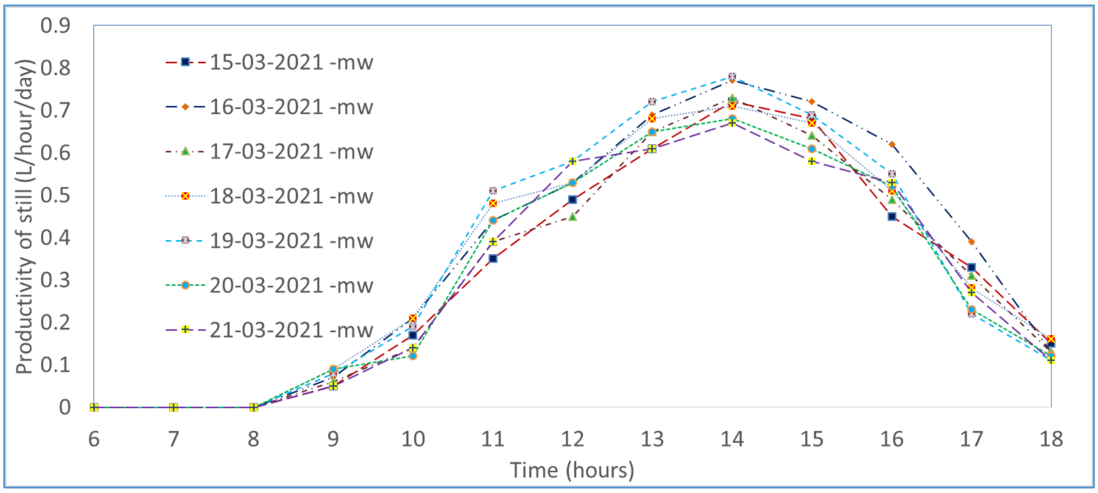


**Figure 10.**Hourly Productivity of still with fins.

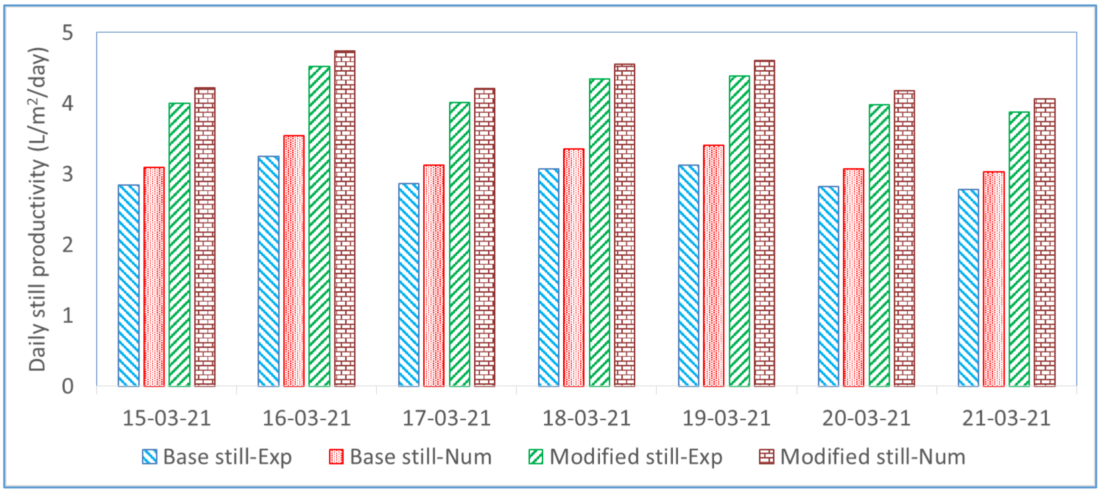


**Figure 11.** Daily Productivity of still with and without fins.

## 5. CONCLUSION

In this study, the experimental and numerical investigation of base triangular solar still and rectangular-fins attached triangular solar still for 7 typical days in the month of March has been performed. The paper also discussed the role of ambient conditions on performance improvement of solar still. The maximum instantaneous efficiency and hourly fresh water output of the still with rectangular-fins were found to be 60.4% and 4.58 liter/$m^2$/day which are significantly higher than the base still. The result from the investigations shows that the daily output of the modified still ranges from 3.87 to 4.58 liter/$m^2$/day which are 41% higher than the basic triangular still.

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