Performance Evaluation of A Solar Still Coupled to an Evacuated Tube Collector type Solar Water Heater

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ABSTRACT

Solar distillation is a promising method for the supply of freshwater to rural communities. Worldwide passive solar still is used for solar distillation plants due to its simplicity in construction and operation, low cost and however the yield is low. Various active methods have been developed to overcome this issue. These developments create additional costs for the system.

The main objective of this project is to effectively utilize the solar water heater for solar still productivity enhancement, which works as a hybrid system. The evacuated tube collector model solar water heater was coupled to a solar still, and the performance study was conducted at various timings with different operating conditions like Solar still operated alone, Hybrid Still operated during daytime and operated for 24 hours and also with various water depths and various water samples. Both Theoretical and Experimental analysis were conducted and the results were compared. The water quality results for different water samples for both untreated and treated water were tabulated.

Keywords: Evacuated tube collector, Productivity, Solar still, Solar water heater, Water quality

1. INTRODUCTION

Today fresh water demand is increasing continuously, because of the industrial development, intensified agriculture, improvement of standard of life and increase of the world population. Only about 3 % of the world water is potable and this amount is not evenly distributed on the earth Large quantities of fresh water are required in many parts of the world for agricultural, industrial and domestic uses. Lack of fresh water is a prime factor in inhibiting regional economic development. Seawater and sometimes brackish water desalination constitute an important option for satisfying current and future demands for fresh water in arid regions.Desalination can be achieved by using a number of techniques.The conventional distillation process namely reverse osmosis, electro dialysis, multieffect evaporation etc are not only energy intensive but also uneconomical when the demand for the fresh water is small

Solar distillation is an attractive Saline water Distillation. The basin type of solar still is simple in design, manufacture and operation. In addition this process is cost free. Enhancing stills yield have been studied by many investigators and they have suggested many approaches like concave wick, tube type, and weir type was also reported for productivity enhancement. Also approaches like using different insulating materials, brine level, double slope concentrators, etc.

2. Literature Survey :

T. V. Ramachandra [13] proposed a solar energy potential assessment using GIS.He proposed that Renewable energy systems use resources that are constantly replaced in nature and are usually less polluting. The potential analysis reveals that, maximum global solar radiation is in districts such as Uttara Kannada and Dakshina Kannada. Global solar radiation in Uttara Kannada during summer, monsoon and winter are 6.31, 4.40 and 5.48 kWh/sq.m, respectively. Similarly, Dakshina Kannada has 6.16, 3.89 and 5.21 kWh/sq.m during summer, monsoon and winterSantosh M. Avvannavar,Monto Mani1, Nanda Kumar [14] conducted a research on Improving access to safe drinking water can result in multi-dimensional impacts on people’s livelihood. They concluded that solar still is the safe and suitable way for water desalination. Hitesh N Panchal [22] worked on the effect of various parameters on productivity of Single slope and double slope solar still. Distilled output of double slope solar still is higher compared with single slope. Distilled output from the solar still is higher at 13:00. Solar insolation is highest at13:00. By use of sprinkler and increased condensation area, the distilled output is increased up to 20%. By use of

2.0 cm water depth, proper utilization of the solar insolation as well as distilled output is increased. So permissible water depth is 2.0 cm and it should be maintained constant by constant head tank. S.L.Jadhav, B.L.Chavan and S.S.Patil [27] conducted the experiment on Designing, fabrication and performance analysis of solar still for purification of water. The highest rate of PRP was recorded between 11.30 am and 12.30 noon in all the solar stills studied. It was 0.0287 L/m^2/hr in unit I, 0.0288 L/m^2/hr in unit II, 0.0279 L/m^2/hr in unit III and 0.0267 L/m^2/hr in unit IV. O.O.Badran, H.A .Al – Tahaineh [10] performed a study on the Effect of coupling a Flat plate collector on the solar still productivity. He carried out experiment for different parameters to enhance the productivity and the same were studied.Single slope Solar still with mirrors fixed to the interior sides of the still was coupled to an FPC.It was found that coupling effect has increased the productivity by 36% compared to that of an active solar still K.Voropolous, E.Mathioulakis, V.Belessiotis [7] conducted an Experimental Investigation of the behavior of solar still coupled with hot water storage tank. G.N.Tiwari, J.N.Thomas and Emran Khan [4] studied on thermal analysis of solar distillation to optimize the inclination of the glass cover for maximum yield.

From the literature survey, it can be summarized that

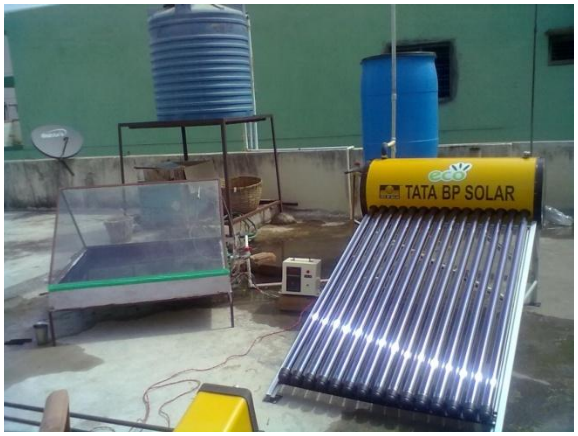
Solar distillation is an attractive Saline water Distillation. The basin type of solar still is simple in design, manufacture and operation. In addition this process is cost free. These advantages are greatly offset by the low productivity of fresh water of 2.5l/m^2 day on an average

Enhancing stills yield have been studied many investigators and they have suggested many approaches like concave wick, tube type, and weir type was also reported for productivity enhancement. Also approaches like using different insulating materials, brine level, double slope concentrators, etc. However there is a scope to study the enhancement of the yield assisted by solar collectors.

The single basin solar still was coupled with a flat plate collector (FPC) in natural circulation mode, which resulted in a productivity enhancement of 30 to 52% compared to the simple solar still. Over 50% of the productivity enhancement was achieved by coupling the solar still with a flat plate solar collector in forced circulation mode. The solar still coupled with a parabolic concentrator increased the productivity by 35 to 45%, and this increase was larger in the double effect still.

The solar water heater is the best option for increasing the basin water temperature. The evacuated tube collector (ETC)-type solar water heater is more advantageous than the flat plate collector type due to its greater reduction in heat losses caused by the vacuum present in the tubes. Evacuated tube solar collectors have improved performance compared to the flat plate collectors, particularly for high temperature operations

3.Experimental Setup :



A double slope single basin solar still coupled with an ETC solar water heater is designed and constructed for the experimental work. It is as shown in the figure 3.1 .The basin of the solar still is square in shape with an absorber area of 1m^2. The basin structure of the solar still is composed of a galvanized iron sheet. The inner side of the basin is painted black to maximize the absorption of solar radiation. The bottom and sides of the still basin were well insulated with a Glass wool layer that was 0.025 m thick. The box surrounding the still basin is made of plywood. An inlet pipe was fixed to the rear side of the solar still to supply brackish water. One additional pipe was fixed at the left side of the solar still to drain out the dirty water after the distillation is finished. An ordinary clear window with a glass thickness of 0.005 m was used as the top cover of the solar still and inclined at an angle of 45°. The total experimental setup was arranged to face in the southern-northern direction to receive the maximum solar radiation. A silicon rubber sealant was used as the seal between the glass cover and body of the solar still to prevent leakage at the stem. The distillate water condensed from the glass cover was collected in a distillation trough fit on the lower side of the solar still. Additionally, a rubber pipe was connected to the collection tray to collect desalinated water into a measuring jar. Holes were drilled in the body of the still to attach the thermocouples that measured the temperature at various locations. The hybrid solar still unit was operated in the month of April – May 2012 under local conditions.

The above designed single basin solar still was coupled to an ETC-type solar water heater that was manufactured by TATA BP SOLAR, which is an approved manufacture of ETC-type solar water heaters by the Ministry of New and Renewable Energy Sources (MNRE), Government of India. The collector consists of 15 evacuated tubes with an inner diameter of 0.037 m, an outer diameter of 0.047 m and a length of 1.5 m. The inlet pipe of the solar water heater was connected with a non-return valve from a 200-liters capacity overhead tank to the solar water heater to connect a cold water supply. A second pipe was used to make a connection between the other end of the Collector and the bottom of the solar still with a gate valve. The outlet pipe from the header was connected to the storage tank. This arrangement moved the hot water supply from the evacuated tube collector to the still basin. The ball valves and pipes were attached between the still and the collector and were well insulated to avoid heat losses.

4.Working Principle

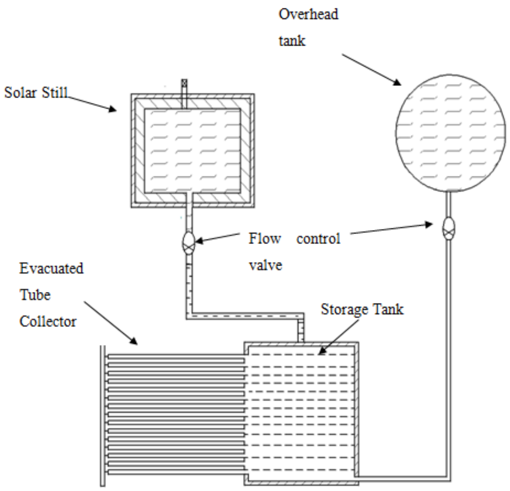


Fig 3.10: Schematic Diagram of the Experimental Set up

Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the blackened base. This interior surface uses a blackened material to improve absorption of the sunrays. The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The heated water vapour evapourates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. Feed water should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evapouration process. If the still produced 3 litres of water, 9 litres of make-up water should be added, of which 6 litres leaves the still as excess to flush the basin.

5.Methodology

Initially, the tap water was supplied to the ETC solar water heater and run for a day to reach a steady state condition. The quantity of water in the basin of the solar stills was maintained at 10 kg for both passive and active modes of operation. The experiment commenced two days after assembly of the glass cover and after reaching steady state conditions in the storage tank. For each experiment, the glass cover was cleaned in the morning to avoid dust deposition over the outer layer of the glass. The amount of water collected in each 10 min was noted in measuring jar and the same amount of water was replaced in the solar still to maintain a constant water depth and the yield was measured on hourly basis. The experimental setup was investigated at various times through a series of tests. The experimental performance tests were conducted from April to July 2010. To find the effect of coupling an ETC solar water heater with the solar still, Different tests explained below were performed:

A. Solar Still Alone
B. Hybrid Still (Solar Still + ETC type Solar Heater) operated from 8AM till 5PM
C. Hybrid Still operated for 24 hours

These experiments were conducted for different parameters like,

A. Water samples (River water, Borewell water and Synthetic water (KMnO4)

B. Water depths

C. Inlet water temperatures

Case A: Solar Still Alone:

This is a passive solar still which is operated from 8AM till 5PM and the amount of distillate output and its efficiency was calculated

Case B: Hybrid Still (Solar Still + ETC type solar heater) operated from 8AM till 5PM:

The purpose of this test was to understand the performance of the solar still for an entire day. For most hot clear days of the year, the solar water heater is not utilized; however, it may be utilized for productivity enhancement of the solar still.

Case C: Hybrid still operated for 24 hours

The hybrid still was operated for 24 hours to study the performance of the solar still and to evaluate the improvement in its efficiency

6. THEORETICAL ANALYSIS

Design Parameters for Theoretical Analysis:

Parameter	Value	Unit
A_s	1	m^2
C_w	4190	J/kg°C
M_w	10	Kg
T	3600	S
α_w'	0.34	
α_g'	0.05	
α_b'	0.38	
L_g	0.005	M
K_g	0.78	W/m°C
L_i	0.025	M
K_i	0.08	W/m°C
V	0–6	m/s
Σ	5.67×10−8	W/m^2K^4
ε_{eff}	0.82	
A_L	3.32	m^2
A_{ET}	1.0575	m^2
F_R	0.831	
$(\alpha\tau)_c$	0.8	
U_{LC}	0.81	$W/m^2°C$

Table 4.1: Various Parameters for Theoretical analysis

1. The outer surface of the glass cover:

$$T_{go} = \frac{\frac{Kg}{Lg} T_{gi} + h_{t,g-a} T_a}{h_{t,g-a} + \frac{Kg}{Lg}} \quad \ldots\ldots\ldots\ldots (4.1)$$

Total heat transfer coefficient from the glass cover to ambient is given by,

$$h_{t,g-a} = 5.7 + (3.8 * V) \quad \ldots\ldots\ldots (4.2)$$

2. The inner surface of the glass cover.

$$T_{gi} = \frac{\alpha'_g * I(t)_s + h_{t,w-g} T_w + U_{c,g-a} T_a}{h_{t,w-g} + U_{c,g-a}} \quad \ldots (4.3)$$

Where,

$$U_{c,g-a} = \frac{\frac{Kg}{Lg} h_{t,g-a}}{\frac{Kg}{Lg} + h_{t,g-a}} \quad \ldots (4.4)$$

The total heat transfer coefficient between water and glass is given by,

$$h_{t,w-g} = h_{c,w-g} + h_{e,w-g} + h_{r,w-g} \quad \ldots (4.5)$$

The radiative heat transfer coefficient between water and glass is given by,

$$h_{r,w-g} = \varepsilon_{eff} \sigma [(T_w + 273)^2 + (T_{gi} + 273)^2] \text{ x } (T_w + T_{gi} + 546)] \quad \ldots . (4.6)$$

The convective heat transfer coefficient between water and glass is given by,

$$h_{c,w-g} = 0:884*(\Delta T')^{1/3} \quad \ldots\ldots\ldots (4.7)$$

Where,

$$\Delta T^1 = (T_w - T_{gi}) + [(P_w - P_{gi}) \text{ x } (T_w + 273) / (268.9 \text{ x } 10^{-3} - P_w)] \ldots\ldots (4.8)$$

$$p_w = e^{[25.317 - \left(\frac{5144}{274+T_w}\right)]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ldots (4.9)$$

$$p_{gi} = e^{[25.317 - \left(\frac{5144}{274+T_{gi}}\right)]} \quad \ldots\ldots\ldots\ldots\ldots\ldots . \ldots\ldots\ldots (4.10)$$

The evapourative heat transfer coefficient between water and glass is given by,

$$h_{e,w-g} = 16.273 \text{x } 10^{-3} \text{x } h_{c,w-g} \text{x} \frac{(p_w - p_{gi})}{(T_w - T_{gi})} \quad (4.11)$$

The total heat transfer coefficient between water and glass is given by,

$$h_{t,w-g} = h_{c,w-g} + h_{e,w-g} + h_{r,w-g}$$

The inner surface of the glass cover: From equation (3),

$$\mathrm{T_{gi}} = \frac{\alpha'_{g} * I(t)_{s} + h_{t,w-g}T_{w} + U_{c,g-a}T_{a}}{h_{t,w-g} + U_{c,g-a}}$$

3.The basin liner :

$$\mathrm{T_b} = \frac{\alpha'_{-b}I(t)_s + h_wT_w + h_bT_a}{h_w+h_b} \quad \ldots\ldots (4.12)$$

Where,

$$\alpha'_{-b} = \alpha_{-b}\left(1-\alpha'_{g}\right)(1-\alpha'_{w})$$

The overall heat transfer coefficient from the basin liner to ambient is given by,

$$h_b = \left[\frac{L_i}{K_i} + \frac{1}{h_{t,b-a}}\right]^{-1} \quad \ldots\ldots (4.13)$$

Since there is no velocity in the bottom of the still , $h_{t,b-a} = h_{t,g-a}$

The convective heat transfer co-efficient between basin to water is given by,

$$h_w = \frac{K_w}{X_w}\,C\,(Gr * Pr)^n \ldots\ldots\ldots (4.14)$$

$$Gr = \frac{\beta g X_v^3 \rho_v^2 \Delta T'}{\mu_v^2}$$

$$Pr = \frac{\mu_v C_p}{K_v}$$

The overall bottom heat loss coefficient is given by,

$$U_b = \frac{h_w h_b}{(h_w + h_b)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.15)$$

The overall top heat loss coefficient from the water to the ambient is given by,

$$U_t = \frac{h_{t,w-g}h_{t,g-a}}{(h_{t,g-a} + U_{wo})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.16)$$

Where,

$$U_{wo} = \frac{h_{t,w-g}\dfrac{K_g}{L_g}}{\left(h_{t,w-g} + \dfrac{K_g}{L_g}\right)} \ldots\ldots\ldots\ldots\ldots (4.17)$$

The basin liner: From Equation (4.12),

$$\mathrm{T_b} = \frac{\alpha'_{-b}I(t)_s + h_wT_w + h_bT_a}{h_w+h_b}$$

4. The water mass:

$$T_w = \frac{\overline{f(t)}}{a}\left[1-e^{-at}\right] + T_{wo}e^{-at} \ldots\ldots\ldots\ldots (4.18)$$

Where,

$$a = \left[\frac{U_{eff}}{(MC)_w}\right] \qquad f(t) = \left[\frac{I_{eff} + U_{eff}\,T_a}{(MC)_w}\right]$$

$$I_{eff} = F_R(\alpha\tau)_C I(t)_c + (\alpha\tau)_{eff} I(t)_s$$

$$U_{eff} = U_{LS} + F_R U_{LC}$$

Assuming $F_R = 0.81$, $U_{LC} = 0.86$

$$U_{LS} = U_t + U_b \ldots\ldots\ldots (4.19)$$

$$(\alpha\tau)_{eff} = \left[\alpha'_b \frac{h_w}{(h_w+h_b)} + \alpha'_w + \alpha'_g \frac{h_{t,w-g}}{(h_{t,g-a}+U_{wo})}\right] (4.20)$$

$$I_{eff} = F_R(\alpha\tau)_C I(t)_c + (\alpha\tau)_{eff} I(t)_s$$

Hence the water temperature is calculated as ,

$$T_w = \frac{\overline{f(t)}}{a}\left[1-e^{-at}\right] + T_{wo}e^{-at} \ldots\ldots\ldots\ldots\ldots (4.21)$$

The hourly yield is given by,

$$m_{ew} = \frac{h_{e,w-g}\left(T_w - T_{gi}\right) \text{ x } 3600 \text{ x } A_s}{L} \quad \ldots\ldots (4.22)$$

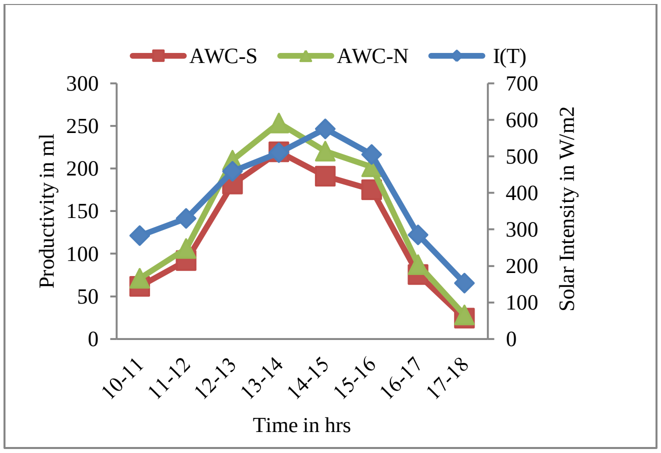
Theoretical calculations were done for water depths of 1.5cm and 2cm and for various operating conditions for hybrid still operated from 8AM till 5PM and hybrid still operated for 24hours.Also the calculations were done for different water samples and the same has been tabulated below.

Operation	**Still Alone**			**Hybrid Still operated from 8AM to 5PM**			**Hybrid Still operated for 24 hrs**		
Water Depth	1	1.5	2	1	1.5	2	1	1.5	2
River water	2.69	2.37	2.27	4.43	4.24	3.84	6.47	5.50	4.84
Borewell water	2.47	2.22	2.20	4.33	4.22	3.67	6.37	5.45	4.50
River water + kmno4	2.98	2.49	2.41	4.58	3.72	3.91	6.61	5.50	5.21

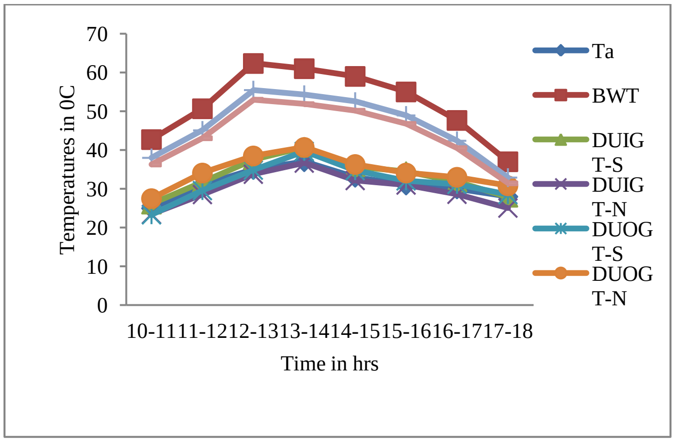
Table 4.5: Tabulation of Theoretical amount of water collected

RESULTS AND DISCUSSIONS

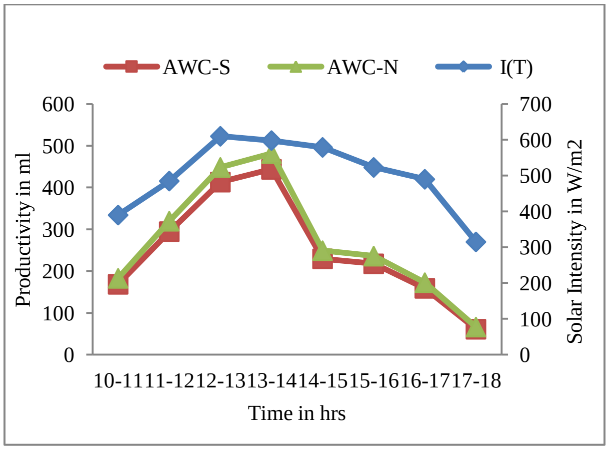
Experiments were conducted to understand the performance of the solar still coupled with the solar water heater for comparison with the passive solar still alone. As can be seen from the hourly yield equation, the water temperature and the inner glass cover temperature were the most influential parameters on the yield calculation. Therefore, for the present discussion, only variations in the water temperature, inner glass cover temperature and yield were considered. Experiments were carried out on the test rig for river water, Borewell Water and artificially created synthetic water (River water + KMnO4).



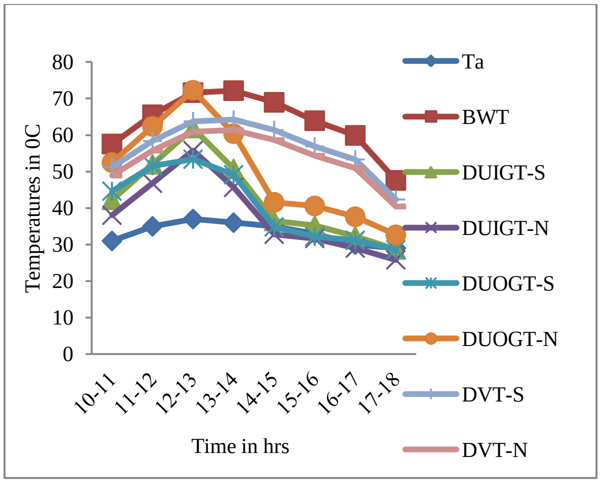
Graph 5.1: Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 1cm water depth for River Water



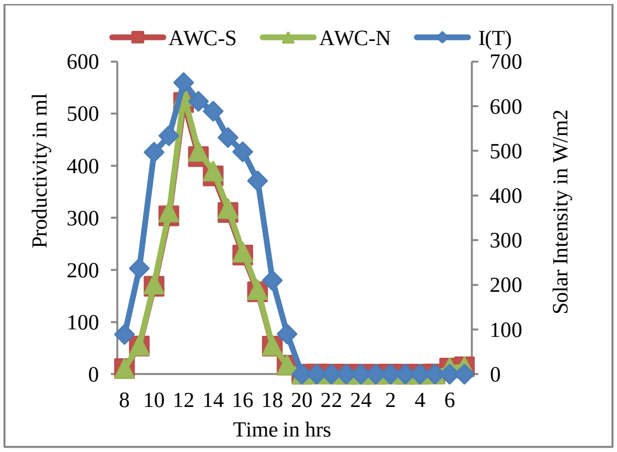
Graph 5.2: Hourly variation of various Temperatures for a Solar Still Alone with 1cm water depth for River Water



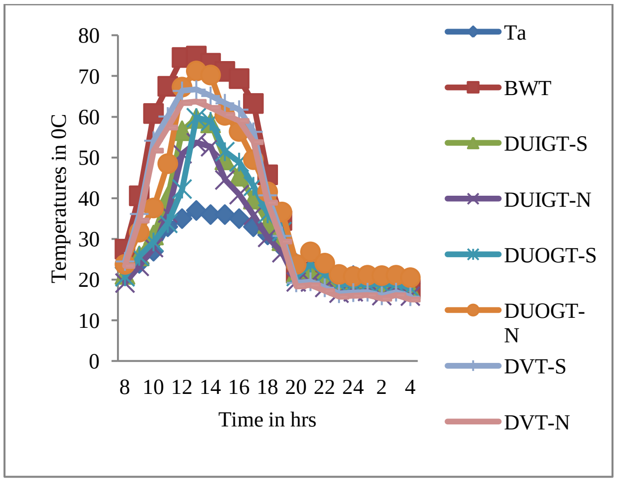
Graph 5.3: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1cm water depth for River water



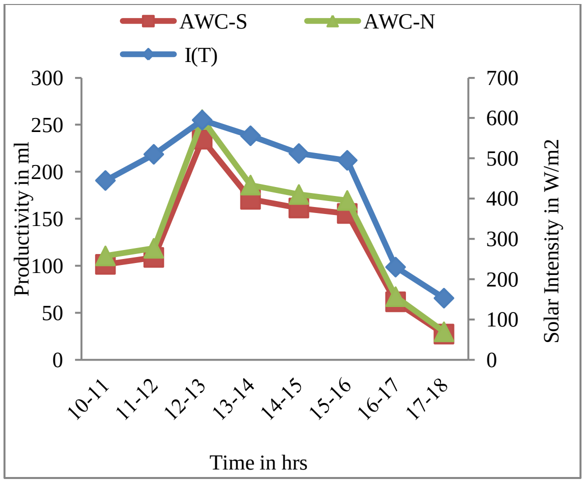
Graph 5.4: Hourly variation of various temperatures for an Hybrid still with 1cm water depth for River water



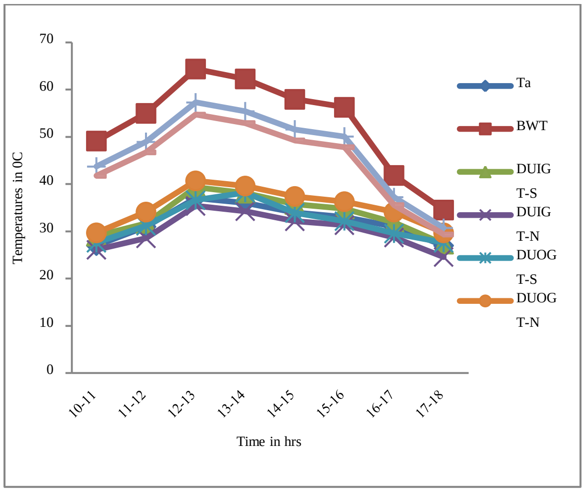
Graph 5.5: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1cm water depth for River water



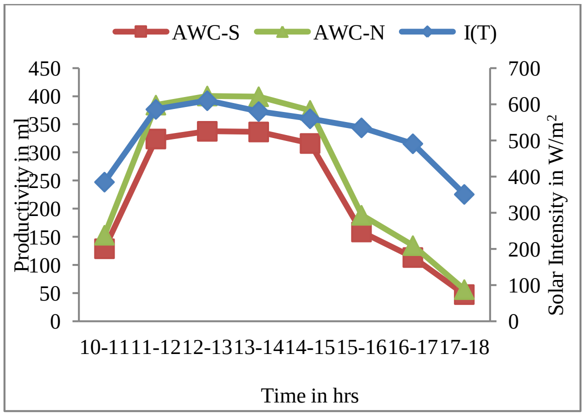
Graph 5.6: Hourly variation of various temperatures for an Hybrid still with 1cm water depth for River water



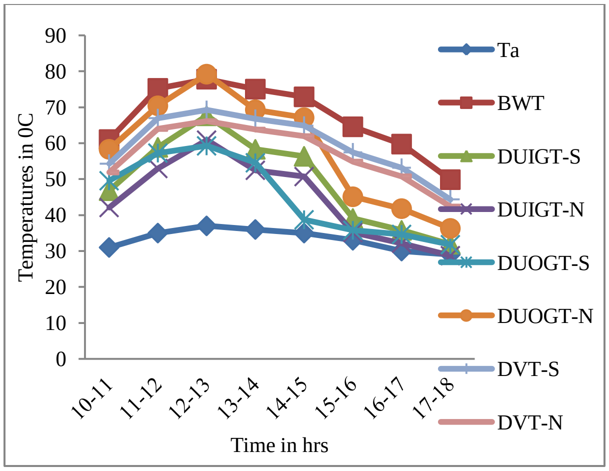
Graph 5.7 Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 1.5cm water depth for River Water



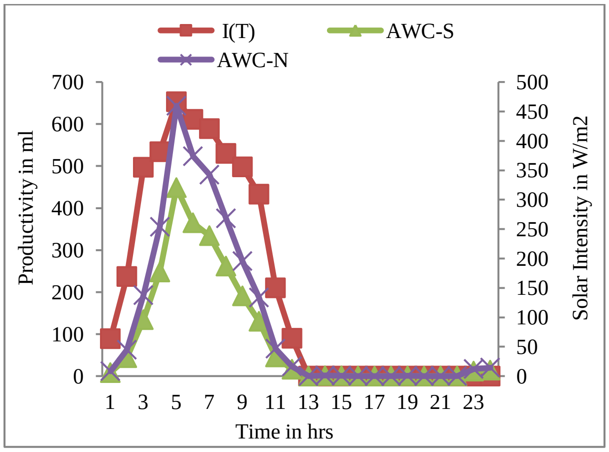
Graph 5.8: Hourly variation of various Temperatures for a Solar Still Alone with 1.5cm water depth for River Water



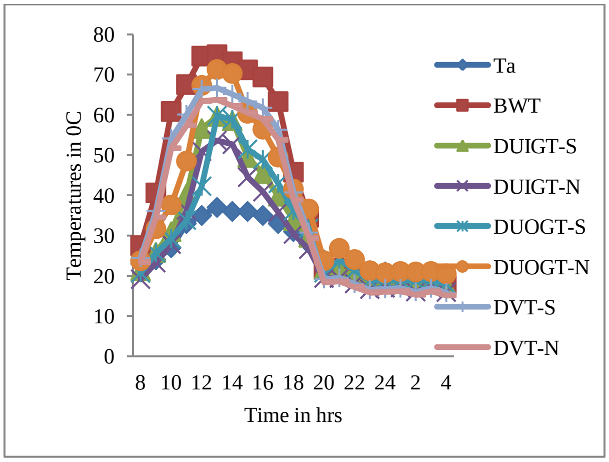
Graph 5.9: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1.5cm water depth for River Water



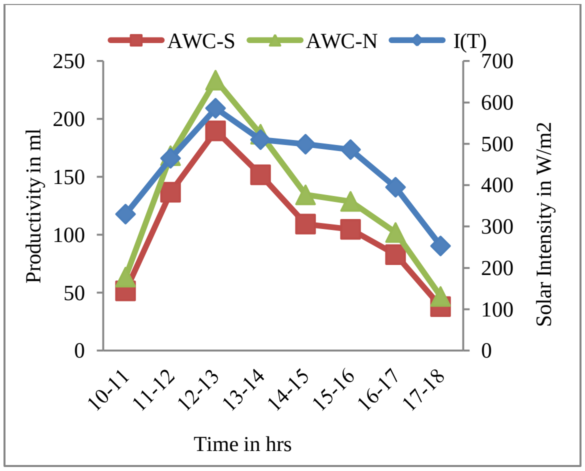
Graph 5.10: Hourly variation of various temperatures for an Hybrid still with 1.5cm water depth for River Water



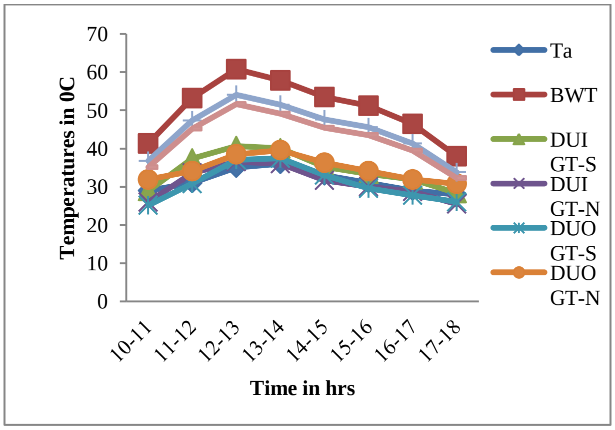
Graph 5.11: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1.5cm water depth for River Water



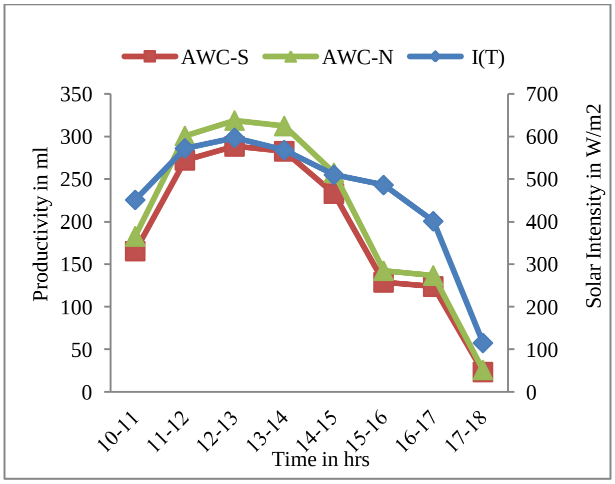
Graph 5.12: Hourly variation of various temperatures for an Hybrid still with 1.5cm water depth for River Water



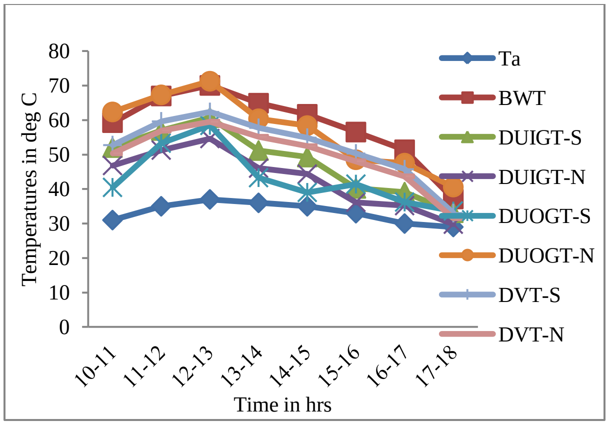
Graph 5.13: Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 2cm water depth for River Water

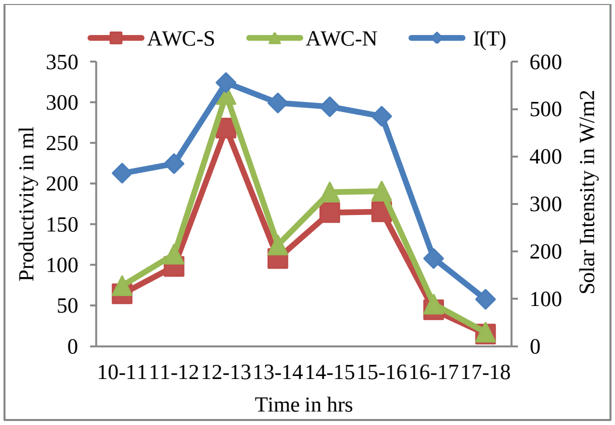


Graph 5.14: Hourly variation of various Temperatures for a Solar Still Alone with 2cm water depth for River Water



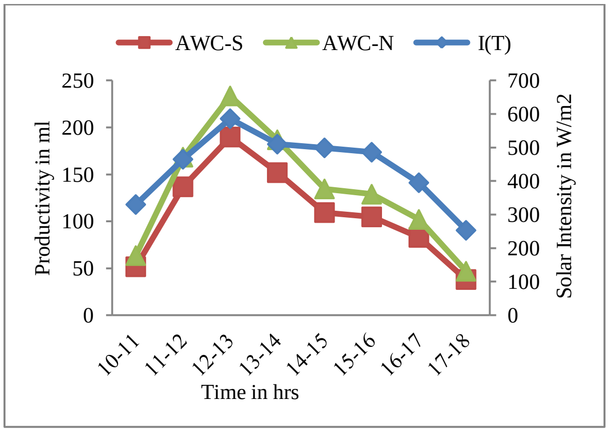
Graph 5.15: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 2cm water depth for River Water

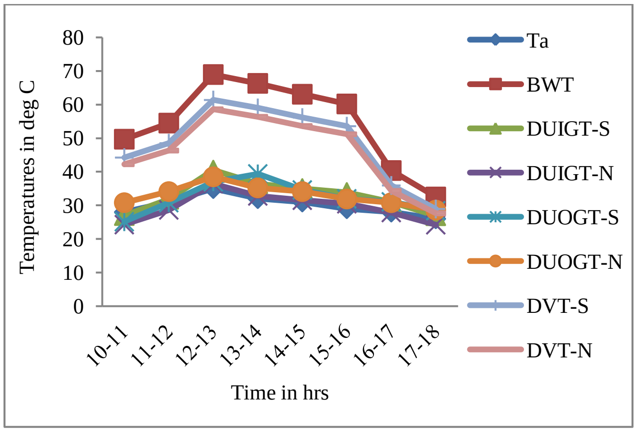




Graph 5.16: Hourly variation of various temperatures for an Hybrid still with 2cm water depth for River Water

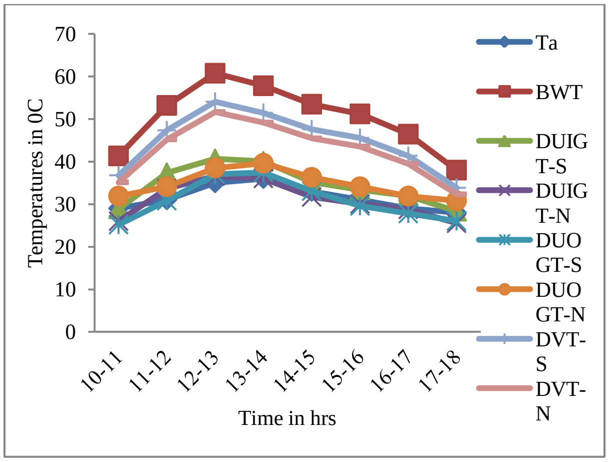
Graph 5.19: Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 1cm water depth for Borewell Water

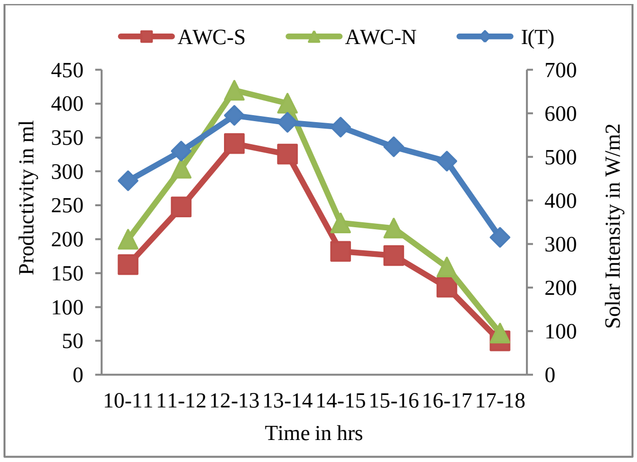




Graph 5.17: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 2cm water depth for River Water

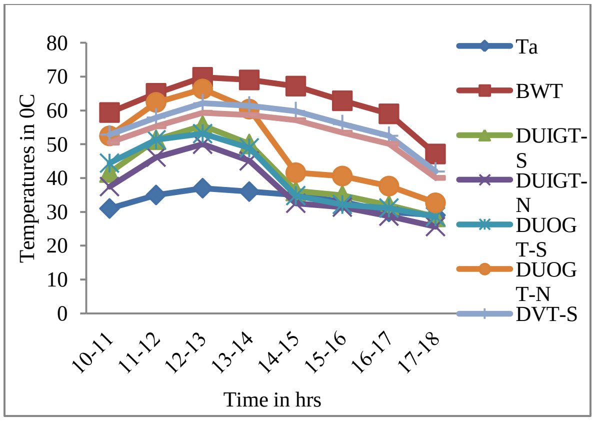
Graph 5.20: Hourly variation of various Temperatures for a Solar Still Alone with 1cm water depth for Borewell Water



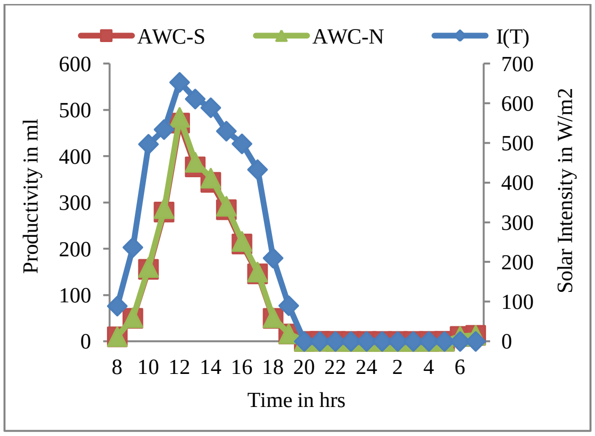


Graph 5.18: Hourly variation of various temperatures for an Hybrid still with 2cm water depth for River Water

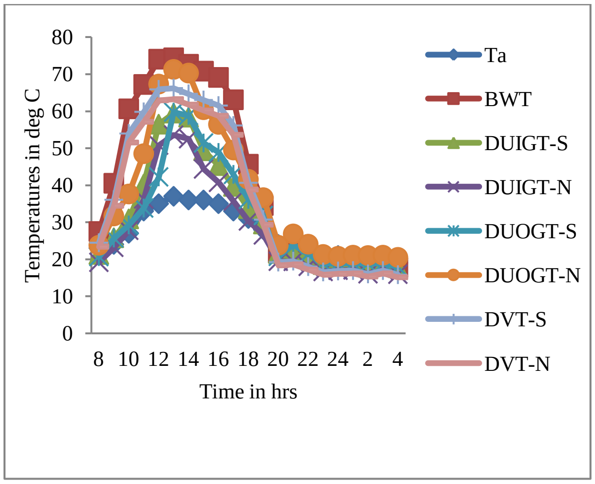
Graph 5.21: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1cm water depth for Borewell water



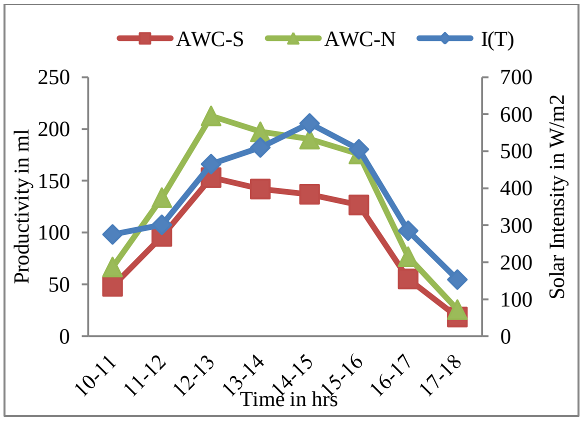
Graph 5.22: Hourly variation of various temperatures for an Hybrid still with 1cm water depth for Borewell water



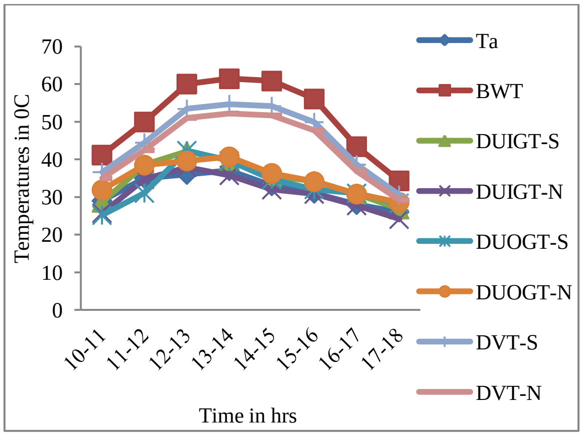
Graph 5.23: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1cm water depth for Borewell water



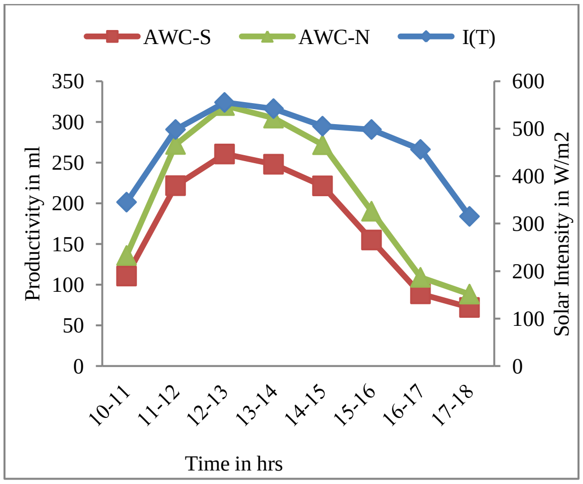
Graph 5.24: Hourly variation of various temperatures for an Hybrid still with 1cm water depth for Borewell water



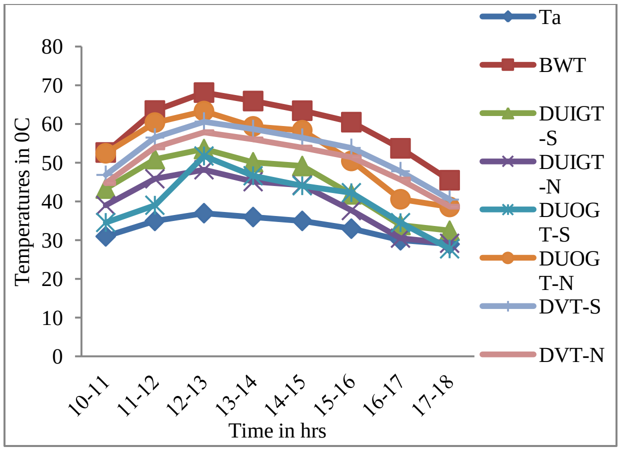
Graph 5.25: Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 1.5cm water depth for Borewell Water



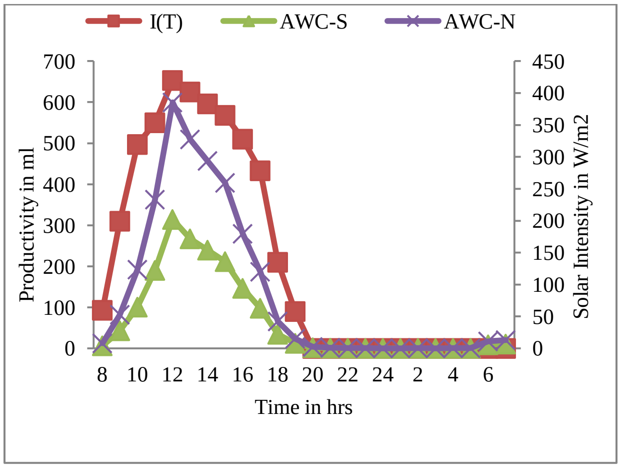
Graph 5.26: Hourly variation of various Temperatures for a Solar Still Alone with 1.5cm water depth for Borewell Water



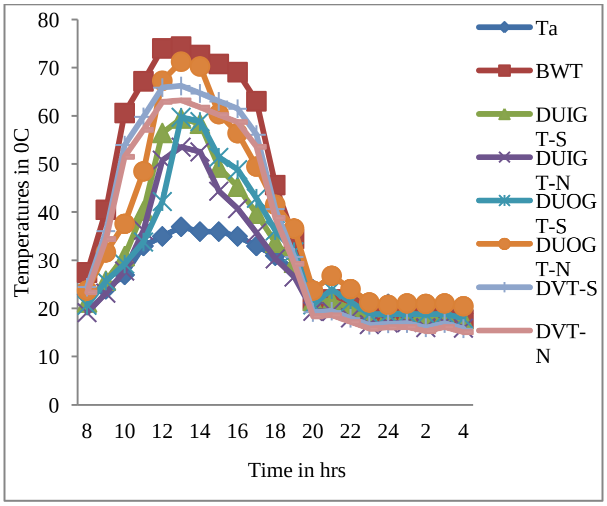
Graph 5.27: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1.5cm water depth for Borewell Water



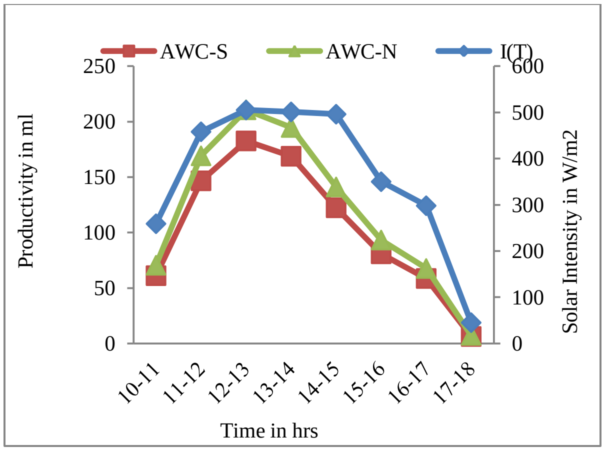
Graph 5.28: Hourly variation of various temperatures for an Hybrid still with 1.5cm water depth for Borewell Water



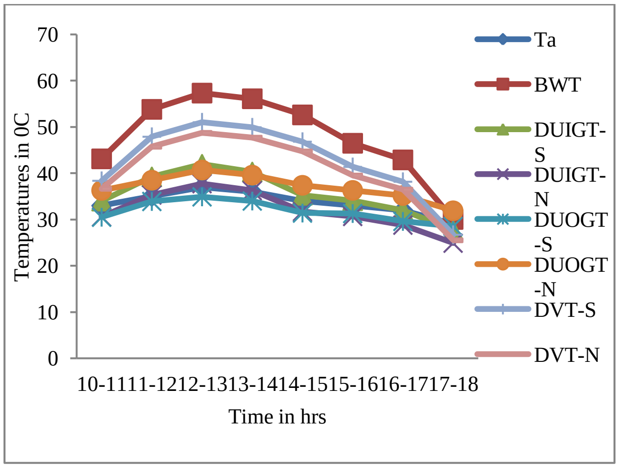
Graph 5.29: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1.5cm water depth for Borewell Water



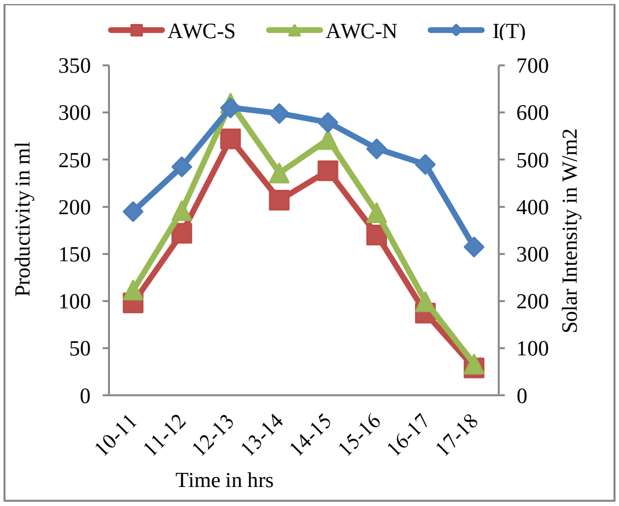
Graph 5.30: Hourly variation of various temperatures for an Hybrid still with 1.5cm water depth for Borewell Water



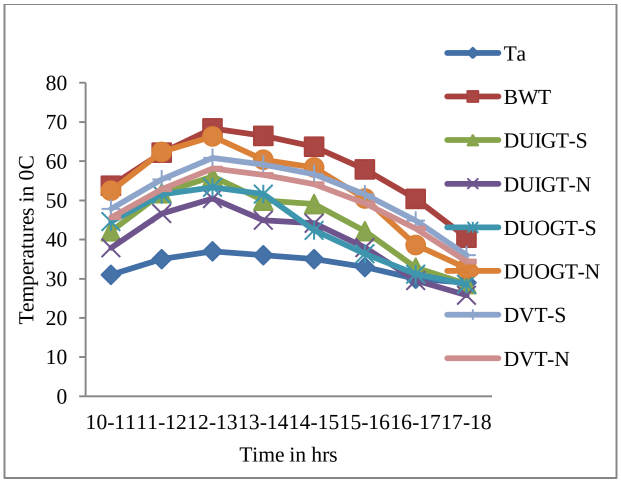
Graph 5.31: Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 2cm water depth for Borewell Water

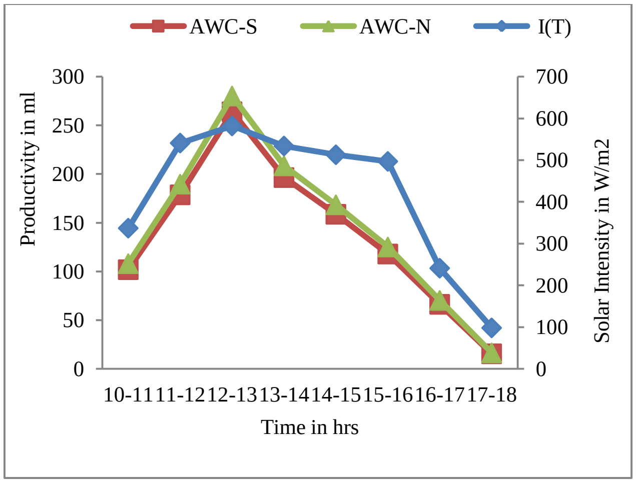


Graph 5.32: Hourly variation of various Temperatures for a Solar Still Alone with 2cm water depth for Borewell Water



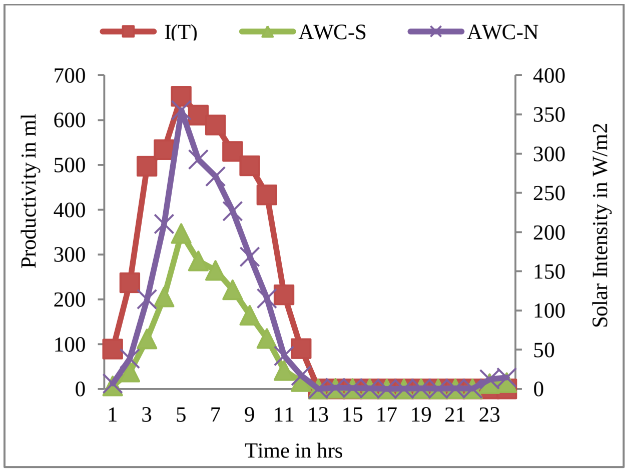
Graph 5.33: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 2cm water depth for Borewell Water

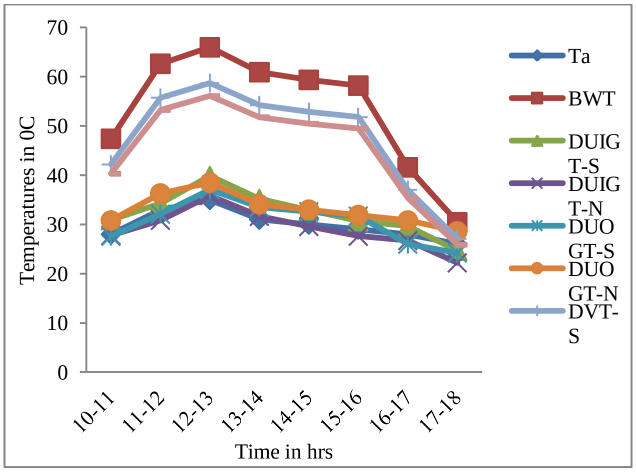




Graph 5.34: Hourly variation of various temperatures for an Hybrid still with 2cm water depth for Borewell Water

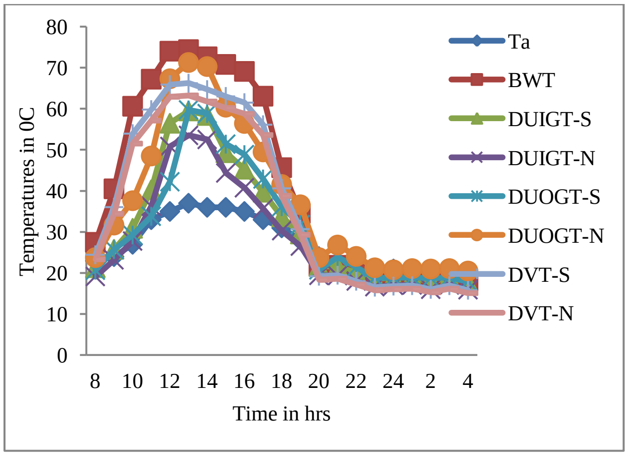
Graph 5.37: Hourly variation of Productivity and Solar Intensity for a Still Alone with 1cm water depth for River Water + $KMnO_4$

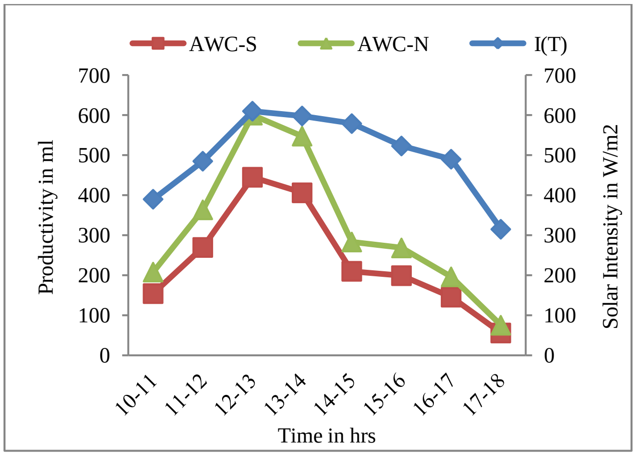




Graph 5.35: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 2cm water depth for Borewell Water

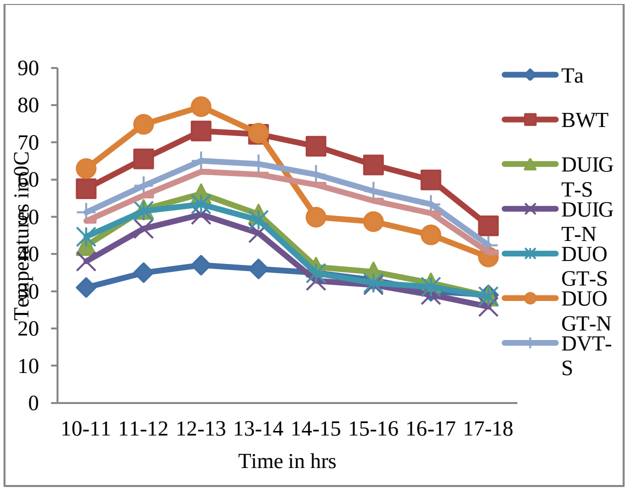
Graph 5.38: Hourly variation of various Temperatures for a Still Alone with 1cm water depth for River Water + $KMnO_4$



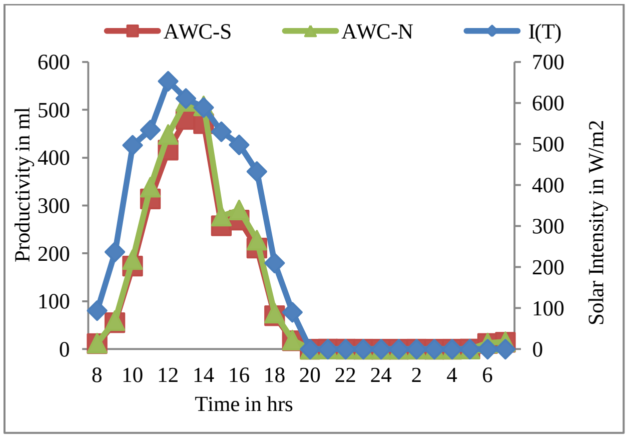


Graph 5.36: Hourly variation of various temperatures for an Hybrid still with 2cm water depth for Borewell Water

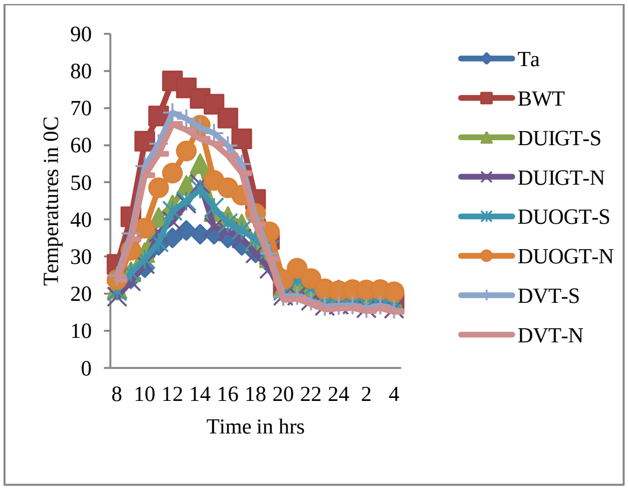
Graph 5.39: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1cm water depth for River water + $KMnO_4$



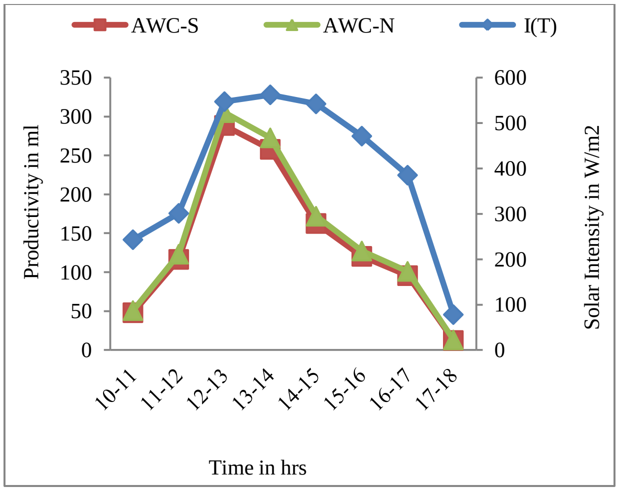
Graph 5.40: Hourly variation of various temperatures for an Hybrid still with 1cm water depth for River water + $KMnO_4$



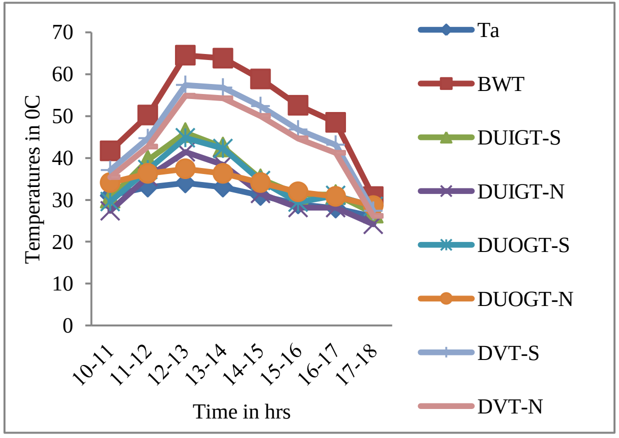
Graph 5.41: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1cm water depth for River water + $KMnO_4$



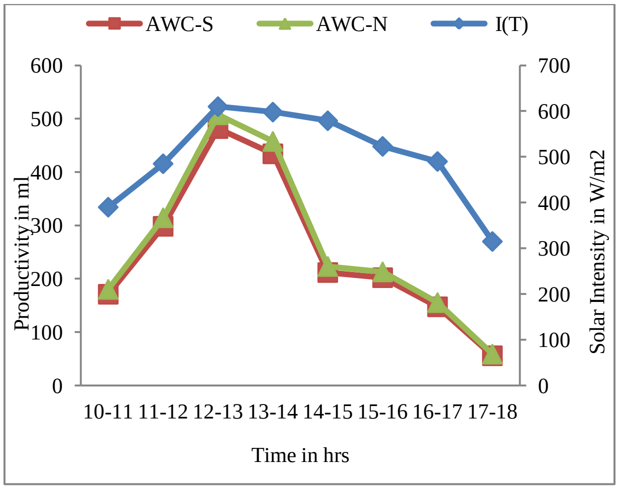
Graph 5.42: Hourly variation of various temperatures for an Hybrid still with 1cm water depth for River water + $KMnO_4$



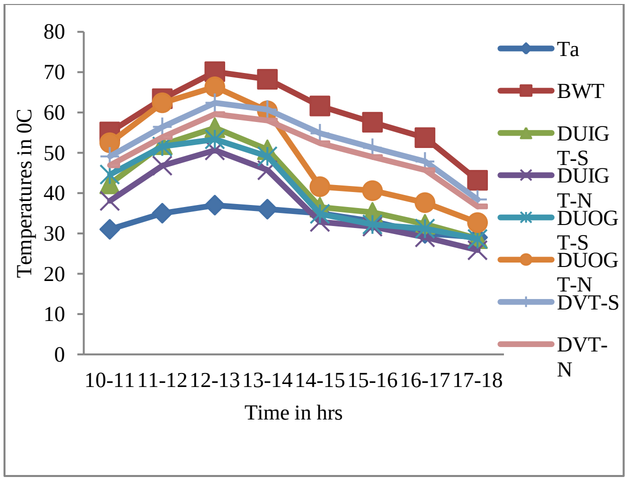
Graph 5.43: Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 1.5cm water depth for River Water + $KMnO_4$



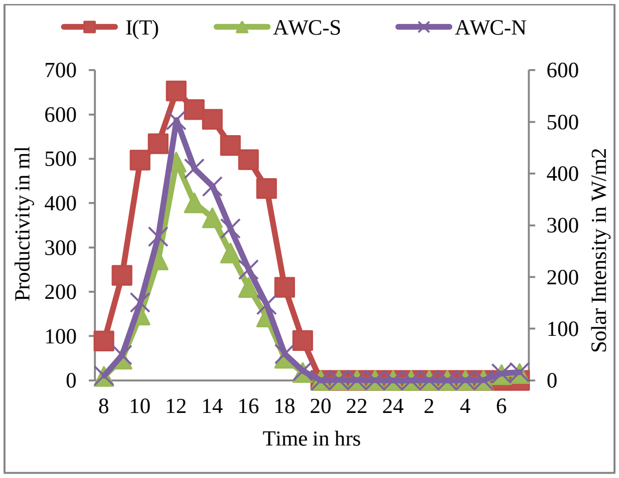
Graph 5.44: Hourly variation of various Temperatures for a Solar Still Alone with 1.5cm water depth for River Water + $KMnO_4$



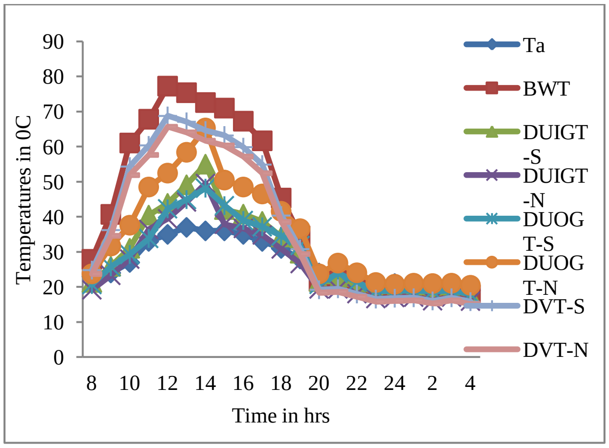
Graph 5.45: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1.5cm water depth for River Water + $KMnO_4$



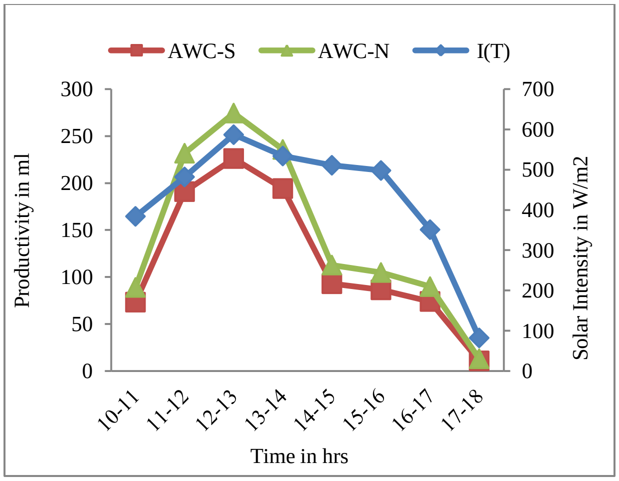
Graph 5.46: Hourly variation of various temperatures for an Hybrid still with 1.5cm water depth for River Water + $KMnO_4$



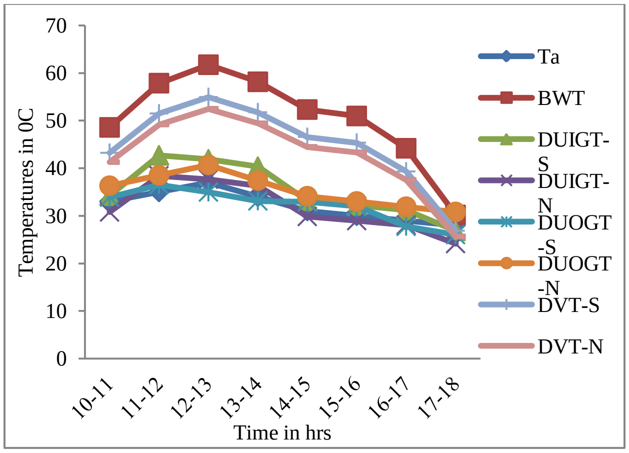
Graph 5.47: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 1.5cm water depth for River Water + $KMnO_4$



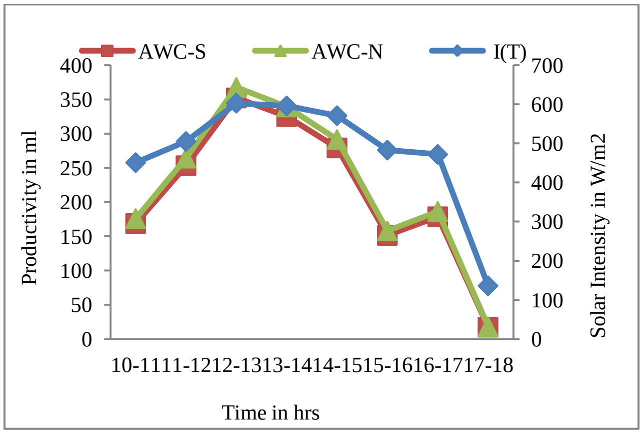
Graph 5.48: Hourly variation of various temperatures for an Hybrid still with 1.5cm water depth for River Water + $KMnO_4$



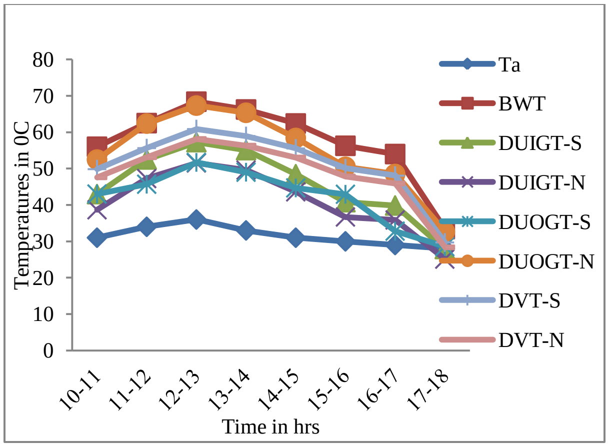
Graph 5.49: Hourly variation of Productivity and Solar Intensity for a Solar Still Alone with 2cm water depth for River Water + $KMnO_4$



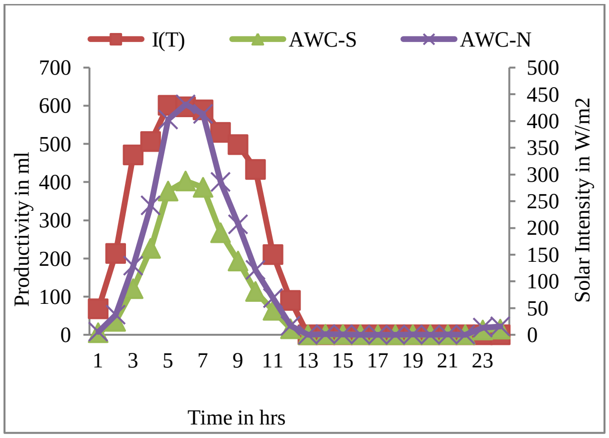
Graph 5.50: Hourly variation of various Temperatures for a Solar Still Alone with 2cm water depth for River Water + $KMnO_4$



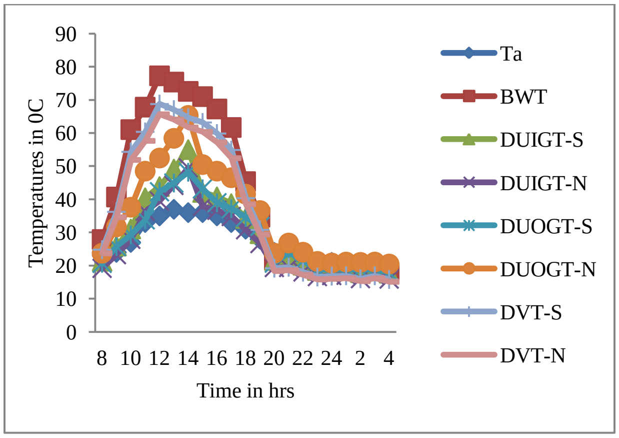
Graph 5.51: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 2cm water depth for River Water + $KMnO_4$



Graph 5.52: Hourly variation of various temperatures for an Hybrid still with 2cm water depth for River Water + $KMnO_4$



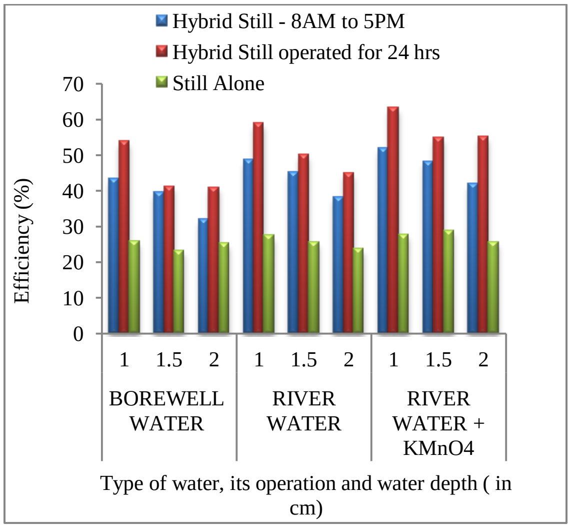
Graph 5.53: Hourly variation of Productivity and Solar Intensity for an Hybrid still with 2cm water depth for River Water + $KMnO_4$



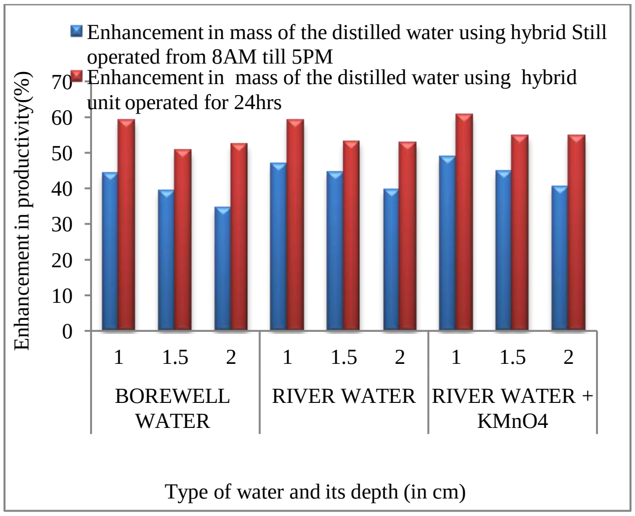
Graph 5.54: Hourly variation of various temperatures for an Hybrid still with 2cm water depth for River Water + $KMnO_4$

5.10.3 Enhancement in Efficiency of a Solar Still :

Experimental results shows that Solar Still coupled with an Evacuated tube collector type of solar heater increases the solar still productivity when operated for 24hours by 59% for 1cm water depth of river water compared to solar still alone and the productivity improved by 46.91% when the hybrid still was operated from 8AM till 5PM compared to still alone. Other enhancement details are tabulated for different water depths and various water samples are given below:



Graph 5.55: Comparision of Efficiency for various conditions

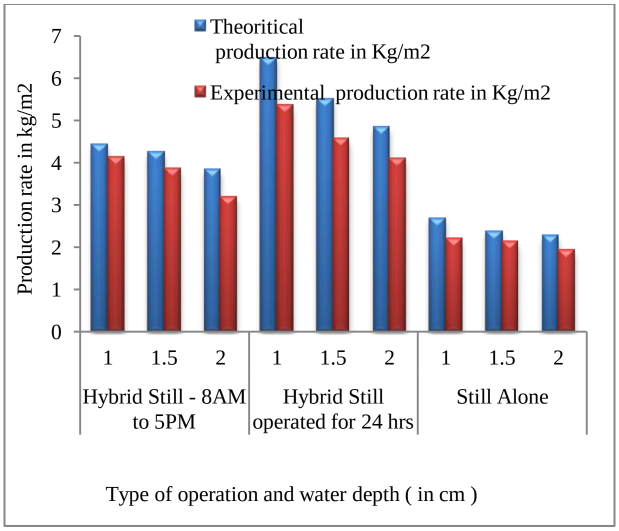


Graph 5.56: Comparision of Enhancement in Efficiency for various conditions

From the graph.5.55 and 5.56, it is concluded that the efficiency increases with the decrease in water depth. Also it can be concluded that the efficiency increased by 46.91% when Solar still was coupled with an ETC type solar heater operated from 8AM till 5PM.Also it can be seen that operating a hybrid still for 24hours increases the efficiency by 59.04% compared to still alone.

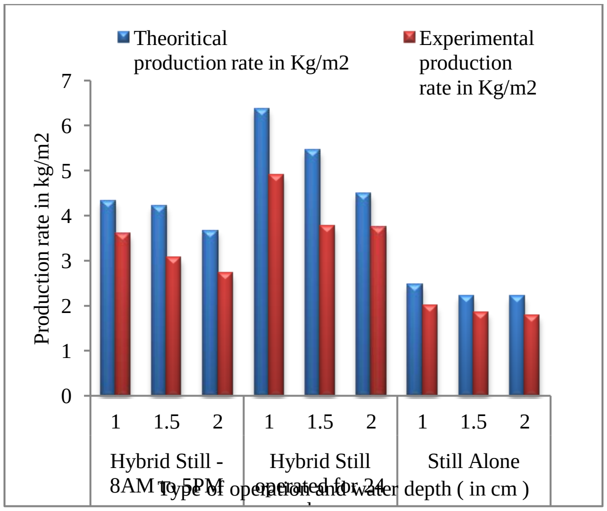
5.11 Comparision of theoretical and Experimental results:

5.11.1 River water:



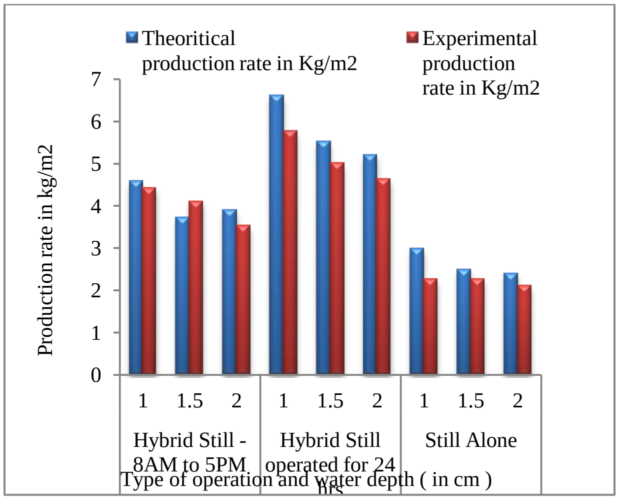
Graph 5.57: Comparision of Theoretical and Experimental production rate for river water

5.11.2 Borewell water :



Graph 5.58: Comparision of Theoretical and Experimental production rate for Borewell water

5.11.3 River water + $KMnO_4$:



Graph 5.59: Comparision of Theoretical and Experimental production rate for River Water+$KMnO_4$

The tabulation of both theoretical and experimental results for the amount of water collected are shown in graphs 5.57, graph 5.58 and graph 5.59

It can be concluded that

Amount of distillate output obtained both theoretically and experimentally almost agree with each other.

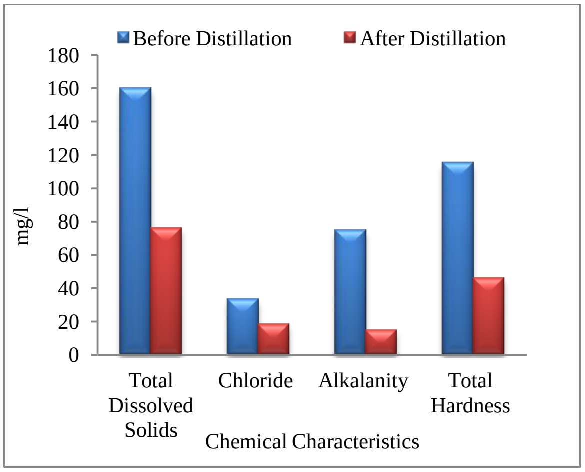
With the decrease in water depth, productivity increases.

Also with Hybrid Solar Still operated for 24 hours gives a better amount of distillate output

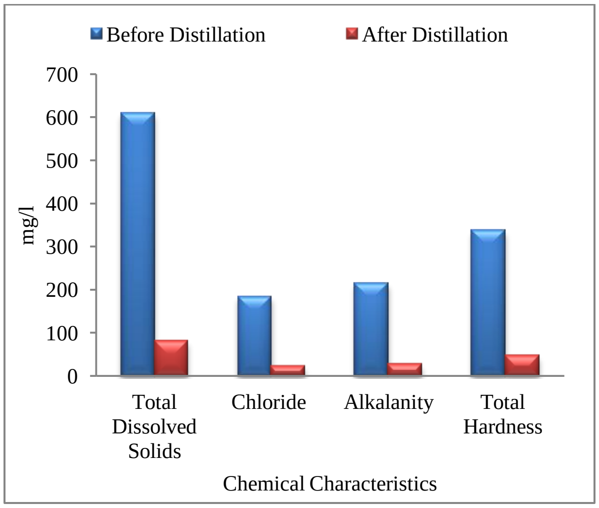
5.12 Water Analysis:

To determine the purity of distilled water collected from the solar distillation unit. The following tests have been carried for the water entering and leaving the distillation unit.

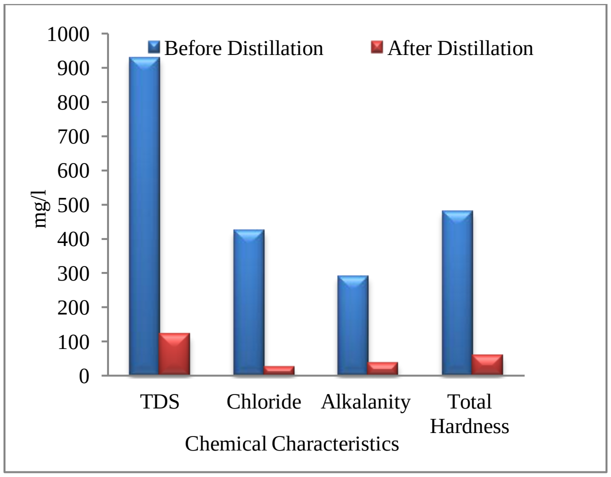
The acceptable characteristics for the portable/edible water as per BIS is given in the below table. The summarized test reports for distilled and non-distilled water are shown in the bar charts.



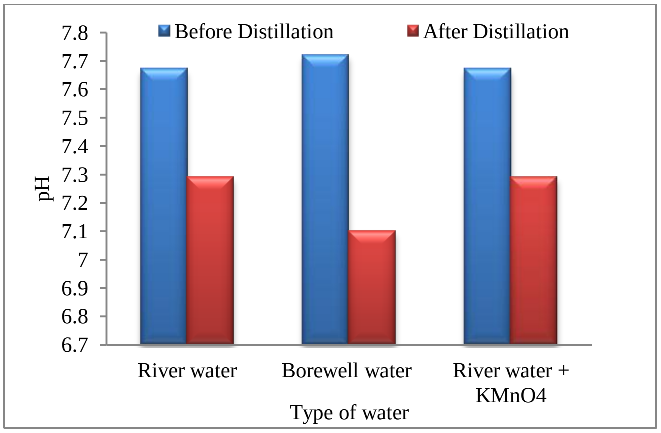
Graph 5.60: Water analysis chart for River Water



Graph 5.61: Water analysis chart for Borewell Water



Graph 5.62: Water analysis chart for River Water + $KMnO_4$



Graph 5.63: pH Variations for various water samples

Water taken for the experimental purpose were tested before and after the distillation Water test reports for both untreated and treated water are tabulated in table 5.33 and 5.34.The variations of various chemical characteristics of the water before and after the treatment are plotted in the graph 5.60 for river water. Also for borewell water and river water + $KMnO_4$, the variations are plotted in graph 5.61 and 5.62. pH variation for various water samples are plotted in graph 5.63. It can be concluded that Solar Still is the best method to purify the water since all the chemical properties have reduced to the permissible limits which is safe for drinking purpose.

CONCLUSIONS

An experimental investigation is done for comparing a passive solar still and an ETC solar water heater coupled with a solar still.

- Productivity of Solar Still increases from 39 to 59% with hybrid unit.i.e when a Solar Still is coupled to an ETC type of solar water heater and operated from 8AM to 5PM and also the productivity increases from 50 to 61% when operated for 24 hours.
- The efficiency for 1cm water depth ranged from 43 to 52%, for 1.5cm it ranged from 39 to 48% and for 2cm it ranged from 32 to 41% for a Hybrid Solar Still operated during day time. Hence it can be concluded that the efficiency of the still decreases with the increase in water depth
- The thermal efficiency of active solar still is higher than the passive solar still. It ranges from 32 to 48% for hybrid unit operated during the day and 41 to 59% for hybrid unit operated for 24 hours.

- Adding the dissolved salt like $KMnO_4$ to river water increased the efficiency from 46.91 to 48.83% for a water depth of 1cm.
- It can be concluded that in order to obtain higher productivity, hybrid still can be operated for 24hours using Solar water heater as a heat source. The proposed system will be more useful for applications in all areas, where the quality water is not suitable for drinking.
- The theoretical analysis was in good agreement with the experimental results.

Solar energy is the best alternative heating energy source. It is renewable and easily available in all parts of the world which is cheap and clean. The hybrid solar still tested confirms the high quality drinking water from the source water of very poor quality. Finally, it can be concluded that use of solar distillation promises to enhance the quality of life and to improve health standards in remote areas also.

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