



Experimental Evaluation of Basin Type Solar Still for Saline and Fluoride Water Purification (A Case on Giby-Deep Well Water, Dupti, Afar-Ethiopia)

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Abstract: In Ethiopia 61 percent of the rural population lacks an access to improved water sources and 62 Percent of rural households are travelling 30 minutes or more to fetch drinking water daily, mostly by child and women. This study presents the purification of water that contains saline and fluoride by using solar distillation. Three different alternatives: single slope, double slope and double slope solar still integrated with parabolic solar trough were designed and installed in the compound of Samara University and daily production and purification performance was investigated from April 6/2015 to April 8/2015. Daily yield was reduced, when water level increased from 3cm to 7cm. The 3cm water level was established for all three alternatives to compare the daily yield of the three alternatives. Single basin single slope solar still, having an area of 1mx1m basin causes the recirculation of distilled water, as a result its full production capacity couldn't be obtained. Double slope solar still integrated with parabolic solar still produces a yield 7% higher than double slope solar still of 3.16kg. The purification efficiency stills were: TDS=99.66%, Total hardness=94.7%, Total alkalinity=93.8%, Salinity=100% and fluoride=96.5%. As a result any brackish and fluoride problems currently determinant to the society to access clean water in Afar can be purified with a solar still distillation.

Keywords: Solar Still, Fluoride, Saline, Parabolic Solar Concentrator, Trough

1. Introduction

Adequate supply of safe drinking water is universally recognized as a basic human need and right. Along with food and air, water is a basic necessity for human beings. It is a basic human requirement for domestic, industrial and agricultural purposes. Of all water on this earth less than 3% is fresh and remaining is salt water and undrinkable. Of this 3% over 2.5% is frozen, locked up in Antarctica, the Arctic and glaciers, and not available to human. Thus 0.5% is the only available form of fresh water as ground water, lakes and rivers, which supply most of plants, animals and human needs [1]. This water is reducing and being contaminated day by day continuously due to industries, agricultural and

population growth during the current year. There will be almost no water left on Earth that is safe to drink without purification after 20-25 years from today [2].

Supply of potable water is a major problem in underdeveloped as well as in many developing countries. Roughly 1 billion people (14.7%) of the earth's population still do not have an access to clean, safe, drinkable water and they are suffering from the incapability of supplying pure drinking water to their communities living especially in their arid regions. Globally, 200 million man hours are spent each day, mostly by females, to collect water from distant, often polluted sources [3]. This is true in Ethiopia, where 62 Percent of rural households are travelling 30 minutes or more to fetch drinking water daily [4].

In the world, 3.575 million people die each year from

water related diseases. The majority of the rural people are still unaware of the consequences of drinking untreated water [3]. Remote and arid regions depend on underground water for drinking. In arid areas, potable water is very scarce and the establishment of a human habitat in these areas strongly depends on how such water can be made available. In some instances, the salinity is probably too high for the water to be considered as fresh; instead it is called brackish water. The salinity of brackish water varies with locations. For example, Ethiopia has several lakes, covering about 7, 000 km², a number of saline and deep lakes as well as several wetland areas. But, all the lakes founding in the Rift Valley are saline except Lake Zway [5]. If the fresh water is not available, it has to be either transported for long distances or connected to an expensive distribution water network at extremely high cost for a small population [6]. One of the most important properties in such analysis is salinity. Salinity is usually expressed in parts per million (ppm). The excessive brackishness (salinity) causes problems of taste, stomach problems and laxative effects.

For this research fluoride was the next major parameters taken into consideration. In terms of chemical water quality, an estimated 11,000,000 people are at risk of contracting fluorosis, in the rift valley with manifestations ranging from unsightly dental staining to chronic joint pain and crippling skeletal deformation [7].

Solar distillation is an affordable and reliable source for safe water. Distillation has long been counted as a method of making saline or brackish water drinkable and purifying water in remote areas. Solar stills, operating on saline or brackish water, can ensure safe supplies of water during a drought time. Solar distillation of course uses free of cost energy to purify water than other methods [8]. Keeping in view the above mentioned importance of solar distillation, solar desalination plants (solar stills) therefore are the feasible solution for providing sufficient amount of safe water for a small community or family in the region where sufficient amounts of solar energy and access to saline or brackish water is available. The solar still technology is simple, low cost and low-tech, and therefore, local people can easily adopt it for treatment of brackish water [9].

2. Method

For this research a basin type solar still was designed and constructed in the compound of Samara University and water sample was taken from Giby-Deep Well Water found in town of Dupti, Ethiopia.

2.1. Equipment Preparation

All materials required for this work were collected from the local market. The solar still basins were fabricated from the local fabricator workshops in the Logia town. Aluminum having a thickness of 2.8mm was chosen as a basin material being light weight and easily available material and shaped to form a water holding basin, and it is coated with black paint to improve heat absorption.

Locally available glazing materials were having a thickness of 3mm, 4mm and 5mm. Glass having a thickness of 4mm was selected and used as a glazing material due to its average fragility and transmitting solar radiation. The 3mm and 5mm glass were not chosen because of their fragility and low solar transmission capacity respectively.

To prevent heat loss to the ambient insulation of the basin was used. The U Channels, which used for trough, were purchased from the local market. The silicon sealant, which was locally available, was used as a sealing material to make the basin water-tight to control the evaporated water drops.

2.1.1. Design Calculations

For this research, the horizontal single basins with single and double slope solar stills were designed. The design calculations for both types are the same.

(i) Basin Design

For both single and double slope single basin still the following design calculation were followed. Daily solar radiation of the region reaches up to 6.1kwh/m²/day, but taking the lowest 5.6 kwh/m²/day (to make an operational during the lowest solar radiation) [11].

Assumptions

Daily yield=2 liter/day/capita (to meet for individuals daily need)

$$\lambda = 2382.8 \text{ kJ/kg at } 50^{\circ}\text{C.}$$

$$\rho = 1000\text{kg/m}^3$$

$$\gamma = 5.6 \text{ kwh/m}^2/\text{day}$$

$$\eta_s = 0.40 \text{ (40\% is a common still efficiency)}$$

Where, λ = Latent heat of vaporization of water

ρ = density of water

γ = minimum solar radiation of the location

$$\begin{aligned} \text{Useful solar radiation} &= 5.6 * 0.4 = 2.24\text{kwh/m}^2/\text{day} \\ &= 2.24\text{kw/m}^2/\text{day} * 3600\text{s} = 8064\text{kJ/m}^2/\text{day} \end{aligned}$$

$$Y = \frac{\text{useful solar radiation}}{\text{latent heat of vaporization}}$$

This shows a solar still having a surface area 1m² is needed.

Locally available Aluminum sheet has a width of 1m. Therefore, the Length of the basin is 1m. If maximum water level (basin depth) is 10cm the Maximum volume of water can be filled in basin is 100lit. To avoid the contamination of distilled water with feed water a gap of 3cm was chosen for maximum water level water filled in basin during experiment, i.e. 7cm.

(ii) Glassing angle from horizontal

For this research, for both single and double slope an inclination of glass cover selected was 15°.

(iii) Glass cover design

A glass of having an area 1.04m² made to be fit with basin at glazing angle of 15°.

(iv) Components of parabolic solar trough

Generally parabolic solar trough contains the following components.

a The Stand

The two legged stand made up of wooden material holds all

the components up right. It has three parts; the lower part of the stand is connected to the concrete foundation. It was installed using wet concrete while checking the level and sun direction. The stand is bolted to the trough support allowing 270-degree rotation of the trough to trace the sun's daily position.

b Trough support

This part of the parabolic trough connects the lower part of the support to the upper part of the trough. The parabolic troughs are connected to this support using bearings so that it is free to rotate from east to west to trace the solar position. This part also gives a rigid structural support of the trough with the stand.

c Solar Collector

There are two available designs of parabolic concentrator. One is by rotating the two dimensional design along the x-axis to produce a parabolic dish, and the other way is by having a parabolic trough. Both of the designs act as reflectors and are used mostly in concentrating solar power system in big solar power plant.

(v) Design and Manufacturing of Parabolic Solar Trough

Aluminum sheet was selected as reflective and carefully fitted to a parabola having an equation $y = 0.011 X^2 = X^2/91$. The available aluminum sheet has a dimension of 1.90mx1.00m. The collector is designed with simple parabolic calculator 2.0 software. The software requires the depth and width as an input. The other parameters are generated and segments of a parabola were selected to be 44. These 44 points are drawn on square paper and traced on the wooden bar. Then traced bar having a width of 5cm was expurgated with jigsaw.

The solar trough made best fits a parabolic equation of: $Y=1.085 \cdot E^{-2} X^2 + 2.775 \cdot E^{-15} (0.011 X^2)$

The parabola is made up of 44 straight line segments as shown (table 1). It was generated using parabola calculator 2.0 software. An input to software is the Diameter and Depth of parabola preferred. For this work the Diameter of 88cm and Depth of 21cm were preferred for available aluminum sheet. Once these two parameters feed to the software and 44 segments are preferred to minimize the error. Lastly the following parabola curve passes the following points.

Table 1. Points of parabola curve.

X	Y	X	Y
-44.00	21.00	44.00	21.00
-42.00	19.13	42.00	19.13
-40.00	17.36	40.00	17.36
-38.00	15.66	38.00	15.66
-36.00	14.06	36.00	14.06
-34.00	12.54	34.00	12.54
-32.00	11.11	32.00	11.11
-30.00	9.76	30.00	9.76
-28.00	8.50	28.00	8.50
-26.00	7.33	26.00	7.33
-24.00	6.25	24.00	6.25
-22.00	5.25	22.00	5.25
-20.00	4.34	20.00	4.34
-18.00	3.51	18.00	3.51
-16.00	2.78	16.00	2.78
-14.00	2.13	14.00	2.13
-12.00	1.56	12.00	1.56
-10.00	1.08	10.00	1.08
-8.00	0.69	8.00	0.69
-6.00	0.39	6.00	0.39
-4.00	0.17	4.00	0.17
-2.00	0.04	2.00	0.04
0.00	0.00	0.00	0.00

2.1.2. Fabrication of the System

(i) Fabrication of the Solar Still

Next to design, manufacturing of prototypes was done at Logia town and the following three different alternatives were constructed and installed. Using the selected materials and values calculated above basin type solar still was fabricated as shown in figure 2 and figure 3. The fabricated single and double slope solar still made consists of an aluminum basin and a glass support over which a glass is placed to hold the glazing material and sealed using silicon sealant to avoid vapor leakage.

1. Single basin single slope solar still

This type of solar still was selected for its simplicity to make and operate at the start of this research work.

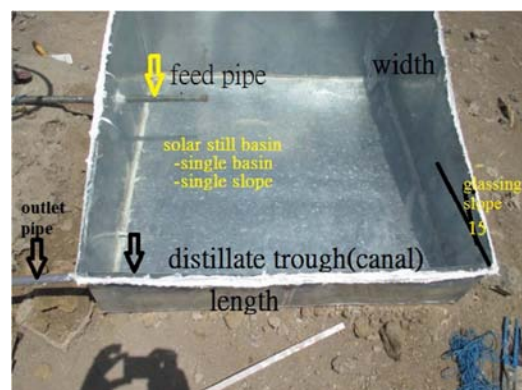


Figure 1. Manufactured single basin single slope solar still.

2. Single basin double slope solar still



Figure 2. Manufactured single basin double slope solar still.

Table 2. Specifications of the solar still.

Item	Values
Type	Single basin
Length(m)	1
Width(m)	1
Effective area of glazing(m ²)	1.04m ²
Glazing material	Glass
Thickness of glazing material	4mm
Slope angle of the glazing	15°
Length of trough (m)	1m
Depth of trough(mm)	1/2"
Depth of basin (mm)	10cm

(ii) Fabrication of Parabolic Solar Concentrator

After design of parabolic solar concentrator of having the above parameters it was manufactured and integrated with double slope single basin solar still. Double slope single basin was chosen because of its higher performance of the above two basins.



Figure 3. Installed Parabolic Solar Concentrator.

Table 3. Manufactured Parabolic solar concentrator Specifications.

Parabola parametres	Dimensions
Linear Diam.	99.95
Diameter	88.00
Depth	21.00
Focal Length	23.05
Volume	63862.30
Focal Length/Diameter	00.26
Area	6082.12



Figure 4. Installed Active Solar Still.

2.2. Theoretical Analysis

The overall efficiency of solar still is given by expression

$$\eta_{solar\ still} = \frac{m_{ew} * \delta}{I_T * A_s}$$

Where η = Overall Thermal Efficiency,

m_{ew} = Total Distillate Output of the Day (in kg) = $\sum mw$,

mw = Hourly Distillate Output)

$\delta = 2.4935 * 10^6 (1 - 7.616 * 10^{-4} T)$, for $T \leq 70^\circ C$

I_T = Total Daily Solar Radiation

=6.5kwh/m²/day=23,400J/m²/day

A_s = Basin Area=1 (m²).

2.3. Experimental Setup and Procedures

2.3.1. Experimental Setup

Selected physical parts of solar still like still basin, transparent top, condensing arrangement, trough, insulation and etc. were designed, constructed and tested for solar distillation process. The transparent glass sheet was selected for the top for providing passage of solar energy. When the cover is placed with an inclination equal to the latitude angle, it will receive the sun rays close to normal throughout the year [10]. In this way, maximum interception is achieved. However, fundamental in the design is that the distillate condenses on the top cover as a film rather than as droplets. Droplets might otherwise drop back into the feed water and represent a loss of output. To prevent this from happening, the cover should be set at an angle $\geq 10^\circ$ (Practical Action). For the study area, which is located at latitude of 11.2°, both types of still can successfully be used.

For experimental purpose a single basin (single and double) slope solar still was designed and manufactured using Aluminum as a basin material. Parabolic solar concentrator was designed and constructed as an integral part of solar still to pre-heat feed water. The design objective is to produce 2l/m²day. As a result single basin (single and double) slope solar still and active solar still (single basin double slope solar still with parabolic solar collector as pre-heater) daily yield was evaluated.

Volume of water filled before operation start =30, 50 and 70kg for basin depth of 3, 5, 7cm respectively on separate day.

2.3.2. Experimental Procedure

Field tests of the solar distillation system under study were carried out with a number of variables. Various data were collected before, during and after the experiment.

Before experiment:

1. A suitable adhesive was applied on all side, at all joints of water carrying channels to ensure leak proof finally the water is filled to check any leakage.
2. Level indicator was checked and marked with a marker.
3. The distillation rate, with the aid of a stopwatch and measuring cylinder, was recorded hourly.

During experiment: The following were the parameters measured every hour for a period of 12 hours during each experiment conducted. The following devices are used during each experiment.

Table 4. Accuracy, range and error for various measuring instruments during field experiment.

S.No	Instruments	Range	Accuracy	%error
1	Thermometer	0-100°C	±1°C	0.25
2	Measuring Jar	0-50ml	±1ml	0.5
3	Measuring cylinder	0-500ml	±1ml	5

Table 5. Equipment used to check water quality parameters at Addis Ababa Environmental Protection Authority.

S.No	Parameters	Instruments	Model	Test methods
1	TDS	P ^h meter	PACON series	Direct
2	Salinity	HORBA	U10	Direct
3	F ⁻	Spectrophotometer	DR3900	Uv-absorption (Direct)
2	Total Alkalinity			Titration

3. Results

During the experiment the following results and corrections were made after checking the wellbeing of the setup. For 15° glazing angle and 1m² Basin (single basin single slope) about 0.75l of distilled water was produced. During the day time some droplets of distilled water fall down to basin causing recirculation. Due to condensate recirculation the experiment for this design was not evaluated at a different water depth.

3.1. Experimental Analysis for Single Basin Double Slope Solar Still (Passive Solar Still)

3.1.1. Measurements

The solar still made up of Aluminum sheet, inside bottom black paint coated is operated at ambient conditions from morning 8:00 to 6:00 afternoon at local time on April 6 to 8 of year 2015 in compound of Samara University. The experiment was done at water depth of 3cm, 5cm, 7cm on April 6, 7, and 8 respectively. The measurements of the temperatures and the production of distilled water are taken hourly to study the effect of each parameter on the still

productivity. In this study various operating conditions have been examined such as; different water depth, ambient temperature and gap between basin and ground. The setup for this activity was to investigate the effect of ambient air on performance of solar still. Variables such as basin temperature, ambient temperature and productivity are measured hourly and summed up for all day. The wind speed was constant throughout measured hours was 4.23m/s. Since, there is no wind speed variation throughout the day of experimenting its effect was not considered.

3.1.2. Experimental Readings

The water level in the solar basin was filled at morning and is maintained to a level of 3cm. the hourly recorded yield is tabulated as on figure 6. The productivity rate varies as time passes from the early morning until late afternoon. In the morning, the temperature of water is low; therefore it needs high energy to change its phase from saturated liquid to saturated vapor phase.

The results show that temperature and required heat are inversely proportional. Because, of water having a low temperature require a higher heat to vaporize.

Readings are tabulated for the different basin put on ground and 25cm height for the same water level (3cm) inside the solar still and graphs are drawn. The readings show the daily yield is higher for basin put on ground. It shows the ambient air passing through the bottom of the basin reduces the yield. Therefore putting the basin on ground was preferred to continue the next experiment to investigate a daily yield at different water level.

3.2. Experimental Analysis for Solar Still Integrated with a PSC

3.2.1. Measurements

The solar still made up of aluminum sheet, inside bottom black paint coated was connected with parabolic solar still made up of aluminum sheet, having parabola specifications given in table 3 and figure 5, by flexible pipe of 40cm (one pipe from feed tank to trough and the other from trough to basin still) operated at ambient conditions from 8:00 am to 6:00 pm on April 9-2015 in compound of Samara University. The measurements of the temperatures and the production of distilled water are taken hourly to study the effect of each parameter on the still productivity. In this study water level was set to 3cm in solar still basin. Various operating conditions have been examined such as; ambient temperature, feed water temperature to parabolic solar trough and basin still, wind speed. Its condition was similar to as shown for double slope single basin discussed for water level of 3cm above.

3.2.2. Experimental Readings

The water level in the solar basin was drained and newly filled at morning and is maintained to a level of 3cm. A continuous feeding to basin from parabolic solar trough was manually set to 1kg/hr. The major purpose of this experiment is to increase the performance of solar still using a preheater.

As obtained from the above experiment, the basin was set on ground to get a better performance. The still readings are tabulated for water level (3cm) in basin, and graphs are drawn. It shows there is no major difference with in yield with experiment of double slope of basin on ground, but, the hourly adjustment and area occupied by parabolic solar trough is twice as 1m^2 solar still. Furthermore, it require additional storage tank because there is no storing area for parabolic trough, while the still basin can be filled once and operate only with solar power without man power requirement.

(i) *Productivity Vs. Time for single and double slope solar still*

1. for basin on ground and 25cm gap from ground: For a solar still made up of aluminum sheet, graphs are drawn for Productivity and Time basin setup: putting on ground and 25cm above ground. It reveals basin on ground provides a better yield. The lower yield for basin at 25cm there a decrease in performance due to ambient air circulation through the bottom of basin. To keep the performance of solar still very well, basin insulation is required.

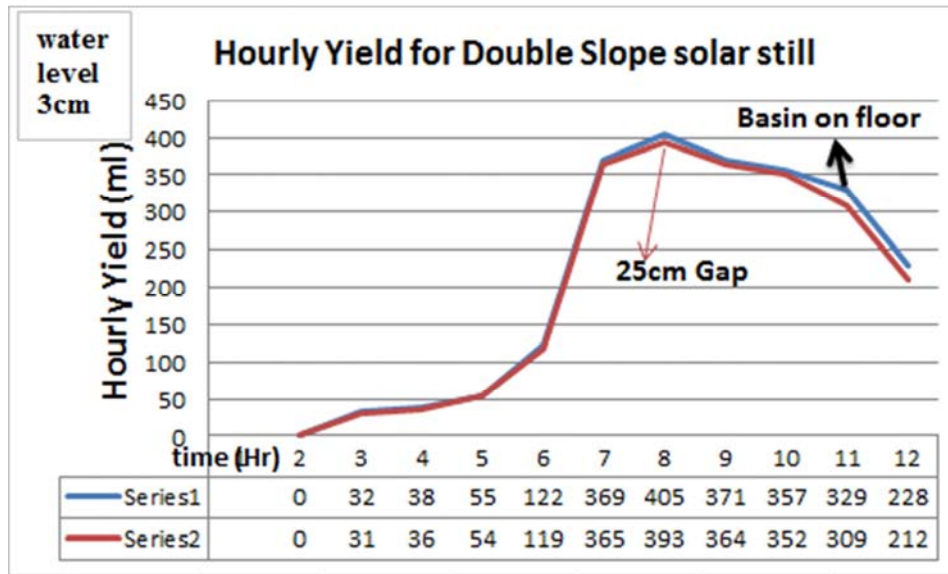


Figure 5. Productivity Vs. Time for basin on ground and 25cm gap (April 6/2015).

On April 6/2015 overall day and night time yield was recorded and added together for basin that was put set on ground. The cumulative yield during the day was 2.306(kg) and 0.85(kg) night. The hourly cumulative yield was recorded and drawn on figure 6 for basin on ground and 25cm higher.

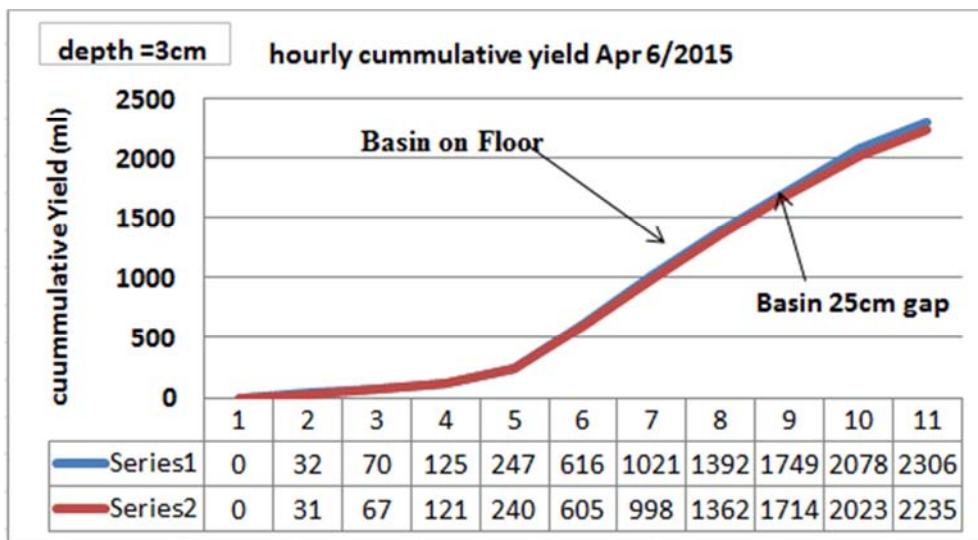


Figure 6. Hourly productivity Vs. Time: April (6/2015).

2. Hourly and cumulative productivity vs. Time with different levels of water: for this experiment based on above result the basin is seated on ground. Graphs are drawn for Productivity and Time for different depths of water level of 3cm, 5cm and 7cm.

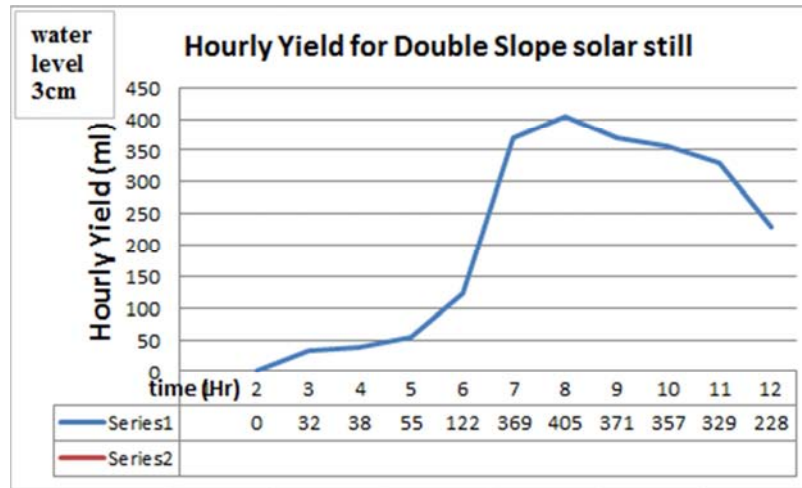
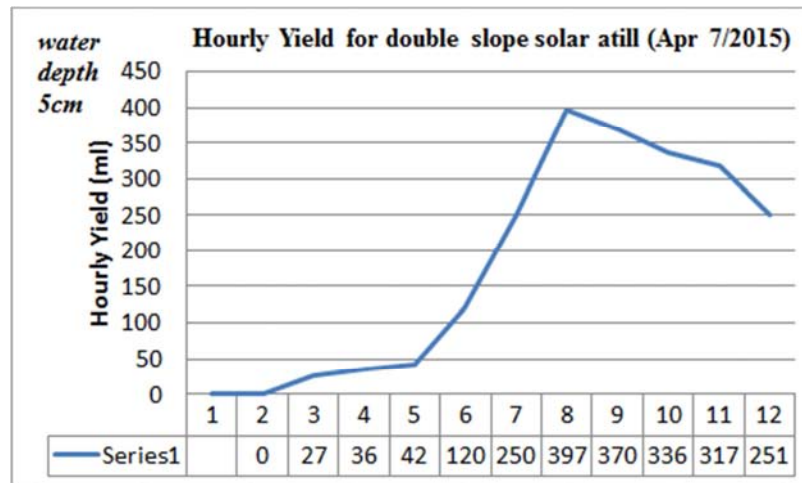
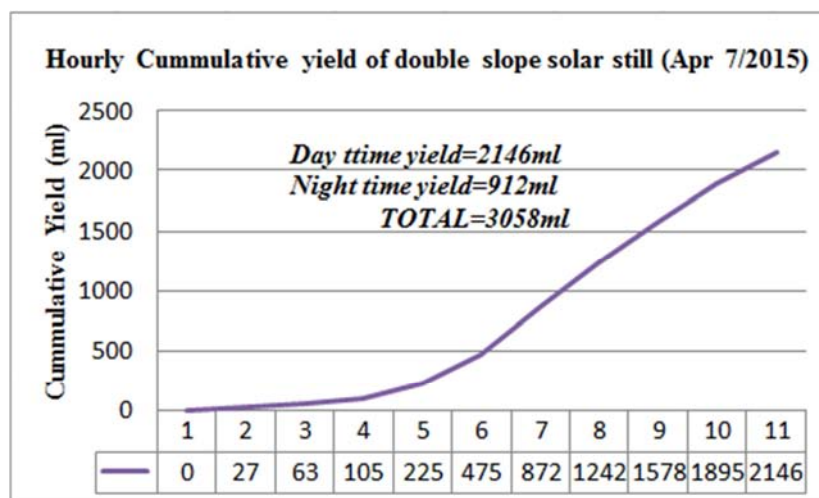


Figure 7. Productivity vs. Time for basin put on ground at water level 3cm (April 6, 2015).

For water filled at 3cm on April 6-2015 the yield slightly increases with time up to 6hr. the increase become very stepper after that up to 8hrs. Finally the production rate starts to decline.

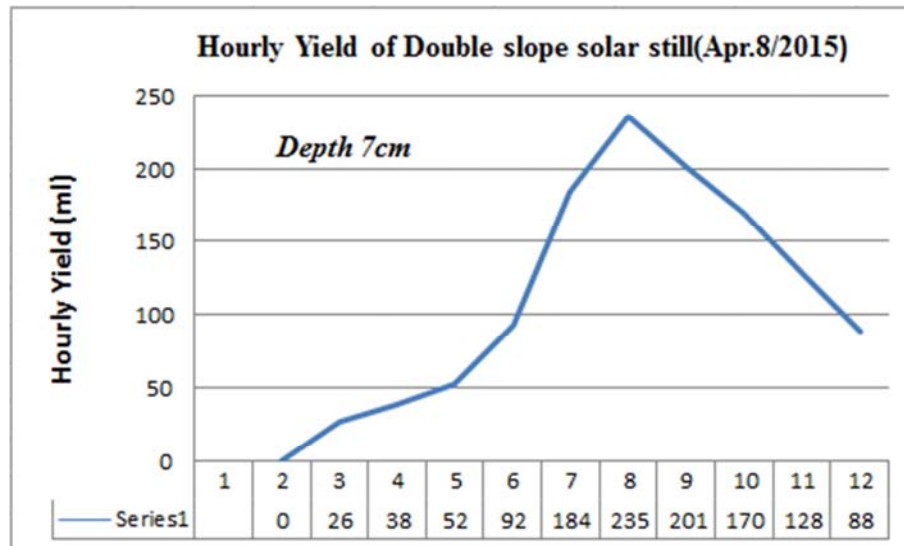


a)

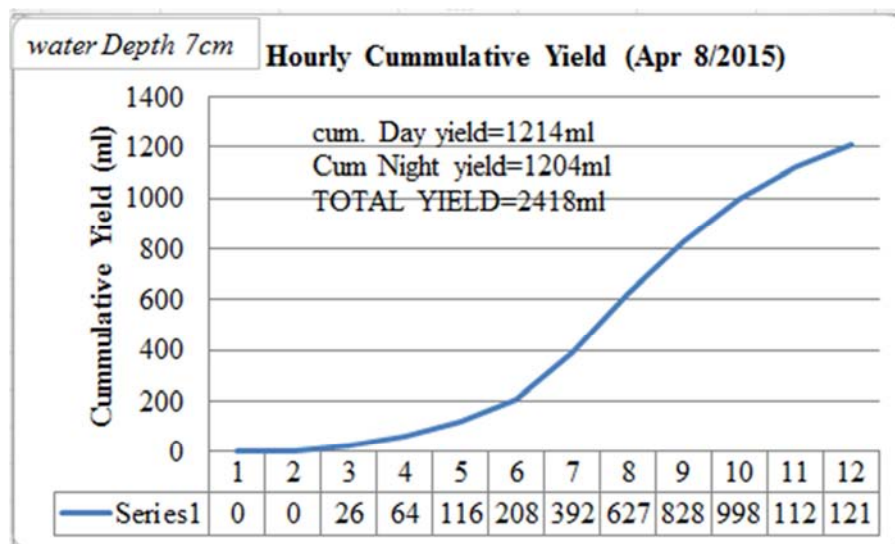


b)

Figure 8. Hourly (a) and cumulative (b) productivity Vs. Time: for water level of 5cm (April 7/2015).



a)



b)

Figure 9. Hourly (a) productivity and (b) cumulative Vs. Time: for water level 7cm (April 8/2015).

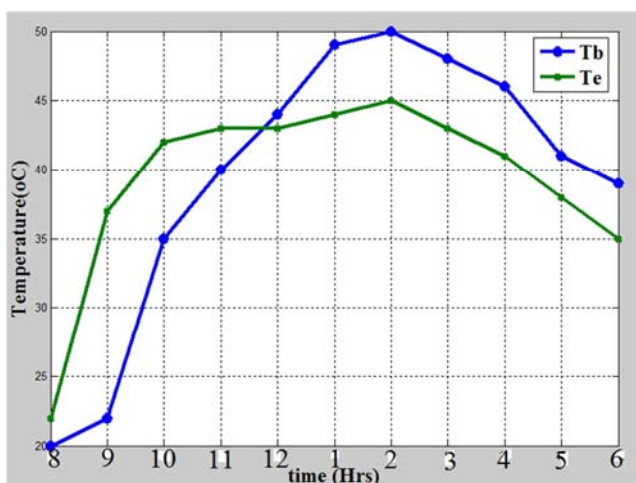


Figure 10. Variation of basin and ambient temperature with time for 3cm.

(ii) Variation of temperatures with time

The variation of temperature with time for the variables such as basin temperature (T_b), and ambient temperature (T_a) are recorded and drawn as follows for double slope single basin for water level of 3cm. The temperature of basin water starts increasing from the start of the experiment to 5:00 hrs. Furthermore the temperature rises and became greater than the ambient temperature as shown in figure 10.

4. Discussion

4.1. Productivity vs. Time for Parabolic Solar Still Integrated to Solar Still

About 3.41kg water is purified in 24hrs; this is only about 7% production improvement. If two basin were installed in place of PSC parallel will the one installed the overall production will tripled while still no need of man power as

parabolic concentrator connected with solar still. Probably this is due to the water from parabolic solar concentrator lose its heat to the environment before reaching the basin, rather than flashing out and condensing on glass surface, it will mix with the water in the basin without increasing basin temperature and flashing to favor condensation..

4.2. Quality of Water and Removal Efficiency

The following parameters are checked at Samara University and Addis Ababa Environmental protection

Table 6. Water quality Analysis and purification efficiency.

S.No	Parameters	Before	After	Removal Efficiency (%)	Ethiopian/WHO Gide lines
1	p ^h	8.6	7.1		6.5 - 8.5
2	Total Dissolved Solids, mg/l	1390	8.9	99.6	500ppm*
3	Total Hardness, mg/l	308.4	16.4	94.7	300
4	Total alkalinity, mg/l	344.2	21.4	93.8	200
5	Salinity, %	0.2	Nil	100	0.1
6	Fluoride	1.72	0.06	96.5	1.5
7	Turbidity, NTU	Nil			
8	Total Coliform	Nil			

*WHO guideline

The best thing we can conclude from this result can be the total removal of salinity and high reduction of fluoride level found in raw water. These two are the most problematic and pollutant of the drinking water found in the Afar region. Almost all total hardness, total dissolved salt and total alkalinities are removed. Finally all the tested parameters for the product water fall within the accepted ranges of Ethiopian and WHO guideline for drinking water.

Authority and Table 6 shows the variation observed pre and a post distillation process parameters. It is found that values agree with WHO and Ethiopian Drinking water standards very well. The water yield is almost free of TDS, hardness, Alkalinity, Salinity and fluoride.

The Removal efficiency of single basin double slope solar still was as follows: TDS=99.66%, TH=94.7%, TA=93.8% and Salinity=100%. The fluoride removal efficiency is 96.5%.

4.3. Efficiency of Solar Still

The overall efficiency of solar still can be calculated using equation:

$$\eta_{\text{solar still}} = \frac{\text{latent heat of vaporization} * \text{daily yield}}{\text{daily solar radiation}}$$

The efficiency was done for basin water temperature of 50°C and an average daily solar radiation of 6.5 kWh/m²/day [11].

Table 7. Efficiency of single basin double slope solar still.

Experimentation day	Yield obtained (mg)	Daily solar radiation(kJ/m ²)	Water level in a basin(cm)	$\eta_{\text{solar still}}$
April 6, 2015	2306	23400	3	22
April 7, 2015	2146	23400	5	21
April 8, 2015	1214	23400	7	12

N. B. if a night yield is added to a day yield an efficiency of still becomes 31%, 29%, 23% for 3cm, 5cm, and 7cm respectively.

5. Conclusion

The solar still distillation is one of the simple methods that remove salts and other water impurities. It is concluded from the distilled water analysis that the water from solar still is pure. The result from this experiment agrees with this fact and all tested water quality parameters agreed with the national water quality standards. The solar still used has a purification efficiency of TDS=99.66%, TH=94.7%, TA=93.8% and Salinity=100%, fluoride=96.5%. Of the three options considered, the parabolic solar concentrator integrated with double slope solar still provided the highest daily water yield of 3.41kg, which is 7% higher than the double slope single basin type. The parabolic solar trough was adjusted following the sun position to track the

highest concentrating power, which requires a man power to operate. Additionally it occupies twice extra land and cost of single basin double slope require.

The single slope solar still of glazing angle at 15° for basin area of 1mx1m considered was also uneconomical at the latitude of 11.2 (Samara) due to condensate return to basin without reaching condensate catchment area. This reduces the daily yield.

As a result of limitation to these two types the double slope solar still of 1mx1m basin can be used in area where there is brackish water or any other form of water like rain and river can be stored and it can be purified using solar still. This system can also help to manage water resources.

Finally with the same removal efficiency of the solar still achieved in this research, for selected parameters especially, salinity and fluorosis problems in drinking water currently occurring in drinking water of Afar region can be resolved using solar still.

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