



Addis Ababa University
School of Graduate Studies
Addis Ababa Institute of Technology
School of Food and Bio-Engineering

*Design and Experimental Evaluation of Basin type Solar Still
for Saline and Fouride Water Purification
(A case on Giby-Deep well water, Dupiti, Afar-Ethiopia)*

By

Chala Diriba

June 2015



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University in partial fulfillment of the Degree of Master of Science in
Environmental Engineering*

June 2015

Declaration

I hereby declare that the work which is presented in this thesis entitled “*Design and Experimental Evaluation of Basin Type Solar Still for Saline and Fluoride water purification*” (A case on Giby-Deep well water, Dupiti, Afar-Ethiopia) is the original work of my own, has not been presented for a degree of any other university and that all sources of material used for the thesis have been duly acknowledged.

Chala Diriba Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge

Dr.-Ing. Belay Woldeyes (Advisor)

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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.

Key words

Solar still, fluoride, saline, parabolic solar concentrator, trough

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Nomenclature

η	Overall thermal Efficiency,
$\sum mew$	Total Distillate Output of the Day (in kg)
Mw	Hourly Distillate Output (ml)
λ, δ	Latent Heat of Vaporization
I_T	Total Daily Solar Radiation
η	product Efficiency
Y	calculated yield (kg)
V_{\max}	maximum volume of basin
A_s	Basin Area (m^2)

List of Acronyms

PET	potential Evapotranspiration
TDS	Total Dissolved Solids
TH	Total hardness
TA	Total Alkalinity
TS	Total Salinity
F ⁻	Fluoride Concentration
MDG	Millennium Development Goal
PSC	Parabolic Polar Concentrator
UV	Photovoltaic Arrays
AAEPA	Addis Ababa Environmental Protection Authority

Chapter One

1. Introduction

1.1 Background

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 is 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 found 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 thesis 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].

Distillation of unsafe water is one of the steps to get the clean water, while the traditional way to get the water is using fuel. Renewable energy that reduces the oil usage and distillation of the unsafe water is the main target of this research; this will present the chances and measures for the appropriate usage of renewable sources and highlighting the importance of achieving distillate water to be used for drinking, industrial processes and medication. The other opportunity is about the available solar energy which is free.

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].

1.2 Statement of the Problem

The problem of drinking water in selected site can be seen from the following perspectives: 1) Lack of access to clean water 2) Population growth 3) Environmental concern and 4) Salinity and fluorosis.

Many parts of the world, Sub-Saharan African countries, like Ethiopia do not have access to a suitable source of clean drinking water. Areas without access to clean water are also usually poverty stricken and do not have the infrastructure necessary to create and support large scale water purification plant. An estimated 844 million people, the majority of developing countries, are not using improved sources of drinking water. This result the avoidable deaths of 1.5 million children every year, many victims to diarrheal disease [10]. Low quality water plays a key role in bad health and living conditions. It is estimated that approximately 1.6 million human lives could be saved every year if access to drinkable water, services of water deprivation and hygiene could be improved upon. Uneven distribution of water has been one of the major causes of social inequalities. In general the population of the richest countries (approximately 11% of humanity), besides owning 84% of the wealth, consumes 88% of the resources, including water.

Population in Afar over the last four decades has almost tripled and the available freshwater can no longer be enough not to mention the water consumption due to the expansion in the industry. The pastoralist community of the region moves from place to place depending on season to search fresh water which has no guarantee of safe potable water. The urban inhabitants will increase in the Awash Basin. The increase of urban population implies an increase in competing for water [5].

From the Environment perspectives most dwells uses pump consuming oil and causing a dependency on fossil fuels, which is costly and unfriendly to the environment. In addition, the weather in Afar is very hot and the ambient temperature can reach up to a maximum of 50°C which is the hottest of this earth. This causes a high evaporation loss of water resource in the region. Potential evapotranspiration (PET) in the Upper Valley at Wonji is 1810 mm over twice of the annual rainfall. At Dupiti, at the lower Valley the mean annual PET is 2348 mm which is over ten times the average annual rainfall [11].

This can possibly satisfy a household of three people through ought a year if the evaporated water is collected only from a water surface area of 2m^2 .

The most source of fresh water in Afar Region is the underground water which is either very limited and cannot meet the increasing demand or contaminated with fluoride or salt. High fluoride concentration in groundwater in and around the Great Rift Valley is a natural phenomenon having a negative impact on public health. The problem is especially obvious in the Rift Valley Lakes basin and also in the Awash Basin [5]. In addition to Fluorosis the salinity problem of the region is high and there is no practice to desalinate in Ethiopia; except the Afdera desalination plant which was launched by USAID in the year 2014.

Water is life, and the threat of unsustainable means of potable water supplies has led to the search of renewable energy sources to create a cleaner and more efficient solution for potable water supply. Various modular technologies existed, in which potable water can be produced, but these have proved to be quite expensive as large and very complex designs are involved. Because this problem is prevalent in the world's poorest countries, there is a need for the technology to be simple in design, affordable and sustainable.

Solar still distillation is the method used to supply potable water using a renewable and free energy source and it does not utilize costly conventional fossil fuels, which creates problems. The solar still is point-of-use technologies that have been proven to remove pathogens, heavy metals and reduce salinity. The product can be used for drinking purposes, charging of the car batteries, laboratory and medical appliances and etc. Despite the fact that this technology can provide a cheap source of potable water they have the disadvantage that they are on average only 30% efficient and require 2m^2 to provide for one person's daily needs [6]. This system is suitable for arid regions or inland with shortage of fresh water, but access to saline/brackish groundwater to create a sustainable environment to settle communities in these arid and remote areas. In recent years, desalination of water has been one of the most important technological works undertaken in many countries.

The solar stills have often been used in the tropics, where there is an abundant supply of solar energy. Afar is one of such an area has abundant solar energy and deficient potable water. In this research, a basin type solar still was designed and installed to investigate the daily performance of solar still in Afar-Samara town for removal of fluoride and saline from Giby-deep well water which is located at Dupti town.

1.3 Objective of the Study

1.3.1 Major Objective

The general objective of this research is to design and investigate the yield and purification efficiency of Passive and Active solar still prototypes in Samara-Afar, Ethiopia.

1.3.2 Specific objectives

The specific objectives are to:-

- ✓ Design and Manufacture the solar still prototypes using appropriate local materials.
- ✓ Investigate the daily yield of the prototypes
- ✓ Evaluate the performance in terms of daily yield and purification efficiency of the prototypes
- ✓ Analyze the physicochemical characteristics of sample water before and after treatment and to compare them with World Health Organization (WHO) and Ethiopian drinking water quality guidelines.

1.4 Significance of the Study

The Afar Region has an area of the driest, hottest, inhabited places on Earth. The under-ground water table is very deep and many depend on surface water they are able to collect. This surface water is typically contaminated with animal and human waste. Consequently, diarrhea is among the top three morbidities for the region. Being such a dry environment, clean water is the crucial need.

The significance of getting an access of drinking water in such area can be seen from the following issues:-

- ✓ Improves livelihood of the community
- ✓ Management of brackish and fluoridated water
- ✓ Gives an opportunity to catch rain water and rivers.
- ✓ Partially substitute the consumable bottled water in the region.
- ✓ Effectively substitute uneconomically distilled water in the region.
- ✓ Gives an opportunity of technological development for local communities.
- ✓ Gives generic information for pastoralist, researchers and local/ national government.

Chapter Two

2. Literature Review

2.1 Introduction

Solar still is possibly the oldest method of desalination of water. Its principle of operation is the greenhouse effect; the radiation from the sun evaporates water inside a closed glass covered chamber at a temperature higher than the ambient. Saline water is filled in the basin of the solar still and then solar radiations are allowed to fall on it. The distillator is subjected to maximum amount of solar insolation and an efficient amount of radiations get trapped inside it. This increases the internal temperature of distillator causing the saline water to evaporate leaving behind all the impurities. These water droplets get attached to the glass cover of the solar still. Further, on condensation these droplets get collected in the condensate channel due to the inclination provided to the glass covers. Finally fresh water is obtained.

Ethiopia has saline water resource. For example, of all lakes, having an area of about 7 000 km², except Tana and Ziway are all saline. Afdera desalination plant, which is based on reverse osmosis, is the only desalination plant in Ethiopia, which was launched by USAID in the year 2014. The Afdera desalination plant has a capacity to refine 120,000 liters/day and can supply fresh water for about 7,000 people.

In Ethiopia the problem of fluorosis still persists. Defluoridation is the only option to avoid the problem. The suffering of the affected people in India as an example provides a strong motivation to work on defluoridation. They express the problem of fluorosis by their own words by saying, “Our shoulders, hips, and ankles are swollen all the time. If we squat on the floor, it is painful to stand up.”[12].

The Ethiopian standard for the desirable limit for the concentration of fluoride in drinking water is 1.5 mg/L,[13] which is the permissible limit prescribed by the World Health Organization [14]. The standard may vary depending on temperature. Prolonged consumption by people of water containing excess F⁻ leads to various ailments that are collectively referred to as “fluorosis” [12]. Considering the fact that fluorosis is an irreversible condition and has no cure, prevention is the only solution to this menace. Providing water, with an optimal fluoride

concentration is the only way by which the generation yet to be born can be totally protected against the disease [15]. This chapter covers the literature related to the necessity of desalination and defluoridation considering the reality of our country, precisely Afar-Ethiopia.

2.2 Water resources

Water resources are divided into different categories based on their composition and basis of their use. Some important types of water resources are [16]:-

2.2.1 Fresh/Brackish/ Sea Water Resources

There is no fixed delineation between fresh and brackish water [17]. TDS concentration value of 1000 mg/l or 0.1 percent salinity is used for the dividing line, which is consistent with many references. The term “brackish”, in general, refers to water that has more salinity than fresh water but less than sea water. There is also no rigid delineation between brackish water and seawater; however, 30,000 mg/l or 3 percent salinity may be used to make a general delineation between brackish and sea water.

2.2.2 Surface Water Resources

Another type of water resource is the surface water resource. Basically, this type of water is used for multi purposes such as industry, agricultural and energy generation, i.e. hydro electrical energy. Ethiopia is endowed with a substantial amount of water resources. The surface water resource potential is impressive, but little developed. The country possesses twelve major river basins, which form four major drainage systems: the Nile basin (including Abbay or Blue Nile, Baro-Akobo, Setit-Tekeze/Atbara, and Mereb) covers 33% of the country and drains the northern and central parts westwards; the Rift Valley (including Awash, Denakil, Omo-Gibe, and Central Lakes) covers 28% of the country; the Shebelli-Juba basin (including Wabi-Shebelle and Genale-Dawa) covers 33% of the country and drains the southeastern mountains towards Somalia and the Indian Ocean and the North-East Coast (including the Ogaden and Gulf of Aden basins) covers 6% of the country. Additionally Ethiopia has several lakes (an area of about 7 000 km²), a number of saline and deep lakes as well as several wetland areas.

2.2.3 Ground Water Resources

It is type of water resource that is fresh in nature. The groundwater potential of the country is not known with any certainty, but so far only a small fraction of the groundwater has been developed and this mainly for local water supply purposes. Traditional wells are widely used by nomads [11]. Many parts of Ethiopia have limited supplies of groundwater because of the poor permeability of the crystalline rocks and variable water-table depths. Groundwater in the Rift zone is influenced by geothermal waters with abnormally high concentrations of fluoride and/or total dissolved salts.

2.3 Factors affecting the water resources

There are a lot of factors that affect the properties of the water resources and sometime enhance or decrease the property of them. Some factors that affect the quality and quantity of the water resources are given below [18]

2.3.1 Climatic factors

Different types of factors related to the climate affect the water resources; for example, the water distribution during the rainfall and time period of falling. Snow factor also affect the water resources because sometimes the water become ice. Other factors related to the plants such as the process of evaporation and the property of the plant to transpire are also affecting the water resources

2.3.2 Physiographic factors

These are the other types of factors that affect the water resources; basically it is the combination of two factors i.e. physical and the geometric factors. The physical factors deal with the type of land used for the cultivation, types of soil and other related factors. In the geometric factors includes the shape, area and the drainage property.

2.4 Drinking water status in Ethiopian

Despite the remarkable progress seen in Ethiopia, more than 48 million people still do not have access to improved water source. About 62 Percent of rural households are travelling 30 minutes

or more to fetch drinking water daily [19]. Furthermore while it is important to treat water at the source, it is not guaranteed that the water treated will arrive to the end user free of contaminants as opportunities for recontamination during transmission and storage exist [20].

Even though the mission of MDG was met in Ethiopia, there is still a need to clean water in most rural areas. Most of the water being consumed in the selected region, Afar, has a high fluoride and salinity problem. The fluoride level in drinking water of Afar region can reach greater than 8mg/l [21]. Furthermore an access to clean water is less than 42 percent.

2.5 Desalination technology

There are many methods for converting brackish water in to potable water [22]. Some of the water distillation ways are described as [23].

2.5.1 Distillation

In this method, the brackish or saline water is evaporated using thermal energy, and resulting vapor is collected and condensed as final product.

2.5.2 Vapour compression

In this process of desalination water vapour from boiling water is compressed adiabatically and vapour gets superheated. The superheated vapour is first cooled to saturation temperature and then condensed at constant pressure.

2.5.3 Reverse osmosis

In this process saline water is pushed at high pressure through special membranes allowing water molecules selectively to pass and not the dissolved salts.

2.5.4 Electro dialysis

In this method water is passed through a pair of special membranes, perpendicular to which, there is an electric field. Water does not pass through the membranes while dissolved salts, pass selectively.

Among non-conventional methods, distillation is the most prominent; the conventional distillation plants, round the globe, are energy intensive and utilizes non-renewable energy. Solar distillation has the inherent advantages of low energy consumption. Moreover, it is simpler and more economical than other methods. It requires simple technology and easy maintenance hence it can be used at any place without much problem [24].

2.6 Solar Still

Carlos Wilson, a Swedish Engineer, was first to design a conventional solar distillation apparatus, called solar still, in 1872, in Northern Chile. After 1880 till the end of world war-I no documented work on solar distillation is available. After wards several designs of solar stills were investigated i.e. roof type, suspended envelope, tubular and air inflated still etc. Subsequently efforts were made to improve the operating efficiencies of the various types of solar stills for better output [25].

2.6.1 Working Principle of Solar Still

The basic principle behind solar distillation using solar still is simple and replicates the natural process of water purification [26].

A solar still is an air tight basin that contains saline or contaminated water (i.e. feed water going to be treated). It is enclosed by a transparent top cover, usually of glass or plastic, which allows incident solar radiation to pass through. The inner surface of the basin is usually blackened to increase the efficiency of the system by absorbing more of the incident solar radiation [27].

The feed water heats up and then starts to evaporate and subsequently condenses on the inside of the top cover, which is at a lower temperature as it is in contact with the ambient air. The condensed water (i.e. the distillate) trickles down the cover and is collected in an interior trough and then stored in a separate basin [28]. This system is also known as passive solar still, as it operates solely on sun's radiation (Figure 2.1) [29].

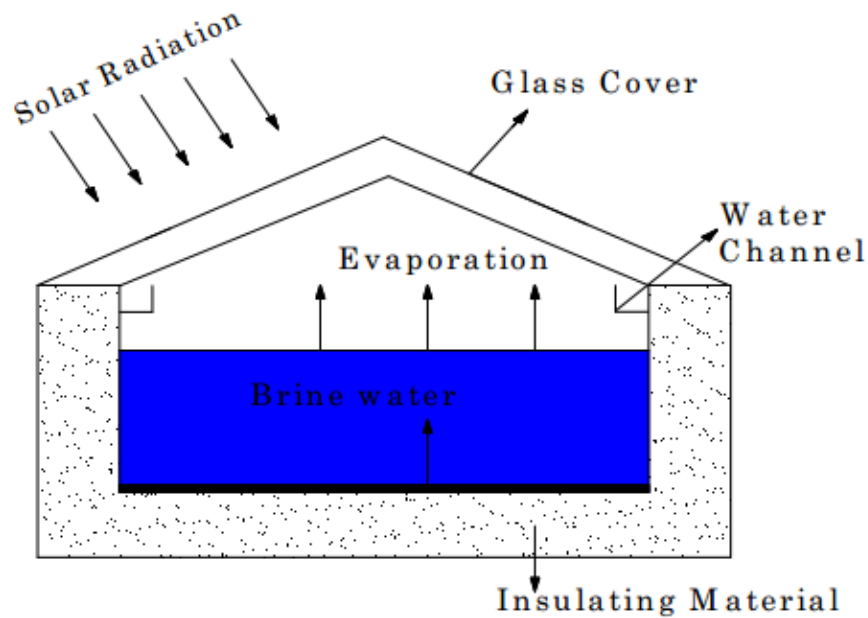


Figure 2.1 Basin Type Solar Still [29]

From solar radiation point of view, the following happens inside the distiller (basin) unit: the part of the solar radiation that is not reflected nor absorbed by the cover is transmitted inside the solar still, where it is further reflected and absorbed by the water mass. The amount of solar radiation that is absorbed is a function of the absorptivity and depth of the water. The remaining energy eventually reaches the blackened basin liner, where it is mostly absorbed and converted into thermal energy. Some of the water heats up, resulting in an increase of the temperature difference between the cover and the water itself.

Then, heat transfer takes place as radiation; convection and evaporation from the water surface to the inner part of the cover. The evaporated water condenses and releases latent heat. This last one is then lost through convection and radiation together with the remaining convective and radiated heat [30].

2.6.2 Classification of Solar Still distillation systems

As a result of large interest for water purification, several types of solar still have been evolved. Distillation process is mainly classified into two types, passive distillation and active distillation. Passive distillation which works passively without external supply of heat source or preheated feed water, includes conventional solar still with reflector or with condenser, multi effect solar still, inclined solar still and new design solar still like tubular, regenerative and spherical [31]. Active distillation works actively on either sunny or cloudy days because of its solar collectors and a heat storage area. Generally Active distillation is of two type's high temperature distillation and nocturnal distillation [32].

According to number of glass cover used solar still can be classified as two types as discussed below. In addition to classification based on number of glass, several designs for the solar stills have been proposed and investigated. The common objective behind these new designs is to maximize the output by increasing the efficiency of the system. It is possible to classify the passive solar stills as: basin, wick, diffusion or other type of stills [33].

1. Single Effect type

Single effect type Solar Still is the most common conventional solar still. It generally consists of a basin with black bottom having tray for saline water with shallow depth. A transparent air tight glass or a plastic slanting cover encloses completely the space above the basin. Incident solar radiation passes through the transparent cover and absorbed by black surface of the basin. Brackish water is then heated and evaporates, the vapor is allowed to condense over the cool interior surface of the transparent cover. Condensate flows down the glass and gets collected in troughs installed as outer frame of solar still. Distilled water is then transferred in to storage tank (see fig. 2.2). The system is capable of purifying sea water with salinity of about 30,000 mg/litre with production rate is about 3 l/m²/day.

2. Double effect type Solar Still

Double Effect Solar Still consists of two storage basin type solar still with glass covers for both basins. The first basin glass cover is used as the base for the second basin with the advantage that heat of condensation of bottom basin can be used to heat the water on top basin, so that the output yield increases more than the single effect type solar still. In the case of double effect type solar still, upper and bottom solar still separated by sloped glass (fig.2.3).

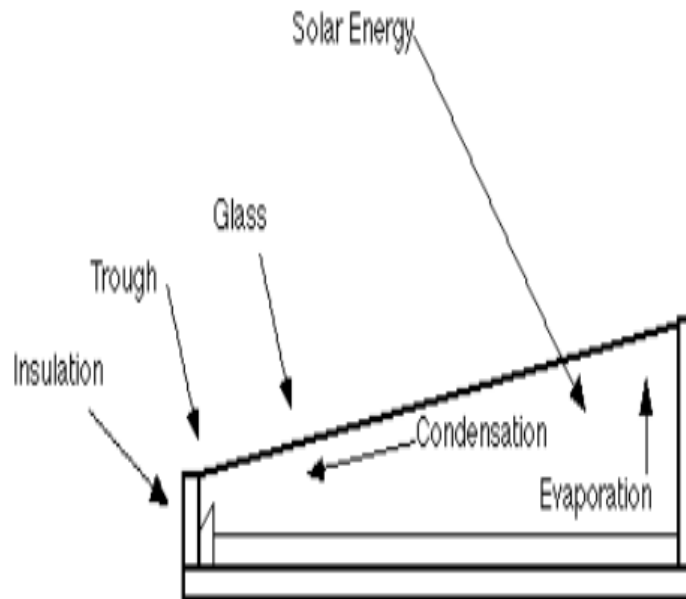


Fig.2.2 Single effect type solar still

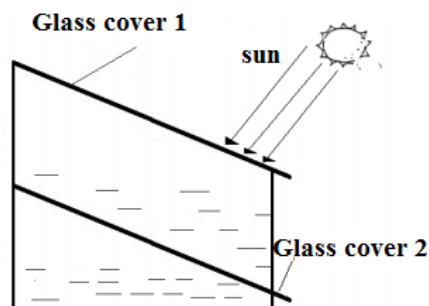


Fig.2.3. Double effect type Solar still

2.6.3 Basic Components of Basin Still

A basin still consists of the following basic components: basin, support structures, glazing, a distillate trough, and insulation.

2.6.4 Parameters affecting the output of a Solar Still

The productivity of a still is under the effect of three groups of conditions. These are ambient conditions, Operating conditions and Design conditions. It is clear that ambient conditions are not under control, and an optimum design must satisfy the requirements of the operating conditions and design conditions [34-35]. They are summarized in table 2.1 and discussed in the following subsections.

Table2.1: Factors affecting solar still

Climate Parameters	Design Parameters	Operating Parameters
Ambient temperature	Single slope or double slope	Water depth
Wind speed	Glazing material	Preheating of water
Outside humidity	Water depth in basin	Coloring of water
Solar radiation	Orientation of still	Input water supply
	Inclination of glazing	Rate of algae growth
	Button insulation	Arrangement
	Spacing b/n water and glazing	
	Type of solar still	

2.6.4.1 Effect of Water Depth

The depth of water in the basin affects the performance of a still considerably. The average water mass temperature remains high for low water depths due to faster rate of heating of the shallow water mass resulting in higher outputs. Water depth becomes important especially in the morning when low energy from the sun is available and it is required to heat the water quickly to producing fresh water.

2.6.4.2 Effect of wind velocity

Wind velocity has little effect on productivity, but even low wind speeds increases the production rates as compared to zero wind conditions [34].

2.6.4.3 Effect of ambient air temperature

The effect of ambient temperature variations on solar still productivity is examined by the several researchers. The numerical results showed that a slight increase of 3 % in the solar still productivity is obtained by increasing the ambient temperature by 5°C[34].

2.6.4.4 Effect of the gap distance

Reducing the gap distance between the evaporating surface and the condensing cover improves the still performance. The effect of the gap distance is much important than the effect of the cover slope. Reducing the gap distance will reduce the height of the walls of the still and hence will reduce the shadowing effect of these sides. Also less time is elapsed by the saturated air to reach the condensing surface and therefore continuous and quicker air movement in the still is established. Reducing the gap distance from 13.0 cm to 8 cm for the same cover slope increases the output by 11.0 % [35].

2.6.4.5 Effect of number of covers

Number of transparent covers used in a solar still does not increase the output, because it increases the temperature of the inner cover (condensing surface). But it also keeps the still airtight. Due to double glass cover reduction of 25-35 % of the output was noticed. Also uses a double glass cover and increases the initial cost of the still[35].

2.6.4.6 Other effects

Some other effects may be mentioned like the degree of salinity of water. As salt concentration of the water is increased, the yield of the still decreases, also with time if the salt sticking to the absorbing plate is not removed completely, this will reduce the efficiency of the absorbing plate. Also salty water damages the materials of the still by corrosion. In some experiments to increase the absorptivity of water in the basin and hence the output of the

still, the water is colored with some dyes or charcoal pieces are added. Charcoal pieces have the properties of wettability, large absorption coefficient for solar radiation and that they scatter rather than reflect the solar radiation. It was concluded that their effect is most noticed in the mornings and on cloudy days when the value of the solar radiation is low. However, the presence of the charcoal pieces reduces the start-up time of evaporation [35].

2.6.4.7 Design

Latitude is one of the factors that determine whether single or double slope still should be used. At latitudes higher than 20°, single slope stills with equator facing cover are recommended [36].

2.6.5 Efficiency of a solar still

The efficiency of a still is based on the amount of useful energy that the still converts as a function of the incoming total radiation. In this thesis, the source of energy used is freely available. The energy varies depending on the time of the day and also due to seasonal and climatic changes. For high efficiency the solar still should maintain a high temperature of the feed (un-distilled) water which can be obtained if a high proportion of the incoming radiation is absorbed by the feed water as heat. Hence a system with low absorption glazing and a good radiation-absorbing surface are required. There is also a need to keep heat losses from the floors and walls low and make the water shallow enough so that there is less to heat. The efficiency is also affected by the temperature difference between the feed water and the condensing surface. The difference needs to be large enough so that condensation is enhanced and this can be achieved if the condensing surface absorbs little or none of the incoming radiation.

2.6.6 Yield quality

Salinity

Salinity is a measure of the total amount of ions dissolved in water. Total salinity is fairly easy to measure. Water quality standards for human consumption have been developed for total salinity. Although the specific composition of ions in water is important, salinity measurements do not provide information on the type of ions present in the water solution. Salinity of water is commonly expressed as TDS.

Many researchers found for different capacities of solar stills TS, TDS, TSS, sulphates, phosphates and chlorides reduced to zero after treatment [37]. Furthermore solar stills have proven to be highly effective in providing safe drinking water. The effectiveness of distillation for producing safe drinking water is well established and recognized [38].

2.6.7 Solar Still distillation for defluoridation

In contrast to several works on solar distillation use for desalination of seawater and brackish water studies on its use for defluoridation have been reported only recently. For fluoride concentration of (0.2–0.4 mg/L) in feed water the distillate contained F^- is lower (<0.05 mg/L). For water feed having a fluoride concentration of 20 mg/L, a product contained 1.1–1.2 mg/L obtained which is below the permissible limit of 1.5 mg/L [11].

2.6.8 Other application Areas of Solar Still

Solar Still distillation has the advantage of cost saving over other types of water treatment. The Solar still can be used in such as the following specific areas [39]:-

- ✓ Industries
- ✓ Hospital and dispensaries
- ✓ Garages and automobile workshop
- ✓ Telephone exchange
- ✓ Laboratory use
- ✓ Marshy and coastal area
- ✓ For industrial processes
- ✓ Radiator and battery maintenance

2.7 Energy System

2.7.1 Solar

Energy from the sun is said to be the solar energy. This is the earth's primary energy flow and equally too, the most abundant on the earth crust. There are two major ways in which the solar energy can be used or harnessed. It can be used either as a thermal energy by heating a fluid or by converting it into electricity using photovoltaic arrays (PV). The former would be looked in detail in the design of the solar still. Solar energy is a relatively diffuse source of energy. It is also available almost everywhere, unlike geothermal, wave, wind or even conventional fuels. Depending on the energy demand of the application, it may require large areas. Yet, most solar energy conversion systems are modular and can be installed almost everywhere which relieves the space availability problem.

The solar energy can be deployed and use for simple desalination systems especially, the solar still for production of potable water in the tropics and arid regions of the world where there is abundance of this natural resource. These regions are well endowed with this resource and it should be fully exploited.

2.7.2 Solar Thermal

Solar thermal energy is one of the most promising applications of renewable energy to seawater desalination.

Chapter Three

3. Material and methods

3.1 Materials

3.1.1 Basin Material

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 with a high thermal conductivity of 205 W/mK at 25°C, shaped to form a water holding basin, and it is coated with black paint to improve heat absorption.

3.1.2. Glazing

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.

3.1.3 Insulation

Insulation of the basin is used to prevent heat loss to the ambient.

3.1.4 Others

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.

Table 3.1 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 3.2: Equipment used to check water quality parameters (AAEPA)

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

3.2 Methods

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 [40]. 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.

3.2.1 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.

3.2.1.1 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 $6.1 \text{ kWh/m}^2/\text{day}$, but taking the lowest $5.6 \text{ kWh/m}^2/\text{day}$ (to make an operational during the lowest solar radiation) [41].

Assumptions

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

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

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

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

$\eta_s = 0.40$ (40% is a common still efficiency) [32]

Where, λ = Latent heat of vaporization of water

ρ = density of water

γ = minimum solar radiation of the location

Useful solar radiation = $5.6 * 0.4 = 2.24 \text{ kWh/m}^2/\text{day}$

$$= 2.24 \text{ kW/m}^2/\text{day} * 3600 \text{ s} = 8064 \text{ kJ/m}^2/\text{day}$$

$$Y = \frac{\text{useful solar radiation}}{\text{latent heat of vaporization}} \text{-----3.1}$$

$$= \frac{8064}{2382.8} = 3.38 \frac{\text{kg}}{\text{m}^2/\text{day}}$$

$$A_s = \frac{\text{design target}}{\text{calculated yield}} = \frac{2}{3.38} = 0.6 \text{ m}^2 \approx 1 \text{ m}^2 \text{-----3.2}$$

Where, A_s = total area of solar still required (m^2)

Y = calculated yield (kg)

A_s = basin area

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.

3.2.1.2 Glassing angle from horizontal

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

3.2.1.3 Glass cover design

A glass of having an area 1.04 m^2 made to be fit with basin at glazing angle of 15° .

3.2.1.4 Components of parabolic solar trough

Generally parabolic solar trough contains the following components.

1. 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.

2. 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.

3. Solar Collector

Currently, 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.

3.2.1.5 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 1.90m x 1.00m. 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.

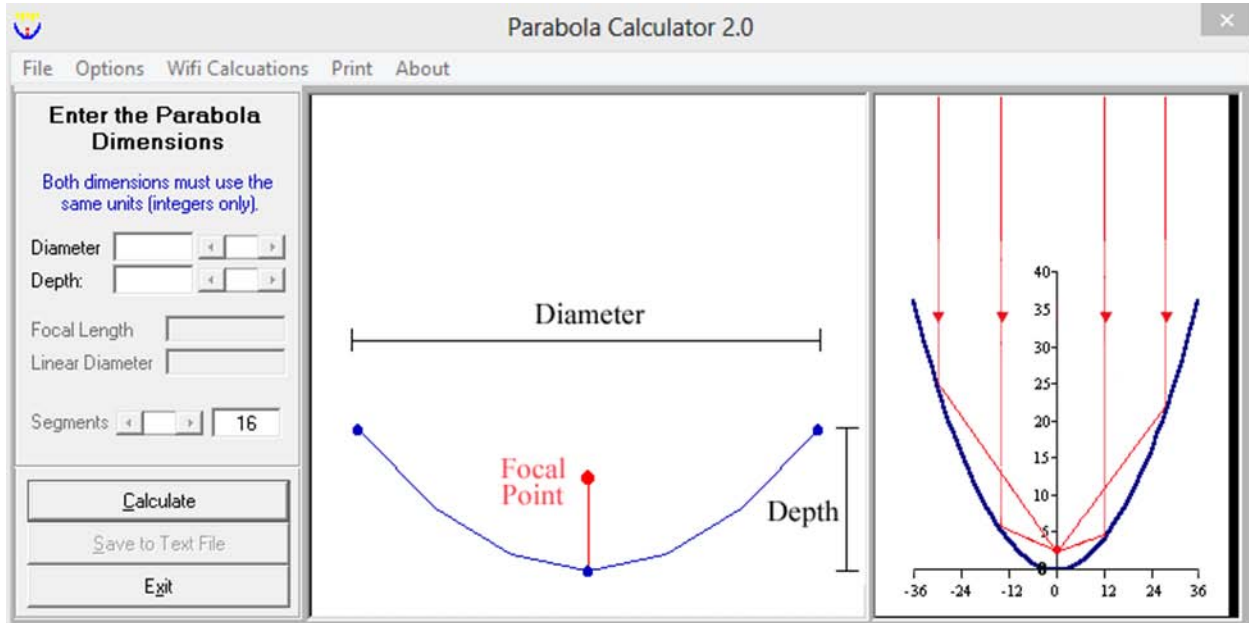


Fig 3.1: feature of parabola calculator 2.0 software

The Equation of parabola best fits an 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 4). In input to parabola calculator 2.0 version is Diameter and depth of parabola preferred. I preferred Diameter of 88cm and Depth of 21cm 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 (as shown in the table 3.3)

Table3.3: 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

3.2.2 Fabrication of the system

3.2.2.1 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 fig3.1 to 3.3. 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 thesis work.

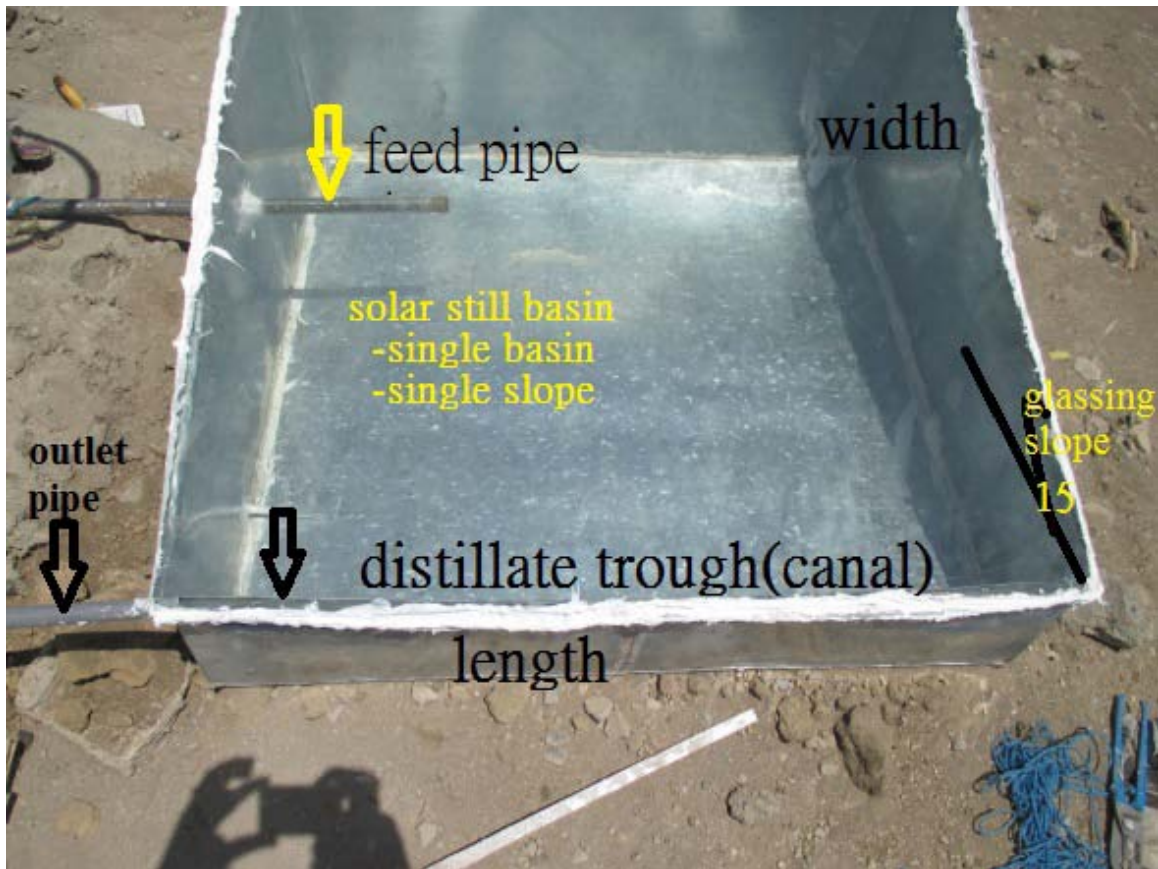


Fig: 3.2 Manufactured single basin single slope solar still



Fig: 3.3 Manufactured single basin double slope solar still

Table 3.4 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	15^0
Length of trough (m)	1m
Depth of trough(mm)	$\frac{1}{2}$ "
Depth of basin (mm)	10cm

3.2.2.2 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.



Fig 3.4: Installed Parabolic Solar Concentrator

Table 3.5 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



Fig. 3.5 Installed Active Solar Still

3.2.3 Theoretical Analysis

The overall efficiency of solar still is given by expression [40]

$$\eta_{solar\ still} = \frac{m_{ew} * \delta}{I_T * A_s} \dots\dots\dots 3.7$$

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 $T \leq 70^\circ\text{C}$

I_T = Total Daily Solar Radiation = $6.5\text{kwh}/\text{m}^2/\text{day} = 23,400\text{J}/\text{m}^2/\text{day}$

A_s = Basin Area = $1 (m^2)$.

3.2.4 Experimental Setup

The experimental setups, after completing manufacturing at Logia Woods and Metal workshops, look the following. 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 $2l/\text{m}^2\text{day}$. 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.

3.2.5 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.

After experimenting: Analysis has been carried out as discussed under result and discussions.

Chapter 4

4. Result and Discussion

During the experiment the following results and corrections were made after checking the wellbeing of the setup. For 15° glazing angle and $1m^2$ 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.

4.1 Experimental Analysis for Single basin double slope Solar still (Passive Solar Still)

4.1.1 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.

4.1.2 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 fig 4.1. 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 vapour 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.

4.1.3 Discussion on Results

4.1.3.1 Productivity Vs. Time

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 conclude and to keep the performance of solar still very well, basin insulation is required.

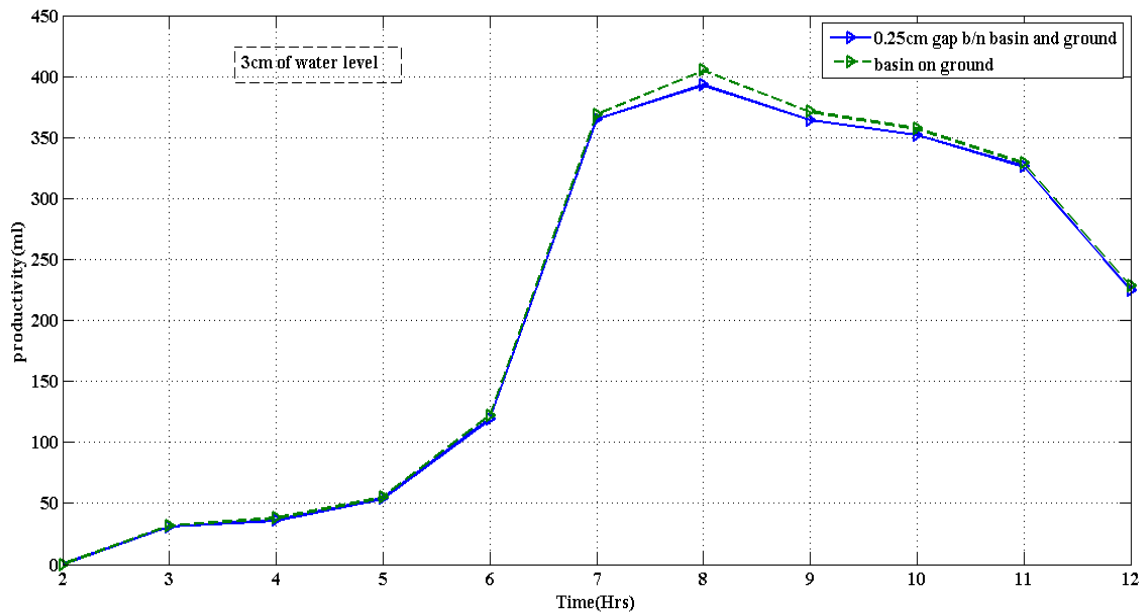
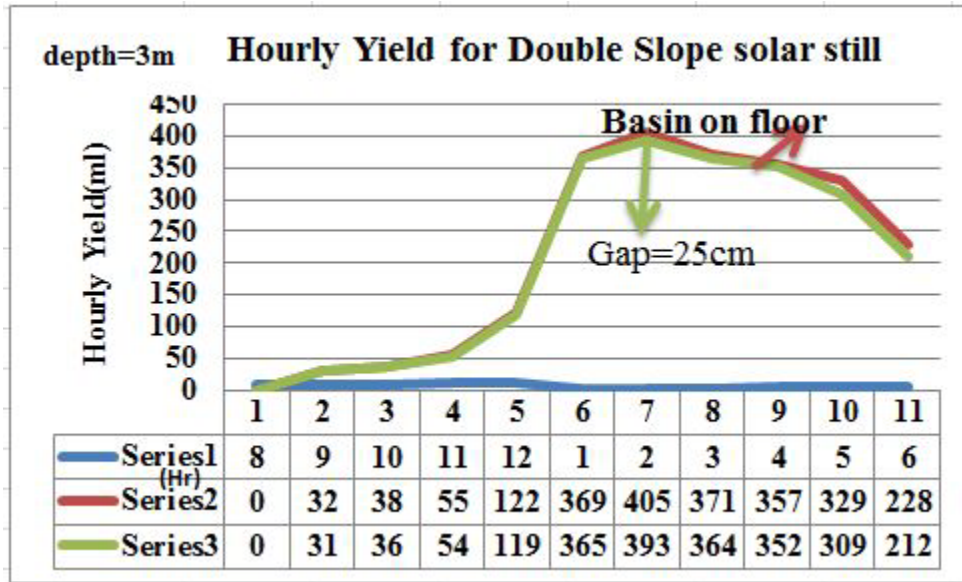
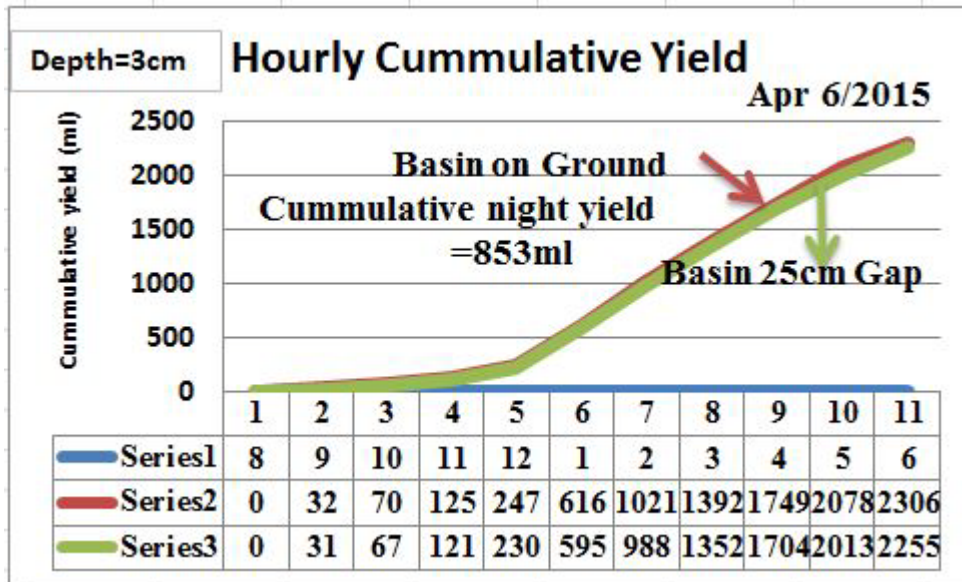


Fig4.1: Productivity Vs. Timefor basin on ground and 25cm higher (April 6/2015)

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 fig (4.2) for basin on ground and 25cm higher.



a)



b)

Fig4.2: Hourly (a) and cumulative (b) 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.

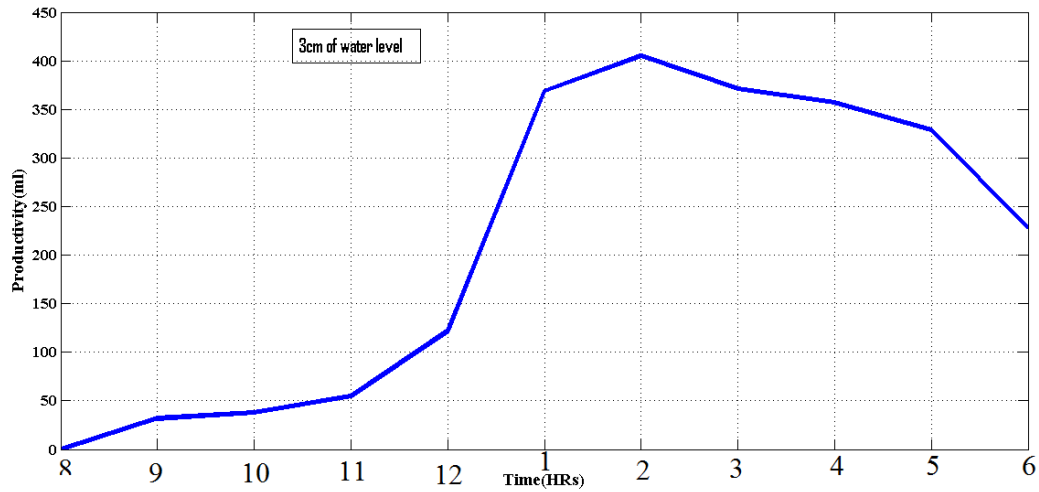
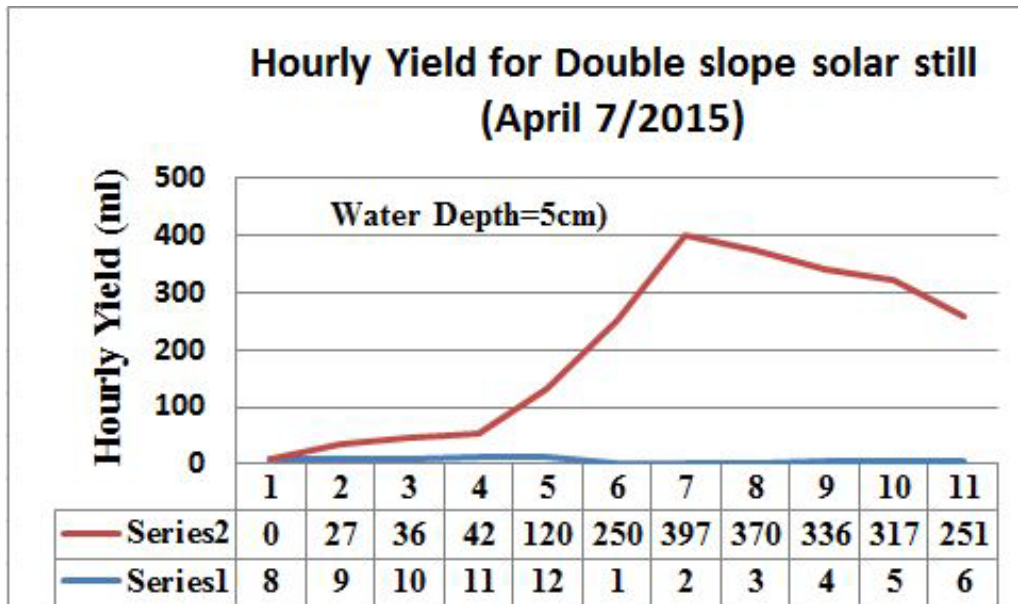
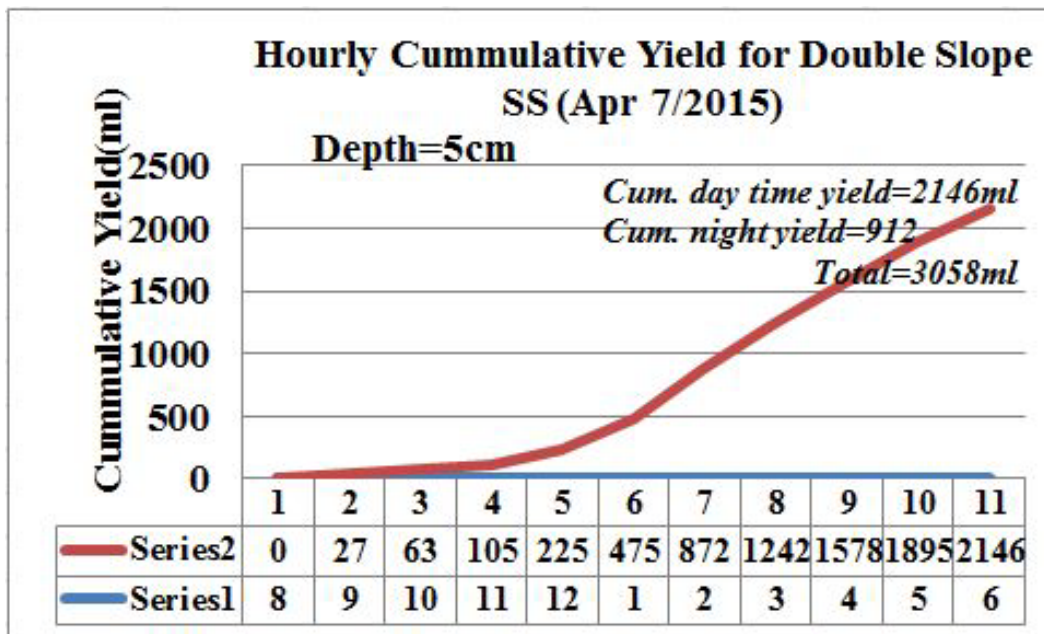


Fig4.3: Productivity vs. Time for basin put on ground at water level 3cm (April 6, 2015)

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.

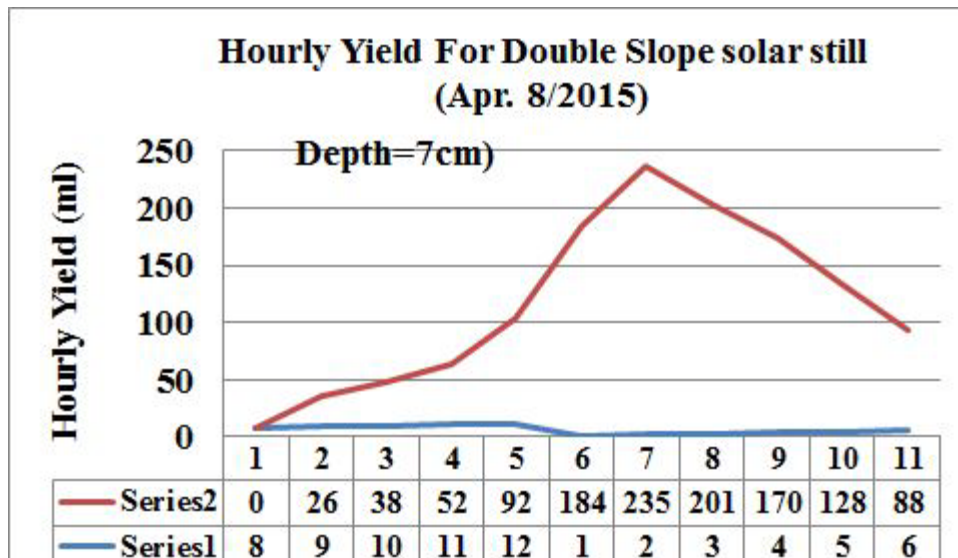


a)

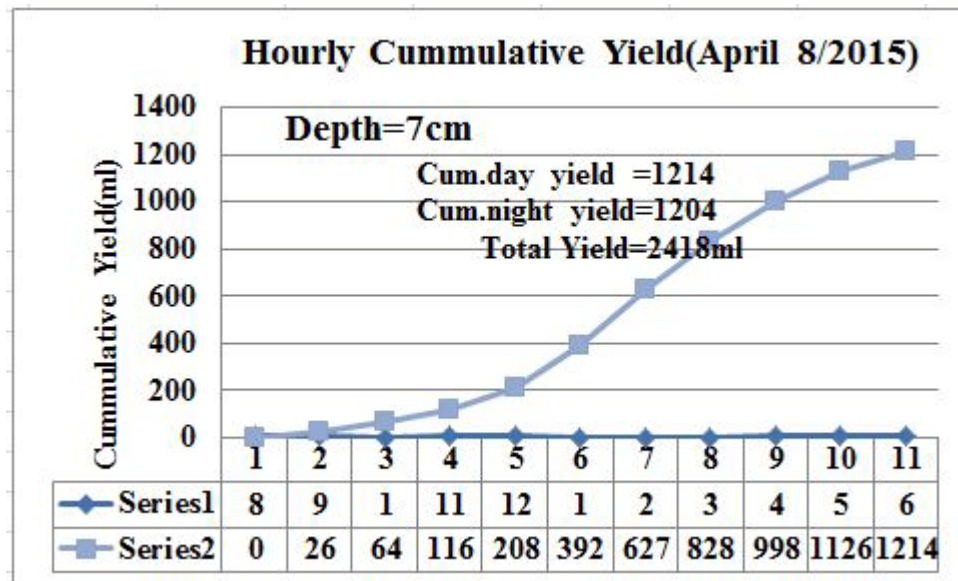


b)

Fig4.4: Hourly (a) and cumulative (b) productivity Vs. Time: for water level of 5cm (April 7/2015)



a)



b)

Fig4.5: Hourly (a) and cumulative (b) productivity Vs. Time: for water level 7cm (April 8/2015)

4.1.3.2 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 fig.4.6.

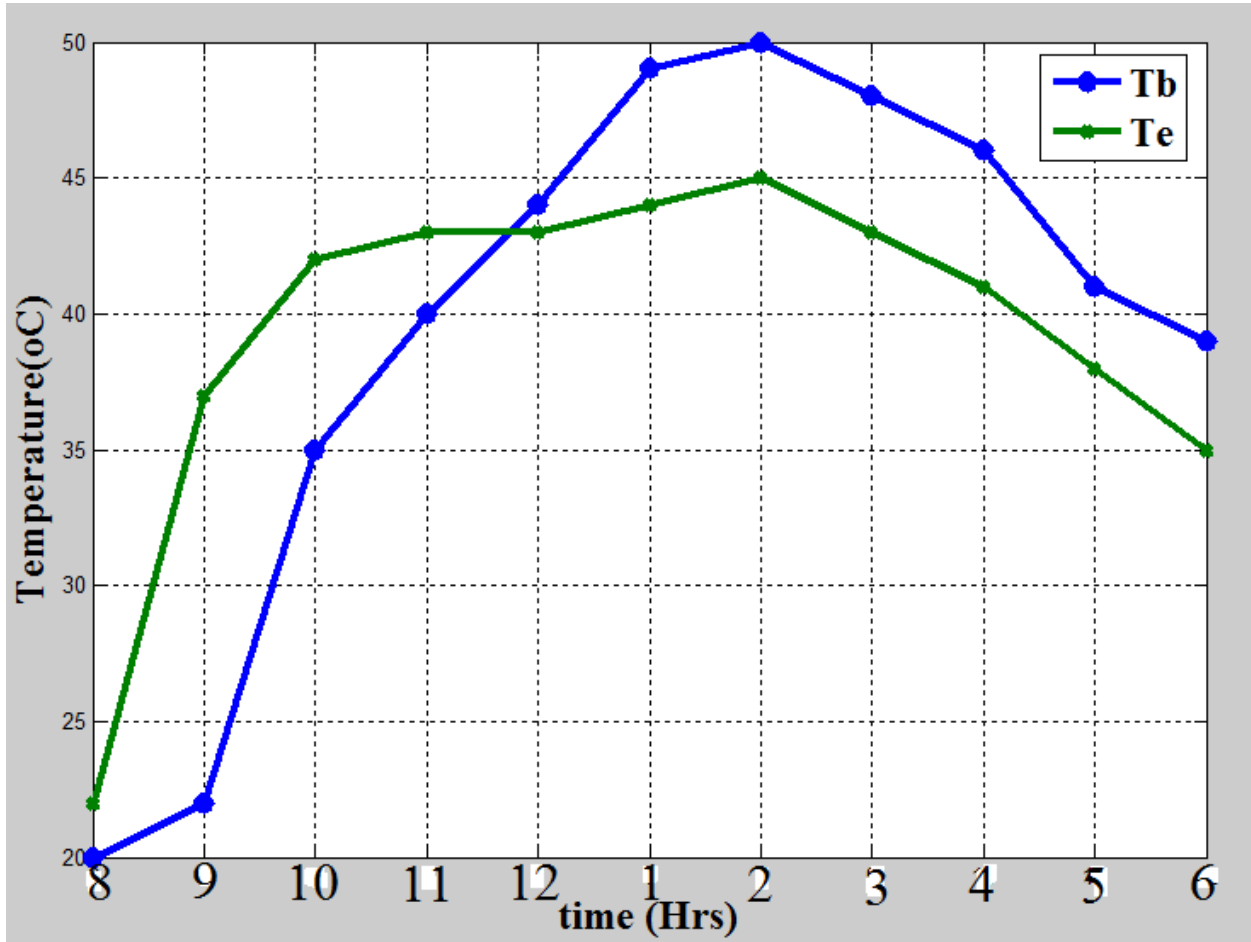


Fig4.6: Variation of basin and ambient temperature with time for 3cm

4.2 Experimental Analysis for Solar Still integrated with a PSC

4.2.1 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 3.4 and as shown fig 3.5, 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 is 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.

4.2.2 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 1m² 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.

4.2.3 Discussion on Results

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 until it reaches 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..

4.3. Quality of water and removal Efficiency

The following parameters are checked at Samara University and Addis Ababa Environmental protection Authority and Table 4.1 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%.

Table4.1. 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 guide line

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.

4.4 Efficiency of Solar Still

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

$$\eta_{\text{solar still}} = \frac{\text{latent heat of vaporization} * \text{daily yield}}{\text{daily solar radiation}} \text{-----} 4.1$$

The efficiency was done for basin water temperature of 50°C and an average daily solar radiation of 6.5 kWh/m²/day[42].

Table4.2 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.

Chapter Five

5. Conclusions and Recommendations

5.1 Conclusion

The solar still distillation is one of the simple methods that removes salts, fluoride ion and other water impurities. It is concluded from the distilled water analysis that the water from solar still of any size is pure. The result from this experiment agrees with this fact and all tested water quality parameters agreed with the national water quality standards with 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 no sustainable brackish water or any other form of water like rain and river can be stored, even by calculating yearly consumption of drinking water and it can be purified.This system helps to manage water resources.

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

5.2 Recommendations

Where there is no supply of fresh water for small community or households with an access to contaminated water and high solar radiation, solar still technology is recommended to purify raw water. Raw water having high TDS and fluoride can be treated effectively by solar still technology. The daily yield, $3.16 \text{ kg/m}^2/\text{day}$ for double slope solar still. To increase the quantity of distilled water further it is recommended to increasing surface area, which resultshigher exposure to solar radiation orusing capillary still is recommended. Parabolic solar trough integrated with solar still in this way is not recommended to continue further study due to its high operational and construction costs.

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