Performance investigation of parabolic trough solar collector for desalination: A case of Diguna Fango Dimtu water

Mebratu Baza

A Thesis submitted to

Thermal and Aerospace Engineering Department

School of Mechanical, Chemical and Material Engineering

Presented in partial fulfillment of the requirement for the degree of Master of Science in Thermal Engineering

Office of Graduate Studies

Adama Science and Technology University

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DECLARATION

I here to declare that this thesis work entitled “Performance investigation of parabolic trough solar collector for desalination: A case of Diguna Fango Dimtu water “in partial fulfillment of the requirement of the degree of Master of Science in Thermal engineering is an authentic my own work carried out under Supervision of Dr.Gezahegn Habtamu, Assistant Professor of Thermal Engineering program, Adama Science and Technology University.

The matter presented in this thesis work has not been submitted for the award of degree in any other university at the time before. All basically important resource information used in this paper has been greatly acknowledged.

Mebratu Baza	………………	……………….
Name of Student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled” Performance investigation of parabolic trough solar collector desalination: A case of Diguna Fango Dimtu water”prepared under my guidance by Mebratu Baza submitted in partial fulfillment of the requirements for the degree of Masters of Science in Thermal Engineering. Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Dr. Gezahegn Habtamu	……………….	…………..
Advisor	Signature	Date

Approval Sheet

I,the advisor of the thesis entitled “Performance investigation of parabolic trough solar collector desalination: A case of Diguna Fango Dimtu water” and developed by Mebratu Baza Gebre;hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr.Gezahegn Habtamu	……………….	…………………
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Mebratu Baza Gebre have read and evaluated his thesis entitled’ **’Performance investigation of parabolic trough solar collector for desalination: A case of Diguna Fango Dimtu water’’**and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Thermal Engineering.

Dr.Dawit Gudeta	………………	……………..
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TABLE OF CONTENTS

CONTENTS **PAGE**

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

ABBREVIATIONS

IAE	International Energy Agency
PTC	parabolic trough collector
SEGS	Solar Thermal Electric Generation Systems
TDS	Total dissolved solids
RO	Reverse Osmosis
ED	Electro dialysis
PVED	photovoltaic Electrodialsis
HD	Humidification-Dehumidification
FPC	Flat-plate collector
ETC	Evacuated tube collector
PDC	Parabolic Dish Concentrator
MEH	Multi-effect humidification
LCOW	levelized cost of water
FLD	Fresnel linear distiller
RTD	Resistance Temperature Detector
HTF	heat transfer fluid
HCE	Heat collection element

SYMBOLS

Co_2	Corbondioxide
MW	Mega watt
km	Kilo meter
kcal	Kilo calorie
mg/l	Milligram/liter
Mpa	Megapascal
ET	Equation of time

h	Hour angle
z	Solar azimuth angle,
$\overline{H}$	Monthly average daily radiation on horizontal surface.(w/m2)
$\overline{Ho}$	Monthly average radiation out side of the atmosphere (J/m^2)
$\bar{n}$	Monthly average daily hours of bright sunshine.
$\overline{N}$	Monthly average of the maximum possible daily hours of bright sunshine
GBt	Beam radiation on a tilted surface (W/m^2)
GB	Beam radiation on a horizontal surface (W/m^2)
RB	Beam radiation tilt factor
S	Absorbed radiation (w/m^2)
f	Focal length(m)
S	Arc length (m)
A	Area ($m^{2)}$
CG	Geometric concentration
D, d	Diameter (m)
H	Convective heat transfer coefficient (W/m^2k)
I	monthly average hourly radiation on a horizontal surface (W/m^2)
k	Thermal conductivity(w/m.k)
m	Mass(kg)
$\dot{m}$	Mass flow rate (kg/s)
N	number of turns
Nu	Nusselt number
P	Pressure (pa)
Pr	Prandtl number
Q	Heat flow (W)
R, r	Radius (m)
Ra	Rayleigh number
Re	Reynolds number
T	Temperature (℃)

U	Speed (m/s)
T	Time(s)
V	Volume (m^2)
W	Width (m)
A_f	Geometric factor
F'	Collector efficiency factor
U_L	Over all heat transfer coefficient (W/m^2.k)
F_R	Collector heat factor of the concentrator
F''	Flow factor
Δp	Pressure drop (pa)
L	length, Effective length (m)

GREEK LETTERS

δ	Declination Angle
α	Solar altitude angle
ϕ	solar zenith angle
θ	Incidence Angle
β	Surface tilt angle
Ψ	Rim angle
γ	Intercept factor
ε	Emittance
λ	Specific latent heat
μ	Dynamic viscosity
ν	Kinematic viscosity
ρ	Density
τ	Transmissivity
η	Efficiency
σ	Stefan-Boltzmann
α	Absorptance
ρ	Reflectance

SUBSCRIPTS

a	Ambient
st	Standard
loc	Local
max	Maximum
min	Minimum
ap	Aperture
sca	Solar collector assembly
avg	Average
b	Beam
o	Optical
u	Useful
l	Loss
eff	Effective
abs	Absorbed
c	Cover,coil
sh	Shell
i	Inner
o	Outer
e	Equivalent
h1	Hot fluid inlet
h2	Hot fluid outlet
c1	Cold water inlet
c2	Cold water outlet

ABSTRACT

Solar energy employing desalination is basically fast growing field of the research now a time. Solar thermal energy employing water desalination is most sustainable solution for dry region like Dimtu where there is the shortage of drinking water. This region also has high potential of solar energy .This thesis aim to study experimental chemical composition of Diguna Fango Dimtu water and desalination of this water by using parabolic trough solar collector for drinking purpose. Chemical analysis of both raw saline water of the region and desalinated water were analyzed by using different instruments like TDS meter or conductivity meter,photo meter (model 7100).PH,turbidity tube at ASTU chemistry department laboratory. The total dissolved solid before the desalination plant is 3690 mg/l and after desalination the TDS of the average of nine day is 911.5 mg/l and according to the WHO standard it is possible for drinking purpose. Desalination experiments were performed by manufacturing parabolic trough solar collector composed of solar energy receiver system, reflective mirror,heat exchanger and desalination assisted by PTC and horizontal north-south orientation tracking system operated manualy. Firstly,the amount of solar radiation incident up on the Earth is estimated using sunshine hour of Dimtu meteorological conditions and compared with Adama solar radiation. For small scale PTC the length of 3 m, width of 0.88 m and Aperture area of 2.64 m^2can be used for manufacturing purpose to fulfill daily water requirement for small family as per WHO guideline and the assembly drawing done in CATIA software. The experimental test was carried out between January 9 to 17, and the temperature values were measured by using thermocouple. The result shows that the maximum desalinated water was 3.2 lit/ 6 hr (from 9:00am to 3:00pm).This water production was achieved at the feed water flow rate of 0.000583 kg/s and also the maximum heat transfer fluid temperature was 118℃ and the maximum efficiency obtained during the experiment is 41% but, the efficiency values is less than the expected due to tracking error, alignment of the receiver error, the alignment of mirror error. Besides, the mass flow rate is the most important parameter to control the outlet temperature of HTF in parabolic trough collector.

Key words: Desalination, Solar energy, heat transfer fluid, total dissolved solids (TDS), parabolic trough collector (PTC).

CHAPTER ONE
INTRODUCTION

1.1 Background

The world's population is augmenting and fresh water has always been one of the most vital requirements for life to continue on the earth. However, while water covers almost 75% of the earth's surface and only 3% is fresh water from several sources and from this finite quantity a small portion of it can be used for drinking. Hence, water treatment is usually necessary. It is proved that the most efficient way for providing fresh water is desalination of brine and/or seawater. But, this method is quite energy intensive and needs lots of oil and wood and the operational cost would be high.

Higher fossil fuel costs impact the poor countries that spend a lot of money to buy fossil fuels in order to cover the energy needs of people. Besides high fossil fuel prices, global warming is another impact of highly utilizing fossil fuels. By burning fossil fuels, green gases such as carbon dioxide (Co_2) are brought out which lead to rise the temperature of the dry land and cause global

Warming. According to International Energy Agency (IAE), fossil fuel emissions of carbon dioxide (Co_2)) have hit 30,326 million tons in 2010 compared with 15,637 million tons in 1973 [1]. So, cost-effective alternative method would be using solar energy which is safe, free and renewable for the desalination process and in the areas with greater fresh water shortages that are most of the time semi-arid region of Diguna Fango Dimtu region.

The shortage of drinkable water causes several serious diseases and causes death of young children. According to water.org organization, 332 million people are still without excess to the potable water in Africa. The universal problem still needs more collaboration in order to minimize the number of people in need for drinkable water. This project targets to solve the problems in order to help such people to enjoy desalinating and purifying their own water through the use of renewable energies. The system designing will mainly target the transformation of brackish water (ground saline water) into drinkable water using PTC (parabolic trough collector) technology. This technology works by concentrating the sunlight into the pipes and causes change of the phase of water.

Current world energy consumption shows that approximately 84.7% of the world energy is supplied by fossil fuels and only 9.9% by renewable energy sources and the figure 1.1 shows that the world energy consumption is projected to increase by 50% from 2005 to 2030[3].

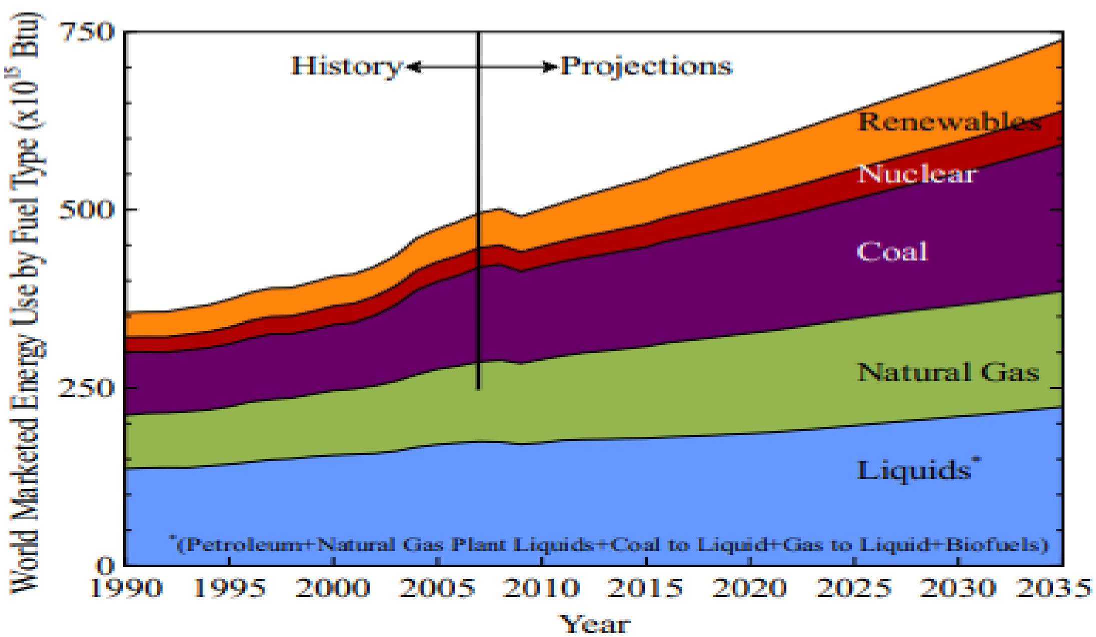


Figure 1.1 Current and projected world energy use by fuel type[3]

Desalination is one of the suitable process for removing salts and contaminated elements. Among different desalination methods renewable energy using water purification techniques are preferable than conventional methods.

Large cost of fuels and pollution using fossil fuels leads to the usage of renewable energy source as alternatives in desalination plants. Among different solar thermal concentrating systems, mainly parabolic trough type equipment's are chosen for desalination process. Parabolic trough solar collectors have high efficiency for converting solar energy to heat energy and stable performances at high temperature range when compared with other methods. Parabolic trough collectors (PTCs) are preferred for solar steam-generation since high temperatures can be obtained without any serious degradation of the collector efficiency [2]

Most of the published studies of PTCs with tubular absorbers (receivers) are concerned with the Trough collector used in the Solar Thermal Electric Generation Systems (SEGS) plant [4].

Parabolic trough technology had not been developed for the following 60 years. However, PTSC activities started again in the mid-1970s in response to the oil crisis. Honeywell international Inc. and Sandia National Laboratories developed two collectors in the mid-1970s in the United States, and they were designed to function with temperatures below 250℃ . In Africa, a solar thermal plant in Cairo based on 1,900 m_2 of parabolic trough collector provides steam for pharmaceutical plant. Globally parabolic trough power plants technology with existing commercial operating systems include: A larger solar based facility already exists in Mojave Desert in USA generates 354 MW of solar energy power. In Spain have a 50 MW parabolic trough based plants located in Seville Cadiz[7].

The most important thing to consider here is in Ethiopia, large number of industries are growing, for this purpose energy demand for the factory itself increasing automatically. In Ethiopia, as the number of industries are growing drastically the process heat energy demand is also increasing. So, the use of renewable energy source like solar energy is very essential and addition to industry use, desalinating salt water by the use of renewable energy is the most critical.

One of the main potential area of solar energy is solar desalination .The energy that required to desalinate can be obtained from concentrated solar collector is the most used one. Concentrated solar collectors are the most widely used solar collectors used in industries for process desalinating water due to their high-quality solar power. Parabolic trough collectors is the most commonly used type and there are a number of manufacturers in different parts of the globe. Parabolic trough collectors are the most matured of the concentrating solar power technologies and the majority of worldwide installed capacity is of this type.

The working principle of parabolic solar desalination, solar radiation coming from sun collected over area of reflecting surface of parabolic trough and concentrated in to the focus of parabola. Receiver tube is placed on the focal line axis, so working fluid inside is heated up due to concentrating solar irradiation using collector surfaces and the vapor formed was moved to the condenser side and it is cooled in the condenser into pure water as an output. The salts and impurities due to phase change of saline water under go gravity settlement. So many problems are enhanced in Diguna Fango Dimtu region due to lack of the electricity and potable water. So, one of the problem can be solved by using solar energy for desalinating saline water. Since, solar energy is abundant in diguna fango. So, desalinating demand can be partially replaced by using solar energy. In country with high population growth rate and by some extent increasing socio-economic development, water demand is getting wider than usual. Fortunately, efficient technologies have been developed to treat saline water via desalination for communities where fresh water is scarce. A number of such communities in arid regions have turned to desalination technologies because of it being a relatively feasible alternative for fresh water production for Dimtu regions which is semi-arid regions located at southern nation in Wolaita zone. The high incident solar radiation in the Diguna Fango Dimtu and the shortage of drinking water encourages to an attempt to manufacture and test parabolic trough collector for desalination purpose.

1.2 The research problem (statement of the problem)

Currently, most of desalinating technologies in Ethiopia are using electricity or fossil fuels to meet their heat energy demand. However, this has a negative economic impact for desalinating as the price of electricity and fossil fuels is increasing each year and also using fossil fuel that influences the environment and also Diguna Fango Dimtu area is a semi-arid region of Ethiopia large number of people away from drinking water. Since this study concerns on small scale parabolic trough desalination, investigation can be taken into account for small number of groups and it works for whole peoples by increasing the length and number of solar collector assembly. For the Dimtu area the only source of natural water is the saline water which is not preferable for drinking purpose.

Dimtu is one of rural area which do not have access to electricity, thus they are not able to use electrically desalinate saline water. The people who are in this region suffer from drinking water and they get drinking water from hawassa town that is 100km away from Diguna Fango Dimtu region.

To bought water from hawasa is too cost relatively compared with the economy of people and pure water is the most requirement for healthy life and economically poor people use this saline water and their healthy is under full of question. In order to tackle this problem it is found to be the best and appropriate idea to introduce a solar desalination which uses a freely available solar energy(cost free) to carry out the desalination process thus it provide desalted water for the community.

1.3 Objectives of the study

1.3.1 General objective

The general objective of this project is to make a development of small scale parabolic trough solar collector desalination technology that can be used to produce fresh water for drinking purpose.

1.3.2 Specific objective

The specific objective of this project are

- To study of the chemical composition of Diguna Fango Dimtu ground water by using photo meter (model 7100) and microprocessor based conductivity/TDS meter (model 1601).
- Estimation of solar radiation (beam) at Diguna Fango Dimtu climate condition according to meteorological data.
- Manufacturing of parabolic trough solar collector desalination system
- Field test the performance of parabolic trough solar collector desalination system.

1.4 Significance of the study

Now a days, the world is basically searching how to get drinking water from saline water for the area where there is no electricity and how to minimize the shortage of water in semi-arid region of the country (where there is a lot of incoming solar radiation from the sun). The project is used to prevent drinking of saline water and to protect economically poor people from being infected by some other health related issue. The lack of potable water is huge problem in Diguna Fango Dimtu region which is semi-arid where pure water is becoming very expensive and even not existed in Diguna Fango Dimtu region due to the absence of electrical power .So to desalinate water by using solar energy is one of basic option for the society and also this work minimizes the number of peoples who are bought water from somewhere else and also their economy does not affected in some extent.

The concentrated solar collector has many advantages for use when compared to flat plate collector. Reflecting surfaces require less material and are structurally simpler than flat plate collectors, The absorber area of a concentrator system is smaller than that of flat plate system for same solar energy collection, Heat lost to the surrounding per unit of solar energy collecting area is less than that of flat plate and also working fluid achieve maximum temperature in parabolic trough solar collector.

1.5 Scope and limitation of the project

1.5.1 Scope of the study

In this work, the procedure carried out by desalinating water by using parabolic trough solar collector from the material commercially available in local market. And the main components are collectors from AISI 304 steel to resist corrosion and the receiver tube which is made from copper with high thermal conductivity. Semi-arid region of like Diguna Fango Dimtu which accounts highest amount of solar energy. The scope is mainly targets on the performance investigation of small scale parabolic trough solar collector for saline water desalination to produce drinking water for the society and studying of chemical analysis of Diguna Fango Dimtu water by using photo meter and TDS and conductivity meter is critical in this study .Manufacturing of the parabolic trough collector and the field test of the experiment is carried out.

1.5.2 Limitation of the study

The study of this work focuses on the performance investigation of parabolic trough collector and since the work mainly focuses on experimental set up and un availability of some materials nearby, excess cost of the materials and manufacturing when compared to the given amount of money for the research are some of the limitation of the study.

1.6 Research Question

A lot of questions can be raised regarding to parabolic trough collector for desalination plants. But, for this work, specific question to be answered are the following:

- What are the factors that affect the performance of the parabolic trough collector?
- How much amounts of energy is required to satisfy the small group people's demand of desalinated water?
- By what method the chemical analysis of water can be studied?
- How to achieve desired output temperature for desalination purpose?

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of desalination

The process of desalinating saline water to make it drinkable has a long and rich history. Some of the earliest appearances of desalination in history date back to experiments by Aristotle and other intellectuals in ancient Greece. The brilliant minds of that era came up with distillation and filtration using soil deposits to try and obtain drinking water from the sea.

Desalination has been used for many centuries. In the fourth century BC, Aristotle (384–322 BC) told of Greek sailors desalting water using evaporation techniques. Sand filters were also used. During the first century, the Romans employed clay filters to trap salt.

By the 1500s, methods included filtering water through sand and distillation to absorb the salt. The techniques have become more sophisticated, but distillation and filtering are still the primary methods of desalination for most of the world. The first desalination patent was granted in 1869, and in that same year, the first land-based steam distillation plant was established in England, to replenish the fresh water supplies of the ships at anchor in the harbor.

There are two main basic process for desalination technologies .These are discussed below under:-
a) Membrane technologies b) Thermal technologies
Thermal desalination uses thermal energy to induce a phase change that separates water vapor from the dissolved salts. The second method is membrane separation which uses a pump to force the solution through a semi-permeable membrane, overcoming the osmotic pressure necessary to separate the fresh water from the brine. The above technologies are discussed in following sections.

2.2 Reverse Osmosis (RO)

Reverse Osmosis is the most widely used desalination technology around the world. RO involves applying high pressure to force the water to move from a more concentrated solution to a weaker one .That means, Reverse osmosis is a pressure driven process where a pressure difference larger than the osmotic pressure is applied across an appropriate semi permeable membrane .The semi-permeable membrane allows water to pass through, but blocks the passage of the bulkier salt molecules. As a result, fresh water is accumulated on one side and brine on the other. The main advantage of this system is that reverse osmosis process is used in cases where water is high in salinity (from 500 to 50,000 ppm) and allows a good removal of solids and bacteria.

And this technology works only for large capacity and are expensive for small amounts of drinking water and cannot be used in the place where shortage of maintenance and repairing facilities as whole .

RO desalination plant basically comprises of four major systems (1) Pretreatment (2) High-pressure pump (3) Membrane assembly (4) Post-treatment. The high-pressure pump provides the pressure required to allow the water to pass through the membrane and have the salts discharged. RO is regularly chosen as the method for purification of brackish water, where only small to intermediate pressures are necessary. The operating pressure varies from 15 to 25 bar (225 to 375 psi) for brackish water and from 54 to 80 bar (800 to1180 psi) for sea water [2].

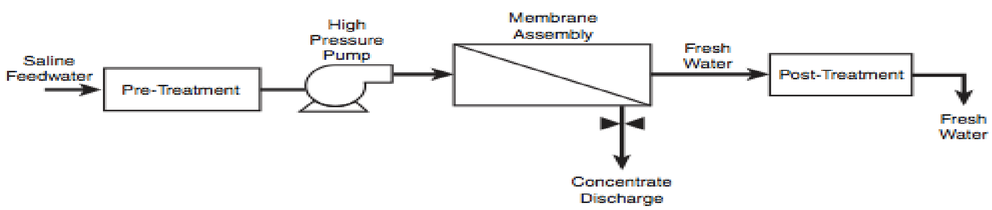


Figure 2.1: Schematic of small scale RO system [2]

2.3 Electro dialysis (ED)

It is a less popular type of membrane separation, developed 10 years before RO system. Electro dialysis (ED) is an electrochemical process that can be used to desalinate water. Due to the energy requirements of the process, electro dialysis is much more cost effective for lower salinity water and it is typically implemented for purification only with brackish water source. It uses an electric current to draw dissolved salts and metal ions through a selective membrane, leaving behind fresh water. It can be used for desalination of brackish water at a small (1-50$\frac{m^3}{day}$) or medium (50-250$\frac{m^3}{day}$) scale and requires an energy input of 0.5–2.5$\frac{kWh}{m^3}$ and in this method 85-94% of water can be recovered with total dissolved solids content of 140-600mg TDS/L. The energy consumption is a proportional to the amount of salts removed, not the volume of water treated therefore making the system more efficient for less saline feed water. However, typical systems of electro dialysis can only handle brackish water (up to 12,000 mg TDS/L) [3].

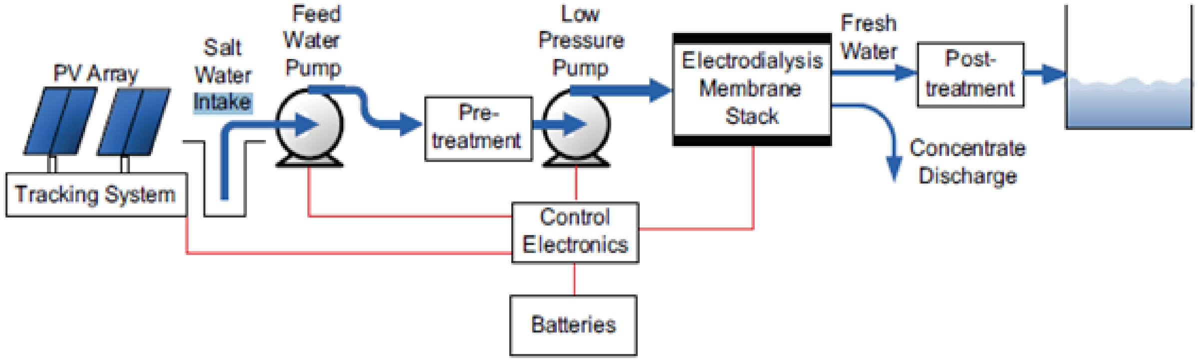


Figure 2.2: PVED system [3]

2.4 Humidification-Dehumidification (HD)

One of the problems that negatively influence still performance is direct contact between the collector and saline water; this may cause corrosion and scaling in the still. And it reduces the thermal efficiency of the plant. In HD desalination air is used as working fluid which eliminates this kind of problems. This type of plant utilizes dry air to evaporate saline water, thus humidifying the air. Vapor carrying capability of the air increase with temperature.1kg of dry air 0.5kg of vapor and about 670 kcal when its temperature increase from 30 to 80℃.Fresh water is produced by condensing out the water vapor, which results in dehumidification of the air. The advantage of the system is works for low pressure, temperature desalination but it is cost competitive [5].

2.5 Solar still

The solar still is the oldest and the fundamental. In solar still, the transparent cover (commonly glass or plastic) encloses a basin of saline water. As the sun radiates through the glass water heats up to bubble, causing evaporation and condensation of the inner surface of the transparent cover. The distillate produced is very high quality as all salts and other inorganic and organic components remain in the basin. The plant is cheap and easy to produce but the problem here is it has low production rate. Expected yield from a sun light based still does not exceed 4-5 L$\frac{l}{m^2}$/day which implies that $20m^2$ of area would be required to produce 100L/day. If there is limited space area solar still is not feasible as generally [6].

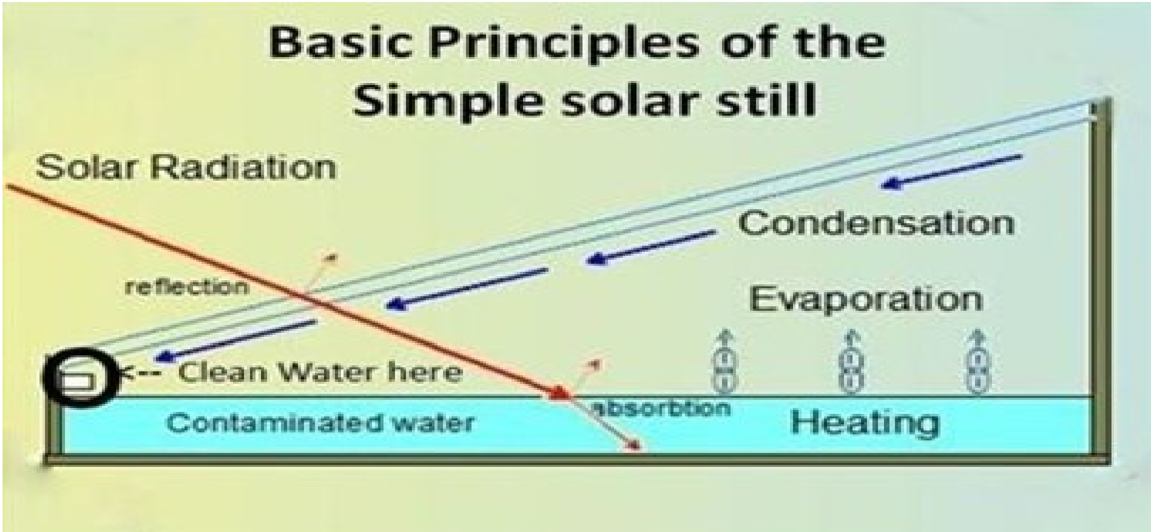


Figure 2.3: solar still operation [6]

2.6 Salinity-gradient solar ponds

A Salinity-gradient solar pond a salt-gradient non convecting solar pond consists of three zones: The upper convecting zone (UCZ) is almost constant low salinity at close to ambient temperature; The non-convecting zone (NCZ) is in which both salinity and temperature increase with depth of the pond ,and the lower convecting zone (LCZ) is almost constant, relatively high salinity at a high temperature. In this system denser saltier water stays at the bottom of the pond and does not mix with the upper layer of fresh water. The lower salty layer gets very hot (70-80°C). Hence, solar pond collects solar energy by absorbing direct and diffuse sun light. The salt concentration can increase with depth and the bottom layer of the solar pond is also called storage zone and it is very dense and heated up to 100°C.This hot brine can be used as day or night heat source from which a special organic fluid turbine can generate electricity. The middle gradient layer in solar pond acts as an insulator, preventing convection and heat loss to the surface [7]

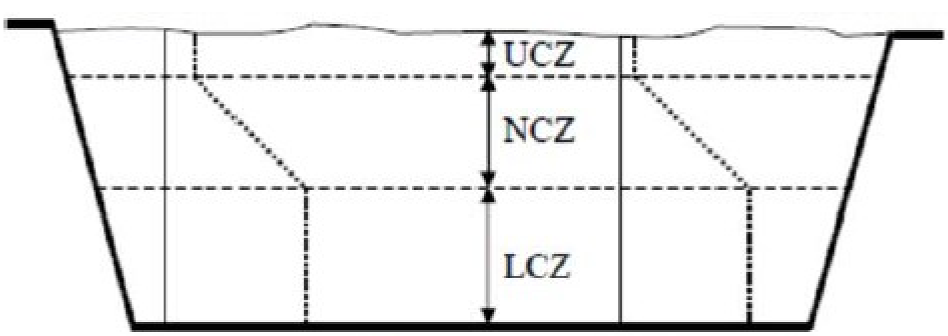


Figure 2.4: Schematic vertical sections through a salt gradient solar pond [7].

2.7 Flat-plate collector (FPCs)

Flat-plate collectors are used as heat transfer fluid, which is circulated through absorber pipes made of copper. The absorber pipes are assembled on a flat plate and they usually have transparent protective surface in order to minimize heat loss. They have also different selective coating to reduce heat loss and to increase radiation absorption. The thermal efficiency increase although the collector cost also increase. It is used only for small desalinated water production volumes. The flat plate collector is collecting solar energy for the application that requires at the temperature range up to100 °Cand it is less efficient in most of the time [12].

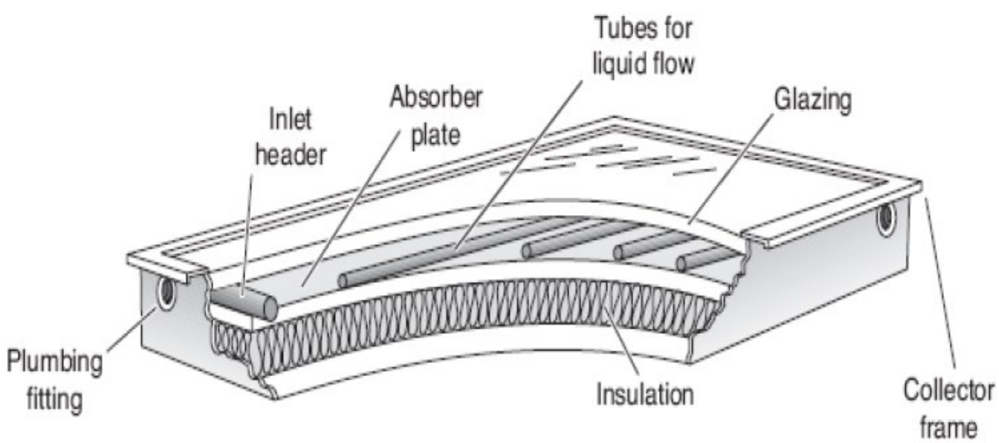


Figure 2.5: Glazed flat-plate solar collector [12]

2.8 Evacuated tube collector

Heat losses are minimized in evacuated tube collectors (ETC) by evacuated cover of the receiver. This cover is tubular and made of glass and a selective coating of the receiver minimizes the losses due to infrared radiation.

Usually a number of evacuated tubes are assembled together to form a collector. Evacuated tube Collectors require more sophisticated manufacturing facilities than flat-plate collectors. With evacuated tube collectors, higher temperature can be reached and efficiency tend also to be higher. For the most of the time evacuated tube collectors are preferred to flat plate collectors. Evacuated tube collectors produce temperatures of up to 200°C and they are particularly suited as an energy source for high temperature desalination [11].

2.9 Parabolic Trough Concentrator (PTC)

A parabolic trough is a linear collector with a parabolic cross-section. Its reflective surface Concentrates sunlight onto a receiver tube located along the trough's focal line, heating the heat Transfer fluid in the tube. Parabolic troughs typically have concentration ratios of 10 to 100, leading to operating temperatures of 100–400℃.

Parabolic trough collectors (PTCs) require sun tracking along one and/or two axis only. In this Way, the receiver tube can achieve a much higher temperature than flat-plate or evacuated-tube Collectors. The parabolic trough collector systems usually include a mechanical control system that keeps the trough reflector pointed at the sun throughout the day. Due to the high temperatures parabolic troughs are capable of producing high-grade thermal energy that is generally used for desalination plants. The unit cost of these solar thermal energy production methods directly increases with the temperatures they can yield also increase. Flat plate collectors and solar ponds are the least expensive and parabolic trough is expensive in some extent .And parabolic trough solar collector have higher efficiency if it can manufactured in well manner and with minimum error of reflective material [31].

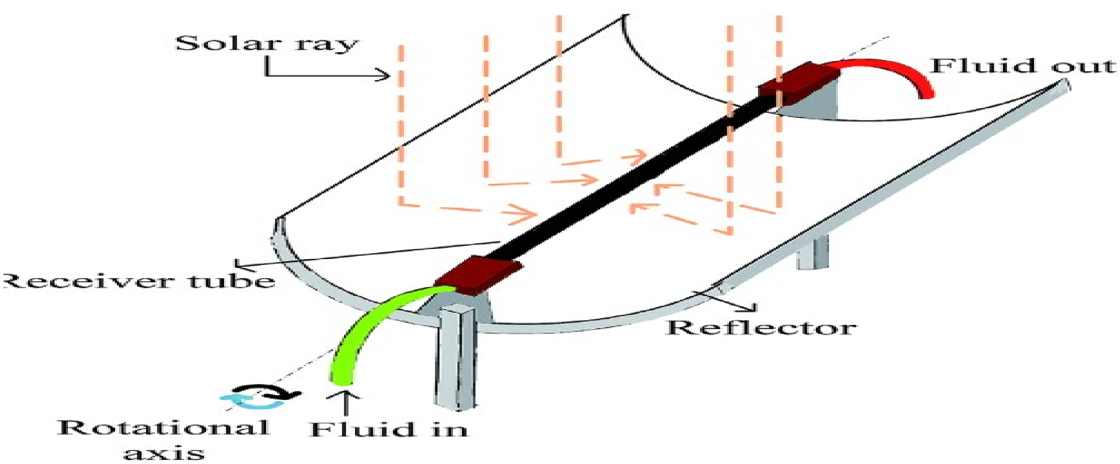


Figure2.6: parabolic trough concentrator [30]

2.10 Parabolic Dish Concentrator (PDC)

A parabolic dish concentrator is a point-focus collector that tracks the sun in two axes and concentrating solar energy onto a receiver located at the focal point of the dish. It is at this precise location where maximum thermal efficiency and maximum temperatures are achieved. The maximum temperature achieved is the highest of all concentrators – approximately 600ºC.The advantages of this system include high efficiency ,they are always pointing at the sun, high concentration ratios in the range of 600-2000 suns and the disadvantage of parabolic dish concentrator is not commonly used for large production volumes [7].

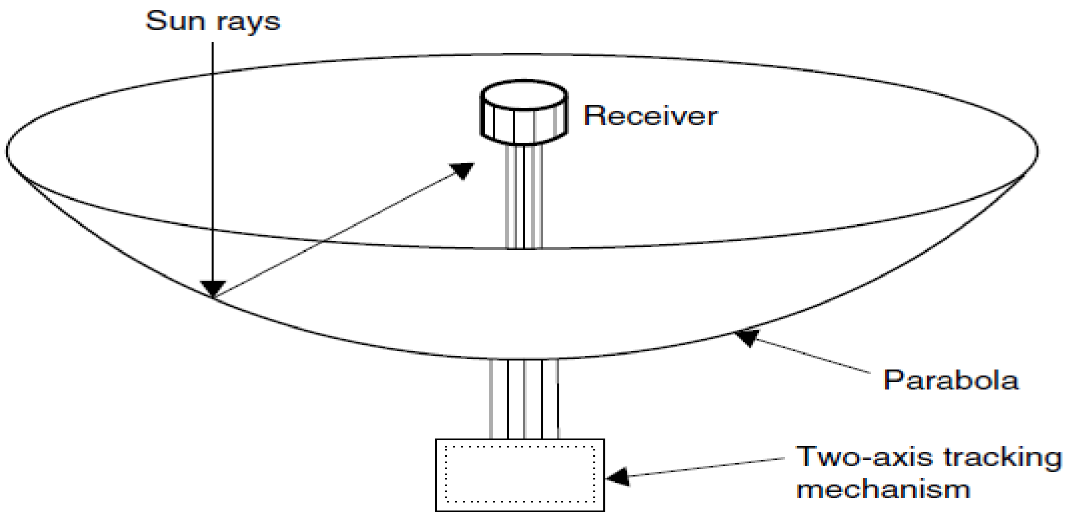


Figure 2.7: Schematic of parabolic dish concentrator [7].

Some studied works at the time before are discussed below under for desalination plants:

Amidpour et al[8] experimentally evaluate and optimize the humidification–dehumidification desalination process for production of fresh water from brackish water by using flat plate collector. Experimental results show that two-stage humidification -dehumidification desalination unit can increase thermal recovery in condensers and hence, reduce thermal energy consumption and investment cost of the unit. Productivity can also be increased by 20% compared with the single-stage. So, he concluded that it is better to use two stage rather than one stage to produce high thermal efficiency and high flow rate according to his experiment.

Elkader [9] experimented on a three stage multi-effect humidification (MEH)-dehumidification process with energy storage system which was designed, manufactured, installed and outdoor tested in the Faculty of Engineering in the Suez Canal University, Port Said, Egypt. The thermal collection part of the system (three flat plate collectors) has been designed to provide hot water to the desalination chambers. The investigation test results showed that, the increase of seawater mass flow rate through the setup from 0.1 liters to 0.13 liters increases the efficiency of the system by 10 %. It can also observed from the experiment that, the use of energy storage increases the output by 13.5%. Finally he concluded that the use of three stage multi-effect humidification (MEH)-dehumidification has better efficiency and thermal performance than two stage multi-effect humidification (MEH)-dehumidification process.

Dai et al. [10] reported the parametric analysis to improve the performance of a solar desalination unit with a humidification and dehumidification with flat plate collector. The performance analysis of a desalination unit of the following parameters are discussed here under: The fan of rated power is 500 W, the humidifier volume is $800 \times 700 \times 600\ \mathrm{m}^3$, the solar water collector area is $1.5 \times 1\ \mathrm{m}^2$, the solar air collector area is $2 \times 1\ \mathrm{m}^2$ and the dehumidifier heat transfer area is $0.8\ \mathrm{m}^2$. Another different parameters are showed in the present problem were measured. The temperature of water and air, the relative humidity at the inlet and the outlet of each component and the water and air mass flow rates are measured. The wind and radiation are measured. The mass flow rate is determined by measuring the air velocity by rotating vanes anemometer (measuring range of 0.2 m/s up to 40 m/s with a resolution of 0.01 m/s).

The air temperature is measured by standard K type thermocouple (Measuring range -50°C to 1000°C resolution: 0.1°C up to +199.9°C and 1°C above). And result shows that cumulative water production rate increase with increasing inlet temperature of water and relative humidity of the installed plant .The water productivity increases with the increase of collector tilt angle in winter and decrease in summer region (that is mostly cloudy and rainy season).

Mayruresh et al. [11] fabricated a setup of flat plate Solar Water desalination. According to theoretical design of their experiment and a sample of purified water from the setup was sent to water testing laboratory. The results obtained from above procedure it was found that the sample was free from particulate matter(any dissolved substance) or disease causing pathogens .Hence the water was fit for drinking purpose and human consumption as whole .Temperature from the setup easily rose up to 70°C in 2 hours and thereby killing the pathogens through the process of Water Pasteurization. And also comparison was made between the existing filters like which were dependent on electricity like R.O filter, and it was found that the Solar Water Purifier had many advantages over the conventional filters in terms of manufacturing and maintenance cost and also it can be successfully implemented in rural areas where there is lack of electricity but abundance of solar energy areas that is most of the time semi-arid regions of the country.

Aycompe et al [12] conducted the field study to compare the performance investigation of a flat plate collector and heat pipe evacuated tube solar collector for domestic water desalination. The investigation taken into account with similar working and environmental conditions, the collector efficiency were found to be that 46.1% and 60% and the overall plant (system) efficiency were found to be 37.9% and 50.3%for flat plate collector and evacuated tube solar collector. Finally they concluded that evacuated tube solar collector has more efficiency than flat plate collector.

Petros et al [13] studied experimental investigation of solar powered reverse osmosis desalination plant .The investigation carried out with solar radiation ranges from 5.46 kWh/m2/day in August to 6.82 kWh/m2/day in April, with an average of 6.09 kWh/m2/day. The values indicated above for solar radiation shows that there is almost good sun exposure favoring for implementing solar photovoltaic (PV) reverse osmosis (RO) desalination technology. The feed water with nearly constant TDS around 2800 ppm from the study area has reduced to fairly constant TDS of about 100 ppm after desalination. And TDS value after desalination indicates that suitable for drinking purpose. The average desalination capacity of the system is 50 liters per hour. And the experiment shows that an increased in system voltage with an increased in pressure, which resulted to the increased purification process of the plant.

Sando et al. [14] have presented a simulation model for multi effect thermal diffusion stills, obtained by formulating the rate equations and the heat and mass balance equations with respect to the process variables. They observed that, the simulation showed acceptable results with the experimental data taken from the laboratory test plant having five stages and one m2 frame area. Calculation with the model showed the effect of design and operation parameters such as solar intensity, heat transfer coefficient through the partition and feed rate of brine to each stage on the distillate productivity. The results showed that the distillate productivity is independent of overall heat transfer coefficient through the partition if its value becomes greater than 230 W/m2.K. Correlation to obtain the feed rate at each stage required to maximize the efficiency of distillate was obtained as a function of the solar intensity and ratio of brine feed between two successive stages.

Schafer et al. [15] described the design and field-testing of a photovoltaic (PV)-powered desalination system. The system defined was proposed for use in isolated areas of the Australian outback, where fresh water is particularly inadequate and it is often essential to drink high salinity water. The system based on a hybrid membrane configuration was implemented, with an ultra-filtration module for eliminating particulates, bacteria and viruses and RO membrane for removing dissolved salts. The setup created pure drinking water from a diversity of feed waters, as well as high salinity (3500 mg/L) water. The specific energy consumption varied from 2 to 8 kW h/m3 of disinfected and desalinated drinking water.

Neskakis et al. [16] reported on the feasibility of a small Photovoltaic driven RO desalination plant, with a normal daily production of drinking water with discharge of 0.8-3 m3/day. They examined the effect of feed pressure on produced water quality, on plant productivity and on total energy consumption. At the feed water pressure of 48 bars, the specific energy consumption of the project was 16.3 kWh/m3. Productivity of the project was 124 L/h using permeate concentration of 450 mg/L. When the feed pressure was raised to 63 bar, the specific energy consumption fell to 15 kWh/m3, and productivity improved to 155 L/h with permeate concentration of 330 mg/L.

Schmid et al. [17] presented a feasibility study of water desalination in Egyptian deserts and rural areas. Where there is a shortage of fresh water in spite of the presence of large sources of brackish water and using photovoltaic energy as the primary source of energy. They also proposed an economic design of a PV powered small scale reverse osmosis water desalination system. It was estimated that the cost of producing 1 m3 of fresh water from the PV-RO system is approximately $3.73. If the system capacity and the daily range of operation are raised, the cost of generating fresh water will be diminished in these areas. The authors of the this feasibility study also mentioned that using different systems fueled by renewable sources of energy would be beneficial in keeping the environment clean for the people living in these remote areas and desalinate water by using solar energy source is the best choice for semi-arid regions of the country he said in his feasibility study.

Palenzuela et al. [18] did a techno-economic analysis on the integration of desalination with a 50 MWE parabolic trough CSP (parabolic) plant in the Mediterranean and MENA region. The aim of the study was to find the most suitable CSP+Desalination configuration for the respective regions by evaluating the thermodynamic and economic plant performance. The study concluded that the integration of a multi-effect distillation (MED) system into a CSP plant is the most efficient choice for both locations. The site locations are relatively low above sea level (150 m), but the 60 km distance from the coastline would still contribute to additional pumping requirements and making the CSP+MED plant configurations less competitive. However, the study still suggests that CSP+MED is more attractive than reverse osmosis (RO).

A study done by **Moser et al. [19],** from the German Aerospace Agency investigated long-term scenarios for the demand of water and electricity which are based on the potential integration of desalination with concentrated solar power. The two main desalination technologies considered is RO and MED. The study found MED to be the cheaper option in the Arabian Gulf due to its robust behavior against higher seawater salinity and temperature. The site selection criteria of the study done by the involve much lower elevations (< 20 m) and closer proximities to the coast. In terms of LCOE, the CSP+RO only outperformed. In the MENA region, using a hybrid mode to run the plant at base load makes sense because of the availability of cheap fossil fuels in this regions.

A theoretical case study in Northern Chile was done on the synergies of solar power and desalination [20]. The study investigated the feasibility of two solar desalination alternatives (PV+RO and CSP+MED) compared to the conventional grid connected RO plant solution. The case study scenario involved desalinating seawater to be used for the mining industry located 100 km from the coast and 2200 m above sea level.

The levelized cost of water (LCOW) was used as an indicator to compare the feasibility of the investigated configurations and was calculated for plant lifetime scenarios of 10, 15, 20 and 25 years using a real discount rate of 12%. The study determined that solar desalination in the Atacama Desert in Chile could technically be feasible with MED + CSP being the most favorable option rather than PV+RO in this regions. The study done in Chile highlights that currently, the cheapest option for desalination is still probably RO and the grid. However, it also illustrates the advantage that CSP has over other renewable energy technologies in terms of storage. The RO+PV configuration was significantly more expensive (LCOW) than the CSP+MED option, because the latter had greater plant availability. The configurations in this study does not focus on the production of a large amount of excess electricity.

Badran and Al-Tahaineh [21] experimentally investigated the effect of FPC on the performance of single slope solar still. Productivity of the developed solar still was observed to be increased by 36% in comparison to conventional still. The experiment is carried out in sea water desalination and shows that low thermal efficiency and low flow rate is obtained .Because the experiment carried out in the rainy season of the day.

Muller-Holst et al. [22] fabricate an experimental Multi Effect Humidification (MEH) facility driven by solar energy and considered its performance over a different range of operating conditions. Since the process is driven by solar energy, the production of fresh water vary with the seasonal changes. The average quantity of drinking water production was likely about 6000 L per month with a maximum of 10,500 L in May and a minimum of 1700 L in January. The principle of MEH plants is the distillation under atmospheric conditions by an air loop saturated with water vapor. The obtained result showed that there is maximum solar radiation in May than any other months of the year.

Müller-Holst et al.[23] Solar MEH(FPC) -desalination system studied in used 2 m3 hot water storage tank, which increased the production rate to 500 L/day with 38 m2 collector area (about 13 L/m2).This study shows that if there is heat storage tank more production of fresh water obtained at the same collector area.

Odeh et al. [24] modeled direct steam generation parabolic troughs. They have obtained efficiencies up to 65% for beam radiation greater than 600 W/m2 at a saturation temperature 324°C. Besides that, efficiency of about 70% can be obtained at a saturation. Temperature of 212°C between 600 and 800 $\frac{W}{m^2}$ of beam radiation of solar energy is obtained. They also be tilted 8°to improve the two phase fluid flow arrangements in their experimental investigations.

Dayem [25] experimentally and numerically investigated the performance of multi effect humidification–dehumidification (HDH) process based solar distillation system. The experiment show that distillate output of 24 Liters/day was collected, and optimum collector area was observed to be 6 m2. However many performance parameters have not been considered in his study.

Zambolin and Delcol [26] compared the performance of a flat plate collector and an evacuated tube collector for steady state and for daily operations. A single-glazed flat plate collector and an evacuated tube collector were installed side by side and tested at the same working conditions and the evacuated tube collector was a single-phase thermosiphon type with external compound parabolic concentrator reflectors. It was found that flat plate collector has better steady- state efficiency and daily efficiency at low working temperature level. That is in other word an evacuated tube collector has better steady- state efficiency and daily efficiency when the collector temperature is on average much higher than the ambient temperature.

Klemens et al. [27] presented a theoretical and experimental study of a modular solar desalination system with flat plate collector to enhance the performance of conventional solar still. Its desalination tower had six stages. The area of each stage was 1 m2. Their results showed that the water production rate 1.49 L/kWh/m2 of collector area as 2.67 times greater than the tank type distillers in the same day. Finally they concluded that flat plate collector has less thermodynamic efficiency than concentrated solar power, because high heat loss in flat plate collector.

Abbasali et al.[28] Experimental analysis of a multistage water desalination system utilizing a parabolic solar trough with a solar tracker. Experimental results showed a very good output compared to the ordinary basin type. The fresh water production capacity of the investigated two-stage still with solar parabolic trough system was found to be about 3.6 kg/m2which is for only 5 hours i.e. from 10 A.M. to 3:00 P.M. and it will be more if the solar

Collector tracks the sun for all day long. The production is higher than that of conventional basin stills and even multi-stage stills coupled with flat plate collectors.

Erich [29] Design and construction of a Fresnel linear desalination. The design shows that 5.6 m^2 reflective surface concentrator of the distiller was constructed with 32 rectangular mirrors, the heat absorber cavity was made with a rectangular blackened aluminum tube 1 m long an installed 2.5 m over the plane mirror. The Fresnel linear distiller was installed at the University of Lima and experimental tests were performed during no cloudy summer days. There were measured ambient temperature, heat absorber cavity temperature, radiant flux and fresh water volume. From above experiments the following data was obtained a production of 0.89 liters/hour and 0.79 L/m2, and it was calculated a total performance of 34.5% in desalting sea water. Finally, it is presented a comparison between Fresnel linear distiller (FLD) and parabolic trough distiller (PTD) with similar dimensions and characteristics. It is obtained that parabolic trough distiller produced almost 32% more fresh water than the Fresnel linear distiller and also according to the cost of the plant at the same time, the Fresnel linear distiller is almost 20% cheaper than parabolic trough distiller. Since, cost of water production with both distillers using is nearly the same value. In this experiment parabolic trough is more efficient.

Venegas [30] Design, construction and testing of parabolic trough solar concentrator for water desalination. This work presents the design, construction, optical and thermal evaluation of PTC with rim angle of 45 degrees, length of 4.75m and an aperture area of 5.8 m^2 and direct solar radiation of 865W/m2 and also the concentration ratio of 15. It was also found to reach peak efficiencies close to the 60% with flow rate 35 liters /day of the plant. An optical error analysis was also investigated in PTC and the efficiency is close to 65%. In this design consideration, the maximum stress of 7.5 MPa for the lateral loads which is extremely less than the permissible stress of aluminum that is 145 MPa .Therefore, the structural resistance of the collector is sufficient.

John [31] Modeling and performance evaluation of parabolic trough solar collector desalination system. The investigation shows that the collector efficiency increases with the increase of the optical efficiency that means with direct proportional relationship. For example when the optical efficiency was 49% the collector efficiency was of 20.5%, while when an optical efficiency 61.5% the collector efficiency was 25.4%. Thus it is important to increase the optical efficiency to increase the collector efficiency and also the collector efficiency increases with the increase of the feed water flow rate i.e. with direct proportional relationship. For example when the feed water flow rate was 1100 ml/hr the collector efficiency was in range of 23-26%. While when the feed water flow rate was 8200 ml/hr the collector efficiency was in range of 41-53% and finally thermal loss comparison was taken into account ,that is among the thermal losses the conventional heat transfer from glass to ambient by wind is the largest. For example on time of 11-12 hr the conventional heat transfer from glass to ambient by wind was 51.99$\frac{W}{m^2-k}$ the radiation heat transfer from receiver to glass was 9.07 W/m2-k, the conventional heat transfer from receiver to glass was 7.7 W/m2-k, the radiation heat transfer from glass to ambient was 6.82$\frac{W}{m^2-k}$ and the overall heat transfer co-efficient was 15.04 $\frac{W}{m^2-k}$.

Choksi [32] design and fabrication of solar parabolic trough collector for water desalination in remote areas in India. And the parabolic trough has the following specification in the design. These are: aperture width of 0.8m, Area of aperture 1.6m2 with trough length of 2m and the concentration ratio of 10.18. The initial temperature of water is 25°C and the duration of temperature measurement time is 30minute and the maximum temperature obtained from the experiment is 78°C. This shows that it was decided to get steam from water through parabolic trough but did not get the steam because the following reason; manufacturing defects, there may be some errors in construction of parabolic trough, less intensity of solar radiation due to winter season the experiment is carried out.

Kalogirou et al [33] Design and performance characteristics of a parabolic-trough solar-collector system for desalination. The design is carried out with collector aperture area 10 to 2160m2, the collector aperture width is 1.75m, the optimum rim angle was 90°, the receiver material made of copper tube with inner diameter is 40 mm and thermal conductivity of the material is 386w/m.k. Locally fabricated wooden support frame used and parabolic trough mirror is made of silvered glass sheet with thickness 2mm and the reflectivity is 0.94.The solar beam radiation was 3991kj/$m^2$when the tilt was 10.2° and this tilt angle the temperature of the receiver is 150℃.Feed water flow rate 4800 ml/hr the collector efficiency was in range of 38-48% , the produced distilled water was (10.4 Lt/ (5 hrs (11:00 am to 16:00 pm). The collector efficiency increases with the increase of the optical efficiency i.e. with direct proportional relationship. When the optical efficiency was 55% the collector efficiency was of 23%, while when an optical efficiency 65% the collector efficiency was 27%. Thus it is important to increase the optical efficiency to increase the collector efficiency. Finally by increasing these two parameters it possible to increase the plant efficiency as a whole.

Brooks et al [34] Performance of a parabolic trough solar desalination. The performance carried out in the system has collector area of 4.375 m^2 $c$ollector dimension 2.5 m*1.75 m and the the rim angle was 90°, $absorber\ diameter$ 25mm and glass tube diameter 40mm. Condenser is copper tube with 1cm diameter coiled and the receiver is by using stainless steel and glass covered copper tube with the same dimension. The solar radiation measured was 700W/m^2. Using glass covered receiver tube maximum temperature of 113 °C and using stainless steel receiver tube using maximum of 85°C temperature is only reached. So, stainless steel receiver tube have poor performance and high temperature obtained in copper tube since it has high thermal conductivity. Desalination plant have the rate of production 2litre/m2 and the efficiency of the system 27%.
Chemical and physical analysis result shows that hardness, calcium, magnesium, and chlorides levels are more than acceptable limits in brackish water. So, it better to use copper tube to increase the production rate and the efficiency of the plant.

Alaydi [35] construction of parabolic trough collector for water desalination. The construction were carried out in the following specifications; the collector aperture of 1.46m,the receiver diameter is 22mm,the rim angle which is optimum to be taken as 90°,the concentration ratio of 22.1,the tracking system E-W horizontal .The initial temperature of water is 19℃ and the out put temperture after experiment is 175℃.The collector efficiency of the system is 45% when the optical efficiency is 61%.so production amount of desalted water depends the quality of constructed parabolic trough ,the aperture area and the solar radiation data of the specific area of the study.

Yovany [36] described the comparison between solar desalination with and without solar concentrator. The investigation were carried out in three types of distillers. These are parabolic trough distiller (PTD) and a Fresnel linear distiller (FLD) are concentrator types and stepped basin distiller (SBD).The experimental measurements were taken to determine the production rate performance and cost of the plant. As a result, fresh water production the same atmospheric condition are taken into account was 990 cm^3/m^2/day with an efficiency of 45.8% for the PTD, 855 cm^3/m^2/day with 38% of efficiency for the FLD and 5910 cm^3/m^2/day with an efficiency of 4.4% for the SBD. When compared these three plants together, the result shows the SBD has 10 times lower efficiency than the PTD, it produces almost 6 times more fresh water per m^2 of distiller's surface. Regarding the cost of production of each liter of desalinated water, it was calculated in € 0.086, € 0.103 and € 0.034 for the PTD, FLD and SBD, respectively. The experimental investigation concludes parabolic tough concentrator has higher efficiency than the other.

2.11 Comparison of FPC, PTC and CPC

From the most competitive solar collectors developed, three types merit further consideration for steam generation: the flat plate collector (FPC), the parabolic trough collector (PTC) and the compound parabolic collector. PTC requires sun tracking along one and/or two axis only whereas the last two are the stationary collectors. The above indicated technologies are compared in energy and the financial terms in order to determine the most suitable choice for every application. The PTCs are generally of medium concentration ratio (15-50) whereas CPCs are generally of low concentration ratio. The low concentration ratio of the latter one allow them to work without a need for tracking sun. The FPC is collecting solar energy for the application that requires at the temperature range up to 100 ℃ and is used only for small desalinated water production volumes and less cost whereas PTC require the temperature range from 100-400℃and it works for large amount of water production. . The working fluids used for above technologies can be water, steam, thermal oils or molten salts. In the efficiency comparison, from the figure shown below collector type selection the efficiency in the PTC remains high at high inlet water temperatures. Therefore, at temperature of 100℃, which occurs at $\frac{\Delta T}{I}$ value of about 0.1, PTC works at an efficiency of about 62%, CPC at about 32% and the FPC at about 10%. This clearly suggests that the PTC is the best type of collector for this application [37].

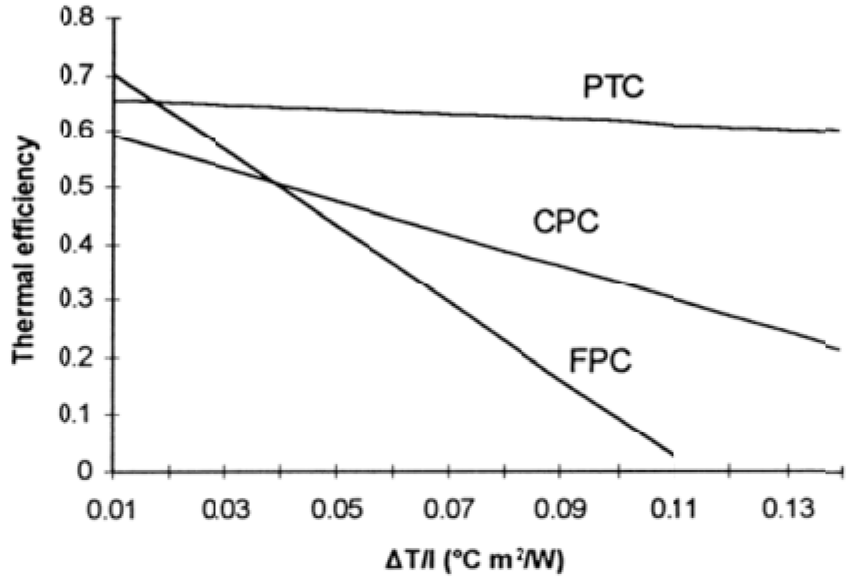
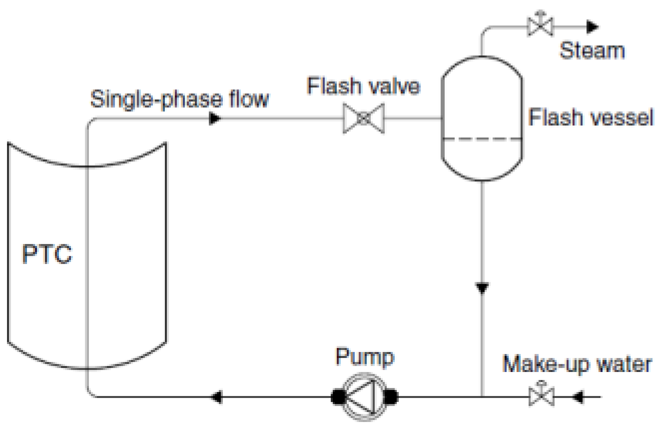


Figure 2.8 Typical collectors performance curve.[37].

2.12 Solar Steam Generation Systems

Mostly parabolic trough collectors are frequently employed for solar steam generation because relatively high temperature can be obtained without series degradation in the collector efficiency. Most of the time three methods have been employed to generate steam using parabolic trough collector [38]. These methods are:- The steam- flash concept, in which pressurized water is heated in the collector and flashed to steam in a separate vessel as shown in Figure 2.9 , the direct or situ concept in which two-phase flow is allowed in the collector receiver so that steam is generated directly as shown Figure 2.10 and the unfired boiler concept, in which a heat transfer fluid is circulated through the collector and steam is generated via heat exchanger in unfired boiler as shown in Figure 2.11.



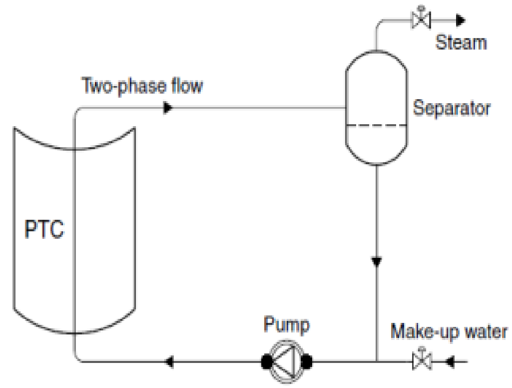


Figure 2.9 Direct steam generation concept [38]   Figure 2.10 Steam-flash generation concept [38]

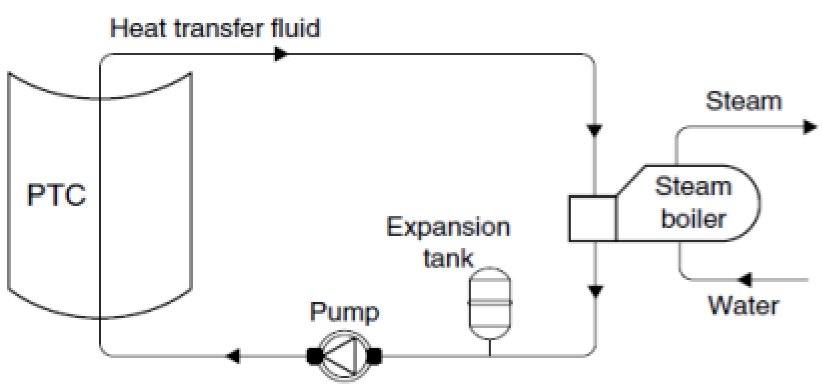


Figure 2.11 Unfired boiler steam generation concept.[38]

2.13 Worldwide Installed Projects Based on PTC

In besides to theoretical and experimental studies, projects related to process desalination through parabolic trough collectors have been done for the place where high solar energy. The projects can be divided by parts using small scale experimental setups and full-sized material installation setups. Globally parabolic trough power plants technology with existing commercial operating systems and one of the larger solar collector platform of 600 m2 solar field with the thermal power of about 300 kW was built in Langfang city by Institute of Engineering Thermophysics, Chinese Academy of Sciences. The project's mostly target on to analyze the performance of the collector and suggest possible improvements in design in order to come up with a set of guidelines for future projects. The material of the steel pipe electric welded AISI316Ti steel and the material of the glass made from borosilicate glass with transmittance of 96%.According to the experiments conducted the maximum operating temperature of the receiver tube was 360°C with 72% average absorber efficiency[39].

Figure 2.12 PTSC [39]

In addition to experimental prototypes, an operational industrial setup is installed in Hassi Rmel region, in southern Algeria, a power plant hybrid gas / solar is being built in collaboration with Spanish. This power plant will combine parabolic mirrors (25MW of solar power, an area of 180000 m2) in conjunction with a gas turbine plant (130 MW).For linear concentrator, the only one coordinate needs to follow the sun with an optimized collector adjustment. With the collectors aligned in the North-South direction a simple orientation and perpendicular in the East-West direction bring back whatever the hour of the day the image concentrated of the sun on the receiving tube laid out on the focal of the concentrator. The solar concentration parabolic trough collector obtained varies according to the season and the hour. This type of concentration represents the main part of the thermodynamic installations of the world [40].

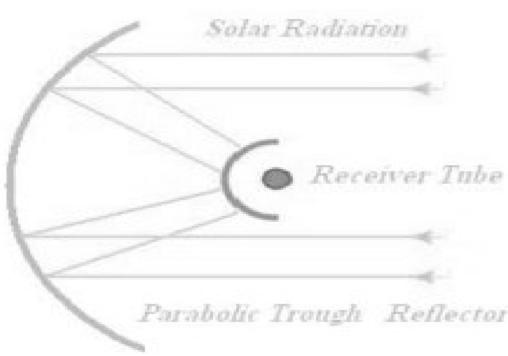


Figure 2.13. Line focusing parabolic trough collector ,the solar parabolic trough mirror (Algeria)

2.14 Conclusion from literature review and Research gap

This study focuses mainly on parabolic trough solar collector. Here, the utilization of parabolic trough thermal collector specifically focuses on solar desalination which proceeds the conversion of solar energy into thermal energy. The performance mainly depends on the quality of constructed parabolic trough, the aperture area, conductivity of material, the rim angle, tracking system weather conditions (solar radiation) etc. Most of the previous studies do not clearly defined relationship between different water flow rates with produced distilled water by using a parabolic trough collector .About 80% of above review related with sea water desalination but in this work desalination of parabolic trough taken into account for ground saline water.

The performance investigation of system has been accomplished by performing an optimum value of rim angle, the selection of the receiver's diameter depends up on availability of material in the market and studying chemical analysis of ground saline water by using photo meter (model 7100) and microprocessor based conductivity or TDS meter (model 1601)as modification in my research. And from this view of literature, parabolic solar desalination are important for our climate to desalinate saline water and produce drinking water for human consumption and at the time before no experimental testing was done in Diguna Fango Weather condition. Due to unavailability of this project in Diguna Fango Dimtu, it is necessary to come up for our climate especially for remote areas where there is no electricity and solar radiation is the most abundant which semi-arid regions of Diguna Fango Dimtu region.

The research gap identified for the present study are:

- Chemical and physical analysis of Diguna Fango Dimtu water by using the instrument like photo meter (7100 model), microprocessor based conductivity/TDS meter, PH meter and turbidity tube was not studied.
- Most of the researches presented on the literature review mainly focused on the sea water desalination but in this work ground saline (brackish) water can be used.
- Solar desalination experimental study on purifying Diguna Fango Dimtu water by using parabolic trough solar collector was not conducted.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 CHEMICAL ANALYSIS OF GROUND SALINE WATER OF DIMTU

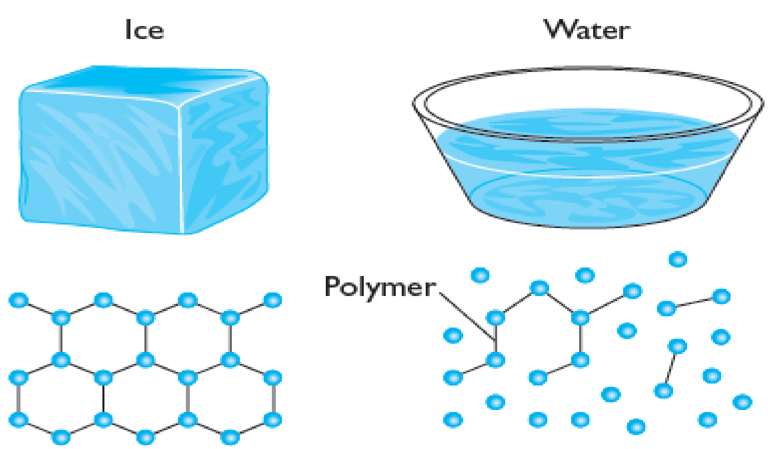
3.1.1 INTRODUCTION

In this portion of the study water chemistry analyses are carried out to identify and quantify the chemical components of the water and properties of saline water samples. This parts of study discuss the classification of saline water resources and the major constituents of this water, the chemical and physical properties of saline water. The amount of salinity of most expected elements are taken to be considered in the experimental testing of the water.

3.1.2 Basic physical notions of water

One of the most important notion that we consider in order to understand the behavior of water is physical concept of heat, the property that one measures with the thermometer and that results from the physical vibration of atoms and molecules. These physical vibration represents the energy of motion, what we call kinetic energy. If there is more heat in a material, the greater agitations of its atoms and molecule.

Generally water exists in three forms states in nature which depend on the temperature and pressure. These are solid, liquid and gases and their molecular structure can be seen figure below.



a) Solid water b) liquid water c) gaseous water

Figure 3.1 Molecular structure of water

3.1.3 Classification of the water resource based on total dissolved solids

In this study the most basic thing to consider is knowing the total dissolved solids (salinity content of the water) since separating salt by solar energy system is critical issue. Depending up on total dissolved solids most of the time water resources can be divided into five categories. These are expressed in the following table below and the amount of total dissolved solid indicated on the table as standard from the literature [1].

Table 3.1 classification of water resources based on total dissolved solid [1].

Water sample	Total dissolved solids,mg/l
Well water	300-500
Typical river water	200-750
Typical brackish water	1500-6000
Typical sea water	36000
Water for irrigation purpose	1000

The total salt concentration of the saline water can be expressed in the terms of salinity (s), which is defined as total amounts of solids (grams) contained in the 1Kg of saline water.

And according to above standard in the table which classification category include the study of Diguna Fango Dimtu saline water is one of the question will be raised. The testing of the water by using two instruments which are photo meter and TDS or conductivity meter indicates the value of 3690mg/l. This tested value indicates that the water under the category of brackish. And the salinity value can be reduced by using parabolic trough desalination from solar energy.

3.1.4 Properties of Saline Water

The chemical and physical properties of saline water can be determined by the following methods and instruments as follows:

3.1.4.1 Turbidity

Turbidity can be defined as the amount of cloudiness in the water and it is because of suspended solids and colloidal matter. It is also due to eroded soil caused by the growth of micro-organisms in the water. The water in this study was the spring water which appears relatively almost low turbidity can be determined out. The cause of turbidity are silt, sand and mud, bacteria and other germs in the water, chemical precipitates. The instruments used to measure the turbidity can be either electronic turbidity meter or turbidity tube. Both of the methods have their own merits and demerits.

a) **Turbidity meter**: The turbidity meter is the most commonly used instruments of turbidity of water. One of the advantage is very accurate and especially useful for measuring not very high turbidity value and its disadvantages are high cost, need power supply and easily damaged.

b) **Turbidity tube:** The advantages of this instrument are simple design, low cost and not easily damaged and its disadvantage is cannot measure very low turbidity (usually minimum is 5NTU (nephelometric turbidity units) [1].

Since the turbidity tube is simple to use and due to availability of the instrument in Adama University, the measurement of turbidity done in turbidity tube .Before the use of parabolic trough collector the turbidity is 6 NTU. This value indicates that the water is not much turbid because it is from the ground and there is no more mud contents in it and there is some amounts of mud on it and to avoid this it is fundamentally critical to desalinate water. And after the experimental desalination the value of turbidity can be reduced as 5NTU and it is described in the figure below.

Figure 3.2 Turbidity before desalination   Figure 3.3Turbidity after desalination

3.1.4.2 Hardness

Hardness (hard water) is one of the most important common water quality problems throughout the world and the priority of the consideration of the hardness testing is mandatory issue.

By general speaking a total of 70% of the earth's surface is covered by water. From this amount of water 97% is only sea water (not preferable for the drinking purpose) and only 3% of fresh water is accessible for the human use and as for drinking purpose. Hard water is found at the rate of 85% as water picks up minerals such as magnesium and calcium ion from the rocks and soils, leading to hard water [20].

Basic character of the hard water which prevents the lathering of the soap. The primary cause of this is due to the presence of certain salts of magnesium, calcium and other heavy metals that are dissolved in it. The water which does not produce lather with soap solution readily is called hard water and water which lathers easily on shaking with soap solution what we call soft water. Soft water does not contain dissolved calcium and magnesium salts in it. However, calcium, magnesium, less aluminum, iron and other cations are mainly caused due to hard water. Calcium and magnesium are two major cations responsible for hardness [2].

In generally there are two types of hardness. These are temporary and permanent hardness of the water.

a) **Temporary or carbonate hardness:** This type of hardness caused by presence of dissolved bicarbonates of calcium, magnesium and other heavy metals and the carbonate of the iron. It can be mostly destroyed by the mere boiling of water and bicarbonates are decomposed and will produce insoluble carbonates or hydroxides which are deposited as a crust at the bottom of vessel and it is also sensitive to temperature and precipitate easily. It is also the primarily caused by carbonate and bicarbonate of calcium and magnesium.

b) Permanent or non-carbonate hardness: It is mainly due to presence of chlorides and sulphates of calcium, magnesium iron and other heavy metals. It is not destroyed by boiling of water. It is also measure of calcium and magnesium salts other than carbonate and bicarbonate salts (such as calcium sulfate, $CaSO_4$, or magnesium chloride, $MgCl_2$).

The degree of hardness of the water has been classified into four categories in terms of equivalent $CaCO_3$ concentration as follows [3].

Table 3.2 Classification of the degree of hardness [3]

Soft	0-60mg/L
Medium	60-120mg/L
Hard	120-180mg/l
Very hard	>180mg/L

The hardness of Diguna Fango Dimtu water is 35mg/l by using the instrument of photo meter before desalination and the value indicated here shows that the water not such much hard and its hardness value can be reduced by mere boiling of water by using parabolic trough collector and its value after desalination reaches to be 22mg/l.

3.1.4.2a Determination of hardness by calcium and magnesium hardness

Hardness caused by calcium is called calcium hardness regardless of the salts associated with it. Similarly the hardness that caused by magnesium is called magnesium hardness. Since calcium and magnesium are normally the only significant minerals that cause hardness and can be expresses in the following formula as [2].

Total Hardness (mg/L as $CaCO_3$) = Calcium Hardness (mg/L as $CaCO_3$) + Magnesium Hardness (mg/L as $CaCO_3$)

= 2.50 X Calcium conc. (mg/L as Ca^{2+}) + 4.12 X Magnesium conc. (mg/L as Mg^{2+})......................3.1

The hardness can be calculated as follows by using the magnesium and calcium concentration according to above empirical formula. The calcium and magnesium concentration from the measurement of saline water are 8 and 4mg/l respectively.

Total hardness =2.5*8+4.12*4=32.36 mg/l.

The above calculated value and the direct measurement from photo meter are nearly similar. Since, there is small difference is due to the measurement error of the machine is taken into considered.

And hardness value can be determined after desalination the value of calcium and magnesium are 4 and 3mg/l respectively.

The total hardness after desalination =2.5*4+4.12*3=22.36 mg/l

The directly measured value of hardness from the instrument is 21mg/l and calculated value using magnesium and calcium is 22.36 mg/l. This indicates the values are nearly similar.

3.1.4.2b Effects of hardness on human being

Both calcium and magnesium are basically essential minerals and beneficial to human health in Several aspects. Inadequate intake of either nutrient can result in adverse health consequences. Inadequate intake and excess intake of both calcium and magnesium has its own effects on health and can be discussed here by under below.

a) Inadequate intakes of calcium: Inadequate intake of calcium have been associated with increased risks of (kidney stones), hypertension, insulin resistance and obesity.

Those individuals who avoid dairy products or lack access to them throughout life may be at increased risk of calcium deficiency [3, 4].

b) Excess intake of calcium: The excess intakes of calcium by a tightly regulated intestinal absorption. When calcium is absorbed in excess of need, the excess is excreted by the kidney in healthy people who do not have renal impairment.

c) Inadequate intake of magnesium: it is the fourth most abundant cation in the body and the second most abundant cation in intracellular fluid.

Low magnesium levels are associated with increased vascular reactions and decreased insulin sensitivity. Alcoholism and intestinal malabsorption are conditions associated with magnesium deficiency [3, 4].

d) Excess intake of magnesium: Increased intake of magnesium salts may cause a temporary adaptable change in bowel habits (diarrhea) .One basically important thing to be considered to reduce the hardness of the saline water in this work is parabolic trough solar desalination technique. Desalination of saline water converts water with a high dissolved solids content to water with a very low dissolved solids content. For human beings average amount of calcium and magnesium content is basically critical thing to be considered and in this case the desalination was one of the problem solving technique by using solar energy. The value of calcium is 8mg/l and magnesium 4mg/l before desalination. Most chemical analysis as measured by using photo meter (7100 model) and only calcium and magnesium value expressed in the figure and all the other analysis are tabulated in the table.

Figure 3.4 Magnesium hardness before desalination Figure 3.5 Calcium hardness before desalination

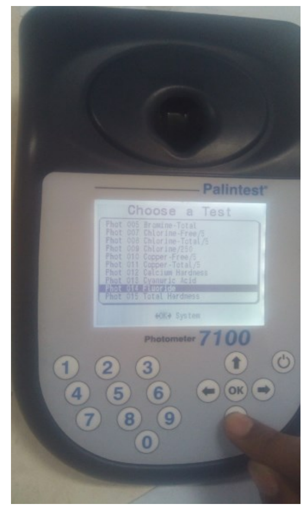


Figure 3.6 Magnesium hardness after desalination Figure3.7 Photo meter (7100) Figure3.8 elements in photo meter

3.1.5 PH

PH is a measure of hydrogen ion concentration. It is an indicator of relative acidity or alkalinity of water. Where the most of the time, the PH Values of 9.5 and above indicate high alkalinity while values of 3 and below indicate acidity. Low pH values help in effective chlorination but cause problems with corrosion. The Values below 4 generally do not support living organisms in the marine environment [4]. According to the world health organization (WHO) standard the drinking water should have a pH between 6.5 and 8.5 interval are the accepted value and the PH value of the water which is tested in case Diguna Fango Dimtu saline is 8.45 by using the instruments of PH /EC/TDS meter. The value indicated is possible for drinking purpose but it is maximum according to world health organization criteria and the value after by using parabolic trough solar collector desalination is 7.97. This value indicates that the water is preferable for drinking purpose for the society and expressed in the figure below.

Figure 3.9 PH before desalination Figure 3.10:PH after desalination

3.1.6 Electrical conductivity of water

When we consider the solids in general, they found in nature as dissolved form. Salts that dissolve in water break into negatively and positively charged ions. Conductivity is the ability of water to conduct an electrical current and the dissolved ions are the conductors. Moreover, the major positively and negatively charged ions that are contributors to conductivity are as follows. The major positively charged ions are sodium (Na^{+}), calcium (Ca^{+2}), potassium (K^{+}) and magnesium (Mg^{+2}). The major negatively charged ions are chloride (Cl^{-}), sulfate (SO_4^{-2}), carbonate (CO_3^{-2}), and bicarbonate (HCO_3^{-}). Nitrates (NO_3^{-2}) and phosphates (PO_4^{-3}) are minor contributors to conductivity. When dissolved ions increase salinity as well as conductivity increase and they are related to each other.In generally the conductivity will vary depending up on the water source such as like ground water, water for irrigation purpose, the rainfall water and municipal waste water. The instrument to measure conductivity of saline water is by using microprocessor based conductivity/TDS meter. Since, the raw water is measured primarily and after construction of parabolic trough, the water is flowing through receiver tubes and get vaporized and condensed in the condenser coil. The conductivity of salt water before experiment of using parabolic trough is 5.48 msemiens/cmor 5480µs/cm by using microprocessor based conductivity meter /TDS meter at 16.2℃ and 5.66 by using another instrument called photometer of the model (7100).The value indicated by using two instruments are not such much different and the average value will be taken into account for the accuracy of the result. So, the conductivity of this salt water is 5.57msemiens/cm or 5570µs/cm. After desalination by using parabolic trough the conductivity obtained is 3.66 ms/cm or 3660µs/cm. Conductivity is commonly used to determine the level of impurities in water. If more impurities in the water, the higher conductivity value can be obtained. If the water electrical conductivity rely between 2000 and10, 000 µS/cm, then the water is moderately saline [12].

Figure 3.11 Conductivity before desalination

Figure 3.12 Conductivity after solar desalination

3.1.7 Total dissolved solid (TDS)

Total dissolved solids can be defined a, measure of the dissolved combined contents of all organic and inorganic substance present in the liquid water in molecular or ionized form. Most of the time this term related with salinity of the water and salinity is defined the total amount of solid material in grams contained in one kilogram of salt water when all the carbonate has converted to oxide ,the bromine and iodine replaced by chlorine and all organic matter completely oxidized. And from total dissolved solids chloride ion make up 55% approximately and can be determined with ease [3].The total dissolved solids can be measured by using two instruments are taken into accounted. The total dissolved solids from the measurements of photometer (model 7100) is 3830parts per million or mg/l and microprocessor based conductivity/TDS meter (model 1601) is 3550 parts per million or mg/l. The average value of two instrument is 3690mg/l and the average value is used for the purpose of accuracy of the measurements and after desalination the total dissolved solids for different days have different values are obtained depending up on the amount of sun light variation on the parabolic trough collector .And after the experimental testing of parabolic trough collector for nine days data recorded and testing results of total dissolved solid values are 1167ppm, 1115ppm, 529ppm, 980ppm, 1009ppm,525ppm, 911,1007ppm and 960ppm.So,the average value can be 911.5ppm or 911.5mg/l. This value indicates that the TDS value can be reduced more amount and it also possible for drinking purpose

Figure 3.13 TDS before desalination Figure 3.14 TDS after desalination

The salinity content of the water is 3.69g/kg. And from above discussed the total dissolved solids of the brackish (saline) water interval is 1500-6000mg/l [1]. So, the measured value of TDS indicated that the water is really saline or brackish in nature. And also the salinity contents of the water after desalination was 0.9115g/kg.

3.2 ESTIMATION OF SOLAR RADIATION

3.2.1 Solar radiation

Detailed information about solar radiation availability at any location is essential for the performance investigation of parabolic trough collector for desalination plants and most of the time measured data of solar radiation are available for large number of locations in Ethiopia and for this location where there is no measured data available use satellite data from internet and solar radiation data can be determined by using sunshine hour from metrology is mandatory issue considered.

The sun is the source of most energy on the earth and is a primary factor in determining the thermal environmental situations and also one of the wondering source of energy in reality. It is basically important for the person who are working knowledge of the earth's relationship to the sun in this real world. These peoples are able to make calculation of solar radiation intensity according to meteorological and sun-earth relation for the estimation of solar data and know how to make simple solar radiation measurements. One of basically important thing to determine the estimation of solar data with addition to sun shine was geographical location of the study area that is geographical station of Diguna Fango Dimtu. Geographical coordinates of Diguna Fango Dimtu station :Latitude(L)= 5 40’ 17.6’’ N=$5.667°N$,Longitude=37 44’ 56.2’’ E=$37.749°E$ and Altitude is 1854m above sea level .However, manufactured parabolic trough solar assembly set up testing will take into account in Adama because of Diguna Fango is far away from Adama and it almost 360 km from Adama town. Basic problem is transportation of the setup is difficult and solar radiation value of this two regions are nearly similar, this implies performance investigation of testing in Adama town doesn’t matters.

Geographical coordinates of Adama station: -Latitude (L) =8 33’ 23.8’’ N = 8.558°; Longitude = 39 17’ 2.5’’ E = 39.28° Altitude = 1648 m above sea level. These two region geographic location indicates that the region are semi-arid and very hot climate condition. After estimation of solar radiation for Adama and Diguna Fango the experimental testing taken account in Adama town and it also works for Diguna Fango since solar radiation value nearly similar.

Table 3.3The sun shine hour duration of Diguna Fango Dimtu for three years of average (2015-2017) (source: S/N/N/P/R ,Hawasa meteorology district)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oc	Nov	Dec
Average(2015-2017)	8.9	9.32	9.02	8.5	8.49	7.1	5.03	6.72	6.56	8.76	9.21	9.5

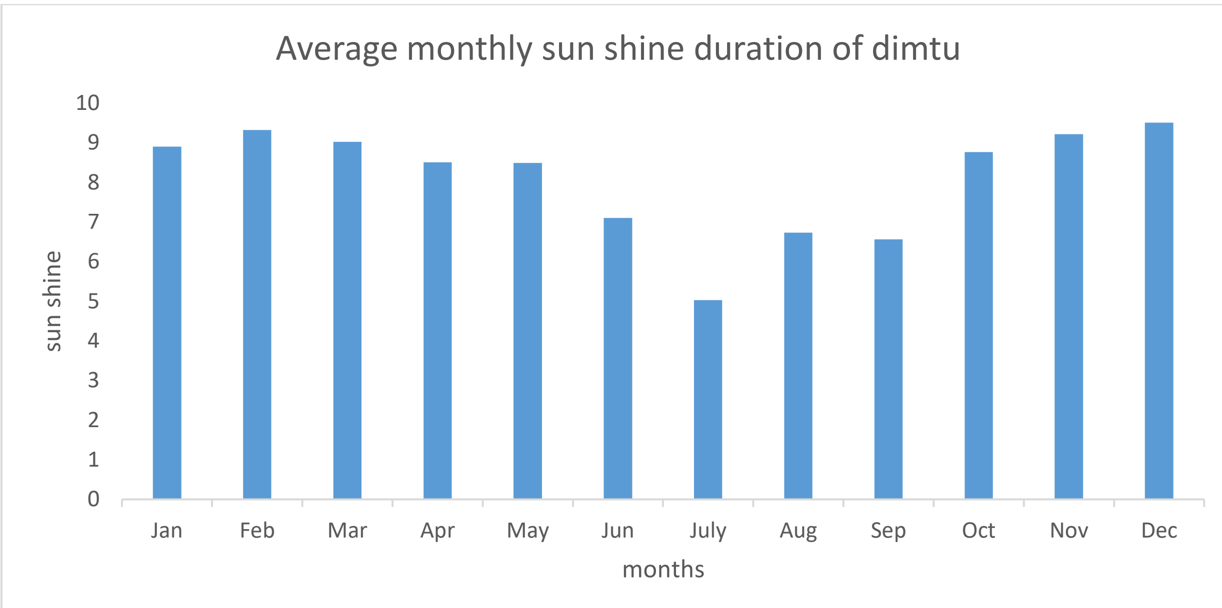


Figure 3.15 Monthly average sun shine duration of the month of Diguna Fango Dimtu

Table 3.4 The sun shine hourly duration of Adama for average of five years (2013-1017) (source: East Shoa meteorology).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oc	Nov	Dec
Average(2015-2017)	8.73	9.25	9.0	8.4	8.23	7.96	6.8	6.86	7.32	8.9	9.38	9.35

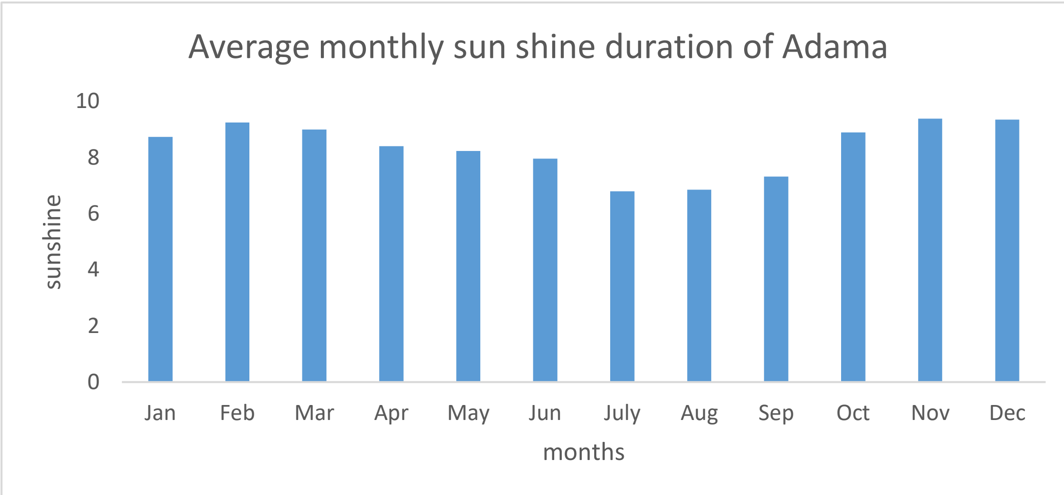


Figure 3.16 Monthly average sun shine duration of the month of Adama

3.2.2 Some of basic important terminology to determine solar estimation

3.2.2.1Solar time

In solar energy estimation, apparent solar time (AST) used to indicate the time of the day.

Solar time is based on apparent angular motion of the sun across the sky with solar noon the time the sun crosses the meridian of the observer. To change local standard time to apparent solar time by using the following two correction are applied accordingly. These are; the equation of time and longitude correction.

3.2.2.2Equation of Time

There are many factor related with earth`s orbit around the sun, the earth's velocity varies throughout the year , then apparent solar time varies slightly from the mean time kept by clock running at the same rate .This variation what we call the equation of time(ET)[37].

Equation of time as a function of the day of the year (N) can be determine from the following correlation [37].

Equation of time [ET]=229.2(0.000075+0.001868cos B-0.032077sin B-0.0014615cos $2B$-0.04089sin $2B$)[min]..3.2

Where, B=(n-1)*(360/365)...3.3

Where n is the day of the year

3.2.2.3 Longitude correction

The standard clock time is reckoned from a selected meridian near the center of the time zone or from the standard meridian the Greenwich which is at the longitude of 0°. Since the sun takes 4 min to transverse 1o of longitude, a longitude correction term of 4 × (Standard longitude – Local longitude) should be used and solar time can be determined from the following equation [33].

Solar time (ST) =Standard time+4(L_{st}_L_{loc}) +ET..3.4

Where, $L_{st}$is the standard meridian for local time zone

L_{loc} is Local Longitude of actual location

ET is the equation of time

3.2.2.4 The Declination Angle (δ)

Declination angle (**δ)** is the angle between the earth -sun line (through their centers) and the plane through the equator. The declination varies between – 23.45o on December 21 to and23.45o on June 21. Declination north of the equator (summer in the northern hemisphere) are positive and for south it is negative. The solar declination, δ in degrees for any day of the year (N) can be calculated approximately by using the following equation below [38].

δ=23.45$\sin(360/365(284 + N)$..3.5

3.2.2.5 The hour Angle, *h*

It is the angle through which the earth would turn to bring the meridian of the point directly under the sun. The hour angle at local solar noon is zero and with each 360/24 or 15_o of longitude equivalent to *1 h*. It is positive for after noon and negative for morning. -

The hour angle can be determined from apparent solar time is given by the following expression.

h=(AST-12)15..3.6

3.2.2.6 The solar altitude angle, α

It is the angle between a line collinear with the sun's rays and the horizontal plane. It is also related to solar zenith angle (ϕ) is angle between the vertical and the line to the sun. The mathematical expression for the solar altitude angle is

$\sin\alpha = \cos\phi = \sin L \sin\delta + \cos L \cos\delta \cos h$..3.7

Where *L= local latitude.*

3.2.2.7 The solar azimuth angle, z

The solar azimuth is the angular displacement from south of the projection of beam of radiation on horizontal plane. The sign convection used is (+) west of south and (-)east of south. The mathematical expression is here in given below [38].

$\sin Z = \frac{\cos\delta \sin h}{\cos\alpha}$..3.8

3.2.2.8Sunrise, Sunset Times and Day Length

When solar altitude angle is zero, the sun is said to be rise and set. Hence, hour angle at sun set is hss, and can be found by

$\cos hss = -\tan L \tan\delta$...3.9

Where, hss is taken to be positive at sun set

The day length (number of day light) is computed from

Day length (N)=2/15*$\cos^{-1}(-\tan L \tan\delta)$

3.2.9 Incidence Angle (θ)

Incidence angle is the angle between the sun's rays (beam radiation) and the normal to that surface. The incidence angle and zenith angles are similar on horizontal plane and mathematical expression computed by [38]

$\cos\theta = \sin L \sin\delta \cos\beta - \cos L \sin\delta \sin\beta \sin Zs + \cos L \cos\delta \cos h \cos\beta +$

$\sin L \cos\delta \cos h \sin\beta \cos Zs + \cos\delta \sin h \sin\beta \sin Zs$..3.10

Where,β= surface tilt angle from the horizontal.

Z_s = surface azimuth angle, the angle between the normal to the surface from true south, Westward is designated as positive.

Incidence Angle for a south-facing, tilted surface in the northern Hemisphere, $Z_s = 0^o$,

With further reduction is given by [38].

$\cos\theta = \sin(L-\beta)\sin\delta + \cos(L-\beta)\cos\delta \cos h$...3.11

3.2.3 Description about how to Estimate solar radiation for specific study area

The developing of parabolic trough water desalination plant requires deep knowledge that is related to availability of solar radiation on the specific site location and its components is basically important issue. Hence, the available solar radiation reaching to the earth's surface is primarily depends on climatic conditions of the site and determination of these solar radiation for Diguna Fango Dimtu region depending up on sun shine hour is critical.

In the case of our country, most of the time solar radiation data are not existed for specific site of study .Because there may be absence or mal function of measuring instruments. Therefore, to estimate solar radiation data empirical formula can be used. These empirical formula use climatological parameters of the study area and from these parameters sun shine hour is the most commonly used parameter and is also available for these study.

3.2.4 Estimation of Hourly solar radiation on horizontal surface

3.2.4.1Extraterrestrial daily Solar Radiation on horizontal surface.

The amount of solar energy per unit time, the mean distance of the earth from the sun received on unit area of the surface normal to the sun (perpendicular to the direction of propagation of radiation) outside the atmosphere is what we call solar constant (Gsc) and the value of solar constant is equal to 1367w/m2.

The modified or solar constant at any day of the year (Nth day of the year) can be determined from the following empirical equation [38].

G_{On}=G_{sc}[1+0.033cos($\frac{360n}{365}$)]...3.12

Gon = Extraterrestrial radiation measured on the plane normal to the radiation on the *N*th day of the year (W/m2).

Gsc = Solar Constant (W/m2).

The rate solar radiation incident on extraterrestrial horizontal surface can be given by the following empirical formula [38]

$G_{oH=G_{on}}\cos\phi$...3.13

G_{OH}=$G_{sc}$$\{$1+0.033cos($\frac{360n}{365}$)$\}$[$\cos L\cos\delta\cos h+\sin L\sin\delta$]...3.14

The total radiation H_o,incident on an extraterrestrial horizontal surface during day can be obtained from integration of equation (4.13) over period from sunrise to sunset expressed in given below [33].

$H_{o=}\frac{24x3600}{\pi}G_{sc}\{1+0.033\cos(\frac{360n}{365})\}[\cos L\cos\delta\cos hss+(\frac{\pi hss}{180})\sin L\sin\delta\}$..3.15

Where *hss* is the sunset hour in degrees. The units of from above equation are joules per square meter (J/m2).

And extraterrestrial radiation on horizontal surface for an hour period (period between hour angles h1 and h2) since h2>h1 is given below [38].

I_o=$\frac{12x3600}{\pi}G_{sc}\{1+0.033\cos(\frac{360n}{365})\}[\cos L\cos\delta(\sin h2-\sin h1)+\frac{\pi(h2-h1)}{180}\sin L\sin\delta$...3.16

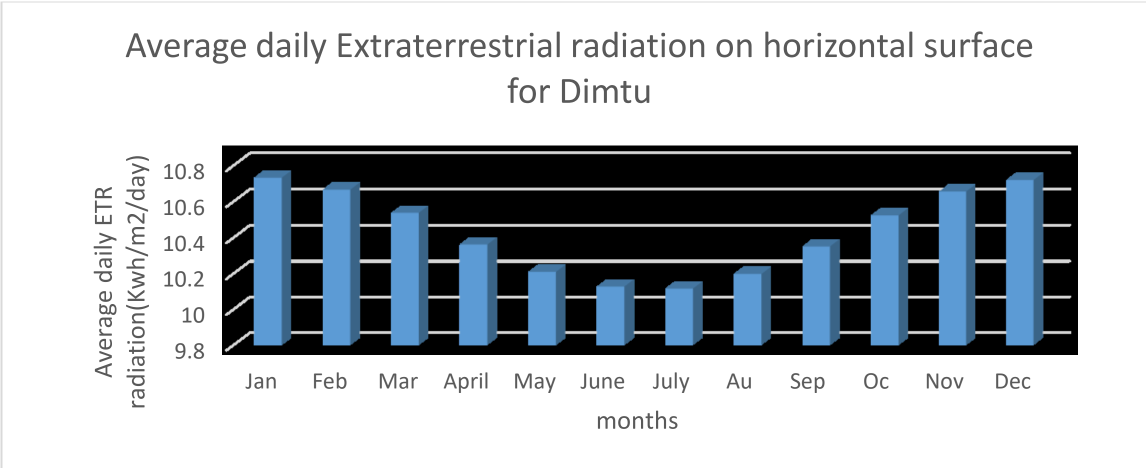


Figure 3.17 Extraterrestrial (ETR) daily Solar Radiation for horizontal surface for Diguna Fango Dimtu.

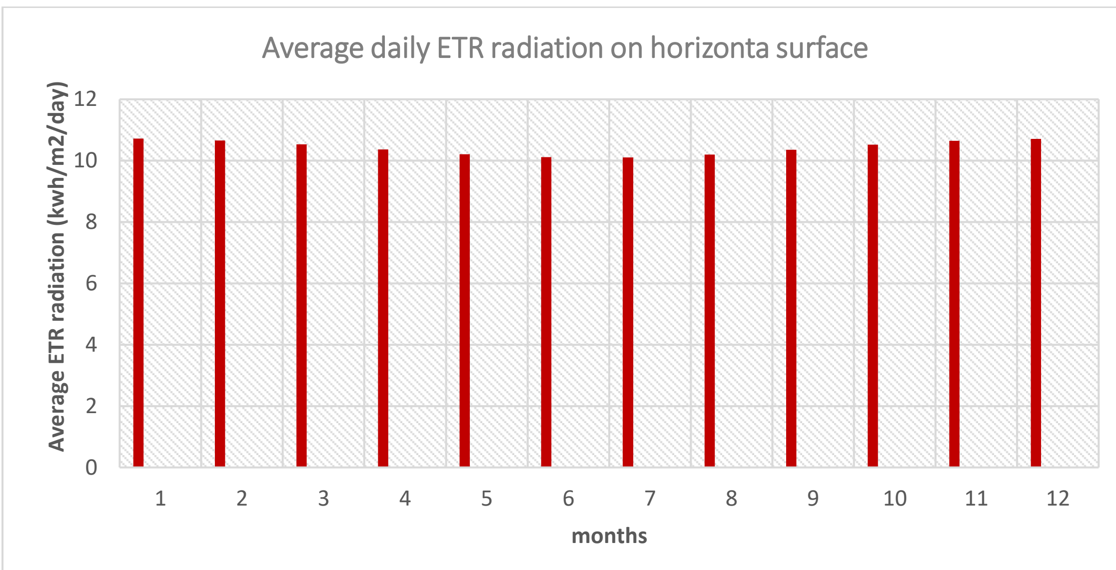


Figure3.18 Extraterrestrial (ETR) daily Solar Radiation for horizontal surface for Adama.

3.2.4.2 Prediction of Monthly Average Daily Global Radiation on Horizontal surface.

For many applications, one needs the knowledge of the monthly average daily global solar radiation available on horizontal surface .By using sun shine hour monthly average daily global solar radiation and expressed in the following correlation [47]

$\frac{\bar{H}}{Ho}$=a+b($\frac{\bar{n}}{\bar{N}}$)..3.17

Where:

$\bar{H}$- Monthly average daily radiation on horizontal surface.

$\overline{Ho}$ -Monthly average radiation out side of the atmosphere (ETR on the horizontal surface) for the same location.

a, b – empirical constants, (Values are obtained by regression).

$\bar{n}$- Monthly average daily hours of bright sunshine.

$\bar{N}$ −Monthly average of the maximum possible daily hours of bright Sunshine.

a and b are the regression parameters can be determined from the following relations.

a=-0.110+0.235cos L+0.323($\frac{\bar{n}}{\bar{N}}$)………………………………………………………....3.17a

b=1.449-0.533cos L-0.694($\frac{\bar{n}}{\bar{N}}$)……………………………………………………………..3.17b

$\bar{H}_o$ Can be determined from equation of Klein relationships:

$\bar{H}_{o=}\frac{24x3600}{\pi}G_{sc}\{1+0.033\cos(\frac{360n}{365})\}[\cos L\cos\delta\cos hss+(\frac{\pi hss}{180})\sin L\sin\delta$........................3.18

$\bar{H}_{o=j/m2}$ n=mean day of the month

hss=sun rise hour angle

G_{sc} =1367W / $m2$, (Solar constant

The length of sun shine hours ($\bar{N}$) are computed from the cooper relationship can be described below.

$\bar{N}$=($\frac{2}{15}$)hss...3.19

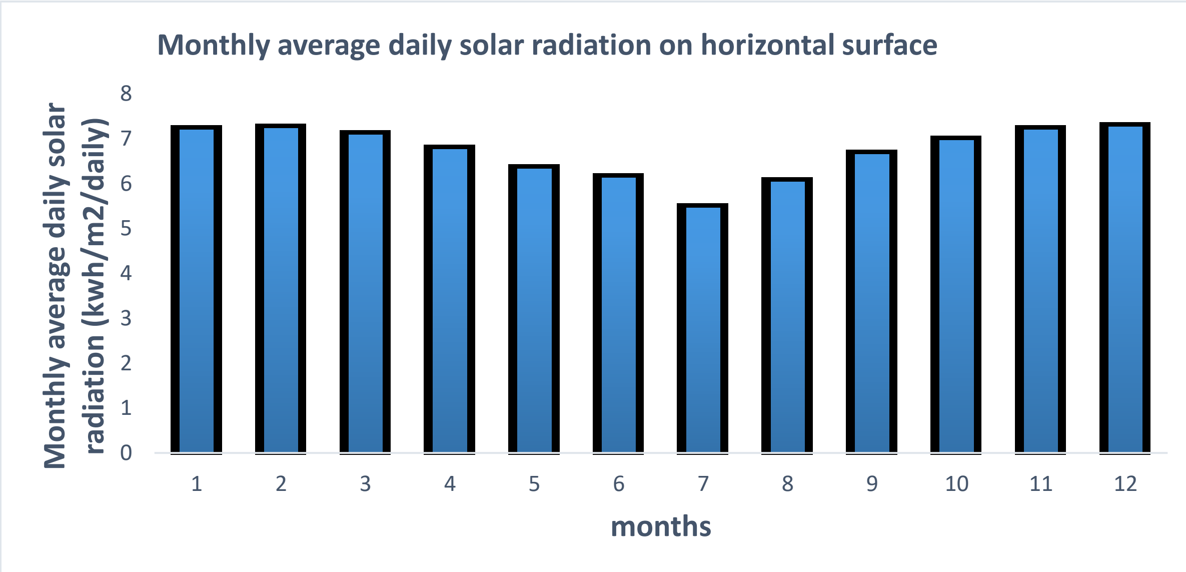


Figure 3.19 Graph of Monthly Average Daily Global Radiation on a Horizontal Surface for Diguna Fango Dimtu.

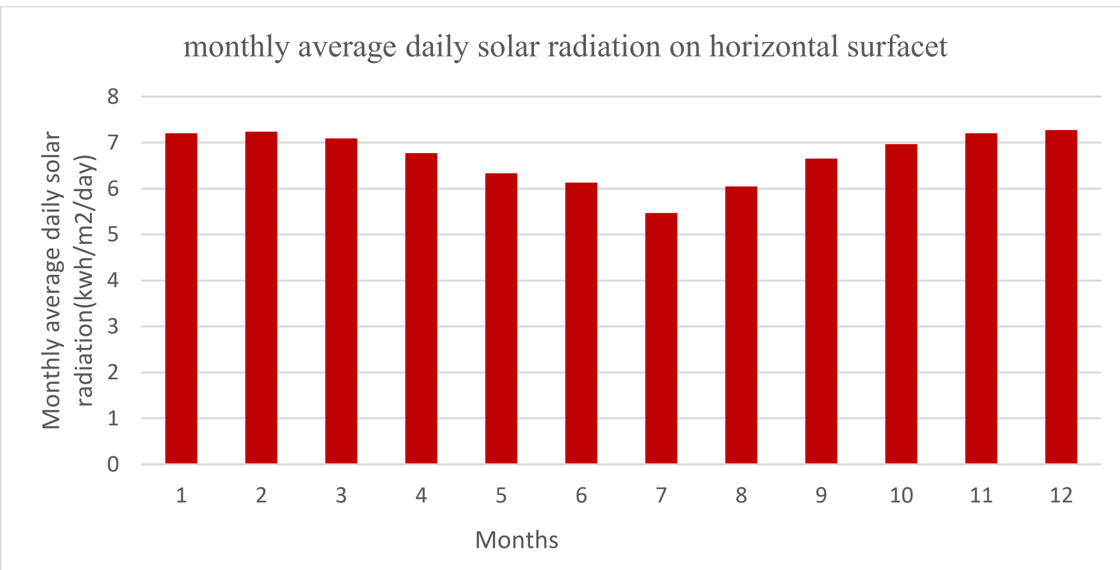


Figure 3.20 Graph of Monthly Average Daily Global Radiation on a Horizontal Surface for Adama.

3.2.4.3 Prediction of Monthly Average Daily Diffuse Radiation on a Horizontal Surface

To predict the performance of a solar system, daily values of radiation are required and it can be determined from monthly average daily global radiation on horizontal surface and number of bright sun shine hours is given in the following mathematical expressions [47].

$\frac{\overline{Hd}}{\overline{H}}$=0.931-0.814($\frac{\bar{n}}{\bar{N}}$)..3.20

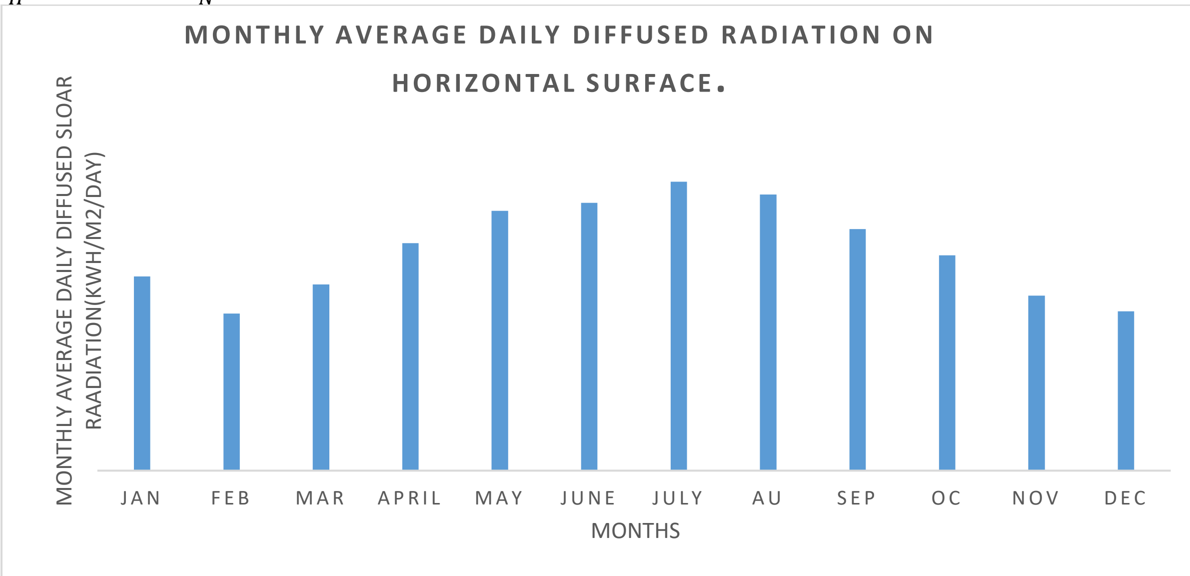


Figure 3.21 Graph of Monthly Average Daily Diffuse Radiation on a Horizontal Surface for Diguna Fango Dimtu.

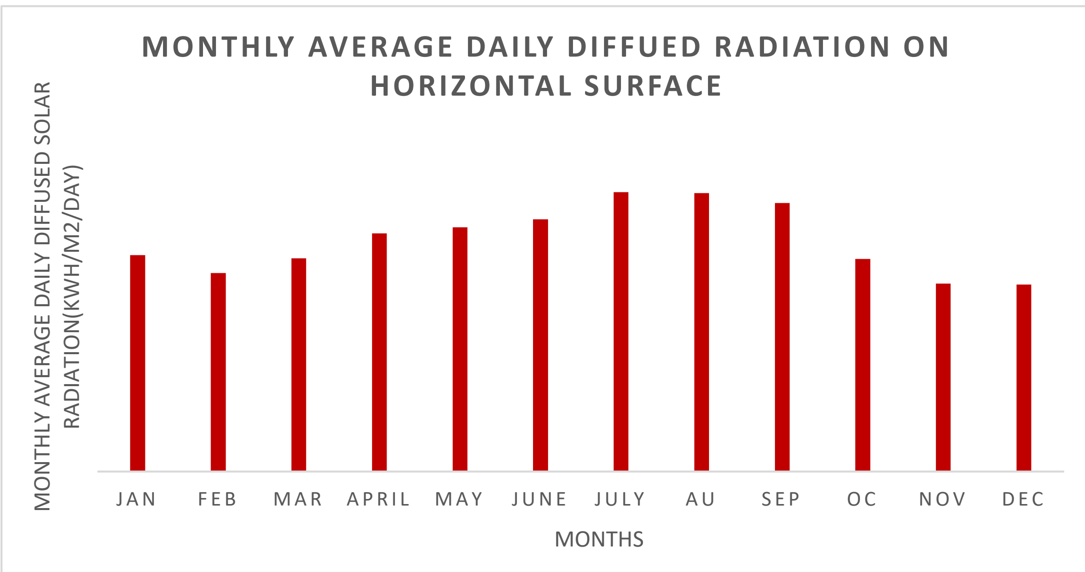


Figure 3.22 Graph of Monthly Average Daily Diffuse Radiation on a Horizontal Surface for Adama

3.2.4.4 Prediction of Monthly Average Hourly Global Radiation on a Horizontal Surface

The monthly average hourly global radiation can be determined from monthly averaged daily global radiation on horizontal surface can be expressed in the following empirical formula [38].

$$\frac{\bar{I}}{\bar{H}}=r=\frac{\pi}{24}(\alpha+\beta\cos h)\frac{\cos h-\cos hss}{\sin hss-(2\pi hss/360)\cos hss} \quad \text{......3.21}$$

Where, $\alpha=0.409+0.501\sin(hss-60)$..............3.21a

$\beta=0.6609-0.4767\sin(hss-60)$..............3.21b

r = ratio of hourly total radiation to daily total radiation

3.2.4.5 Prediction of Monthly Average Hourly Diffuse Radiation on a Horizontal Surface

To investigate the performance of a solar system, hourly values of radiation are required, because in most cases this type of data are not available, long-term average daily radiation data can be utilized to estimate long-term average radiation distribution. For this purpose, empirical Correlations frequently used is given below [33].

$$\frac{\overline{Id}}{\overline{\overline{Hd}}}=r_d=\left(\frac{\pi}{24}\right)\frac{\cos h-\cos hss}{\sin hss-(2\pi hss/360)\cos hss} \quad \text{......3.22}$$

Where, r_d. = ratio of hourly diffuse radiation to daily diffuse radiation

3.2.4.6 Prediction of Monthly Average Hourly direct (beam) Radiation on a horizontal Surface

The direct (beam) monthly average solar radiation on horizontal surface can be obtained from the relation of global and diffused radiation of horizontal surface.

$I_b=I-I_d$..............3.23

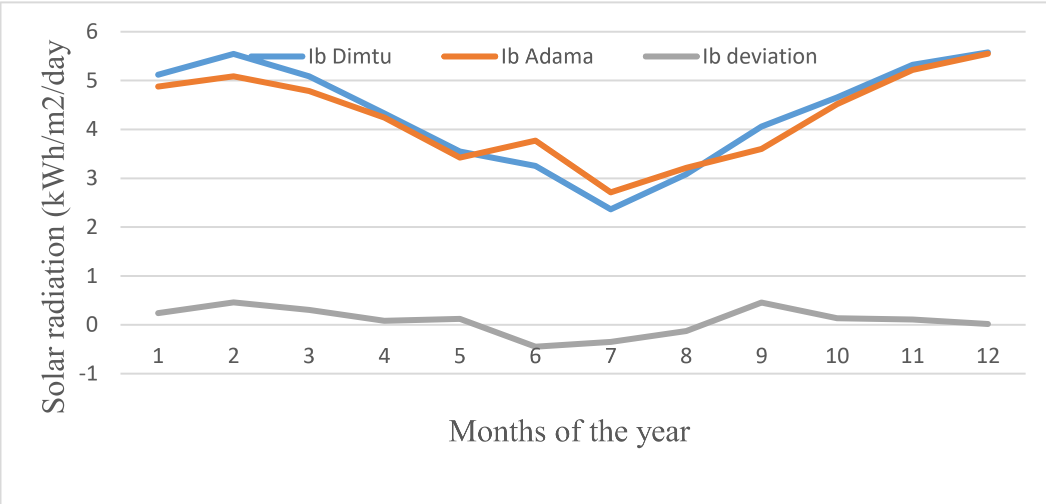


Figure 3.23 Graph of monthly average hourly beam radiation of Dimtu,Adama and the deviation between Dimtu and Adama.

The above described figure 3.23 shows that the amounts monthly average hourly beam radiation of Dimtu,Adama and the devation between two indicates that values are nearly similar with each other and the deviation is very small. Therefore, the performance investigation of the experiment on Adama town works for Diguna Fango Dimtu region.

3.2.5 Total Radiation on Tilted Surfaces

Most of the time collectors are not installed horizontally on the surface and collectors are tilted to some angle to increase the amount of available radiation intercepted and also reduce reflection significant amount of cosine losses.

Therefore, system designers' needs available solar radiation on the tilted surface but mostly available data is either for normal incidence or for horizontal surface. So, converting these data into tilted surface is critical.

The amount of insolation on a terrestrial surface at a given location for a given time depends on the orientation and slope of the surface.

A flat surface absorb beam (G_{Bt}), diffuse (G_{Dt})and ground reflected (G_{Gt}) solar radiation on the surface.

$G_t = G_{Bt} + G_{Dt} + G_{Gt}$..3.24

And the beam radiation on tilted surface and on horizontal surface are given in the following expression respectively and diagrammatical expression on figure below.

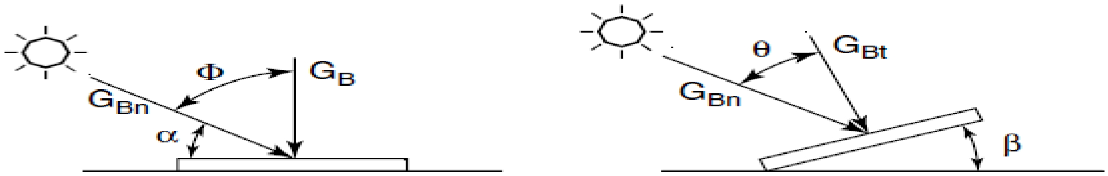


Figure 3.24 Beam radiations on horizontal and tilted surfaces [38]

$G_{Bt} = G_B \cos\theta$..3.25

$G_B = G_B \cos\phi$..3.26

Where

GBt= beam radiation on a tilted surface (W/m^2).

GB= beam radiation on a horizontal surface (W/m^2)

From above equation beam radiation tilt factor can be determined as follows

$R_b = \frac{G_{Bt}}{G_B} = \frac{\cos\theta}{\cos\phi}$..3.27

Where, RB is beam radiation tilt factor .The term $\cos\theta$ and $\cos\phi$can be calculated first. So, beam radiation component for any surface is calculated by:

$G_{Bt} = G_B R_B$..3.28

Prediction of total hourly and total daily radiation on tilted surface can expressed in the following mathematical empirical formula can be in given below respectively.

$I_{T=I_bR_b}$+$I_d(\frac{1+\cos\beta}{2})$+$(I_b + I_d)\rho(\frac{1-\cos\beta}{2})$..3.29

Where,

I_T =Total hourly irradiance on a tilted surface (W/m^2)

$I_{b=}hourlybeamirradiance(\frac{W}{m2})$

I_d=hourly diffuse irradiance (w/m2)

R_b=ratio of beam radiation on tilted surface to that on horizontal surface

β =Surface slope angle

ρ =Ground reflectivity, 0.2 for bare earth and 0.7 for snow

Total daily radiation on tilted surface can be expressed under below [47]:

H_T =$H_B R_B$+$H_d(\frac{1+\cos\beta}{2})$+$(H_b$+$H_d)\rho(\frac{1-\cos\beta}{2})$..3.30

Where,

$H_{T=}$daily total radiation on tilted surface (kJ/m^2/day)

H_B=daily beam radiation on horizontal surface (kJ/m^2/day)

H_d=daily diffuse radiation on horizontal surface (kJ/m^2/day)

R_B=ratio of beam radiation on tilted surface to that on horizontal surface

β=surface slope angle

ρ=ground reflectivity, 0.2 fore bare earth and 0.7 for snow.

To determine the R_b the most important parameters are the angle of incidence, solar zenith angle and the tilt angle.

The study is proposed that south facing fixed surface with tilt angleβ, the incident angle can be calculated as:

$\cos\theta = \sin(L-\beta)\sin\delta + \cos(L-\beta)\cos\delta\cos h$……………………………………….3.31

Zenith angle is the angle between the sun's ray and the perpendicular line to a horizontal plane

$\cos \phi$=$\sin L \sin\delta + \cos L \cos\delta \cos h$………………………………………………….3.32

Collector Tilt angle is the angle between the collector and the local horizontal. In most solar water desalinating applications areas the tilt angle can be approximated as a tilt angle is latitude plus (10°to 15°) is optimum value nearly [38].

Slope β=φ+(10° $up\ to$ 15°)

For Diguna Fango Dimtu latitude is 5.667, then the slope of collector is
β=φ+12.5°=5.667° +12.5°=18.16°

3.2.6 Solar radiation analysis for parabolic trough collector

The determination of collector performance basically requires information on the solar energy absorbed by the collector absorber. There are actually three components for incident radiation. These are beam, diffuse and ground reflected radiation.

Therefore, the general mathematical expression for absorbed radiation S, is given below [47]

S=$I_B R_B(\tau\alpha)_B$+$I_D(\tau\alpha)_D[\frac{1+\cos\beta}{2}$+$\rho_G(I_B+I_D)(\tau\alpha)_G[\frac{1-\cos\beta}{2})$…………………………………………….3.33

But concentrating collectors (study parabolic trough collector) can only utilize beam radiationG_B, on the surface and the other diffuse radiation and ground reflected terms are neglected.

Therefore, absorbed radiation S, can be determined from above equation (3.33) simplified as follows:

S=$I_B R_B (\tau\alpha)_B$...3.34

3.2.7 Diguna Fango Dimtu Climate Condition and Estimation Hourly Variation of Ambient Temperature

3.2.7.1 Climatic condition

Diguna Fango Dimtu is one of the sem arid region and characterized by a tropical climatic condition with having high intensity of solar radiation. The monthly average temperature of ranges between 18.49℃ (July) is the minimum value and 22.7℃ (May) is the maximum value. The meteorological data are taken from Hawasa (southern district) and seven year average temperature and wind speed are discussed in the Table 3.5.

Table 3.5 Monthly average annual climatic condition of Diguna Fango Dimtu (southern Meteorology Agency (Hawasa)

Temperature	Months											
	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Min(°C)	11.78	13.2	14.4	15	14.9	16.5	11.9	16.4	14.5	12.7	11.8	12
Max(°C)	27.32	29.6	29.93	29.3	30.5	29.6	25	26.7	28.2	29.09	27.4	26.5
Average(°C)	19.51	21.4	22.17	22.15	22.7	21.55	18.49	21.55	21.35	20.89	19.6	19.25
Wind speed (m/s)	2.9	2.5	3	2.7	2.85	3.1	2.9	2.3	2.6	3	3.3	2.83

3.2.7.2 Estimation of Diurnal Variation of Ambient Temperature

The Estimation of the variation of daylight of ambient temperature can be determined from daily minimum and the maximum temperature of the day and expressed in the form of sine exponential function. This mathematical model explains the diurnal cycle of sine function during day time linked to decreasing exponential function during night time.

The hourly variation of temperature, T(t) at any time t is given by following equation

$T(t)=T_{max}$ -($\frac{T_{max}-T_{min}}{2}$)[1-sin($\frac{\pi t-9\pi}{2}$)]……………………………………………………………3.35

Where,T_{max} is mean daily maximum temperature at 15:00 h sun time assumed and T_{min} is mean daily minimum temperature.

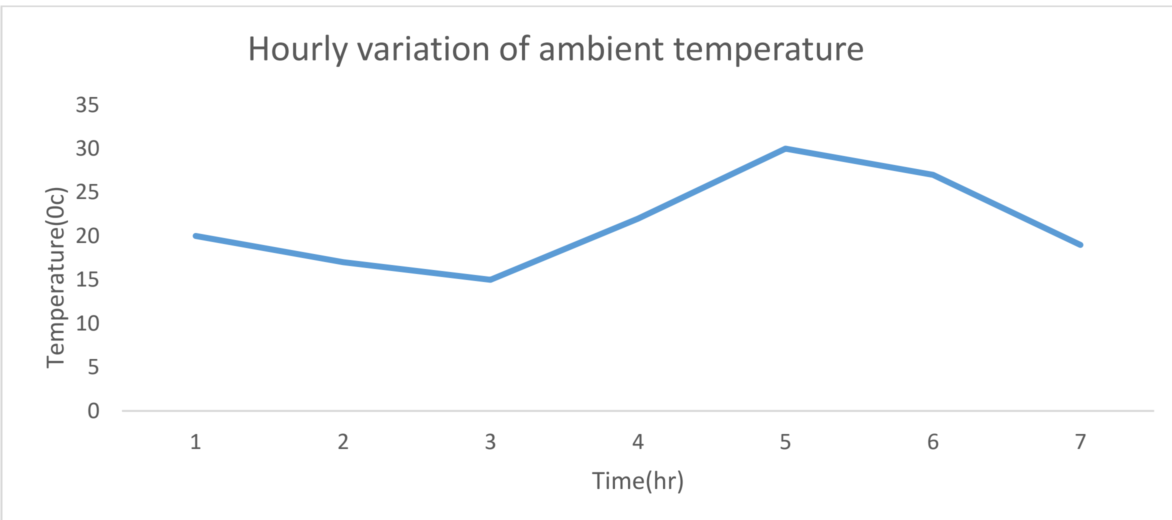


Figure 3.25 Result of average variations of ambient temperature of Diguna Fango Dimtu region.

3.3 Experimental Set-up Preparation and Testing

3.3.1Introduction.

Parabolic trough are the trough with the cross section that has the shape of symmetrical section of parabola around its vertex and it concentrate sun light onto a receiver tube that is positioned along the focal line of the trough.

Parabolic trough collectors are employed in a variety of applications, among these some are including industrial steam production, hot water production and also in this work used for desalination of salt water purpose. The working principle solar radiation coming from sun collected over area of reflecting surface of parabolic trough and concentrated in to the focus of parabola. Receiver tube is placed on the focal line axis, so working fluid inside is heated up due to concentrating solar irradiation using collector surfaces. And the hot heat transfer fluid leaves the collector and the steam produced in heat exchanger [38].

In this part of the work discuss the parabolic trough collector mathematical geometry as a whole, optical efficiency, the effective area of the collector, intercept factor, collector incidence angle modifier, end loss, collector efficiency factor, collector flow factor, collector heat removal factor, useful heat gain, collector efficiency ,manufacturing of parabolic trough collector and condenser.

Figure 3.26 Schematic flow diagram parabolic trough solar collector for desalination

The above figure shows the process of schematic flow diagram for small scale parabolic trough solar collector for desalination. The salt water is flowing through the tube and entering into the receiver inlet and get heated. At the out let of the receiver the fluid is vaporized and the salt and other dissolved solids are separated, the steam formed at the end of receiver entering into condenser and finally the desalted water produced for drinking purpose for Diguna Fango Dimtu region.

3.3.2 Components of parabolic trough solar desalination

3.3.2.1 Salt water container (storage tank)

Salt water container (storage tank) is where saline water collected and stored and it should be made ether from plastic material or any other sheet metal welding to form a tank. Since, transparent material allows sun light penetration through the tank that improves the desalination of water.

Transparent plastic is preferred in terms of cost and for its characteristics since our target is rural area and most of the time their economy is less when compared with urban. Technically, the tank should be placed in elevation higher than the elevation of the parabolic through , so the water flow naturally to the parabolic trough due to difference in elevation(due to gravity) without requiring the pump to minimize the cost of the installation of the plant.

There will be one storage tank that contains two plastic cylinders on it. One is for saline water that is used for desalination purpose and the other is used to condense the vaporized water. As the goal of this thesis is to produce 10 liters of water per day for small member of one family and the storage tank for saline water was set to have 20 liters.

3.3.2.2 Parabolic trough collector

Parabolic trough concentrator works by focusing the direct radiation coming from the sun into the receiver.

3.3.2.3Receiver tube

Receiver tube is made up of copper tube due to its high thermal conductivity material and is placed on the focal line axis, so working fluid inside is heated up due to concentrating solar irradiation using collector surfaces. Receiver tube of one end is connected with collecting tank and other side is connected with condenser setup.

3.3.2.4 Resistance Temperature Detector (RTD）

RTD is inserted at the inlet and outlet of the receiver tube to sense the inlet and outlet temperature of the working fluid. From the arrangement, the temperature at each time interval can be measured.

3.3.2.5 Condenser

Condenser is a container of cold water that the vapor will pass through in order to condense it, and also in this work the shell and coil water condenser can be used.

It doesn’t matter which type of water will be using in order to condense the vapor since there is no contact between the two except the exchange of temperature (the water used here is saline water since it is available). It has a cylindrical shape with a removable cover and a coil inside that is connected to one inlet and one outlet. The inlet will receive vapor from the out let of the receiver to pass through the coil. Since, the condenser has cold water, the water will get condensed in the coil and the pure drinking water as output.

3.3.3 Material for parabolic trough collector

One the basic factors considered into account for the performance of parabolic trough solar collectors are the material properties.

The transmission, reflection, and absorption of solar radiation by the various parts of a solar collector are important in determining collector performance.

When a beam of thermal radiation is incident on the surface of a body, part of it is reflected away from the surface, part is absorbed by the body, and part is transmitted through the body. The Various properties associated with this phenomenon are the fraction of radiation reflected, called reflectivity (ρ); the fraction of radiation absorbed, called absorptivity (α); and the fraction of radiation transmitted, called transmissivity (τ).

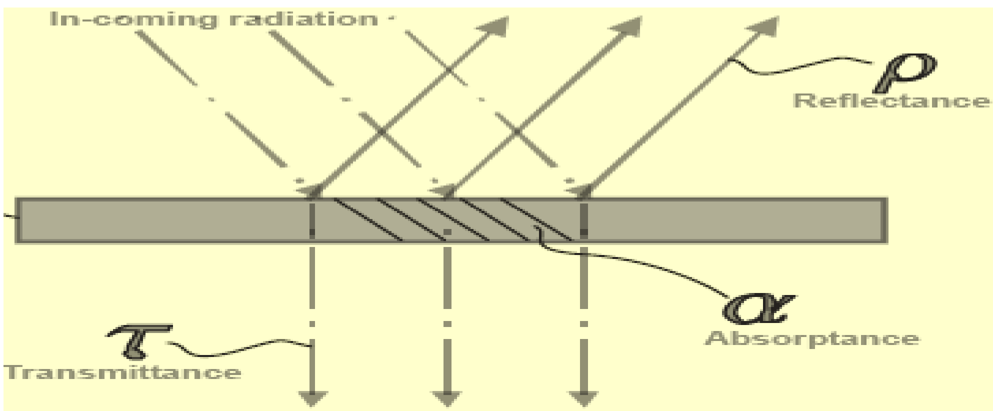


Figure 3.27 Reflection, Absorption and Transmission of incident solar radiation by a solid body [28].

Table 3.6 The material list for the main components of parabolic trough.

Component	Material
Receiver tube	Copper tube
Glass cover	Light fluorescent lamp
Receiver support	Anodized aluminum
Reflector	Solar glass
Mirror panels	Aluminum sheet metal
Supporting structure	Rectangular hollow sheet(RHS)
Condenser	Copper coil

3.3.4 Geometry of parabolic trough collector

The parabolic trough collector has the shape of the parabola and parabolic mirror is the most important aspect of parabolic trough collector. It represents the surface that reflects the direct (beam) normal radiation of the system for specific location of the study to concentrate it onto the focal point where the receiver is located.

There are basically four important parameters are most commonly used to determine the parabolic trough size. And all the other dimensions are calculated by using these parameters.

These are:

- -Focal length
- -Trough length
- -Aperture width
- -Rim angle

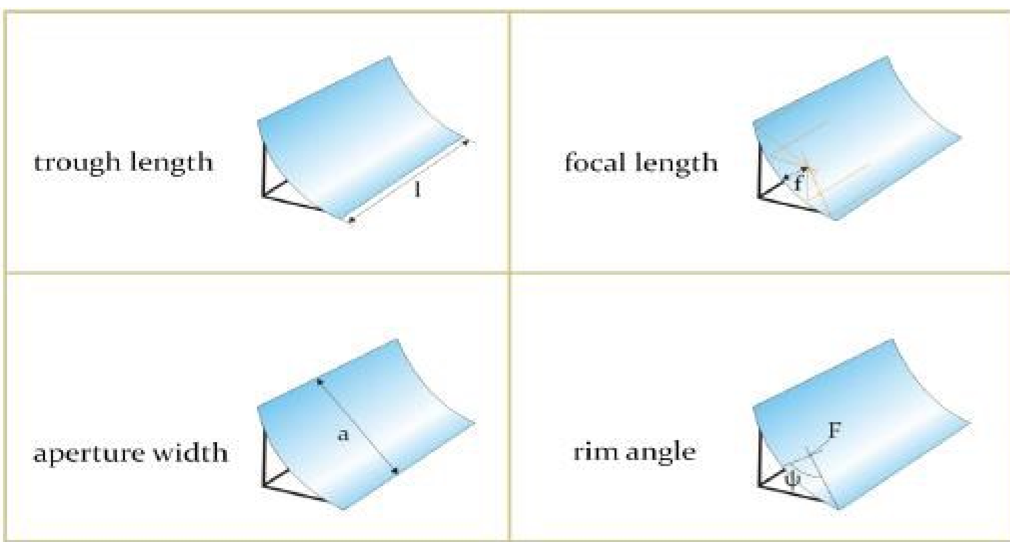


Figure 3.28 Geometric parameters of parabolic trough [2]

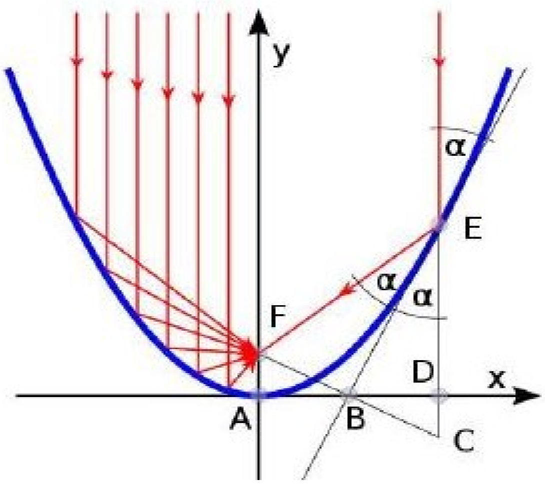


Figure 3.29 Geometric representation of the reflection of rays at the parabolic mirror [2].

The equation of parabola with focal length f can be given by the following expression as

$y=\frac{1}{4f}x^2$ 3.36

From above listed parameters, the input parameters for parabolic trough collector design in this study are optimum rim angle and the aperture width and the others are derived from these parameters.

3.3.4.1The selection of rim angle

The rim angle(Ψ) is the angle from which rim of the collector to the line normal to the collector surface passing through the focus. Possible rim angles are constructed for the same aperture width and it defines the shape of through cross-section. The rim angles decrease as collector surface area decrease and the recommended value of the rim angle can be not too large or not too small. Since, small rim angle indicates there would be minimum irradiance that is reflected in to absorber and the large rim angle leads to large reflection that it decreases the concentration ratio of the parabolic trough collector. From previous research the optimum value of rim angle is 90°[35] . In these case mean focus to reflector distance and hence reflected beam spread is minimized. As result the slope and tracking error are less achieved. So, the rim angle selected finally to be 90° for optimum design in this study [35].

Aperture width can be assumed as 0.88m and the trough length is 3m for easily of tracking of the parabolic trough and depending up on the cost of material for manufacturing parabolic trough. Basically these parameters are important to determine the other parameters like focal length, height of parabola, parabola length and the others are discussed in the following section.

When considering the resistance of wind and rain, to reduce the maintenance of parabolic trough, it is recommended theoretically correct according to the following criteria, that is the aperture width is less than trough length [38].

The rim angleΨ can expressed as the function of the ratio of aperture width to the focal length of the parabola can given as [28]

$$\tan\Psi=\frac{\frac{a}{f}}{2-1/8(\frac{a}{f})^2} \quad \text{.......} 3.37$$

3.3.4.2 Focal length

The focal length (f) which represents the distance between the focal point and the vertex of the parabola. The shape of the parabola is therefore dependent on this parameter. The rim angle represents the angle between the line of the focal length and the optical line. It determines the geometry of the parabola. The radiation that enters in the plane parallel to the optical plane is reflected in such way that it passes through the focal line.

Focal length of parabola can be determined directly from the following relation. That is given below hereunder [31]: $f=\frac{a}{4\tan(\frac{\Psi}{2})}$……………………………………………………3.38

Where aperture width, f is focal length and ψ is rim angle of parabolic trough.

$$f=\frac{a}{4\tan(\frac{\Psi}{2})}= \quad f=\frac{0.88}{4\tan(\frac{90}{2})}=0.22\text{m}$$

3.3.4.3Height of parabola (h)

Height of parabola can be defined as the maximum distance from the vertex to a line drawn across the aperture of the parabola once a specific portion of parabolic curve has been selected. The height of parabola can be written in the form of aperture width and focal length of the parabola and is given by the following formula [32].

$$h=\frac{a^2}{16f} \quad \text{.......} 3.39$$

$$h=\frac{0.88^2}{16*0.22}=0.22\text{m}$$

3.3.4.4 Arc length(S)

Arc length(S) is the length of the curvature of the parabolic trough that depends mainly on the width and the focal length of the parabola.

The parabola length (S) can be determined from equation (5.1) by integrating the differential segment of the curve and by applying the conditions (limits) y=h and x=a/2 can be given as [34]:

$S=(\frac{a}{2}\sqrt{\frac{a^2}{16f^2}+1}+2f\ln(\frac{a}{4f}+\sqrt{\frac{a^2}{16f^2}+1}))$ 3.40

$S=\frac{0.88}{2}\sqrt{\frac{0.88^2}{16x0.0.22^2}+1}+2x0.22\ln(\frac{0.88}{4x0.22}+\sqrt{\frac{0.88^2}{16x0.22^2}+1}))=1m$

3.3.4.5 Mirror area and aperture area

Aperture area is basically important parameter at a given direct normal radiation and at the given sun position it find out the radiation capture from the sun.

By using above parameters to determine the aperture area and mirror area.

Aperture area can be determined as the product of the aperture width and the collector length given as Aa=axl 3.41

Where a is aperture width and l is trough length

$A_{ap=}\ axl=0.88x3=2.64m^2$

The surface area (mirror area) of the parabolic trough is used to determine the need of material for the trough. And it calculated as follows in given below [32].

$A=sxl=(\frac{a}{2}\sqrt{\frac{a^2}{16f^2}+1}+2f\ln(\frac{a}{4f}+\sqrt{\frac{a^2}{16f^2}+1})*l$ 3.42

$Am=\frac{0.85}{2}\sqrt{\frac{0.85^2}{16x0.21^2}+1}+2x0.21\ln(\frac{0.85}{4x0.21}+\sqrt{\frac{0.85^2}{16x0.21^2}+1}))*3m=3m^2$

3.3.4.6 Geometric concentration ratio

Geometric concentration ratio is defined as the ratio of the collector aperture area to the receiver area. It is given by the following formula below [38].

$C_G=\frac{A_{ap,c}}{A_{ap,r}}=\frac{w*l}{d*l}=\frac{w}{d}$ 3.43

In most of the time, the projected area of the absorber tube is chosen. In this case the receiver aperture area is a rectangle with the area, d*l where d is the absorber tube diameter and l is the trough length of the parabola.

There is also another possibility is to take the irradiated absorber surface area as the receiver aperture area. In real parabolic troughs this would mean that the whole absorber tube surface area $\pi * d * l$ is the receiver aperture area. So, the concentration ratio in this case can be determined as follows.

$$C_G=\frac{A_{ap,c}}{A_{ap,r}}=\frac{w*l}{\pi d*l}=\frac{w}{\pi d} \qquad 3.44$$

From the above definition the second possibility would lead to the lower geometric concentration ratio. So, the concentration ratio according to the projected area is most commonly used and is also used for this works.

3.3.4.7The selection of the receiver diameter.

The selection of receiver diameter mostly determines optical efficiency and intercept factor. The intercept factor is defined as energy intercepted by the receiver to the total energy reflected by the focusing device and it is also depends on the receiver size and its value 95% when the receiver diameter 25mm [38].

The selection of the receiver diameter depends mainly on the thermal analysis since the larger diameter gives the larger intercept factor but it has the drawback of higher thermal losses. So, the receiver diameter selection taken into account with optimum and according to the material availability in the market and also depending up on the cost of the material. So, selected diameter of 25 mm with the thickness of 1.5mm.

Table 3.7 parameters used for manufacturing of parabolic trough for desalination.

Parameters	Symbol	Value	Reference
Width of the PTC	W	0.88m	
Trough length	L	3m	
Focal length of the PTC	F	0.22m	
The rim angle	ψ	90°	[35]
Parabola height	H	0.22m	
Arc length	S	1.m	
Aperture area	A_{ap}	$2.64m^2$	
Mirror area	A_m	$3.m^2$	
Concentration ratio	C_G	33	
Receiver inner diameter	d_{ri}	25mm	
Receiver outer diameter	d_{ro}	26.5 mm	
Cover inner diameter	d_{ci}	39mm	
Cover outer diameter	d_{co}	40mm	
Receiver emittance	ε_r	0.2	[36]
Cover emittance	ε_c	0.9	[31]
Receiver absorptance	α	0.96	[32]
Cover transmittance	τ	0.92	[35]
Mirror reflectance	ρ	0.92	[33]
Receiver thermal conductivity	K	386W/m.k	
Intercept factor	γ	0.95	[30]
Tracking mechanisms controller type		Manual	
Mode of tracking		N-S horizontal	

3.3.5 Heat transfer fluid (HTF)

The most important component of the system is the heat transfer fluid HTF (working fluid).

For the effective heat transfer applications the fluid should be stable at high temperature, non-corrosive and safe, it also should be cost effective. The most commonly used working fluids in this work is pressured salt water.

Density(ρ)	999 kg/m^3
Specific heat capacity(c_p)	4.011kJ/k.kg
Viscosity μ at 16.5℃	1.002*10^{-3}kg/m.s

Table 3.8 Properties of saline water at 16.5℃

At this working conditions the mass of the working fluid can be determined as follows in the mathematical expression for average temperature below [32].

$M_{f=}\pi\frac{di^2}{4}L_{sca}N_{sca}\rho(T_{avg})$...3.45

Where

M_f=The mass of heat transfer fluid in solar field (kg)

d_i=inner diameter of absorber tube

L_{sca}=length of one solar collector assembly loop

N_{sca}=number of solar collector assembly

ρ =Density of heat transfer fluid (kg/m^3)

T_{avg}=average temperature of the heat transfer fluid in ℃

Mf= $\pi\frac{0.025^2}{4}*3*1*947 = 1.40\ kg$

Volume of HTF in the solar can be determined as

V=$\pi\frac{di^2}{4}L_{sca}$=3.14*$\frac{0.25^2}{4}$*300=14.7262 cm^3=1.47 litres=0.00147 m^3

But, Considering the total population of Diguna Fango region by increasing the length of the solar assembly 5m and the number of solar collector assembly can be 347.Then,desalination of water by using parabolic trough collector for the community is possible by increasing the length and the number of collectors.

3.3.6 OPTICAL PERFORMANCE OF CONCENTRATING COLLECTORS

Concentrating collector (parabolic trough collector) have the optical properties that is varying with the geometry of the device.

An equation for *S*, the absorbed radiation per unit area of unshaded aperture, can be written as

S=$I_b\rho(\tau\alpha\gamma)$k...3.46

s=the absorbed radiation per unit area

I_b=the direct solar radiation

k=the angle of modifier and the others are stated in below.

3.3.6.1 Optical efficiency of parabolic trough collector

Optical efficiency is defined as the ratio of the energy absorbed by the receiver to the energy Incident on the collector's aperture. And alternatively ratio of the rate of net thermal energy available at the absorber/receiver to the incident beam radiation available at the absorber/receiver after absorption and transmission.

The optical efficiency depends on the optical properties of the material involved, the geometry of the collector, and the various imperfections arising from the construction of the collector [36]. The parameters that are affecting the optical efficiency are indicated on the figure below

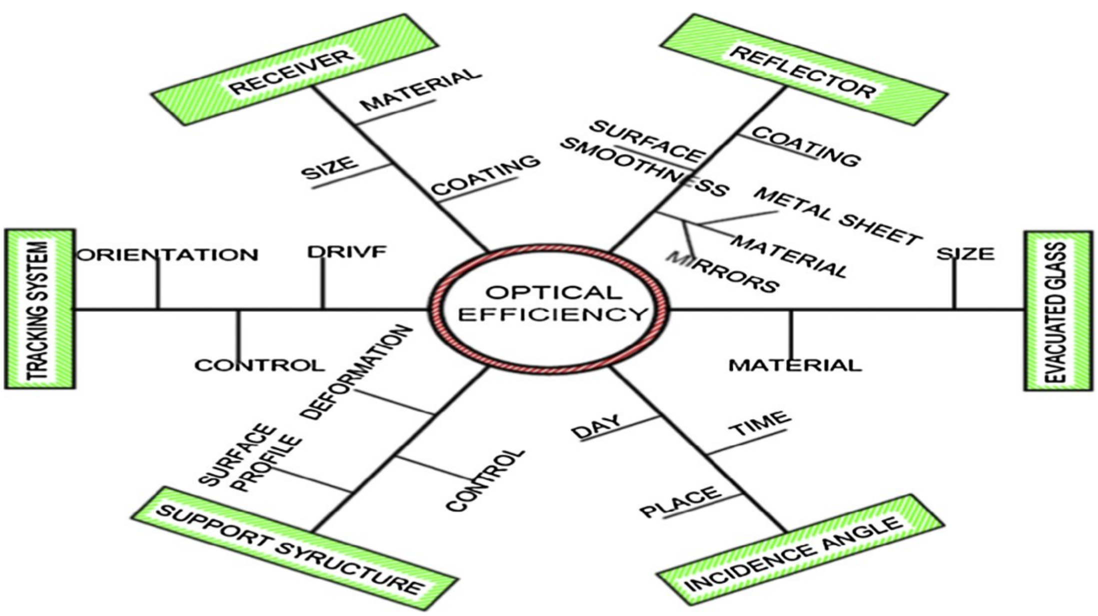


Figure 3.30 parameters affecting the optical efficiency [36]

The optical efficiency can be given as [36]

$\eta_o = \rho\tau\alpha\gamma[1 - A_f \tan\theta \cos\theta]$...3.47

where,

η_0=optical efficiency

ρ =the reflectivity of the mirror

τ=the transmittance of the glass cover

α =Absorptance of the receiver

θ =angle of incidence

γ =Intercept factor

A_f=geometric factor

Alternatively the optical efficiency can be given as

$\eta_o= \rho\tau\alpha\gamma K(\theta)X_{end}$……………………………………………………………………………………3.48

The geometry of parabolic trough collector dictates the geometric factor which is defined as a measure of effective reduction the aperture area due to incidence effects including blockages, shadows and loss of radiation reflected from the mirror beyond the end of the receiver.

During abnormal operation of PTC, some of the rays reflected from near the end of the concentrator opposite the sun cannot reach the receiver. This is what we call end effect.

The amount of aperture area lost is given by

A_e=f$w_a \tan\theta[1+\frac{w^2{}_a}{48f^2}]$……………………………………………………………………………………… 3.49

Where A_e=aperture area lost and all other parameters are indicated in previous part.

Most of the time, collectors of this type are terminated with opaque plates to preclude unwanted or dangerous concentration away from the receiver. These plates result in blockage or shading of a part of the reflector, which in effect reduce the aperture area. For a plate extending from rim to rim the area is shown in figure below can give mathematically as:

$A_b=\frac{2}{3}w_a h_p \tan\theta$…………………………………………………………………………………………………3.50

Where,

hp=height of parabola

A_b=area of blocking

Then, the total loss in aperture area (A_l) is the summation of two above indicated area. That is given by

$A_L=A_e+A_b=$ f$w_a \tan\theta[1+\frac{w^2{}_a}{48f^2}]+\frac{2}{3}w_a h_p \tan\theta$……………………………………………………………………3.51

Finally, the geometric factor is the ratio of the lost area to the aperture area, therefore

The geometric factor would be if there is an opaque plate.

$A_f = \frac{A_l}{A_a}$..3.52

And the geometric factor if there is no opaque plate described in this work can be

$A_f = \frac{Ae}{A_a}$..3.53

And alternative mathematical expression

$\eta_o = \frac{\dot{q}u}{\tau\alpha Ib}$..3.54

The net thermal energy ($\dot{q}_u$) available on the receiver can determined as [44]

$\dot{q}_u = \eta_o \alpha\tau I_b$..3.55

3.3.6.2 Collector Incidence angle modifier

The incidence angle of modifier can be defined as the ratio of collector thermal efficiency at the given angle of incidence to the peak efficiency at the normal incidence.

And also incidence angle of modifier accounts the effects of decreasing and increasing of incidence angle .The incident angle modifier relies on the geometrical and optical properties of the collector. Due to the fact that reflectivity, transmissivity, and absorptivity depend on the incident angle of the solar radiation, an angle modifier is needed to correct for when radiation is not normal to the surface. Incident angle modifiers are used to account for errors in solar alignment, errors in concentrating contours, and errors in displacement of receiver outside of the focal plane. These errors must be accounted for because all of these cause shifts and enlargements of the solar images, which can greatly reduce the efficiency of the system.

It can be generated by empirical fit to experimental data, and it is described as a polynomial function of the absolute value of (θ)[47].

The general formula of incident angle modifier can be given as for longitudinal plane is

$K(\theta) = 1 - \frac{f}{l}(1+\frac{a^2}{48f^2})\tan\theta$..3.56

And also the regression analysis of polynomial function as [47]

$K = \cos(\theta) - B(\theta) - C(\theta)^2$..3.57

where,

k is the incident angle modifier

θ is solar beam incidence angle

B is the coefficient for linear term

C is coefficient for nonlinear term

The above equation can be simplified and the most important equation that works for applied temperature between ambient and 390℃, the incident angles from 0to 60°and at any isolation level from 100 to 1100w/m2 can be given as follows:

K=cos(θ)-0.0003512(θ) $-$ 0.00003137$(\theta)^2$..3.58

And the from above indicated equation, the variation of incident angle modifier with incident angle can be shown in the figure below for longitudinal plane.

Figure 3.31 Incidence angle modifier versus incidence angle

Figure 3.31indicates that incidence angle modifier value between 0.83 to 1 when the incidence angle 0 to 60 degree. This shows the incidence angle modifier approaches to 1 for minimum angle of incidence.

3.3.6.3 End loss

When the incidence angle is zero, the reflected solar radiation from the concentrator hit the entire heat collection element(HCE).If angle of incidence starts to increase some length near the end of receiver tube is not illuminated by solar radiation shown in the figure below. These losses are addressed with the term of end losses.

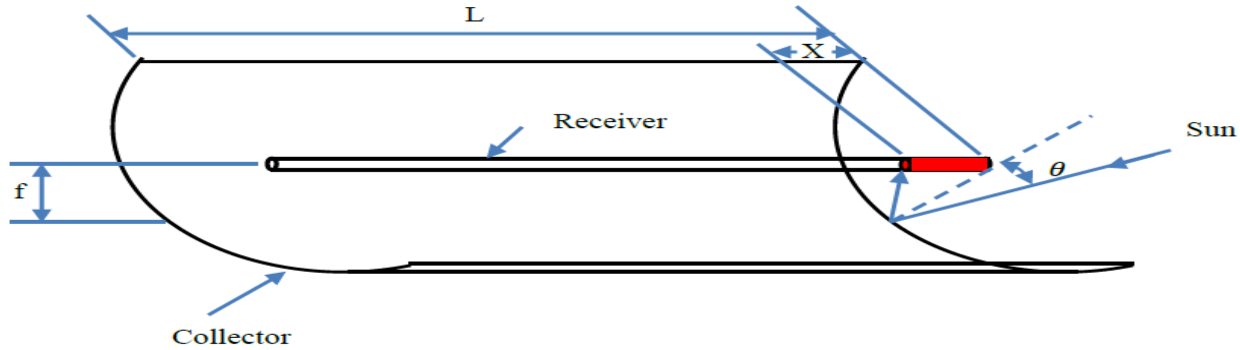


Figure 3.32 End losses [8]

The distance X which is the part of HCE that is not illuminated can be calculated as it follows:

$X = f \tan\theta$ 3.59

The end losses which are a function of the focal length of the collector, length of the Collector, and angle of incidence is defined by the following relation given below.

$X_{end} = 1 - \frac{f}{L}\tan\theta$ 3.60

Where,

f=the focal length of collector

θ=incident angle

L=length of single collector

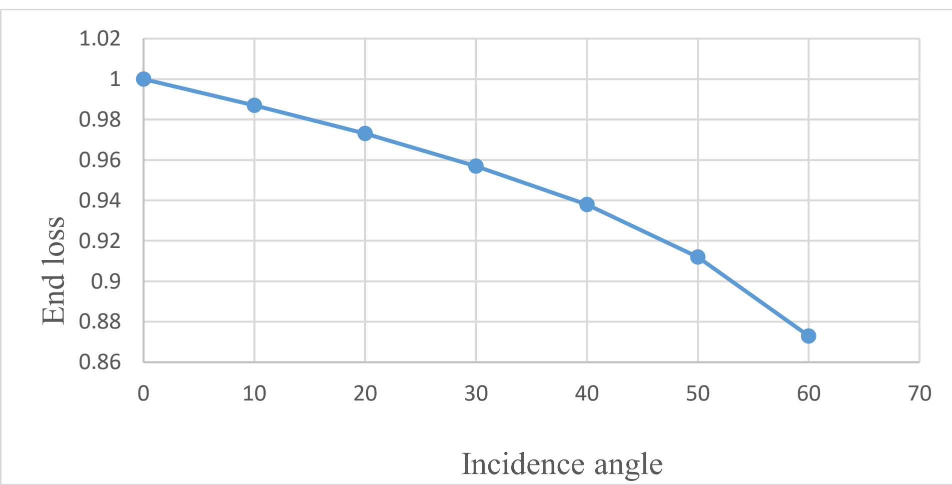


Figure 3.33 End loss versus incidence angle for East west tracking

Figure 3.33 Indicates that the end loss is varies from the value of 0.873 to 1,this implies that the end loss value is very close to 1which means there is almost no end loss occur.

3.3.6.4 Instantaneous thermal efficiency (η_i)

The instantaneous thermal efficiency can be defined as the ratio of useful energy available at the absorber or receiver to the beam energy incident on the aperture. And it is given by the following formula as shown [44]

$$\eta_i = \frac{\dot{q}u}{I_b} \qquad \text{3.61}$$

where,

qu=the rate of useful energy available

Ib=beam energy incident on the aperture

Alternative equation for instantaneous efficiency natural mode can be

$$\eta_i = [\rho\alpha\tau - \frac{1}{C} U_L \frac{T_r - T_a}{I_b}] \qquad \text{3.62}$$

Where,

T_r=the temperature of the receiver in kelvin

C=concentration ratio

Without thermal heat losses from the receiver the optical efficiency is equal to instantaneous thermal efficiency and given by [37]

$$\eta_o = \eta_i = \rho\alpha\tau \qquad \text{3.63}$$

where,

ρ=the reflectivity of mirror

α=is the absorptivity of absorber coating

τ=the transimittivity of the glass cover

3.3.6.5 Intercept Factor, γ

The intercept factor can be defined as the ratio of the energy intercepted by the receiver to the energy reflected by the focusing device.

The value of intercept factor can be depends on the size of receiver, for typical concentrator or receiver design the value of intercept factor is greater than 0.9 and for normal incident (on aperture) radiation it is unity.

Since the diameter was held at 25mm the intercept factor can be determined as 0.95 from the graph indicated [30] and it is also factor affecting optical efficiency. Ideally, if the mirror and receiver are aligned perfectly and the tracking drive system is perfect and the mirror surface is clean without surface imperfections, the intercept factor is unity. But, most of the time some errors related to collector, imperfection of mirror surface and misalignment of the mirror exists as the result of manufacturing and assembly of parabolic trough collector system.

The factors that affect the intercept factor are the following

- Heat collection element (HCE) shadowing (bellows, shielding, and support)
- Tracking error
- Geometry error (mirror alignment)
- Dirt on mirrors
- Dirt of heat collection element (HCE)
- Unaccounted

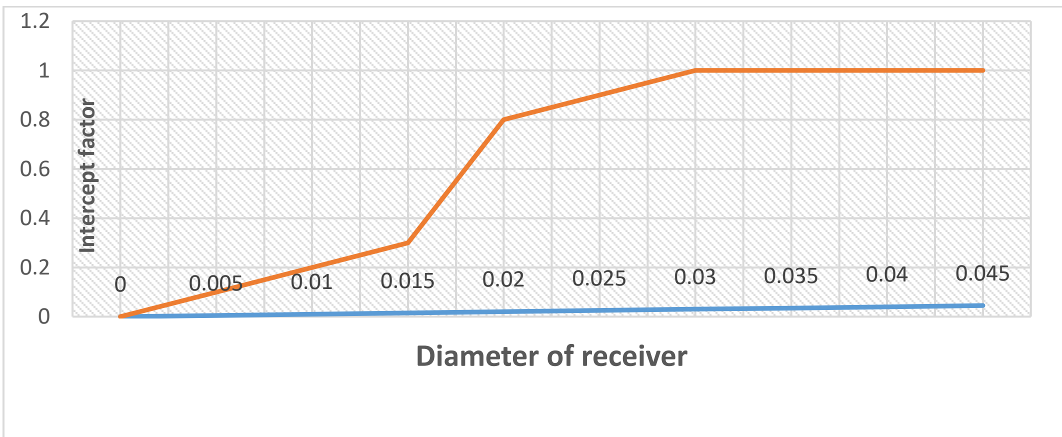


Figure 3.34 The graph of intercept factor versus the diameter of the receiver [30].

3.3.7 The thermal performance of parabolic trough collector

Most of the time, parabolic trough collectors are supplied with accurate tracking systems in order to keep the parabolic trough perpendicular to the sunrays and diffuse the random rays that cannot be reflected on the focal point of the parabola. The performance and analyzing the performance of the PTC requires deep analysis of both gain and losses of the system.

In generally it is the fact that there are four major factors effecting the energy generated by the system which are: the collector's thermal properties, settings of the heat collector's elements, optical properties of the system, and ambient conditions for the chosen region of the site location.

The performance of parabolic trough collector can be determined by using different equation considering the fluid temperature at the field inlet and the out let of the solar collector field accordingly.

Therefore the net heat gain by parabolic trough is given by the following equation [12]

Q_{net}=$\dot{m}c_p(T_{out} - T_{in})$..3.64

And alternatively using [12]

Q_{net}=$Q_{abs} - Q_{pipe} = Q_{gain} - Q_{lost}$..3.65

The heat gained by the receiver of the parabolic trough collector can be given as [12]

Q_{abs}=$A_{eff*Ib*\eta_{sf}}$...3.66

A_{eff}=W*L...3.67

where

A_{eff}=the effective area

w=width of the collector

L=the length of collector

Ib=the direct beam irradiance

η_{sf} =the collector efficiency

3.3.7.1 Piping

In the operation of solar power plant the piping heat losses are taken into account and basically important in mathematical model.

$Q_{pipe} = Q_{loss}$=$A_{ro}U_L(T_r - T_a)$...3.68

Where,

A_C=Area of collector

U_L=Over all heat loss

T_r=Temperature of the receiver in Kelvin measurement

T_a=Temperature of the ambient

3.3.7.2 Estimation of solar collector overall heat loss coefficients.

The loss coefficient considering convection, radiation from the surface and the conduction through support structure. Estimation of the conduction losses requires the knowledge of the construction of collector, the way receiver is supported. But, when compared to radiation and convection, the conduction loss by supports is very small and it is neglected. The heat loss coefficient (U_L), based on the receiver area can be determined by the following formula [47].

U_l=$[\frac{A_r}{(h_{w+h_{r,c-a}})A_c} + \frac{1}{(h_{r,r-c+}h_{c,r-c})}]^{-1}$..3.69

The convective (wind) heat transfer coefficient of the glass cover with atmosphere (ambient temperature),$h_{c,c-a=}h_w$ can be calculated by [38].

$h_{c,c-a=}h_w = \frac{N_u k}{D_c}$……………………………………………………………………..…3.70

First the Reynold's number needs to be estimated at mean temperature $T_{av} = \frac{T_g+T_a}{2}$

R_e=$\frac{V\rho D_c}{\mu}$…………………………………………………………………………………3.71

Where,V=wind velocity (m/s)

$T_{c=}The\ glass$ cover temperature°C

T_a =Ambient temperature°C

For the wind loss coefficient,the Nusselt number(Nu) and the Reynolds number (Re) can be used.

For 0.1<R_e<1000,

N_u=0.4+0.54$(R_e)^{0.52}$……...........………………………………………………………..3.72

For 1000<R_e<50,000

N_u=$(R_e)^{0.6}$……………………………………………………………………………3.73

The radiation heat transfer coefficient,$h_{r,c-a}$ for the glass cover to the ambient is calculated by [38]

$h_{r,c-a}$=$\varepsilon_c\sigma(T_c + T_a)(T_c{}^2 + T_a{}^2)$………………………………………………………....3.74

ε_c=Glass cover emissivity

σ=Stefan Boltzmann constant=5.67*$10^{-8}\frac{W}{m^2k^4}$

The radiation heat transfer coefficient,$h_{r,r-c}$, between the receiver tube and the glass cover is calculated by [45].

$h_{r,r-c}$=$\frac{\sigma(T_r{}^2+T_c{}^2)(T_rT_c)}{\frac{1}{\varepsilon_c}+\frac{A_r}{A_c}[\frac{1}{\varepsilon_c}-1]}$…………………………………………………………………..3.75

ε_r=Receiver emissivity

The convection heat transfer coefficient,$h_{c,r-c}$ from the receiver to the cover can be estimated by [45]

$h_{c,r-c}$=$\frac{N_u k}{D_r}$……………………………………...……………………………………………3.76

The properties of air at the film temperature of $T_{f=}\frac{T_r+T_c}{2}$

The natural convection Nusselt number (Nu) in this case can be determined from

$$Nu=\{0.6+\frac{0.387R_{aD}{}^{\frac{1}{6}}}{[1+(\frac{0.559}{pr})^{\frac{9}{16}}]^{\frac{8}{27}}}\}^2 \quad \ldots 3.77$$

The characteristic length in this case is the outer diameter of the pipe, $L_{c=}D_c$, then the Rayleigh number becomes

$$R_{aD}=\frac{g\beta(T_r-T_c)D_r{}^3}{\vartheta^2} \quad \ldots 3.78$$

To check the temperature of the glass cover, T_c from the energy balance becomes [46]

$$A_g(h_w+h_{r,c-a})(T_g-T_a)=A_r(h_{c,r-c}+h_{r,r-c})(T_r-T_a) \quad \ldots 3.79$$

Solving the above Equation for T_c gives

$$T_c=\frac{A_r(h_{c,r-c}+h_{r,r-c})T_r+A_c(h_w+h_{r,c-a})T_a}{A_c(h_w+h_{r,c-a})+A_r(h_{c,r-c}+h_{r,r-c})} \quad \ldots 3.80$$

In order to estimate T_r, an energy balance is performed on the receiver tube and calculated written equation as [46]

$$T_r=T_{f,m}+\frac{mc_pT_{fo}-T_{fi}}{\pi D_{r\,ext}Lh_{fi}} \quad \ldots 3.81$$

Where, $T_{f,m}$ is mean fluid temperature at the receiver. $T_{f,m}=\frac{T_{fi}+T_{f,o}}{2}$

h_{fi} is convective heat transfer coefficient inside the receiver tube($\frac{W}{m^2k}$)

Another thing to be considered is the estimation of overall heat transfer coefficient (U_o).

When the consideration taken into account linear concentration in the receiver, the heat transfer resistance from the outer surface of the receiving tube to the fluid in the tube should include the tube wall because the heat flux in the concentrating system is high.

Based on the outside receiver tube diameter, the overall heat transfer coefficient between the surrounding and the fluid can be determined as follows [47].

$$U_O=[\frac{1}{U_L}+\frac{D_{ro}}{h_{fi}D_{ri}}+\frac{D_{ro}(\ln D_{ro}/D_{ri})}{2K}]^{-1} \quad \ldots 3.82$$

Where,

k is the thermal conductivity of receiver

h_{fi} is convective heat transfer coefficients inside the receiver tube(w/m2.k)

The heat transfer coefficient h_{fi}, can be obtained from the standard pipe flow equation.

To determine the heat transfer coefficient let us consider whether the flow is laminar or turbulent.

For laminar flow in the smooth circular tube, the nusselt number can be obtained from the Modified sieder-Tate equation:

$Nu=\frac{hD}{Kf}=1.86(\frac{DR_ePr}{L})^{\frac{1}{3}}$..3.83

Where,

D is the inner diameter tube

L is the length of the tube

Re<2300

And also fully developed turbulent flow in the smooth circular tube the nusselt number can be determined from Dittus-Boelter equation:

$Nu=0.023(Re)^{0.8}(Pr)^{0.4}=hD/k$..3.84

Re>2300

After the determining of nusselt number the heat transfer coefficient (h_{fi}) can be calculated as

$h_{fi}=\frac{\text{Nu inside receiver tube x}K_f}{D_{ir}}$ 3.85

Where, Kf is the thermal conductivity of HTF and it should be found from mean fluid temperature. The Reynolds number can be expressed in the following relation

$Re=\frac{U_mD_{ri}}{\nu}=\frac{U_mD_{ri}\rho}{\mu}$...3.86

Where,

U_m=is the mean fluid velocity over the tube cross section.

Another alternative equation for Reynolds number reduces, when for flow in circular tube ($Ac=\pi/4{D_{ri}}^2$)

$R_{eD_{ri}}=\frac{4\dot{m}}{\pi D_{ri}\mu}$..*3.87*

The Prandtl number (pr) can given by:

$p_r=\frac{c_p\mu}{k_f}$...3.88

The kinematic viscosity of the fluid is given by:

$\nu=\frac{\mu}{\rho}$..3.89

Where,

μ=Fluid viscosity (kg/m-s)

It is basically important issue considered to work in mean velocity, when dealing with internal flows because the velocity varies over the cross section and there is no well-defined free streams.

The rate of mass flow through the tube is given by the following expression as follows:

$\dot{m}$=ρu_{mA_c}...3.90

For steady, incompressible flow in the tube of uniform cross section area,$\dot{m}$ and U_m are constant independent of x

The way of calculating the performance of parabolic trough collector similar to the flat plate collector. There are some difficulties are taken into account for determination of thermal losses from receiver or absorber due to the following main factors:

These are: the shapes and the design of the receiver are widely variable, the temperatures are higher, the edge effects are more significant, the conduction terms are very high and the radiation flux on the receiver is not uniform, the optical consideration on energy balance of absorber and this indicates that substantial temperature gradient across the energy absorbing surface.

By considering the steady state energy balance on the fluid element flowing through the pipe length between x and x+dx. The fluid temperature at x and x+dx are T_f(x) and T_f(x)+dT_f(x) respectively when the working fluid inlet temperature T_{fi} is allowed to flow in the x-direction.

Then, the useful energy gain per unit length of collector fluid can be determined as follows (47):

$\grave{q_u}$=$F'\frac{A_a}{L}$(S-$\frac{A_r}{A_a}U_L(T_f - T_a)$=$\dot{m}c_p\frac{dT_f}{dx}$...3.91

The rate of thermal energy in W can be given as

$\dot{Q}_u$ =$F' A_a$(S-$\frac{A_r}{A_a}U_L(T_f - T_a)$..3.91a

And also the rate of thermal energy in w/m2 can be given as

$\dot{q_u}$=$\frac{\dot{Q}_u}{A_a}$=F'(S-$\frac{A_r}{A_a}U_L(T_f - T_a)$..3.91b

Where F' is collector efficiency factor

by solving one order differential equation to determine the out let fluid temperature expression.

Finally the above equation gives

$\frac{T_{fo}-T_a-S/UL}{T_{fi}-T_a-S/UL}$=exp(-$\frac{U_L A_c F'}{\dot{m}c_p}$)...3.92

When the fluid enters the collector at temperature of T_{fi}at initially at x=0 and T_f increases in the temperature until the exit is T_{fo}at x=L can given by:

T_{fo}=[($\frac{A_a}{A_r}$)$\frac{1}{U_L}$S+T_a][1-exp(-$F'\frac{A_r U_L}{\dot{m}c_p}$)]+$T_{fi}$exp($-\frac{A_r U_L}{\dot{m}c_p}$)..3.93

The collector efficiency factor F' defined as the ratio of between the thermal resistance from the receiver /absorber surface to the ambient air and the thermal resistance from the fluid to the ambient. Mathematically determined as follows [47].

$$F'=\frac{U_O}{U_L}=\frac{\frac{1}{U_L}}{\frac{1}{U_L}+\frac{D_O}{h_{fi}D_i}+\frac{D_O}{2k}\ln(\frac{D_O}{D_i}}\ \ldots\ 3.94$$

Where,

U_o=Heat loss coefficient

U_L=Over all heat transfer coefficient

The theoretical useful energy from parabolic trough solar collector for tubular absorber can calculated by equation as

$\dot{Q}_u$=$\dot{m}c_p(T_{fo}-T_{fi})$=$A_a F_R$[S-$U_L$($\frac{A_r}{A_a}$)($T_{fi}$-$T_a$)..3.95

A_r=πD_{rex}L...3.95a

A_P=(W-$D_{r\ ext}$)L..3.95b

Where

$\dot{m}$=mass flow rate of the heat transfer fluid

c_p=specific heat

T_{fo}=out let temperature of solar field

T_{fi}=inlet temperature of solar field

F_R=the collector heat factor of the concentrator

The collector heat removal factor is a quantity that relates the actual useful energy gain of the collector to the useful gain if the whole collector surface were the fluid inlet temperature and is determined as[**38**]

F_R=$\frac{\dot{m}c_p}{A_r U_L}$[1-exp($\frac{F' A_r U_L}{\dot{m}c_p}$)]...3.96

It convenient to define collector flow factor F''as the ratio of $F_R to F'$ to show equation above graphically.

F''=$\frac{F_R}{F'}$=$\frac{\dot{m}c_p}{A_r U_L F'}$[1-exp($\frac{F' A_r U_L}{\dot{m}c_p}$)]...3.97

Experimental thermal efficiency can be calculated as follows

$$\eta_{exp}=\frac{Q_{u\,exp}}{I_b A_a} \quad \text{......3.98}$$

3.3.8 Collector pressure drop and Friction factor

Basically, a drop in the initial pressure occurs due to the viscosity of the HTF and to evaluate the pressure drop in the PTC, the properties of fluids are evaluated at average temperature in the absorber. The estimation of pressure drop is with assumption of internal flow in a straight pipe because this parameter determines the power requirement of PTC.

Friction factor

To determine the friction factor, a correlation for the smooth surface condition that encompasses a small Reynolds number range for laminar flow has been written as

$$f=\frac{64}{R_e} \quad \text{......3.99}$$

And also the pressure drop can be calculated as

$$\Delta p=f\,\rho_{HTF}V^2\left(\frac{L}{2d_i}\right) \quad \text{......3.100}$$

Where,

R_e Represents the Reynolds number inside the absorber pipe

d_i the internal diameter of the absorber pipe

ρ_{HTF} the density of heat transfer fluid

V the velocity of HTF inside the pipe

L the length of absorber pipe

Δp the pressure drop

3.3.9 Helical coil condenser

Condenser which used in this study is shell and coil type water condenser and is basically a tank filled with the water and copper coil immersed in and attached to the tank and when the steam passes through copper coil, it gives heat to the water and gets converted to the liquid form to produce the desalted water to the society. This type of condenser is not that much cost and it is possible to use economically poor people.

Condensers are sized based on the heat load, the logarithmic mean temperature difference between the steam and coolant streams and over all heat transfer coefficient. The overall heat transfer coefficient (U), can be estimated from individual heat transfer coefficient of the gas stream and the coolant.

The important input parameters which are used during the design of helical coil condenser are discused below in detail.

The length of coil that assumed for small mass flow rate of this work is 2m

Tube outer diameter =do=20mm=0.02

Tube thickness=t=2mm

Inner diameter of the shell=Di=192mm

Outer diameter of the shell=Do=232mm

Coil diameter =Dc=212mm=0.212m

From above input parameters the rest ones are determined.

The coil length and the number of turn's relation can be determined as,

L=N$\sqrt{C^2} + P^2$……………………………………………………………………….3.101

Where

C=circumference of the stirrups

P=pitch (spacing of the stirrups)

P=1.25do……………………………………………………………………………….3.102

P=1.25*20=25mm

Circumference of the stirrups (c)

C=πDc……………………………………………………………..……………..3.103

C= $\pi * 212$=665.65mm=0.6656m

The number of turns of the coil N is so calculated from this expression

L=N$\sqrt{C^2} + P^2$

N=$\frac{L}{\sqrt{C^2+P^2}}$=$\frac{2}{\sqrt{0.6656^2+0.025^2}}$=3 the numbers of turn of the coil N=3

The length of the shell can be determined as

L_{sh}=p*N=25mm*3=75mm

The volume occupied by the coil, Vc=$\pi \frac{do^2Lc}{4}$……………………………………..……..……….3.104

Vc=$\pi \frac{do^2Lc}{4}$==$\pi \frac{0.002^2*2}{4}$=6.28*$10^{-4}m^3$

The volume of the shell occupied is Vsh=$\frac{\pi}{4}(Do^2 - Di^2)$ PNcoil…………………….……………3.105

Where

Do=outer diameter shell diameter

Di=inner diameter of shell

P=Pitch

N=number of coils

V_{sh}=$\frac{\pi}{4}$ $(0.232^2 - 0.192^2)$ *0.025*3=9.985*$10^{-4}m^3$

The volume available for the flow of fluid in the annulus Vf=Vsh-Vc……………………………..….3.106

V_f=9.985*$10^{-4}m^3$ −6.28*$10^{-4}m^3$ $= 3.7 * 10^{-4}m^3$

The shell side equivalent diameter of the coiled tube can be determined as

De=$\frac{4Vf}{\pi doLcoil}$…………………………………………………………………………….…3.107

De=$\frac{4*3.7*10^{-4}}{3.14*0.02*2}$=0.011m

From over all energy balance of hot and cold fluid the actual heat transfer rate can be determined as follows:

Q=$(\dot{m}c_p)(T_{h1} - T_{h2})$=$(\dot{m}c_p)_c(T_{c2} - T_{c1})$..3.108

Where,

$\dot{m}c_p$=the capacitance rate of hot side fluid

$(\dot{m}c_p)_c$=the capacitance rate of cold side fluid

Q =the actual heat transfer rate

T_{h1}=The temperature of hot fluid inlet to the condenser

T_{h2}= The temperature of hot fluid out let from the condenser

T_{c1}=cold water inlet temperature

T_{c2}=cold water out let temperature

And also the maximum possible heat transfer rate for both temperature rise of cold and the temperature drop of hot fluid is from($T_{h1} - T_{c1}$) would be:

Q_{max}=$(\dot{m}c_p)_{min}(T_{h1} - T_{c1})$.. 3.109

The actual heat transfer that relates to the overall heat transfer coefficient (U) total surface area and the log mean temperature difference can be determined as:

Q=UAΔT_m.. 3.110

The overall heat transfer coefficient can be related to the inner and outer heat transfer coefficients by the following equation (U) can be

$\frac{1}{U}=\frac{Ao}{Aihi}+\frac{Ao\ln\frac{do}{di}}{2\pi kL_c}+\frac{1}{ho}$……………………………………………………………………………3.111

If there is inlet and out let temperature of the fluid streams are not given, a trial and error procedures are applied to find out log mean temperature difference. Since, to avoid these trial and error procedure another possibility by using number of transfer units (NTU) based on the concept of heat exchanger effectiveness is used.

Effectiveness (ε) can be defined as the ratio of actual heat transfer rate for heat exchanger to the maximum possible heat transfer rate.

$\varepsilon=\frac{Q}{Q_{max}}=\frac{(\dot{m}c_p)_h(T_{h1}-T_{h2})}{(\dot{m}c_p)_{min}(T_{h1}-T_{c1})}=\frac{(\dot{m}c_p)_c(T_{c2}-T_{c1}}{(\dot{m}c_p)_{min}(T_{h1}-T_{c1}).}$..3.112

Effectiveness can be expressed only in temperature terms if the cold or hot fluid has minimum capacitance rate.

The actual heat transfer rate that determined from above expression is given by

Q=$\varepsilon(\dot{m}c_p)_{min}(T_{h1}-T_{c1})$...3.113

The number of transfer units (NTU) is the dimensionless parameter that is widely used for heat exchanger analysis and given by:

NTU=$\frac{AU}{(\dot{m}c_p)_{min}}$..3.114

The dimensionless capacitance rate is given by

$C_r=\frac{(\dot{m}c_p)_{min}}{(\dot{m}c_p)_{max}}$..3.115

By considering the shell side fluid the correlation used can be the following.

Reynolds number shell side Re =$\rho uDe/\ \mu$………………………………………………………3.116

Prandtl number of shell side pr =$cp\mu\ /k$……………………………………………………………3.117

The Nusselt (turbulent) number Nu= 0.023$Re^{0.8}Pr^{0.5}$………………………………………3.118

The nusselt number for laminar flow Nu=1.86$(\frac{DeRePr}{L})^{0.333}$ ……………………………...3.119

For laminar flow Re<2300

And finally the coefficient of convective heat transfer shell-side

hs =$Nu\cdot k/\ De$

For coil side fluid, the properties are determined from the inlet and out let temperature and pressure condition and the correlation are,

Reynolds numbers are determined with considering the centrifugal force on the flux

The average velocity (u) = $\dot{m}/(\rho A)$……………………………………………………3.120

A= $\frac{\pi do^2}{4}$, A is the area of coil and do is outer diameter of tube. That is do=20mm

Then it is possible to calculate the Reynolds and prandtl number of the fluid, by considering the coil diameter Dc,

Rec = 2000$(\frac{do}{Dc})^{0.32}$……………………………………………………………..3.121

The equivalent diameter of the coil can be determined as De = Rec$(\frac{do}{Dc})^{0.5}$………………...3.122

The turbulent Nusselt number (the flow conditions) Nu=0.6$Re^{0.5}Pr^{0.31}$………………..…3.123

Optionally NU=0.023$Re^{0.85}Pr^{0.4}(\frac{do}{Dc})^{0.1}$…………………………………………….…3.124

The laminar nusselt number can be Nu=0.36$Re^{0.55}Pr^{0.33}$………………………………….3.125

The coefficient of convective heat transfer hc=$Nu \cdot k/\ d$o………………………………….3.126

The pressure drops and the friction factor can be determined by

Coil side, friction factor , fc=fs$[Re(\frac{do}{Dc})^2]^{\frac{1}{20}}$…………………………………………….3.127

Where, fs =0.046$Re^{-0.2}$…………………………………………………………………3.128

Pressure drops of the coil is calculated as,$\Delta p = \frac{2\rho f_c L_c u^2}{do}$………………………………...3.129

Shell side, friction factor f_s=8*0.023$Re^{-0.2}$…………………………………………….....3.130

Pressure drops of the shell,$\Delta p = \frac{\rho f_s L_s u^2}{2De}$ ……………………………………………….....3.31

3.3.10Manufacturing of parabolic solar collector

3.3.10.1 Description of fabricated PTC

Manufacturing of small scale parabolic trough collector is shown schematically in figure 5.1 and the parts are indicated as photo in figure 5.2.The PTC has been constructed and tested in this work. The constructed model installed North-South direction and tested on Adama town since it is difficult for transportation purpose of set ups from Diguna Fango and almost the solar radiation value is nearly the same, that implies the set up tested for Adama town works more effective and efficient for Diguna Fango without any kind of difficulties.

The experimental set-up used in this study consisted of the fabricated parts of the parabolic trough solar energy concentrator used for heating up the water to evaporation temperature to generate steam for producing distilled water.

The Parabolic trough collector frame can be tilted upto18.16° to increase the amount of radiation Intercepted and reduce reflection and cosine losses.

Experimental model location at a yard surrounded with high walls that is nearly work shop building of Adama university to reduce conventional heat losses due to wind because it is the major heat loss therefore higher thermal efficiency of the parabolic trough collector, height of the surrounded walls must be too high to avoid solar radiation shadow on the reflector at experiment time.

The fabricated parabolic trough solar energy concentration shown as photo in figure 5.1 below consists of the following components. These are reflector surface, reflector frame support, absorber pipe, the glass cover which is used fluorescent lamp, condenser coil that is shell and coil type, stands and the tracking systems by using manually were fabricated using rectangular hollow sheet sourced materials will be described as follows:

Figure 3.35 The schematic diagram for parabolic trough solar collector assembly for desalination.

And also in the figure 5.2 fabricated parabolic trough collector consists of the reflector surface, reflector frame, absorber pipe, the glass cover which is used fluorescent lamp.

Figure 3.36 parabolic trough collector with the receiver

3.3.10.2 RHS support frame of the PTC

The fabricated RHS support frame as shown in figure below, the parabolic trough collector curve was made by rolling the aluminum sheet metal of the dimension 1m by 1m .When rolling machine makes the aluminum sheet as circular curve and for this purpose, rolling for some extent according to the dimension of parabolic trough and making the support for the curve depending up on mainly on focal length and the height of parabola. Then, the three curves welded together with the support and indicated in the figure 5.3 below. The total supporting structure used for parabolic trough collector without using the condenser and storage tank (RHS) 39m length with the thickness of 4cm. And also the parabolic trough collector dimensioned as 3m by 0.88m.

Figure 3.37 support for sheet metal

figure 3.38 parabolic curve with supporting

Figure 3.39supporting stand for parabolic trough collector

3.3.10.3 Receiver tube, glass cover (florescent lamp) and glass mirror used for reflector.

Receiver tube is made up of copper tube due to its high thermal conductivity material and is placed on the focal line axis, so working fluid inside is heated up due to concentrating solar irradiation using collector surfaces. Receiver tube of one end is connected with collecting tank and other side is connected with condenser setup. The glass cover used in this work is florescent lamp due to its availability and low cost material used to reduce the heat loss of the parabola and the only difficulty in florescent lamp is easily brittle that makes using of the lamp for the setup is more series.

The three fluorescent lamps are used for as glass cover and the glass mirror used for to maximize the reflection of parabola and it dimensioned as 50cm by 4cm. Since if the glass cut into 4cm by 4cm it better to reduce the heat loss but 3m length parabola making it 4cm by 4m is very difficult .For this purpose the dimensions are taken as 50cm by 4cm and totally number of 150 mirrors are used.

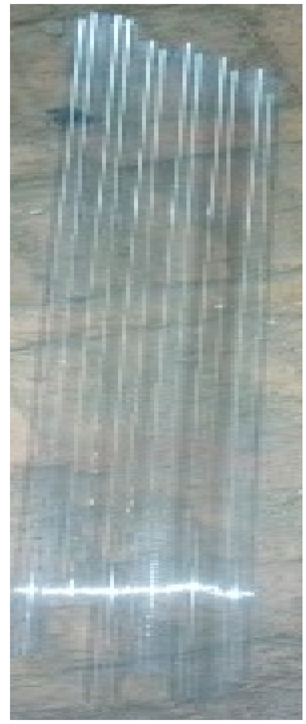
  

Figure 3.40 receiver tube Figure 3.41glass mirror as an reflector Figure 3.42 Florescent lamp

3.3.10.4 Thermocouple

The thermocouple is inserted at the inlet and outlet of the receiver tube to sense the inlet and outlet temperature of the working fluid. From the arrangement, the temperature at each time interval can be measured. The most commonly used digital thermometer is K type thermocouple with the measurement range of -200°C to 1250°C.

Four channel digital thermometer specification

-Temperature range:-50°C°Cto 1350°C

-serial number: 2019002867

-Resolution: 0.1 °C $for < 1000$°C: 1°C $for > 1000$°C

-Accuracy:$\pm$[0.015%rdg + 1°C(1.8°F)

-Storage temperature and humidity:-10 to 60°C and 10 to 75% RH

- Power supply: 9v

-Weight: approx.-230g

Figure 3.43 k type thermocouple (digital thermometer)

3.3.10.5 Fabrication of helical coil condenser.

Helical coil condenser is basically important when,under conditions of laminar flow or low flow rates where a shell and tube heat exchanger would become un economical because of the resulting low heat transfer coefficients.

The most commonly used material for condenser is copper. The basic reason for this material selection is due to its tolerance to high temperature and the resistance to scaling caused by calcium sulphate which would decrease the thermal efficiency and potential cause of mechanical problems.

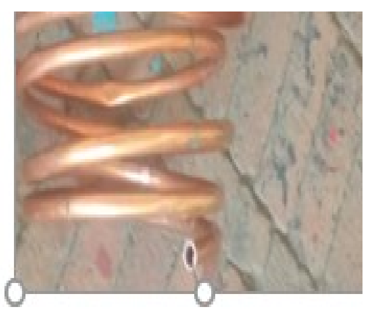


Figure 3.44copper coil

Figure 3.45 shell and coil condenser

3.3.11 Operation procedure

The following steps to be followed before starting the experiment, during the experiment and after finishing the experiment as follow:

1 Cleaning the reflector (mirror strips) from the accumulated dusts or dirt's this can be achieved by clean rug (clothes).

2 Fill the jar of feed water by clean brackish water.

3 Check if there is damaged parts (i.e. broken glass envelope, broken mirror and unfixed heat transfer insulation materials).

4 Regulating the flow rates.

5 Ensure there are not any leaks.

6 Manually check the rotation of parabolic trough collector east to west as per sun's rotation from east to west.

7 Move the parabolic trough collector to be normal to the solar beam radiation.

8 Ensure to insert thermocouples on the required position. i.e As mention earlier 1) inlet water to the absorber 2) at outlet of absorber pipe 3) inlet water before heat exchanger 4) out let water after heat exchanger 5) glass envelope temperature

CHAPTER FOUR

RESULTS AND DISCUSSION

4 INTRODUCTION

In this work the desalination of Diguna Fango Dimtu saline water by using parabolic trough collector carried out. One of the most important terms considered in this works are chemical analysis of saline water, solar radiation estimation of study area by using meteorology data, manufacturing of parabolic trough collector by using available material in the market, performance analysis of the parabolic trough collector and the field test was conducted at adama university on January 9-17,from 4:00 am until 3:00 pm and the reading were recorded with time interval of 40 minutes. Data of inlet and out let temperatures along with thermal efficiency and heat gained are plotted and demonstrated in detail.

4.1 chemical analysis of the water

The analysis of both input saline water and desalinated water from the parabolic trough solar desalination system had done. The physical and chemical analysis are done at adama university chemistry laboratory by using the instruments like photometer(7100model),TDS or conductivity meter, PH meter and turbidity tube.

The basic consideration analysis for water chemistry are total dissolved solids, turbidity, PH value ,electrical conductivity, hardness of the water and major elements considered in the hardness are calcium and magnesium and some of the elements are discussed .

TDS: Total dissolved solids can be defined a, measure of the dissolved combined contents of all organic and inorganic substance present in the liquid water in molecular or ionized form. Most of the time this term related with salinity of the water. The primary concern weather there is high salinity or not can be determined from TDS value .The TDS can be measured by using two instruments .These are photometer (mode 7100) and microprocessor based conductivity /TDS meter (model 1601).TDS value of the water measured before desalination are 3830 mg/l and 3550 mg/l by using photo meter and TDS meter respectively. This value are nearly similar but somewhat different due to machine error or measurement error. The average value of two instrument before desalination plant is 3690mg/l or parts per million. And after the desalination by using parabolic trough collector TDS value can be reduced. Since, the amount of TDS for different days have different value obtained depending up on the incident solar radiation on the parabolic trough (the temperature that is reflected on the receiver). Nine days data are recorded and testing results of

TDS are 1167, 1115, 529, 911,980, 1009,525, 1007and 960. So,the average value can be 911.5ppm or 911.5mg/l.

Above showed value indicates that almost four days values are the best for drinking purpose and the rest values are even possible. The TDS value before desalination and after desalination shows the values are reduced and the performance of parabolic trough collector is good.

Hardness; Hardness of the water is one of the water quality problems throughout the world not only in Diguna Fango region. In general speaking 97% is only sea water (not preferable for drinking purpose) and only 3% of fresh water is accessible for human use and drinking purpose.

The basic character of hard water which prevents the lathering of the soap. The major cause is due to the presence of certain salts of magnesium, calcium and other heavy metals that are dissolved in it. Magnesium for before and after are 4and 3mg/l respectively and also calcium before and after are 8and 4 mg/l. The hardness of water before desalination is 35mg/l and after desalination it was 21mg/l. This value indicates that the water is not more hard as general and it possible to reduce using solar energy.

Turbidity: It is the amount of cloudiness in the water and it is because of suspended solids and colloidal matters. The cause of turbidity are silt, sand, mud, bacteria and other germs in the water. The measurement is taken into accounted in turbidity tube and before desalination the value of turbidity is 6NTU and after using parabolic trough collector the turbidity reaches 5NTU. This indicates the water is not more turbid due to it is the spring water from the ground.

PH: It is hydrogen ion concentration in water and also indicates the relative acidity or alkalinity. According to the world health organization (WHO) standard the drinking water should have the PH value between 6.5-8.5 interval are the accepted value. Before desalination the PH value is 8.45 and it is the maximum according to WHO. But, after using desalination by solar energy its value reaches to 7.92. Therefore, PH value measured after desalination is satisfactory for drinking purpose.

Electrical conductivity: conductivity is the ability of water to conduct electricity and the dissolved ions are the conductors as general. The major positively and negatively charged ions values are measured by using photo meter and microprocessor based conductivity meter/TDS meter and the ions like sodium, magnesium, potassium, calcium, chloride are measured. When dissolved ions increase salinity as well as conductivity increase and they are related to each other.

The conductivity of input water primarily measured is 5570 micro semiens/cm at 16.2℃ and after the parabolic trough collector used for desalination purpose is 3660 micro semiens/cm at Hence, this value indicates that conductivity decreased when the salinity content or TDS value decrease.

Composition of some measured elements and in compound forms analysis of water

Most of the time the chemical composition of water contains the following elements. These are calcium, magnesium, potassium, chloride, fluoride, manganese, sodium, sulphate, Nitrate and the like are indicated in the table below before and after desalination by using parabolic trough collector

Table 4.1 Composition of some measured elements and in compound forms analysis of water before desalination.

Potassium	2.3 mg/l	Nitrate	0.027 mg/l
Sodium	1.9mg/l	Nitrite	0.015 mg/l
Calcium	8 mg/l	Chloride	4.7 mg/l
Magnesium	4mg/l	Fluoride	1.3 mg/l
Boron	1 mg/l	Ammonia	0.02 mg/l
Iron	0.05 mg/l	Sulphate	165 mg/l it has cloudy color due to presence of sulphate ion($SO_4{}^{-2}$
Phosphate	25.4 mg/l		

Table 4.2 Composition of some measured elements and in compound forms analysis of water after desalination.

Potassium	1.7 mg/l	Nitrate	0.016mg/l
Sodium	1.1 mg/l	Nitrite	0.09mg/l
Calcium	4 mg/l	Chloride	2.9 mg/l
Magnesium	3 mg/l	Fluoride	1.09 mg/l
Boron	0.85 mg/l	Ammonia	<< 0.02 mg/l
Iron	0.01 mg/l	Sulphate	80 mg/l
Phosphate	37.2mg/l		

The above indicated values of the chemical analysis of water in elemental and compound forms shows that the values are decreasing considerably and the parabolic trough collector works effectively if there is abundant solar radiation in specific study area.

4.2 Average solar radiation estimation.

To determine average solar radiation, most of the measured data of the solar radiations are available for large number of regions in Ethiopia and for this region there is no measured data available use from weather base satellite (from internet) and therefore sun shine hours duration of Diguna Fngo Dimtu for three years of average (2015-2017) (source: S/N/N/P/R, Hawasa meteorology district). The geographical coordinates of Diguna Fango Dimtu Station: Latitude (L)= 5 40’ 17.6" N=$5.667°N$,Longitude=37 44’ 56.2’’ E=$37.749°E$ and Altitude is 1854m above sea level .

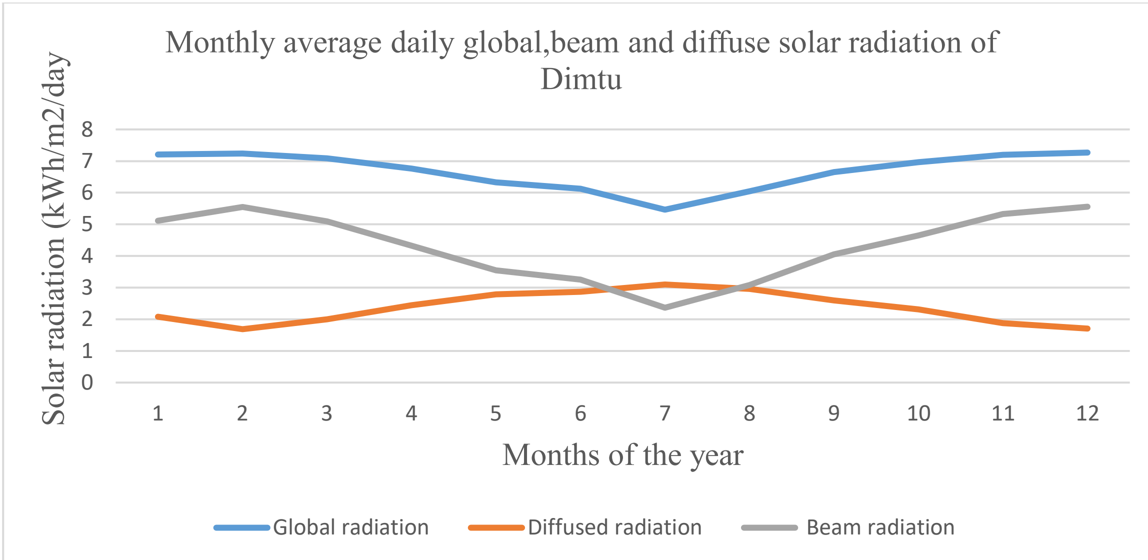


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Figure 4.1 Graph of Monthly average daily global, diffuse and beam of solar radiation of Dimtu.

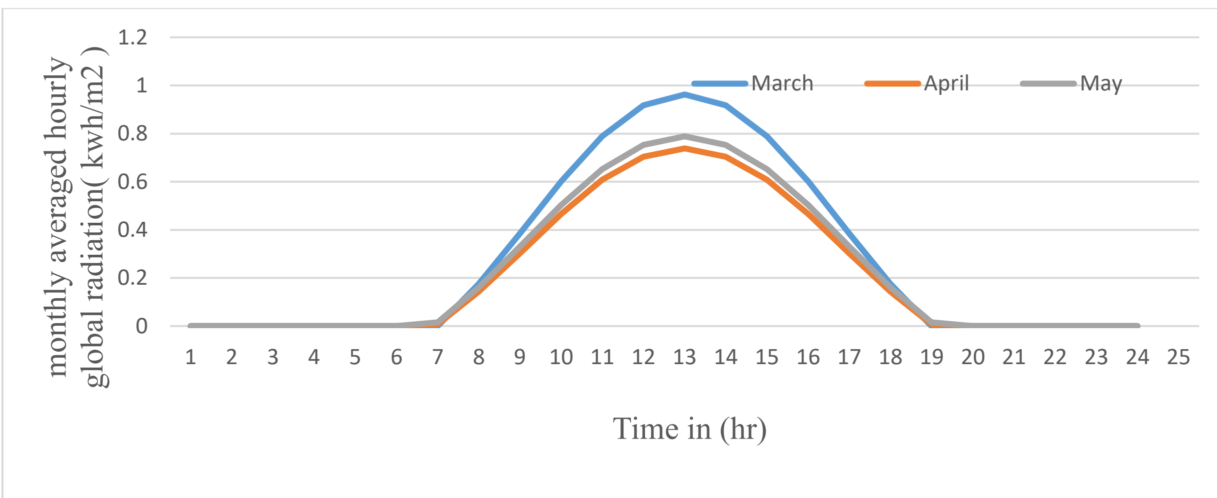

Figure 4.2 Monthly average hourly global radiation on a horizontal surface (kW/m^2) at spring season (March-May)

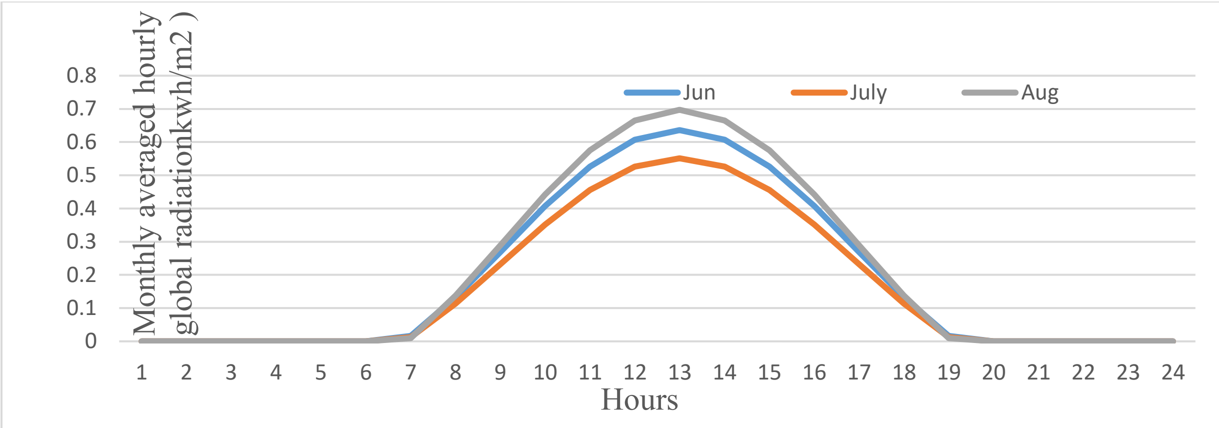

Figure 4.3 Monthly average hourly global radiation on a horizontal surface (kW/m^2) at summer season (June-August)

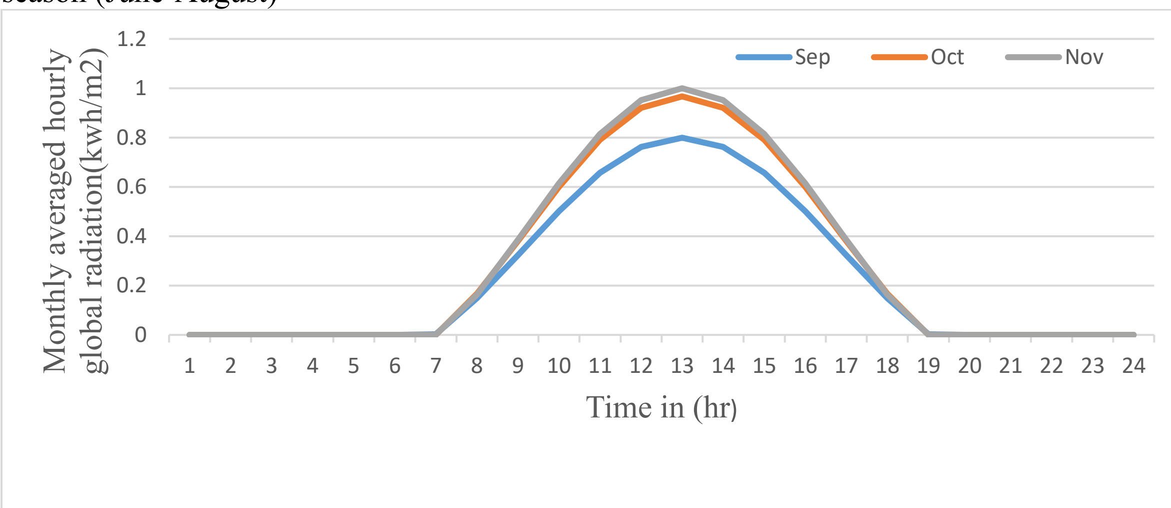

Figure 4.4 Monthly average hourly global radiation on a horizontal surface (kW/m^2) at autumn season (Sep-Nov)

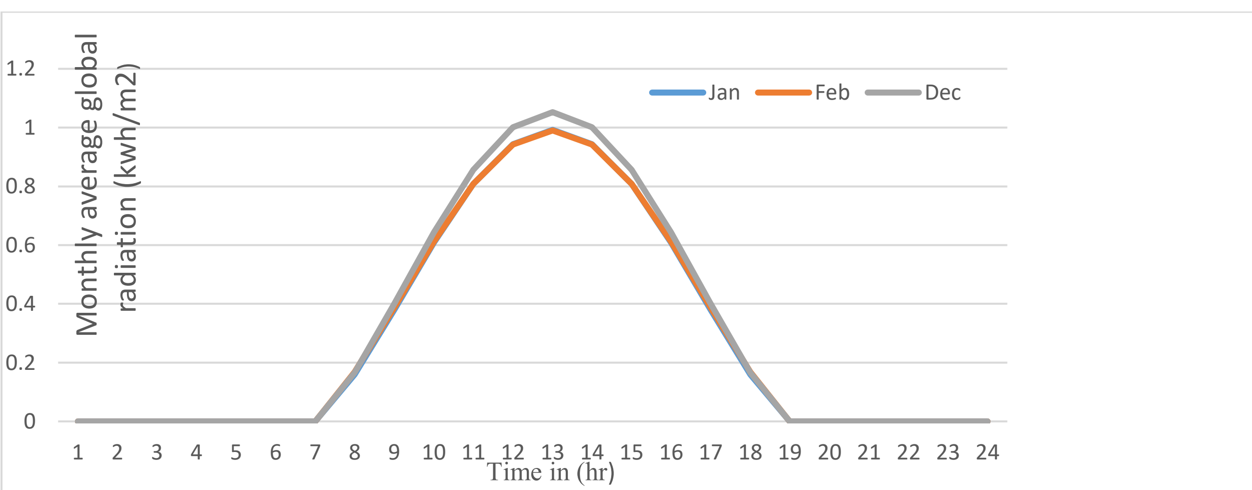

Figure 4.5 Monthly average hourly global radiation on a horizontal surface (kW/m^2) at winter season (Dec-Feb)

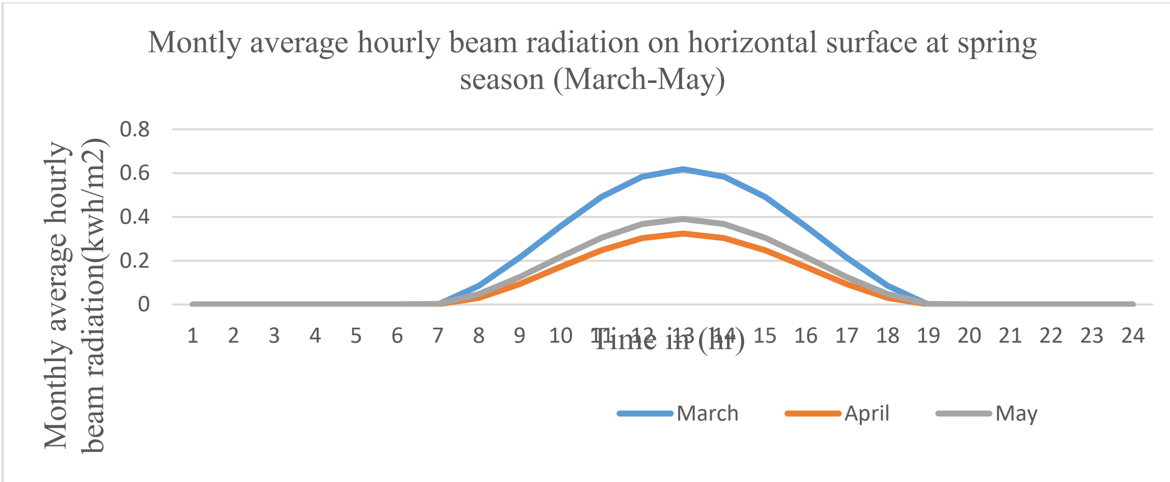

Figure 4.6 Monthly average hourly beam radiation on a horizontal surface (kW/m^2) at spring season (March—May).

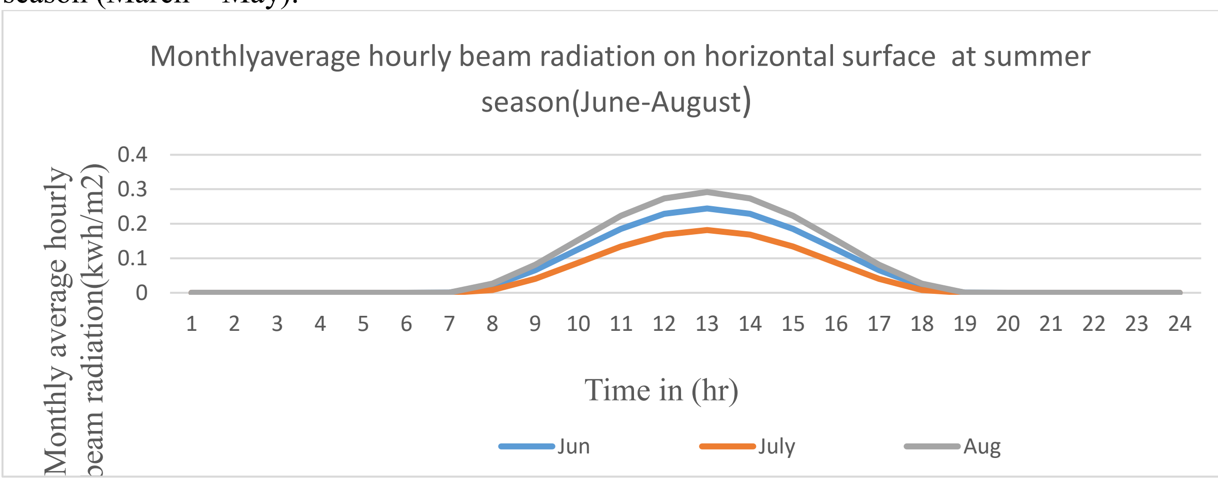

Figure 4.7 Monthly average hourly beam radiation on a horizontal surface (kW/m^2) at summer season (June-August)

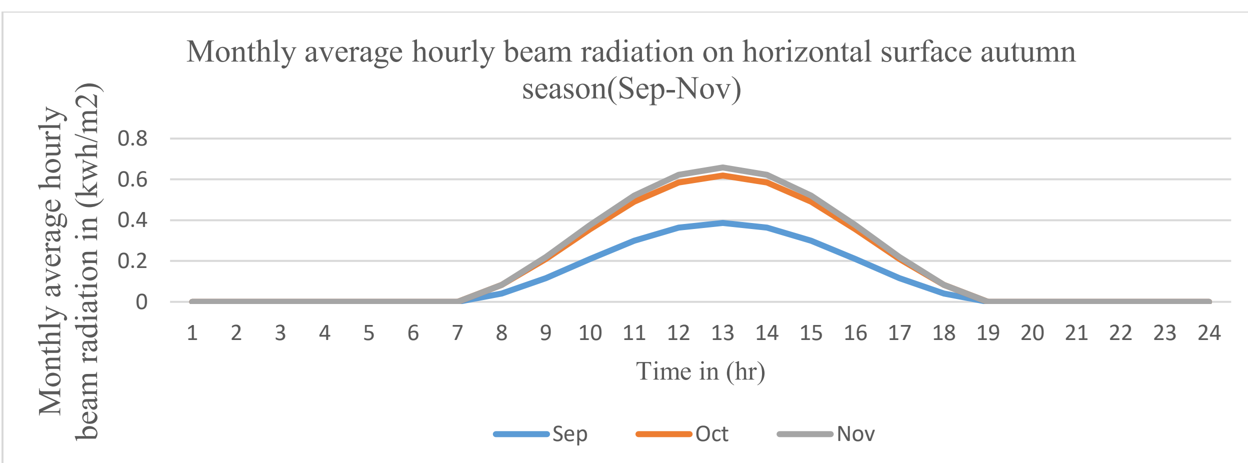

Figure 4.8 Monthly average hourly beam radiation on a horizontal surface (kW/m^2) at autumn season (Sep-Nov))

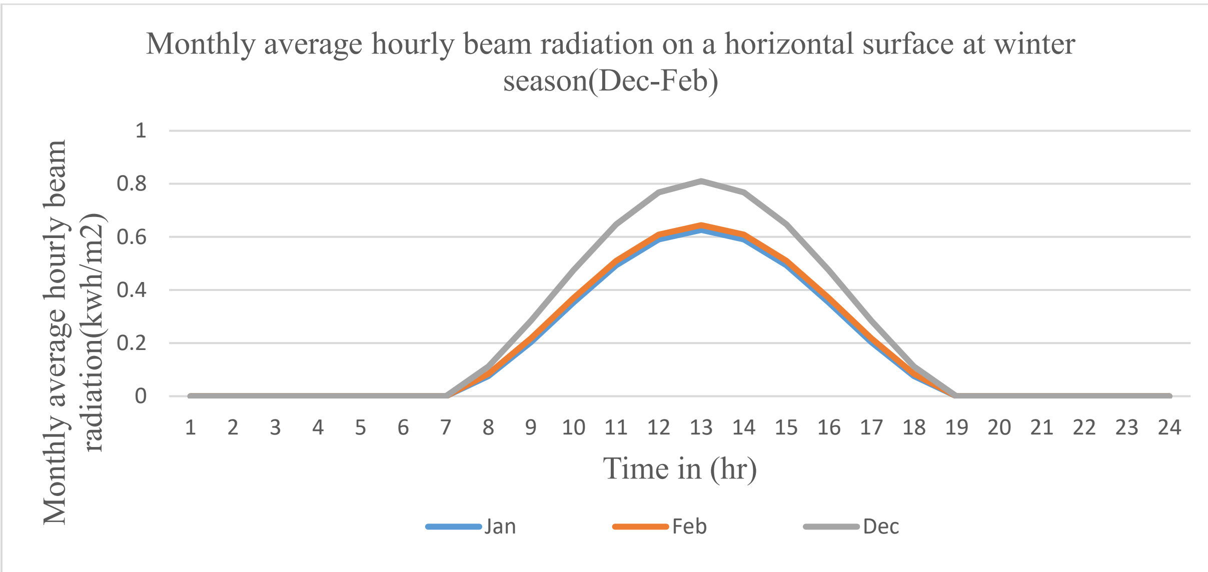

Figure 4.9 Monthly average hourly beam radiation on a horizontal surface (kW/m^2) at winter season (Dec-Feb)

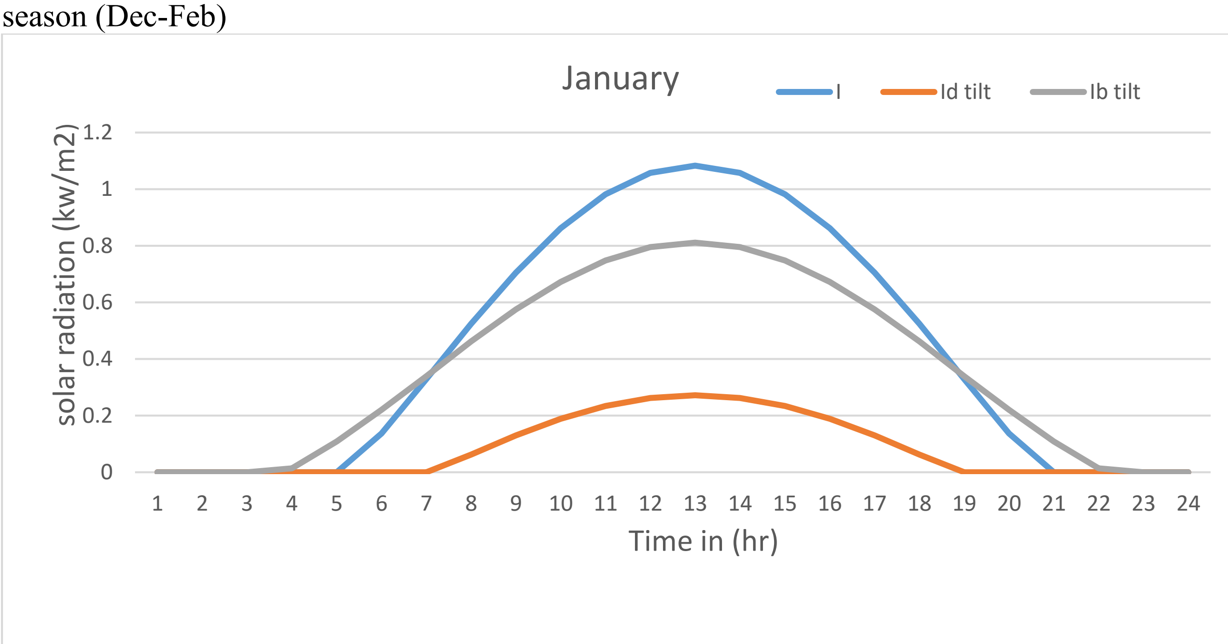

Figure 4.10 Tilted monthly average hourly solar radiation on horizontal surface for Jan.

4.3 Results of parabolic trough solar collector

The performance of parabolic trough solar collector is done by using experimental modeling. The experiment that was used to determine the following the most important parameter .These are mass flow rate, overall heat transfer coefficients ,heat loss of the parabolic trough collector ,optical efficiency , Temperature distribution on HTF, Temperature distribution on the receiver, collector efficiency factor, collector flow factor, collector heat removal factor, useful energy and thermal efficiency . For one family member the water used for drinking purpose assumed to be 10 liters. For desalination plant of parabolic trough solar the constant mass flow rate equal to 0.000583kg/s.

4.3.1 Optical efficiency of parabolic trough

The optical efficiency of the parabolic trough collector depends on the optical properties of the material involved, incidence angle modifier which varies throughout hour as function of incidence angle and the end loss of the parabola. However, the experiment tested on January 9-January 17, for nine consecutive day and taking into the average value for simplify the analysis from the time 10:00am-9:30pm. Shown in Figure 4.11optical efficiency of the parabolic trough collector varies from 71.6% to 58.4% when the incidence angle varies from 0 to 60 degree.

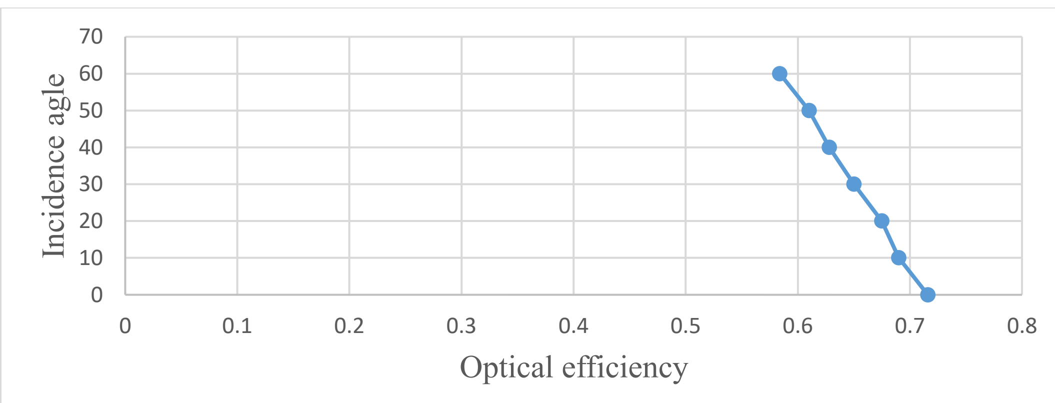

Figure 4.11 Daily mean optical efficiency of PTC

The above figure indicates that the maximum optical efficiency can be obtained when the incidence angle is zero. The graph shows the optical efficiency and incidence angles are inversely proportional to each other. When the optical efficiency decrease for large value of the angle of incidence. Thus, direct solar radiation is reflected and focused by the PTC, so it does not reach the receiver at large angles.

Mass flow rate

The mass flow rate in the collector for experimental testing are described below with corresponding fluid out let temperature for average solar radiation of 650 W/m^2.The mass flow rates are 0.000583, 0.000666, 0.00077, 0.000933 and 0.00116 kg/s.

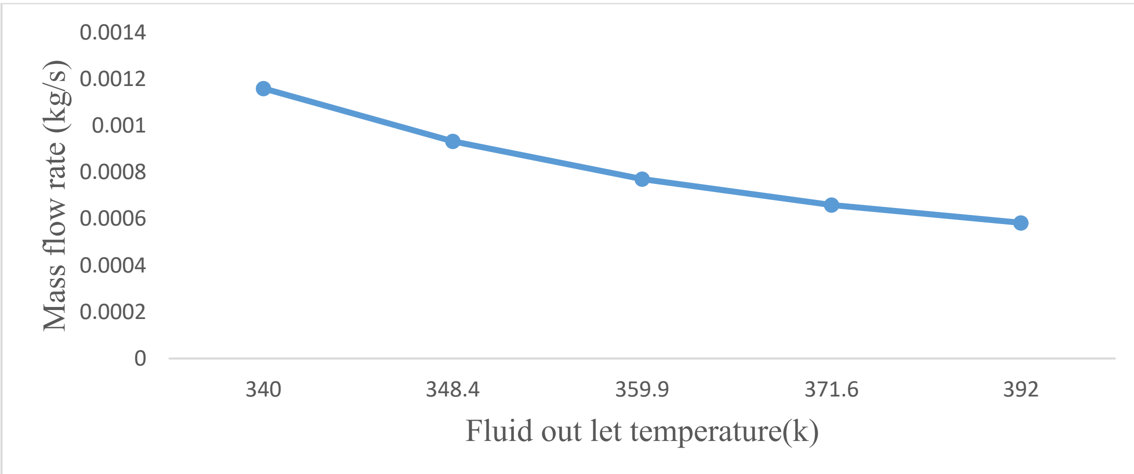

Figure 4.12 The variation of HTF outlet temperature with mass flow rate

As shown in the figure 4.12 above, mass flow rate increases; heat transfer fluid outlet temperature decrease. The mass flow rate of heat transfer fluid is selected depending up on the outlet heat transfer fluid temperature of 392k. Based on these selection criteria the mass flow rate of heat transfer fluid is equal to 0.000583kg/s. The mass flow rate required is very small because it depends up on receiver diameter and also solar radiation in the PTC.

4.3.2 Temperature distribution

Figure 4.13 variation of ambient temperature with time. The ambient temperature varied throughout the test day. As seen in figure 4.13, at the beginning of the test, the ambient temperature is low and it starts to increase as the time goes until it reaches maximum value.

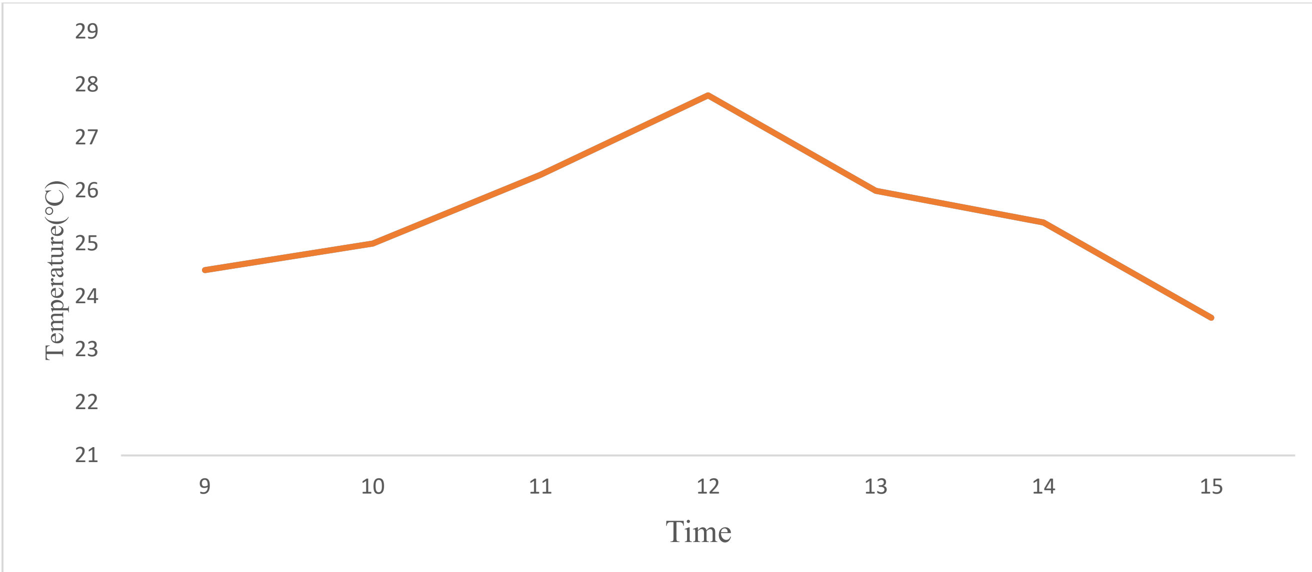

Figure 4.13 Ambient temperature in the test day

4.3.2.1 Experimental Temperature distribution

The data collected from the experimental testing are ambient temperature(Ta),inlet heat transfer fluid temperature(Ti),out let heat transfer fluid temperature,Glass cover temperature,Reciever temperature of PTC,inlet temperature of HTF to condensor,

Out let temperature of HTF from condensor,inlet temperatuture of water into condensor and out from condensor and desalinating time was measured at 40 minute interval for parabolic trough collector from beginning from 9 am up to3pm(9:00am-3:00pm) .The experimental data was measured by using the k-type thermocouple for all temperature values.The temperature distribution that is focused in the following section can be obtained from the experimental testing fom January 9 up to January 17 for nine consecutive days and for simplification purpose the average value can be used.

4.3.2.1a Heat transfer fluid temperature

Figure 4.14 shows the inlet and out let temperature of PTC during the experiment periodAt the beginning of the experiment the inlet and out let temperature of HTF does not show big difference and after then outlet HTF can increase simultaneosly with the increase of solar radiation with time.As it is seen in the figure below the maximum temperature of HTF is attained as 118℃around 12:20 and its value decrease down since temperature value depends on solar intensity.But, the expected temperature should be larger than this value and that is atributed to the error that occurred in the receiver,tracking error , heat loss of PTC and solar radiation of the day.The maximum temperature of HTF occur at 12:20 with sharp ends because the time interval for measuring of heat transfer fluid temperature is 40 minute,at that big time interval the temperature value decreased appropriaty.

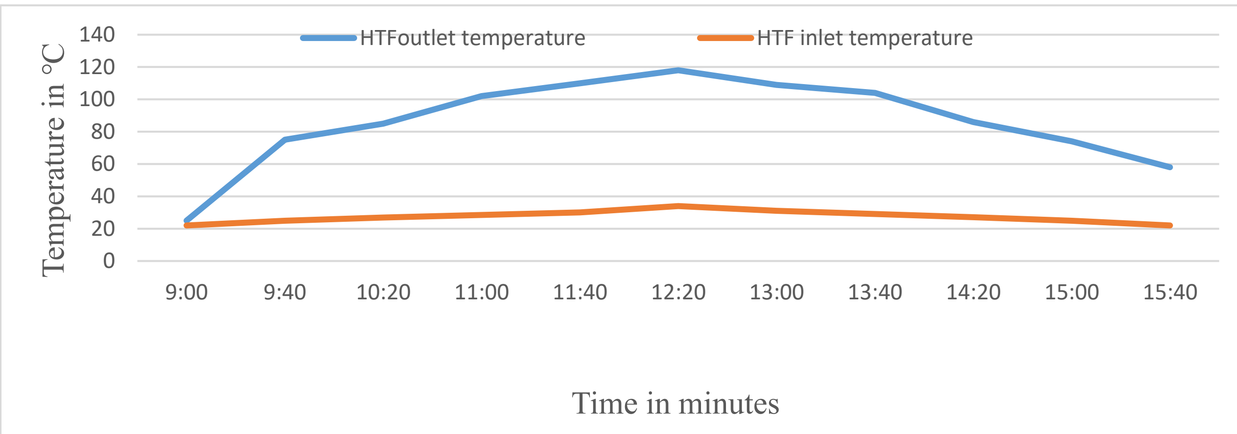

Figure 4.14Inlet and outlet heat transfer fluid temperature

4.3.2.1b Receiver and glass cover temperature

Figure 4.15 shows the temperature distribution of glass cover and the receiver,the result from the experiment indicates that at the beginning the glass cover temperature is 31.8℃ and increase with time and the maximum value obtained was 46.7℃. And also the receiver temperature at the beginning is 64.3℃ and its maximum value in the time 6:20 am is 128.4℃.

The temperature of value of the receiver indicated on the figure below taken from the end length of the receiver.

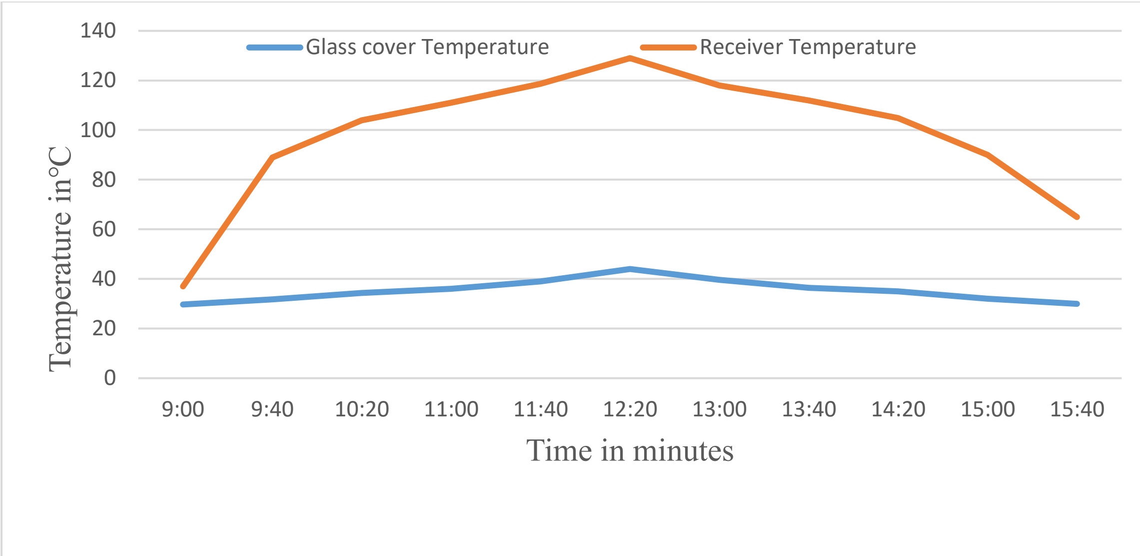

Figure 4.15Receiver and glass cover temperature

4.3.2.1c The receiver temperature versus the length of absorber.

The figure 4.16 shows the receiver temperaure versus the length of the absorber.The absorber length can be divided into 12 parts by 0.25 meter interval for the accuracy purpose and the temperature value increasing when the length of the tube increases and the maximum value attained at the end length. The measuring time was the 6:00 local time and the value of temperature at beginning 104°Cand it increases slightly and its value reaches128.4°Cat the end of the receiver.

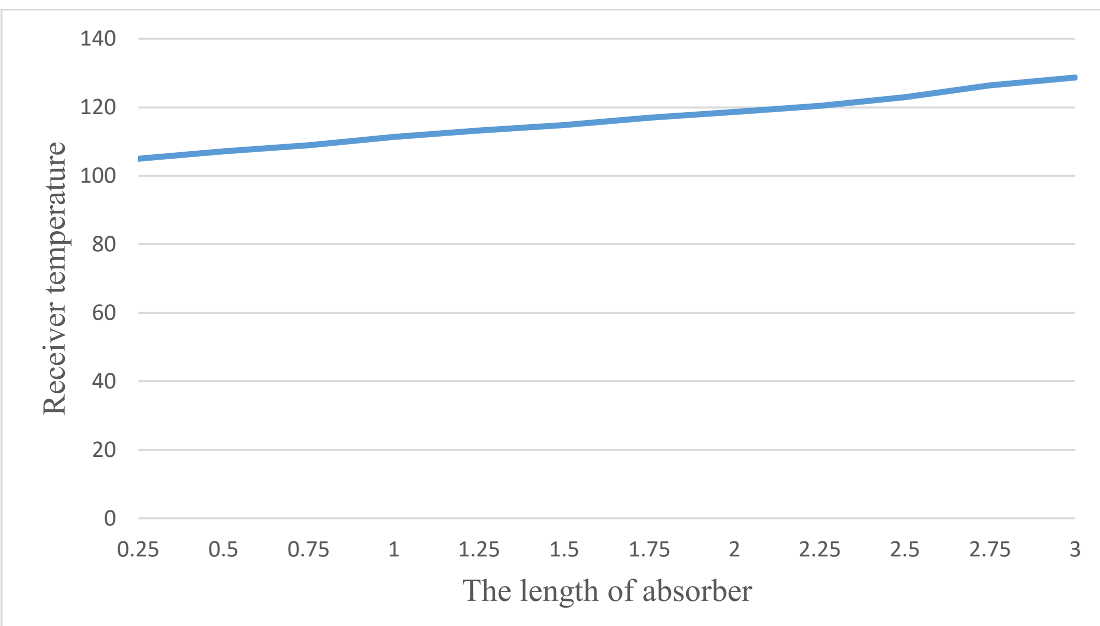

Figure 4.16 The receiver temperature variation with the length of absorber

4.3.2.1d Condensor Temperature distribution

Figure 4.17 shows the experimental results of condensor temperature and Inlet HTF temperature to condensor is almost the same with the outlet HTF temperature from the PTC.But,a little difference can be seen due to heat lost in the plastic tube that is attached with condensor inlet.When considering outlet HTF temperature fom condensor,the temperature value decreased at the time interval and the HTF is hot for some extent and it is possible for drinking purpose for staying 4 up to 5 minute for out side atmosphere. And also out let water temperature increased considerably some extent . From the figure below shows that at the time from 9:00 up to 11:00 and also from 13:40 up to 15:40 the temperature value less than 100°C and in this inteval of time desalination of raw water does not takes place due to the less time gap between test interval. So,it is better to take time interval more than 40 minute to desalinate raw water .

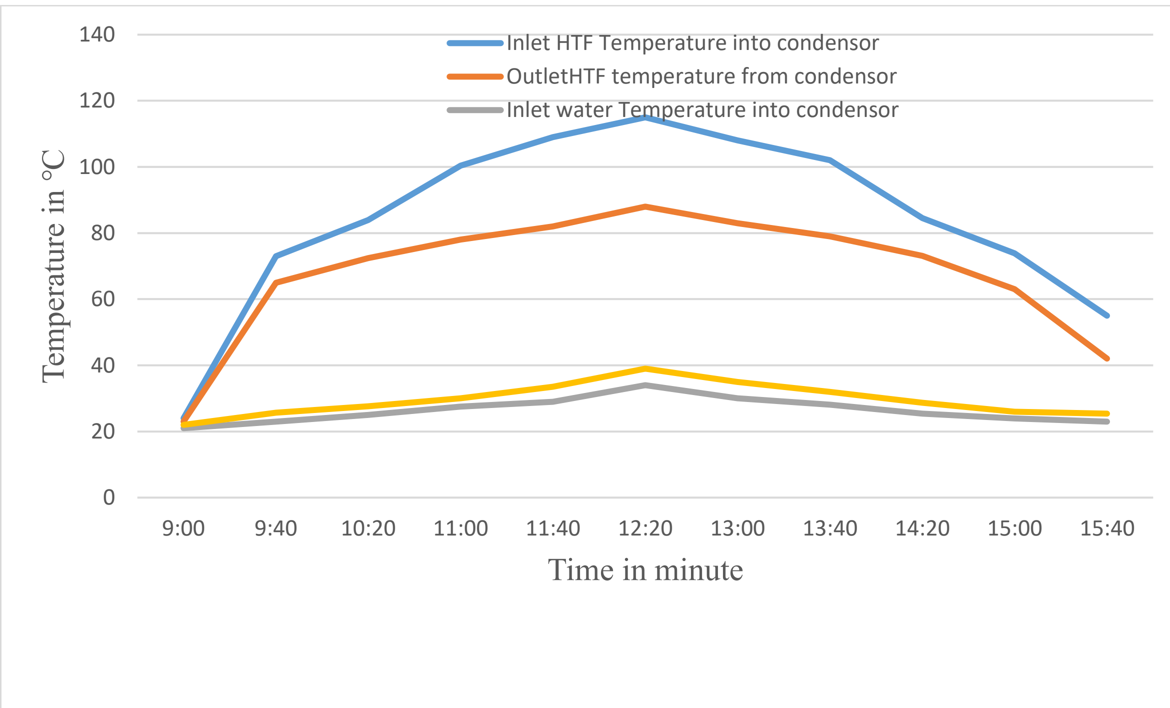

Figure 4.17 Condensor Temperature distribution

4.3.4 Heat losss coefficient

Figure 4.18 shows the thermal heat loss coefficients during experimental testing of PTC. This parameter is dependent on the temperature because the radiation losses are greater with higher operating temperature. It is obserbed that from the figure below ,the heat loss coefficient has low values because the vacuum between the absorber and cover.The loss coefficient value ranges from

1.65 W/m2 K to 2.26 W/m2 K which are low values and prove that there is low heat loss occurs .The maximum heat loss coefficient occurs at 12:20 and at that time temperature was also high.

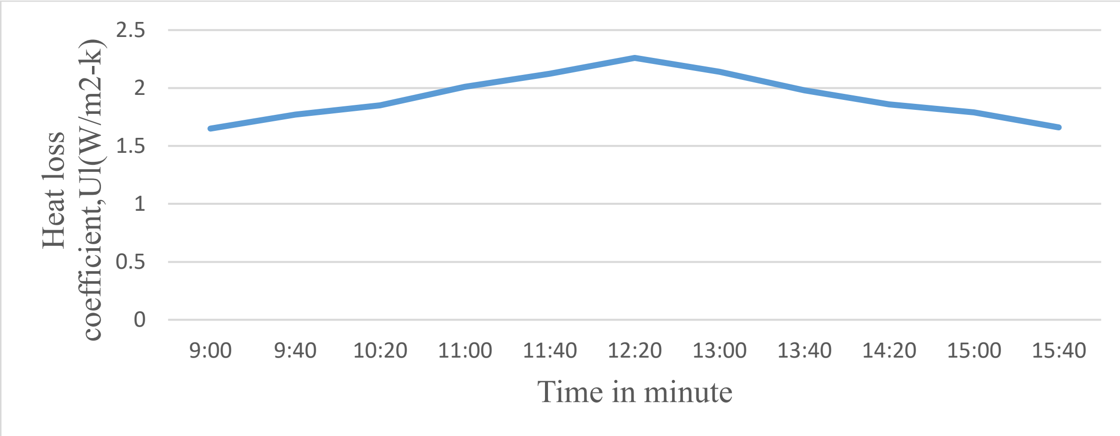

Figure 4.18Heat loss coefficient

4.3.5 Heat loss

Figure 4.19 shows the heat loss of PTC that was experimentally obtained and illustrates heat loss variation with the receiver operating temperature. Heat loss starts with the value of 14.33W at operating temperature of 37.8℃ and increase significantly along with increasing the operating temperature until reaching value of 52.51W at 125.62℃.

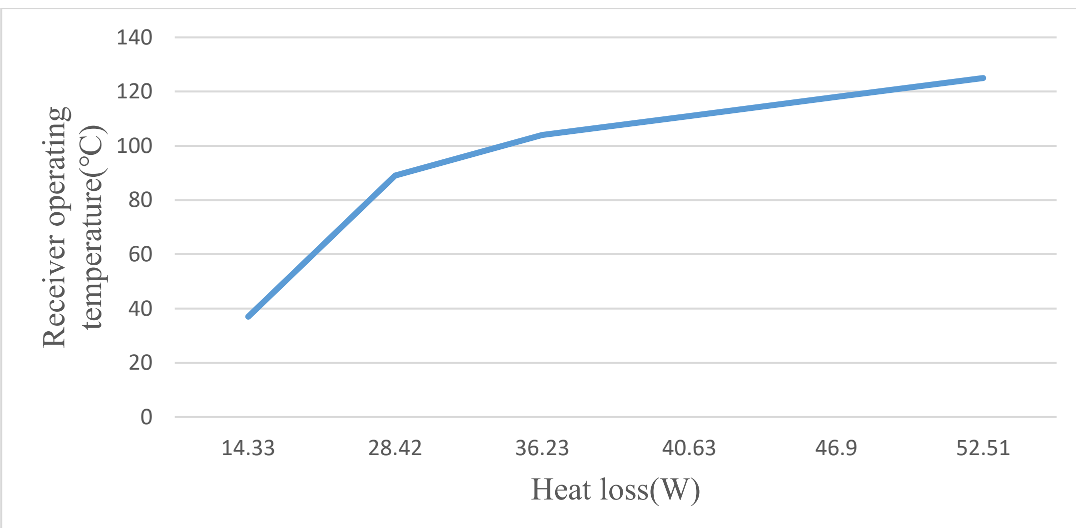

Figure 4.19 Variation of heat loss with receiver operating temperature.

4.3.6 Collector efficiency factor, Collector heat removal factor and Flow factor.

Figure 4.20 shows the relation between collector efficiency factor, collector heat removal factor and flow factor. These parameters are basically important to determine the performance of PTC

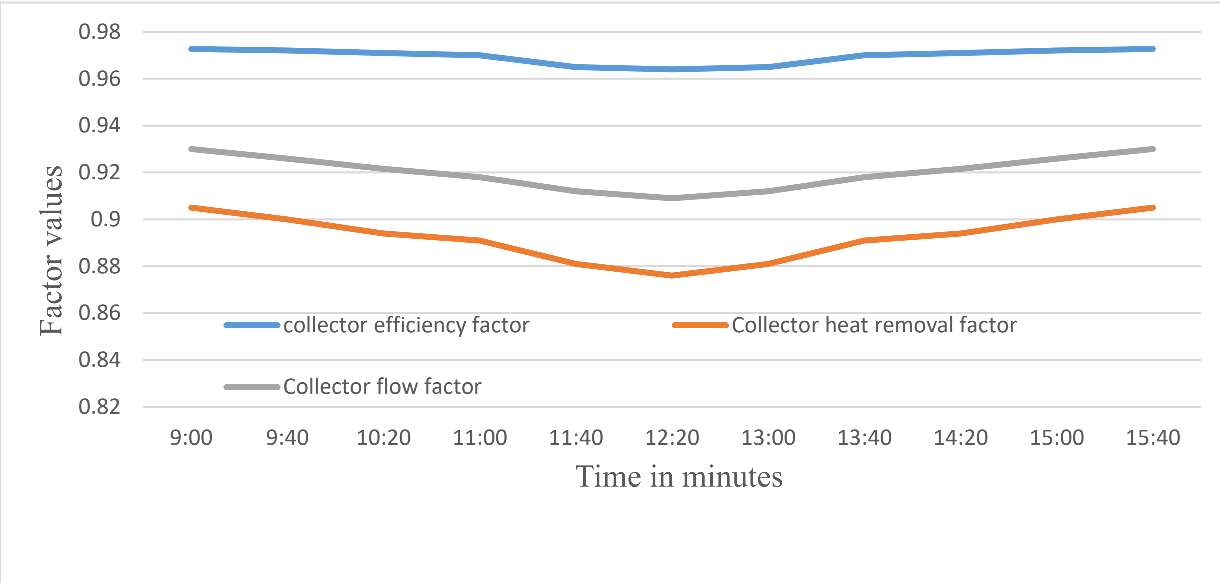

Figure 4.20 Collector efficiency factor, collector heat removal factor and flow factor

4.3.7 Useful heat gain

Figure 4.21 shows the relation between experimental and theoretical energy of PTC. The value in the figure below indicates that theoretical energy much more than actual useful energy. When actual useful energy reaching peak value (251W) at 12:20 and theoretical energy at the peak value is 652.8W at 12:20.

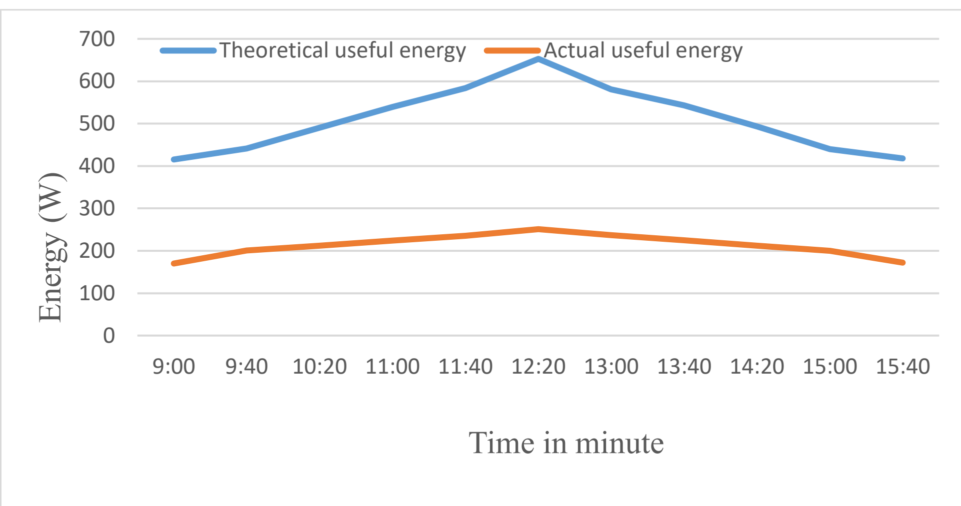

Figure 4.21 Actual useful and theoretical energy of PTC.

4.3.8Thermal efficiency

Figure 4.22 shows thermal efficiency during the experiment period. It can be noticed that the minimum efficiency value is 32.7% and the maximum obtained value is 41%.The maximum efficiency of the parabolic trough solar collector obtained at 12:20 because higher beam solar radiation occurs at this interval of time .The value that indicated in the figure below shows thermal efficiency was expected to be higher, but there are too many factors that affected it:

- Misalignment of the mirrors
- Misalignment of the tubes
- Tracking errors
- Low absorptivity of the absorber (degradation of absorptivity)
- Low transmissivity of the glass cover

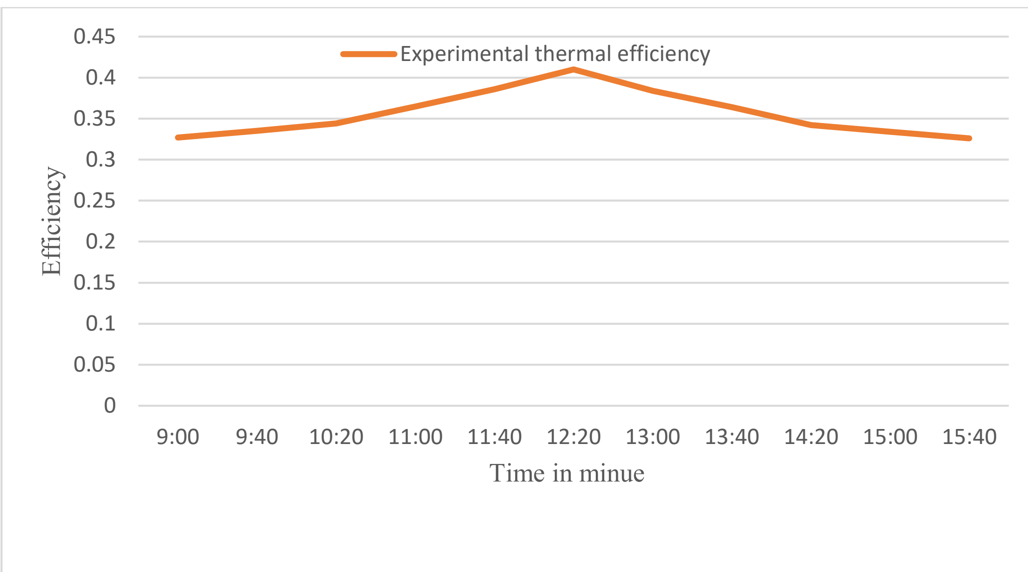

Figure 4.22Thermal efficiency

4.3.9 Pressure drop in PTC

The pressure drop inside the absorber pipe in PTC is calculated based on the formula discussed in section 5.7. Figure 4.23 shows the pressure loss across the PTC at different mass flow rates which logical replies the pressure drop relation, as the velocity increases so as pressure drop occur. The figure below indicates that there is small amount of pressure drop determined because the experimental measurement done with small mass flow rate achieved.

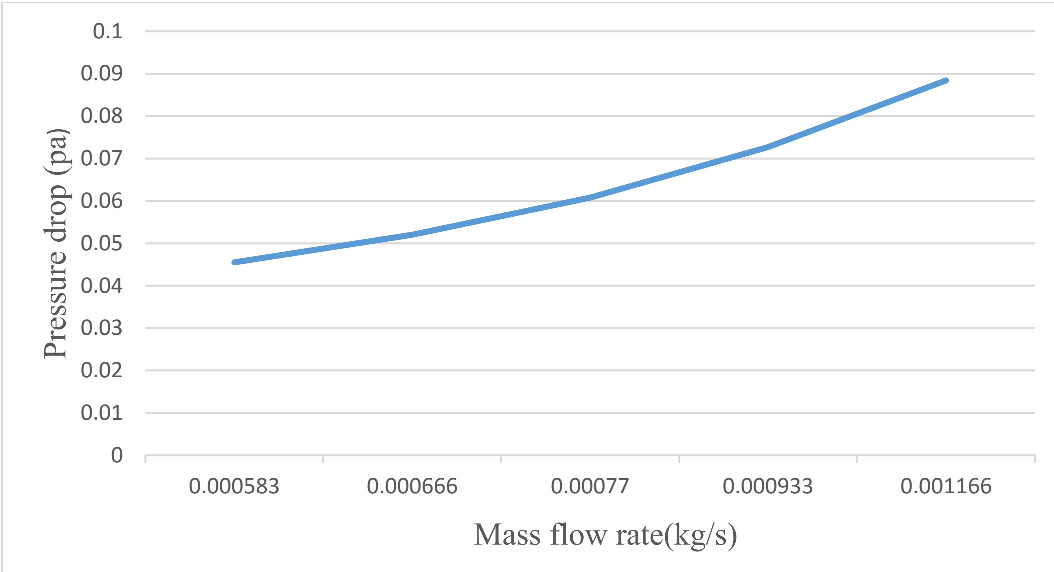

Figure 4.23 pressure drop vs mass flow rate on PTC.

4.3.10 Desalinated water produced

Figure 4.24 shows the desalinated water produced during at the experimental time that for nine respective days from January 9-17.When distilled water production increase with increasing of the solar radiation and the decrease of the incidence angle, thus, higher higher thermal energy available at minimum incidence angle. And also desalinated water production increase with increase of optical efficiency of the system and also increase of mass flow rate. The figure below indicates that the maximum water production obtained at day 5, that is 3200ml (sunny day) and the minimum water production obtained at day6, that is 2300ml(partially sunny day).But, the expected value of distilled water for the small family not obtained due to many factor that affecting it. These are: most of the days are partially sunny, some tracking errors and also the error from the alignment of mirrors.

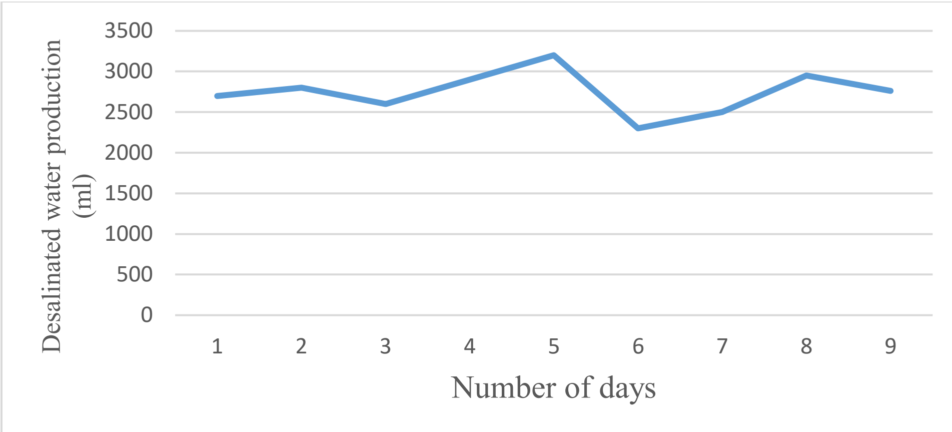

Figure 4.24 Desalinated water production

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, the performance investigation of parabolic trough collector for desalination purpose is performed experimentally. The experimental investigation was carried by manufacturing parabolic trough solar desalination system and condenser to cool the purified water .In addition, chemical analysis of salt water before and after desalination was carried out by using the instrument such as photo meter (model 7 100) and TDS meter or conductivity meter in ASTU chemistry laboratory. The most basic important thing in chemical analysis is TDS for Diguna Fango Dimtu water. The TDS value of the raw water is 3690 mg/l and after desalination its average value of nine respective day of the experiment was 911.5 mg/g. Since the small scale PTC manufacturing is carried for total daily desalted water consumption for small family of 10 liters for a day. But, the desalinated water yield from the experiment was 3.2 liter for a day, this is due to different factors that affected the yield like tracking errors, most of the days were not fully sunny. Detailed analytical derivations of parabolic trough solar collector relations and fabrication of PTC and purified water condenser were taking into account. The useful energy absorbed by the PTC through during the investigation day was found to highly depend up on several factors such as mass flow rates, HTF temperature of PTC, ambient temperature, wind speed and available solar radiation of specific study area. Solar radiation (direct normal irradiance) for Diguna Fango Dimtu city is evaluated based on the data found from the Hawasa National Meteorological Agency. Adama solar radiation data was investigated because the experiment was tested in Adama and also the solar radiation values are nearly similar for both city. Based on the experimental results, the mass flow rate is the mainly important parameter to control the temperature. When the mass flow rate of raw saline water is 0.000583 kg/s, the temperature of HTF for maximum value at 12:200 is 118℃ . The instantaneous thermal efficiency of the system obtained maximum is 41%. It also found that an aperture area of 2.64 $m^2$of selected PTC is required to fulfil the daily process of desalinating energy demand for small family. This efficiency value indicates that thermal efficiency was expected to be higher, but there are too many factors that affected it. These factors are Errors in the alignment of the mirror, Errors in alignment of the tubes and Tracking errors.

5.2 Recommendations

The following recommendations are considered for future work on the performance investigation of parabolic trough collector.

- It is recommended that since Diguna Fango is one of semi-arid region in southern Ethiopia with abundant solar radiation and there is no electricity access, it is better that the government should consider this outcome for implementation of parabolic trough collector desalination purpose.
- If concentrated solar parabolic trough collector is implemented, it is better that the operational cost of fossil fuel for the purpose of desalination can be reduced appreciably.
- The same work with this thesis and to increase the performance it is better if thermal storage can be used for further investigation, the system can work 24 hours.
- Drilling very small holes at the inlet and the outlet of the receiver tube in order to insert thermocouples at appropriate place and prevent recording erroneous result.
- To obtain better performance, it is recommended to use tracking mechanism by electronic controller rather than using manually to determine better sun position.
- Considering heat loss for supporting structure.
- Depending up on the obtained yield of water for small family it is better to scale up the sizes of parabolic trough collector.

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APPENDIX

ANNEX A: Calibration of k-type thermocouple with standard from lab view by boiling of water and then taking into the measurement

Time	K-type thermocouple	Standard from lab view
1min	80.4℃	81.2℃
4 min	74.8℃	75.0℃
8 min	65.2℃	65.4℃
12 min	59.5℃	59.7℃
16min	57.2℃	57.5℃
20 min	54.0℃	55℃
24 min	51.6℃	52.0℃
28 min	48.9℃	49.2℃
32min	47.1℃	47.9℃
36 min	45.8℃	46.4℃
40 min	44.1 ℃	44.8℃
44min	43℃	43.7℃
48min	41.8℃	42.3℃

ANNEX B:Part and assembly drawing by using CATIA software

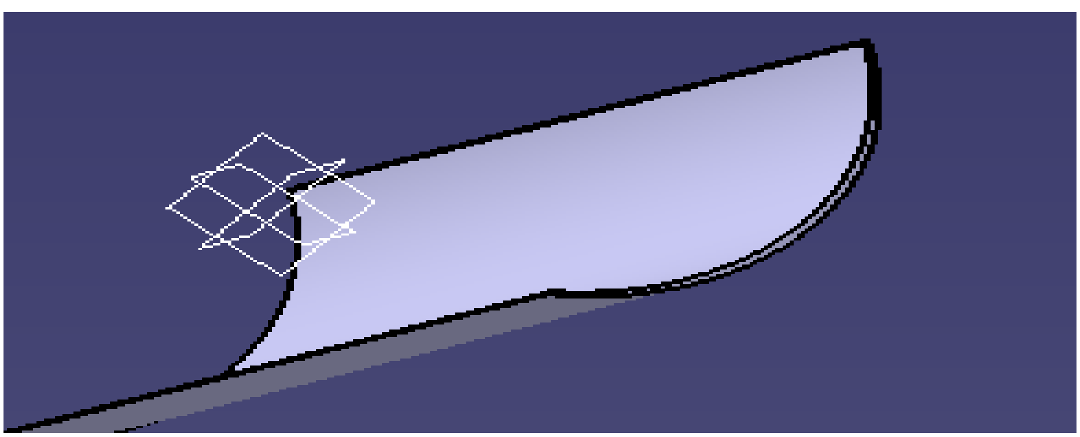

Figure 1 parabolic trough collector

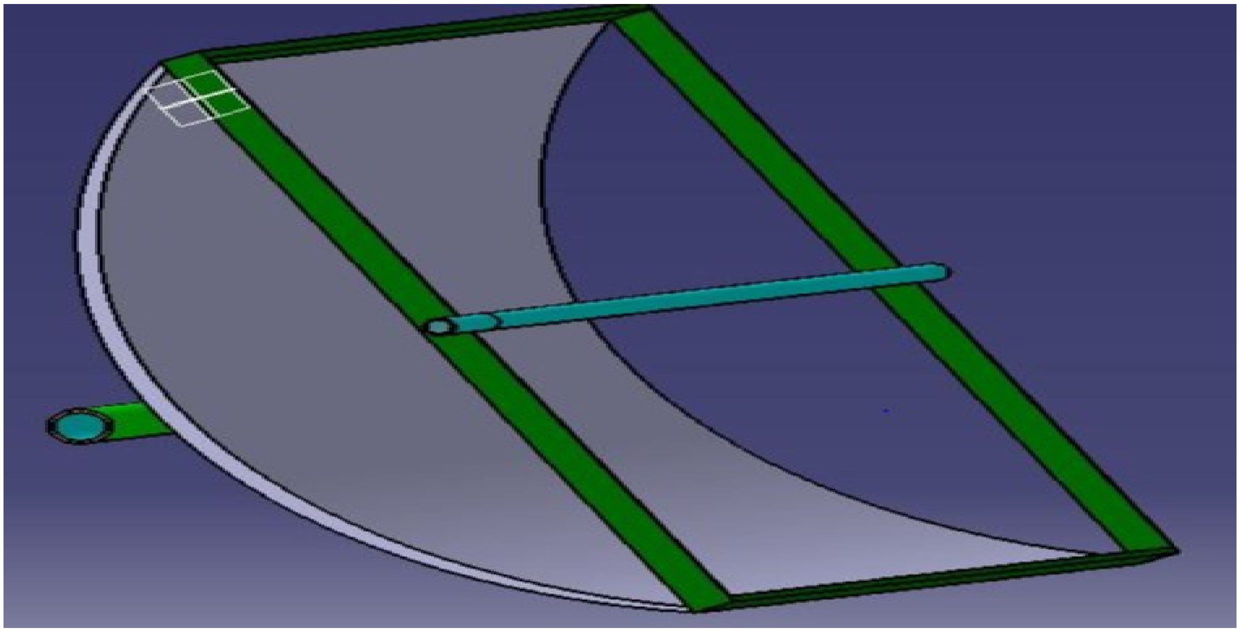

Figure 2 parabolic trough collector with receiver

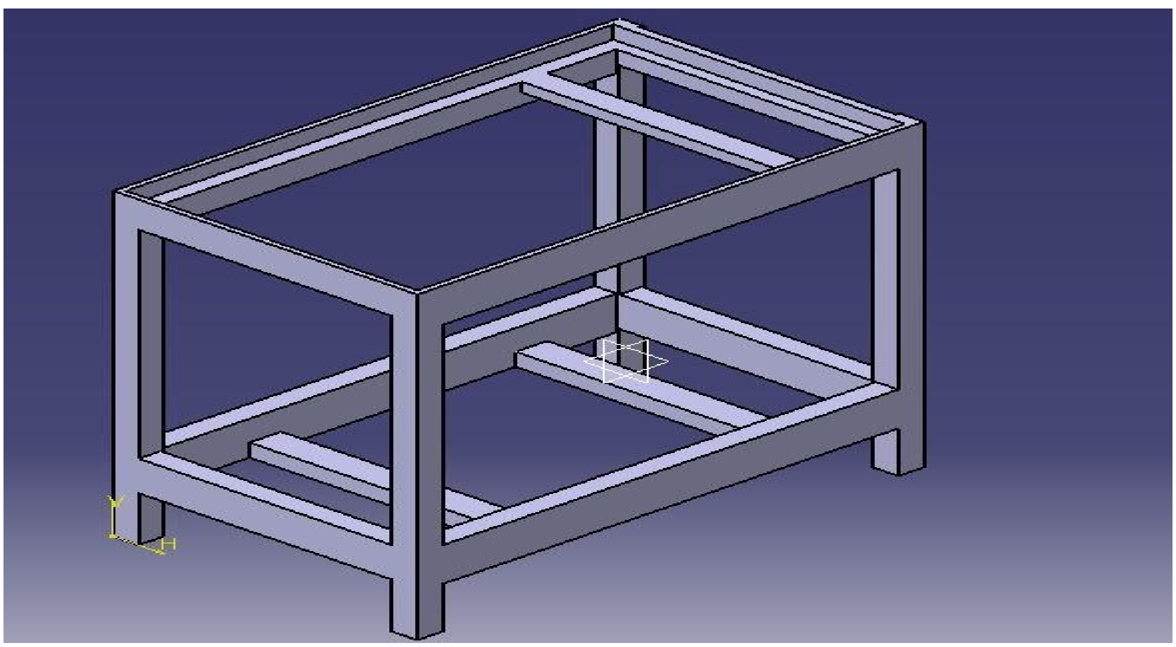

Figure 3 support stand for helical coil condenser

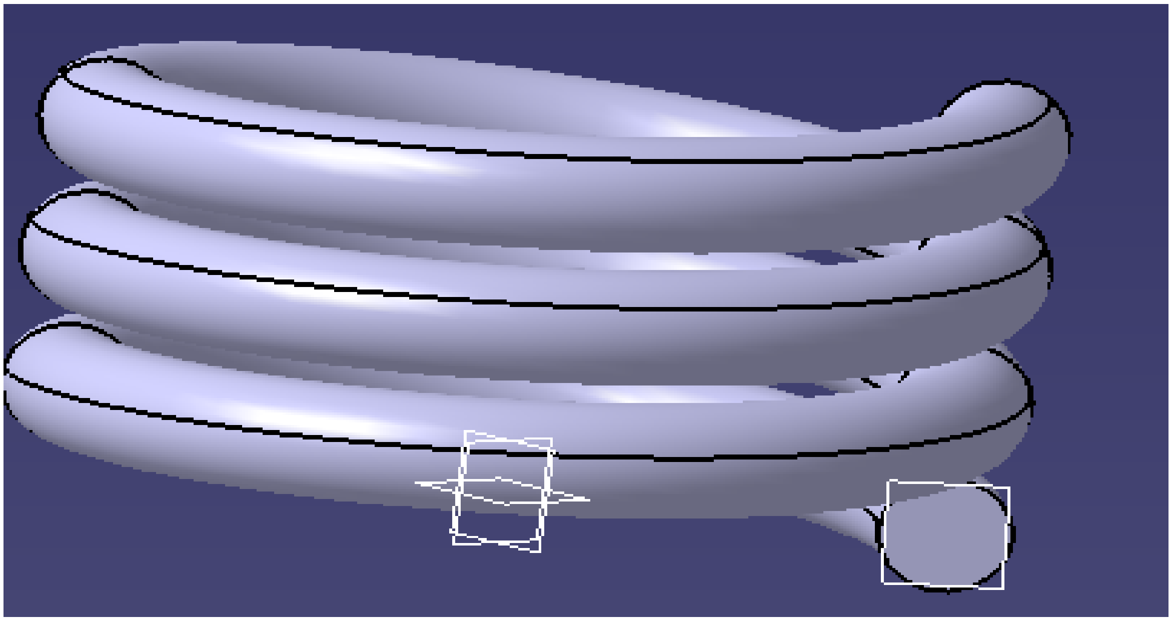

Figure 4 copper coil for condenser

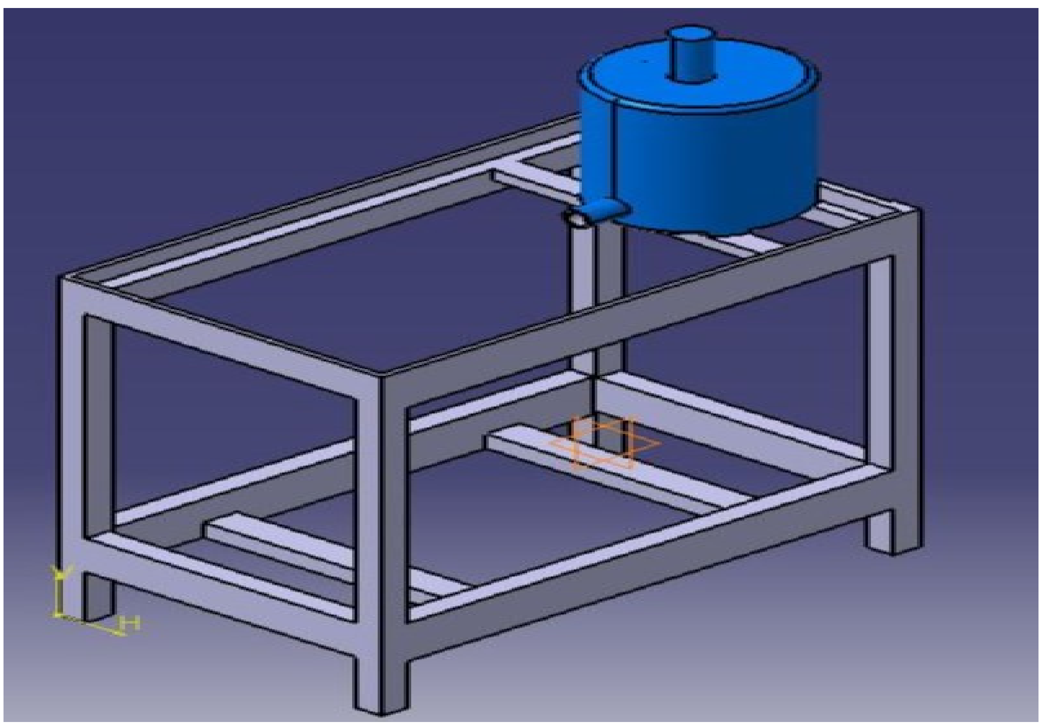

Figure 5 Condenser with support stand

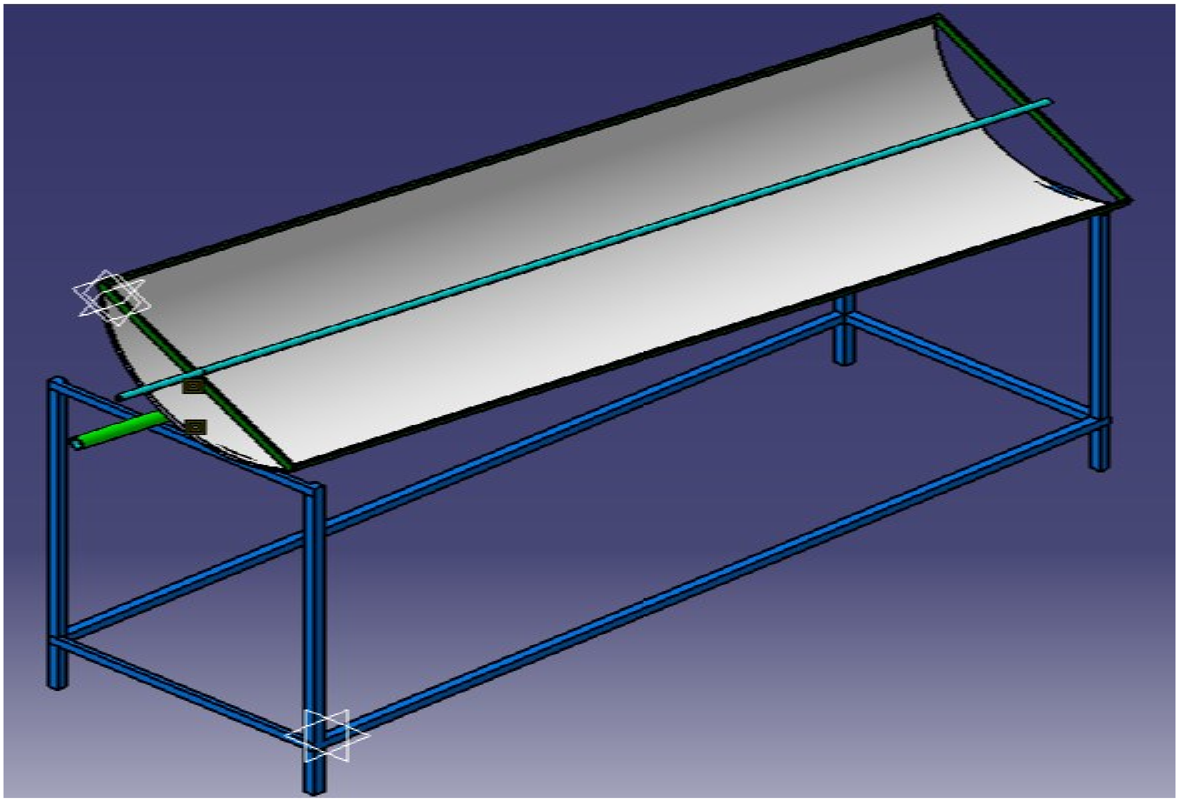

Figure 6 parabolic trough collector with support frame.

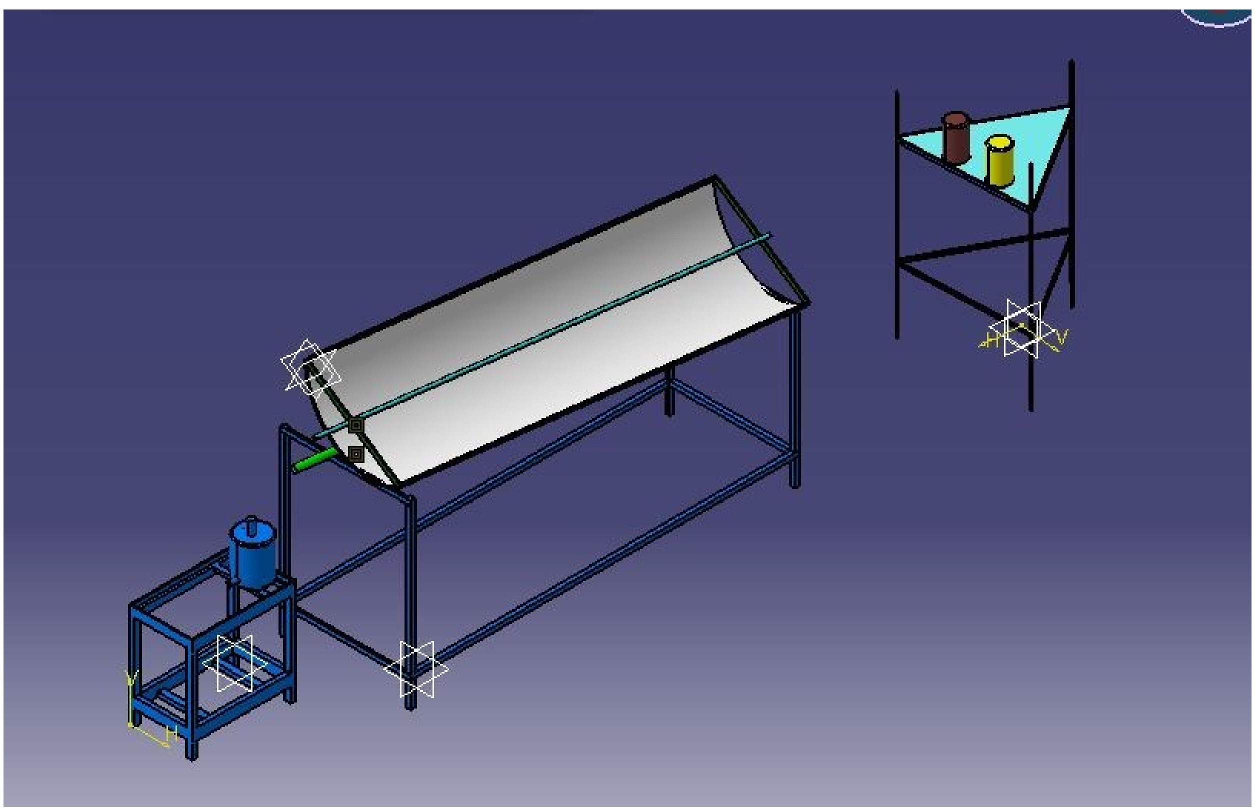

Figure 7 parabolic trough collector, condenser and salt water storage

ANNEX C: Sample photos from chemical analysis and manufacturing of parabolic trough

Figure 8 Magnesium after desalination Figure 9 calcium before desalination Figure 10 photo meter (model 7100)

Figure 11Micro processor based conductivity or TDS meter

Figure 12 parabolic trough collector for desalination

Figure13 measuring receiver temperature

Figure 14 measured receiver temperature

Figure 15 measured HTF

Figure 16 Measured heat transfer fluid

Figure 17 measuring temperature value

Figure18 measuring the amount of water