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ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

INVESTIGATION OF PARABOLIC DISH SOLAR CONCENTRATOR FOR LOCAL *AREKE* DISTILLATION

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University
in Partial Fulfillment of the Degree of Masters of Science in
Mechanical Engineering
(Thermal Engineering Stream)

By: Adane Kassa

Advisor: Dr.-Ing. Demiss Alemu

March, 2015

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Addis Ababa University

Addis Ababa Institute of Technology

Mechanical and Industrial Engineering Department

Graduate Program in Thermal Engineering

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BY

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Declaration

I hereby declare that the work which is presented in this thesis entitled "***Investigation of Parabolic Dish Solar Concentrator for Local Areke Distillation***" is original work of my own, has not been submitted elsewhere for a degree/diploma and that all sources of material used for the thesis have been duly acknowledged.

____________________ ____________________

Adane Kassa Date

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

______________________________ ____________________

Dr.-Ing. Demiss Alemu (Advisor) Date

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"The sun will be the fuel of the future"

Anonymous, 1876, Popular Science

(Solar Energy Perspective, IEA 2011)

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Abstract

Areke is Ethiopian's locally produced traditional fermented alcoholic liquor which is produced from *difedif*- mixture of milled gesho (*Rhamnus Prinoides*), finely ground and cooked/baked cereals, and water left for fermentation for nine to ten days, by the of process distillation.

The heat required for the distillation process is obtained from burning firewood on inefficient three stone stoves. Energy inefficiency, greenhouse gas emission to the environment, human respiratory system diseases and deteriorating household economy are the major negative impacts that resulted from using biomass as energy source for local *areke* distillation.

This thesis work presents the design and manufacturing of parabolic dish solar collector system for local *areke* distillation process as a substitute energy source instead of burning biomass and reports the test results of the system. In order to show design procedure; parabolic dish solar collector system with aperture diameter of 1.6m, depth of 0.4m and focal length of 0.4m was designed in full scale. The parabolic dish is designed for distillation of 24 liters of *difedif* to obtain 3 liters of *areke* with alcohol content of 44% per day (i.e. from 8:00AM to 5:00PM). One cycle of distillation takes on average 3 hours to obtain 1 liter of areke from 8 liters of *difedif*.

However, the parabolic dish frame of aperture diameter of 1.2m, depth of 0.3m and focal length of 0.3m, which already exists in AAIT Mechanical workshop, with a little maintenance and modification was used for the test purpose. Aluminum foil laminated galvanized sheet is used as reflective surface for dish concentrator. The parabolic dish tracks the sun ray manually based on the shadow of pin on the edge of dish aperture. Especially made clay pot with capacity of 4 liters, and having effective surface area of 0.071m^2 was used as absorber. 2.5 liters of *difedif* was used to conduct the test in three different days.

The test result showed it was possible to obtain from 2.5 liters of *difedif* 0.25liters of *areke* with alcohol content of 44% and on the average it took 3 hours. And on average it took 1 hour and 15minutes to reach temperature of 70.4^oC which is the boiling point temperature of alcohol in Addis Ababa at atmospheric pressure of 0.746atm, where the test was conducted. So, with appropriate design of solar energy distiller system for local *areke* distillation as an alternative source of energy showed promising results and has the potential to mitigate the negative impacts related to traditional *areke* distillation method.

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Nomenclature

d_o -outside diameter of absorber

d_i -internal diameter

t -thickness of absorber

V_a -volume of the absorber

V_d -volume of the *difedif*

d_o -outside diameter of absorber

d_i -inside diameter of absorber

r_i -internal radius of the absorber sphere

A_a -effective surface area of the absorber

r_o - out-side radius of absorber sphere

m_{dT} -total mass of *difedif*

m_c -mass of corn

m_b -mass of *bikil*

m_g -mass of gesho

m_w -mass of water

ρ_w -density of water

ρ_y -density of wheat (malted flour)

ρ_g -density of gesho flour

V_c -volume of corn

V_g -volume of gesho

V_b -volume of *bikil*

V_w -volume of water

V_T -total volume of the *difedif*

m_e -mass of ethanol

ρ_e -density of ethanol

V_e -volume of ethanol

m_{we} -mass of distilled water

ρ_w -density of water

V_w -volume of water

η_{th} -thermal efficiency solar concentrator

A_a -aperture area of concentrator

I_b -solar beam radiation

P_{abs} -energy absorbed by absorber

η_o -optical efficiency solar concentrator

Q_{u1} -heat energy required to raise the sensible temperature of *difedif* of mass, m_{dT} from ambient temperature, T_o =20^{o}C to boiling temperature of alcohol in Addis Ababa, T=70.4^{o}C.

Q_{u2} -heat energy required to evaporate 0.35kg of alcohol to vapor.

Q_{u3} -heat energy required to raise the sensible temperature of the remaining mass of *difedif* after 0.35kg of alcohol distilled.

Q_{u4} -heat energy required to evaporate 0.56kg of water to steam.

t_1 -time required to raise temperature of 7kg of *difedif* from 20^{o}C to 70.4^{o}C.

L_e -latent heat of vaporization of ethanol at 70.4°C

t_2 -time required to convert 0.35kg of alcohol to vapor.

t_3 -time required, after 0.44L or 0.35kg alcohol distillation the remaining mass of *difedif* temperature to reach from 70.4°C to 92°C.

L_w -latent heat of vaporization of water at 92°C

t_4 -time required to convert 0.56kg of water to steam.

T_d -total time required for one cycle of *areke* distillation

C -concentration ratio

f -focal length

ϕ -half acceptance angle

ψ_{rim} -optimum rim angle

V -volume of parabola

Abbreviations and Acronyms

ANCEDA-Arsi Negele Nature Conservation and Environmental Development Association

ERG -Ethio Resource Group

FfE -Forum for Environment

GTZ-Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation)

HBF -Heinrich Boll Foundation

HoA-REC & N -Horn of Africa Regional Environment Center and Network

IAP -Indoor air pollution

IEA -International Energy Agency

$kWh/m^2/yr$ -Kilo watt hour per meter square per year

LDCs -Least Developed Countries

MoWE -Ministry of Water and Energy

NGOs -Non-Governmental Organizations

OECD - Organization for Economic Co-operation and Development

SWERA - Solar and Wind Energy Resource Assessment

UNDP - United Nations Development Programme

WHO -World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Nowadays one of the greatest challenges of mankind is the sustainable supply of clean, safe and economical energy to carryout day to day activities. Even though energy plays the lion's role in technological, industrial, social and economic development of the nation; due to different reasons many nations are incapable of fulfilling their nation's energy demand.

Areke is Ethiopian's traditional fermented alcoholic liquor which is produced from *difedif*-mixture of milled gesho (*Rhamnus Prinoides*), finely ground and cooked/baked cereals, and water, by the of process distillation. Distillation is a process in which a liquid or vapor mixture of two or more substances is separated into its component fractions of desired purity, by the application and removal of heat [2]. Arsi Negelle, Debre Markos and Debre Birhan are cities where *areke* is highly produced in the country in traditional ways.

In traditional *areke* distillation process energy-heat required for distillation is obtained by burning biomass in open fire place three stone stoves in most parts of Ethiopia. The use of fire wood/biomass for energy source has negative impact on human health and environment. Green house emission to the environment and respiratory system diseases on human being due to burning the fuel/biomass during *areke* distillation are the major challenges for women and children in rural areas of Ethiopia. In many developing countries (particularly sub-Saharan Africa), traditional biomass energy dominates national energy statistics, leading to significant negative impacts on human health and the environment [19] Especially, women in rural areas travel very far distance to collect fire woods. In *areke* production process large amount of energy is consumed during distillation process. Distillation takes up about 70-85% of total energy consumed in ethanol production [13].

Indoor air pollution (IAP) due to burning solid fuels is the leading causes of child mortality in the world, accounting for up to 20% of fatalities among children under five, almost all of them in developing countries [7] [20], this makes the second most important environmental cause of disease after contaminated waterborne diseases [4] [7], which has received relatively little attention in Ethiopia.

Solar energy is energy transmitted radially from the sun as a form of electromagnetic radiation. Solar energy offers a clean, environment-friendly, very abundant and inexhaustible energy resource to mankind, relatively well-spread over the globe. Its availability is greater in warm and sunny countries [12]. The actual usable radiation component varies depending on geographical location, cloud cover, hours of sunlight each day, etc. The total solar radiation is highest at the equator, especially in sunny, desert areas [17]. Geographical location of Ethiopia being near the equator highest solar radiation can be obtained using appropriate technology. Solar energy is used for various applications. For example, solar distillation is one of the methods which use heat supply from solar-sun to separate two or more components of a mixture by distillation process.

Ethiopia has a huge amount of solar energy potential. Ethiopia Receives 5.5 to 6.5kWh/m^2/day of solar insolation [8]. According to MoWE, 2013 presentation only less than 1% of solar energy potential has exploited so far [16]. All though solar energy has drawbacks- low efficiency, high cost and storage, with recent technological advancement and studies in the area huge amount of energy could be exploited for local *areke* distillation.

To mitigate the effect of traditional way of *areke* distillation using biomass on environment and human health, alternative method of energy sources which are environment friendly and less harm to human health-which Ethiopia has endowed naturally with huge amount, are highly needed.

To the best of the author’s knowledge, despite the seriousness of *areke* related human and environment issues, no substantial study has been conducted in Ethiopia towards improvement of traditional inefficient *areke* distillation stoves by efficient modern stoves or use of alternative renewable energy sources, like solar energy.

As a result it is very important also motivates to conduct different researches on the way of improving the process of local *areke* distillation either by developing energy efficient distillation stoves or by designing the way to use naturally endowed renewable solar energy which is environment friendly and smoke free energy source. This study analyzes the potential of solar energy, for local *areke* distillation process.

1.2 Statement of the Problem

The Ethiopian energy sector, regardless of the nation's enormous energy potential, is high dependent on traditional fossil fuel energy sources and biomass-wood, animal dung and crop residue are used as the main source of energy in rural households for cooking and other purposes [5]. Currently, about 1.5 billion people in developing countries lack access to electricity and about 3 billion people rely on solid fuels for cooking [21].

Even though, Ethiopia is endowed with huge amount of hydropower, geothermal, wind, solar energy potentials dependency on biomass accounts for about 95% [3]. This figure indicates that small portion of these resources have been used so far and the need for more research on the design and development of usage of these potential renewable energy resources to fulfill the increasing energy demand of the country.

Areke distillation is one of the areas where fire wood is voraciously used as a main source of energy for distillation of alcoholic liquor/*areke* in different regions of Ethiopia. According to study conducted by Horn of Africa Regional Environment Center and Network (HoA-REC & N) in Arsi Nagelle town on 3,500 households, annually 95,812 tons of fire wood is consumed to produce 31,397,500.00 liters of *areke* upon which their livelihoods depends [10]. On average 3kg of firewood is used to produce 1 liter of *areke* (Ibid).

A survey conducted by Zenabu Hailu (2010) in Arsi Nagelle town on 100 *areke* distiller households in each household 92.28kg/day, 2030.2kg/month, and 24361.9 kg/year fuel wood could be consumed due to *areke* distillation being total in the town 158912.8042 ton /year this figures show the need for quest to another cleaner and safer energy source as a replacement or as a support to biomass during local *areke* distillation process [22]. Even though as such no study has been conducted in other areas- Debre Birhan, Debre Markos are cities known as where *areke* is highly produced and like other regions energy for the distillation process is obtained by burning biomass, which makes the impact on human health and environment even worse. The burning of firewood in open fire place beside its inefficiency causing women and children for different of health problems and increasing greenhouse gas emissions. According to WHO and UNDP (2009), worldwide almost two million deaths annually from pneumonia, chronic lung disease, and lung cancer are associated with exposure to indoor air pollution/IAP resulting from cooking with biomass and coal, and 99 percent of them occur in developing countries [21]. Emissions from burning solid fuels in open fires and traditional stoves also have significant global warming effects, due to incomplete combustion of fuel carbon (Ibid). In addition using biomass as energy source is deteriorating household economy and damages the environment [3]. There is also a strong economic case for this shift from traditional to fuel efficient heating systems. The increasing price of fuel wood is putting pressure on households [10].

Different solutions have been applied by different NGO's to mitigate the impact resulting from biomass burning/indoor air pollution on human health and damage on the environment.

Arsi Negele Nature Conservation and Environmental Development Association (ANCEDA) in collaboration with HoA-REC &N, has started implementation to replace the traditional fuel wood stoves, that is inefficient which Arsi Negele community has been using for long time for *areke* distillation with modern stoves which fuel efficient briquette run stoves in the area and to maintain the sustainable supply of briquette established briquette factory in Dilla town which has potential of producing 1.5 tons of per hour.

GTZ-SUN energy project has developed an improved *areke* distilling stove (figure 1) that is believed to address the environmental as well as human health impacts of utilization of traditional biomass[9].

Figure 1 Improved *areke* distillation stoves [9]

However, according to WHO and UNDP (2009) modern fuels and improved stoves to meet people's most basic cooking needs are out of the reach of the majority of people living in developing countries, especially for those in rural areas. 56 % of people in developing countries rely primarily on solid fuels, coal and traditional biomass for their cooking needs, with little or no access to more efficient, modern forms of energy [21]. Their access to improved cooking stoves is also very limited. Only 27 % of those who rely on solid fuels-roughly 800 million people are estimated to use improved cooking stoves (Ibid). Access to improved cooking stoves is even more limited in LDCs and sub-Saharan Africa, where only 6 % of those who use traditional biomass are using such options (Ibid). In addition, even though these efforts have made great contribution in the increasing the efficiency of the stove and improved the health of the community by reducing the emission, still it is not free of smoke and using biomass as energy source.

In Ethiopia about 95% of all the primary energy is obtained from biomass and/or fuel wood. Although this statistics represents all parts of the country, because 85% of Ethiopians live in rural regions the highest degrees of dependency on biomass have seen in rural communities. Study conducted by WHO and UNDP (2009) shows traditional biomass such as wood, charcoal, and dung is much more commonly used in rural areas than urban areas [21]. Some 71 % of people living in rural areas use traditional biomass, primarily wood, for cooking, while 70 % of those living in urban areas rely on modern fuels, especially gas (Ibid).

Hence, continued efforts are required from students, researchers, NGOs, governments and different stake holders on the ways to minimize and/or to stop the cause for deaths of millions of people (women and children, especially for those living in rural areas of developing countries), deteriorating household economy, global warming and damaging our planet earth, which is resulting from burning of biomass on open fire.

To overcome the above mentioned drawbacks resulting from using biomass as energy source, this thesis work will investigate the effectiveness of solar energy source as a substitute of traditional biomass fuel for local *areke* distillation using parabolic solar concentrator instead of traditional three stone biomass stoves. Since solar energy is available everywhere in nature free of charge it can be applied to all regions which have potential solar irradiation.

1.3 Objectives of the Research

Given above local *areke* distillation related environmental, economic and human health problems, this thesis aims investigating the effectiveness of use of solar distiller for local *areke* distillation as an alternative approach to traditional *areke* distillation methods. Use of solar distiller helps to avoid greenhouse gas emissions to atmosphere, minimizes time spent travelling long distance for collecting fire woods and improves public health.

1.3.1 General Objective

- The main objective is to assess the effectiveness of using solar distillation for *areke* production as a substitution or support for traditional process.

1.3.2 Specific Objectives

- Design and manufacturing of parabolic dish concentrator system for *areke* distillation based on data obtained from local distillers.
- Analysis the time required for one round *areke* distillation using solar still and compare the result with traditional method.
- Conduct test to determine the distillation rate of solar distiller and compare with local method.

1.4 Significance of the Research

The majority of peoples in Ethiopia depend on firewood as their energy sources for *areke* distillation, so use of solar distiller plays important role economically improving their life. Most people buy the firewood from market, which is additional expense, since solar energy is obtained free from charge, use of solar distiller for *areke* distillation helps to save the money they spent on firewood.

Specially women and children in rural areas of Ethiopia spend much of their time in gathering firewood and they are exposed for health problems due to smoke from burning firewood, using solar distiller helps to improve health problems and conserve their time.

Use of firewood as a fuel leads to cutting trees, which results deforestation, soil erosion, loss of soil fertility, decreasing yields, flood problem and finally desertification. Therefore applying the findings of this research contributes its share to organizations working on environmental protection and countries like Ethiopia, which currently working on green economy policy to achieve their mission.

Therefore, the use of solar as energy source for local *areke* distillation benefit individuals-each households which their day to day activities energy need is fulfilled by burning biomass and the country as a general-human health, environmental and economically.

1.5 Scope of the Research

The scope of this research is limited to designing and manufacturing of solar distiller and conducting tests in Addis Ababa. The test was conducted to determine the amount of distilled *areke*, the time it takes for one round of *areke* distillation and temperature variation of the *difedif* in the absorber pot. Based on test results obtained different conclusions and recommendations are drawn.

1.6 Research Methodology and Materials

The following methods and materials are used in order to achieve the objectives of the research. Different literatures-articles, journals and books written on the area of solar thermal system and on the area of *areke* distillation process were carefully studied. Different individuals-their livelihood is dependent on the income obtain from *areke* distillation, were orally interviewed to understand about traditional *areke* distillation processes. We went to the household where *areke* is produced, experienced the actual *areke* distillation process, examined the distillation apparatus and the challenges related to the distillation method. Parabolic dish concentrator system was designed based on the data obtained from oral interview and literatures; the test was conducted on different days to determine the distillate rate and the time it takes. Based on the test data, reviewed literatures, and field visit experience gained different conclusions and recommendations are drawn.

1.6.1 Experimental Setup

The tests were carried out in the compound of Addis Ababa University, Institute of Technology, which is located at 9.02^{o} N latitudes and 38.45^{o}E longitude during the period November, 2014 to January 2015.

Parabolic dish solar concentrator designed and constructed to conduct tests to analyze the performance of solar energy for local *areke* distillation. A schematic diagram of the experimental setup is shown in Fig. 2 and photograph is illustrated in Fig. 3.

The solar dish concentrator distiller system used for *areke* distillation consists of a solar dish concentrator, absorber pot and condenser (heat exchanger).

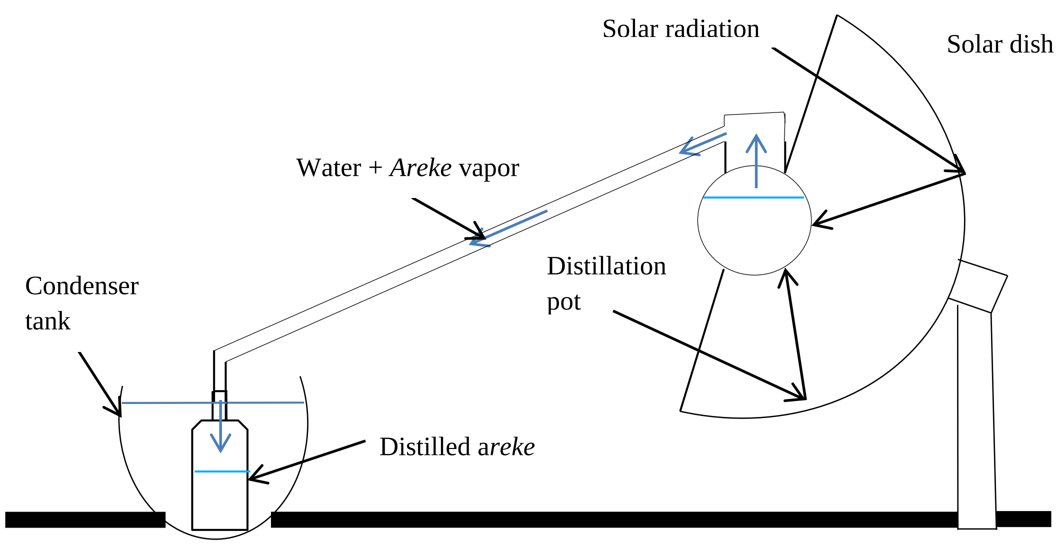

Figure 2 Schematic diagram of the experimental setup

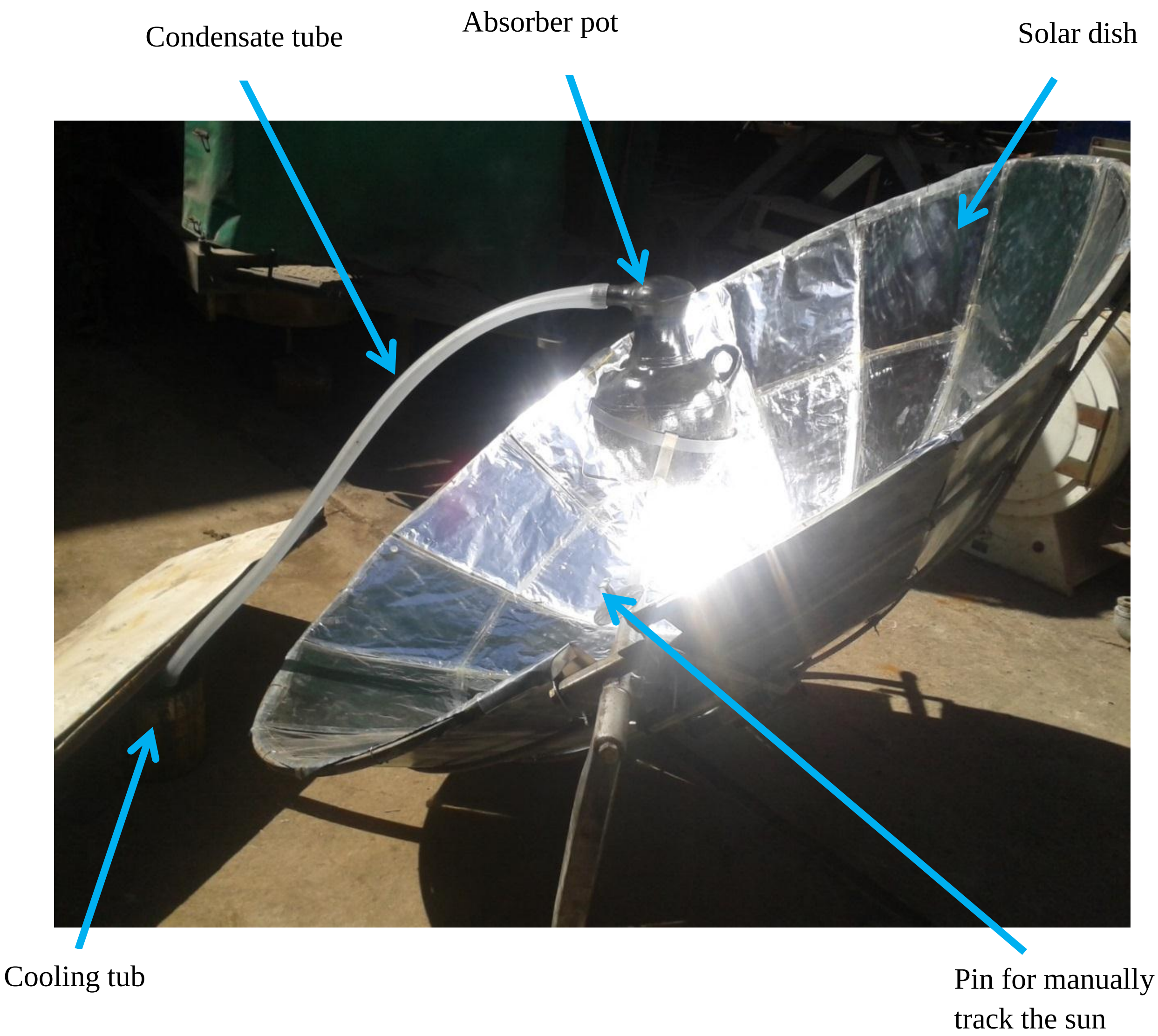

Figure 3 Photograph of developed experimental setup

The parabolic solar dish concentrator system is a point focus collector that tracks the sun manually by constant monitoring of human operator based on pin shadow located on the aperture of the collector. The dish surface was covered by galvanized sheet metal laminated by highly reflective aluminum. The highly reflective aluminum foil laminated galvanized sheet metal was carefully assembled with dish frame to get the focal point precisely. Dimensions of parabolic dish reflector are shown in figure 4.

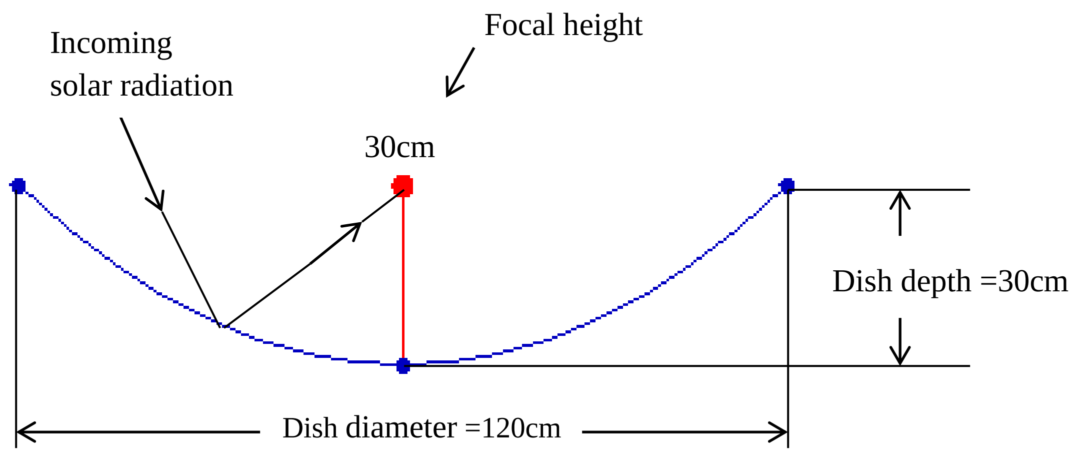

Figure 4 Dimensions of parabolic dish used for testing

The specially designed absorber pot was placed at the concentrator focal point. The absorber pot size is optimized to be just large enough to admit most of the concentrated sun-light but small enough to limit radiation and convection losses.

Figure 5 Photograph of specially designed clay made absorber pot

The absorber pot is made of clay have the capacity of 4 liters and effective surface area of 0.071m^2. The absorber has similar shape as traditional *areke* distillation pot, with some additional features. To reduce heat losses, 50% the surface of the absorber is completely insulated with fiber glass except the bottom part exposed to the solar rays that reflected by the dish surface. The absorber pot was painted black to increase the absorbability of the solar radiation. The photograph of specially made clay absorber pot is shown in figure 5.

Water hose having diameter of 25.4mm and length 1.2m was used to transfer water-alcohol mixture distillate from the distillation pot to the condenser. Cylindrical tank filled with cold water is used as a condenser. The steam produced in the absorber pot passes through the water hose and enters into the condenser system.

Some amount of the steam coming from distillation pot changed to liquid in the hose by air and the remaining steam enters into the condenser and cools by releasing the heat to the cooling water. The distillate is collected into the container immersed in the water.

1.6.2 Operation Principles

The solar radiation intercepted by the parabolic dish concentrator surface is reflected and concentrated on the surface of the absorber pot mounted on focal of the concentrator. The concentrated heat is absorbed by the absorber and transferred to the *difedif* inside the absorber. The *difedif* inside the absorbers gets heated by the intense concentrated radiation at the bottom surface and vaporizes. The produced vapor flows up and enters into the condenser through the hose. The vapor that enters into the condenser cools by giving its latent heat to cooling water in the cylinder tank.

1.6.3 Test Procedures

The experimental setup was evaluated by measuring the amount of final *areke* distillate and the temperature variation of the *difedif* in absorber pot placed on the focal point of the solar collector. The collected distillate amount of *areke* in 3 hours of distillation period was measured by graded flask. The temperature variation of the *difedif* was measured by using HANNA Instruments K-type thermocouple at 15 minutes interval from 11:15AM to 2:15PM for the period of 3 hours. The procedures followed during the testing the experimental setup is listed as follows:

1. **Never stare directly** into the reflecting surface. Always wear **UV protective dark sunglasses** when working with your distiller!!
2. Clear any dust on reflective surface.
3. The parabolic dish solar concentrator was oriented to normal radiation of the sun, by adjusting until the shadow of pin on the aperture becomes a point and fixed at this position by bolt and nut locking mechanism.
4. The absorber pot is filled with the required amount of *difedif* (2.5 liters of *difedif* used for this test), then the openings are sealed and the pot is placed at focal point.
5. The parabolic dish solar concentrator is continuously monitored within some time interval, for pin shadow and the collector system is rotated until the shadow becomes a point-to orient the incoming solar radiation perpendicular to the reflector surface.
6. After 20-30 minutes the system is closed-one end of the hose is connected to the small opening located at the top of absorber pot and the other end is inserted into the distillate collector flask in the condenser. Then the distillate collector flask is placed in the cylinder tank and tied to prevent movement. After that the cylindrical tank is filled with cooling water.
7. The temperature readings were measured at 15 minutes interval from 11:15AM to 2:15PM and carefully noted.
8. After 3 hours of distillation period the distiller system is disassembled. The distillate collector is removed from the cooling water carefully not to spill *areke*, the hose is removed from both end and the absorber pot is unloaded with stillage inside-careful while handling hot surfaces.
9. Empty the absorber pot by draining the stillage and wash with a cold water.
10. Fill the absorber with fresh *difedif* and be ready for the next distillation.
11. Measure the distillate amount using graded flasks or any volume measuring instruments. The measured data is noted on ready table.

CHAPTER TWO

LITERATURE REVIEW

To the best of the author's knowledge there are no significant amount of studies that have been done so far in the area of improving and using solar as a source of energy for traditional *areke* distillation process. However, some efforts have been made on the way of assessing the potential of solar energy for *areke* production. For example, the study conducted by Solomon Haileyesus [30], on potential of solar energy for *areke* production. The finding of the experiment revealed an average boiling point of 74°C. It took 1L of *difedif* about 2:30 hours to reach at this temperature which was longer than the time needed to boil pure ethanol.

2.1 Solar Energy Basics

The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9m and is, on the average, 1.5×10^{ll} m from the earth. Sun is considered as continuous fusion reactor the temperature of central interior region is estimated as 8×10^6 to 40×10^6K. The sun has effective blackbody surface temperature of 5777K.

Solar energy is energy radiated and transmitted from the surface of the sun through space to the earth's surface as electromagnetic radiation. At about 40km from the earth surface the total amount of energy that falls on unit area normal to the sun in unit time when the earth is at mean distance from the sun is known as solar constant or extraterrestrial radiation. At one astronomical unit (equal to 1.495×10^{11}m) the sun radiates energy nearly with constant intensity. Extraterrestrial radiation is radiation that would be received in the absence of atmosphere-has currently accepted value of 1367kW/m^2. Sun ray reaches the earth's surface with different wavelength with their spectral distribution to solar constant-ultraviolet (λ ranges 0-0.38μm)-contributes 6.4%-87W/m^2, visible (λ ranges 0.38-0.78 μm)-contributes 48%-656W/m^2 and infrared (λ>0.78μm)-contributes 45.6%-623W/m^2 of energy to extraterrestrial radiation.

Solar radiation reaches the surface of earth in two forms: Beam or direct radiation-the solar radiations received from the sun without having been scattered by the atmosphere. Diffuse or sky radiation-the solar radiation received from the sun after its direction has been changed by scattering by the atmosphere. The sum of direct and diffuse radiation is known as global or total solar radiation. It takes the sun one hour and 25 minutes to send us the amount of energy we currently consume in a year, or a little more than 4.5 hours to send the same amount of energy only on land [12]. The energy received by the sun in one single year, if entirely captured and stored, would represent more than 6 000 years of total energy consumption (Ibid). The sun, with its by-products (wind, water, biomass, waves) supplies our planet with 15,000 times more energy per day than the earth actually consumes [5].

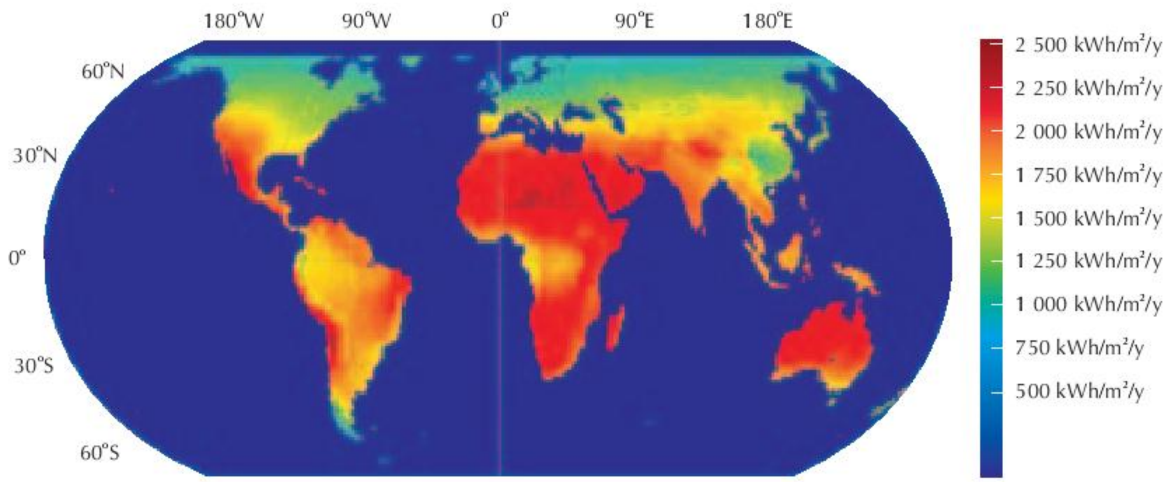

Figure 6 The global solar flux (in $kWh/m^2/y$) at the earth's surface over the year [12]

In above figure 6, United States, Africa, most of Latin America, Australia, most of India and parts of China have good-to-excellent solar resource with $1750kWh/m^2/year$ to $2500kWh/m^2/year$. Ethiopia being located in Africa is endowed with large amount of solar radiation of around $2500kWh/m^2/year$. However, according to master plan of solar and wind for the whole country prepared by the government of Ethiopia with the collaboration of Chinese government by SWERA annual average daily radiation in $kWh/m^2/yr$ ranges from 547-1793 $kWh/m^2/yr$ (Figure 7). The regions richest in solar energy resources in Ethiopia are mainly centralized in Afar state in the northeast, the desert region in Somali state in the southeast and some western and southern regions. Mid north region of Ethiopia is relatively weaker in solar energy resources.

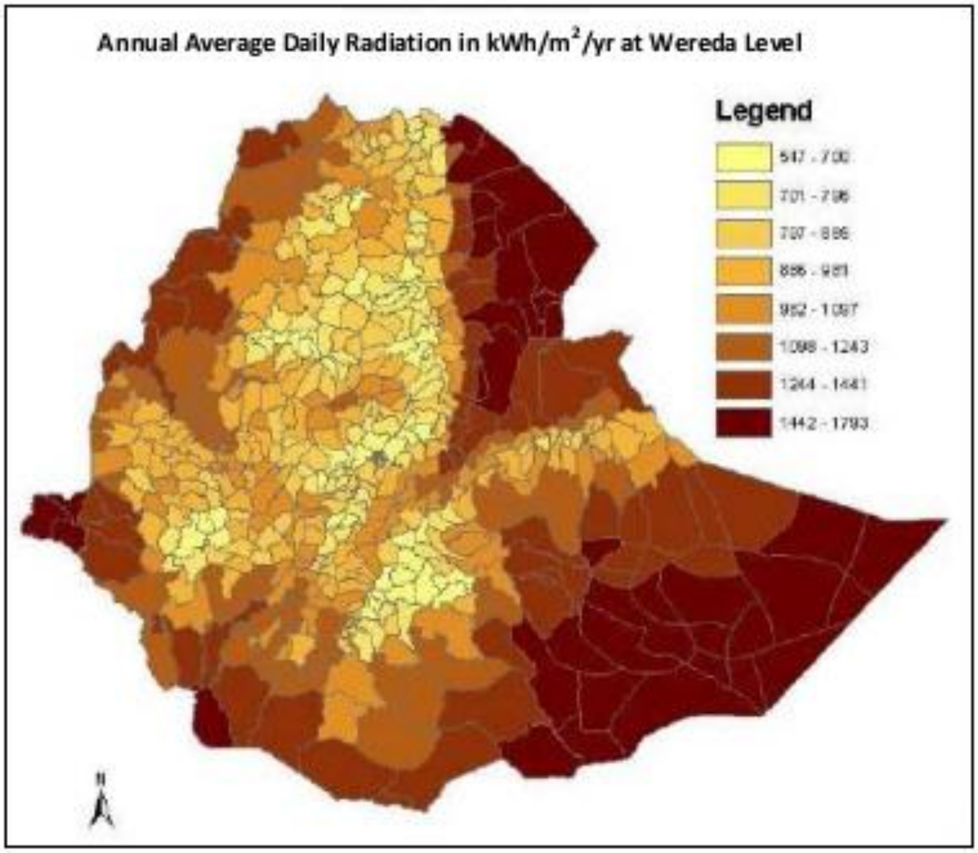

Figure 7 Ethiopian solar energy resource distribution map by SWERA [15]

2.2 Solar Concentrator

Solar concentrator is a device which concentrates the solar energy incident over a large surface onto a smaller surface. A solar collector consists of a concentrator and a receiver. There are three alternative configurations of concentrators.

i. Parabolic trough concentrators
ii. Solar power towers (Central receiver concentrators)
iii. Parabolic dish concentrators

I. Parabolic trough concentrators (PTC)

The parabolic trough system is by far the most commercially matured of the three technologies. It focuses the sunlight on a glass-encapsulated tube running along the focal line of the collector. A PTC is basically made up of a parabolic trough-shaped mirror that reflects direct solar radiation, concentrating it onto a receiver tube located in the focal line of the parabola. Concentration of the direct solar radiation reduces the absorber surface area with respect to the collector aperture area and thus significantly reduces the overall thermal losses. The concentrated radiation heats the fluid that circulates through the receiver tube, thus transforming the solar radiation into thermal energy in the form of the sensible heat of the fluid. Figure 8 shows a typical PTC and its components.

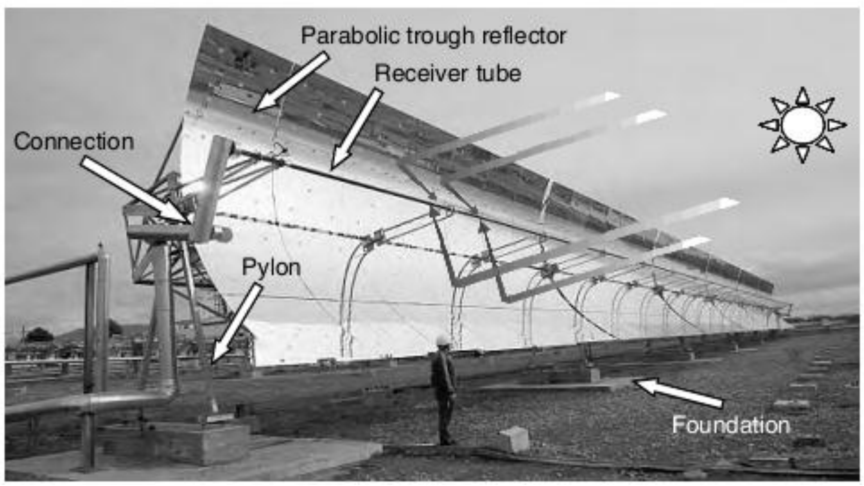

Figure 8 A typical parabolic trough concentrator [26]

II. Central receiver concentrator

In power towers, incident sunrays are tracked by large mirrored collectors (heliostats), which concentrate the energy flux onto radiative/convective heat exchangers called solar receivers, where energy is transferred to a thermal fluid. After energy collection by the solar subsystem, the thermal energy conversion to electricity is quite similar to fossil-fueled thermal power.

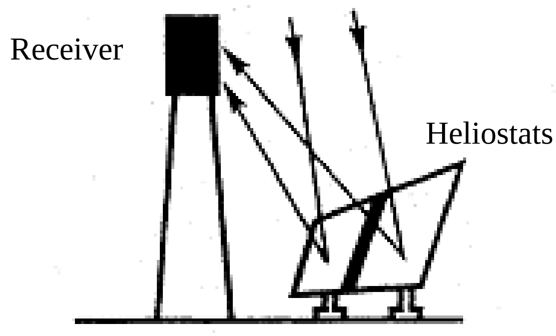

Figure 9 Central receiver concentrator [27]

III. Parabolic dish concentrator

Parabolic dish concentrators is a system consists of concentrator and receiver elements. The concentrator system tracks the sun and reflects the incoming solar radiation back to the receiver located on the focal point of parabolic shaped dish. To constantly keep the reflected radiation at the focal point during the day, a sun-tracking system continuously rotates the solar concentrator on two axes following the daily path of the sun. The receiver absorbs the reflected light energy and transfers the energy to the working fluid. The received energy is used: water heating, space heating, space cooling, process heat, electricity generation or manufacturing of fuels.

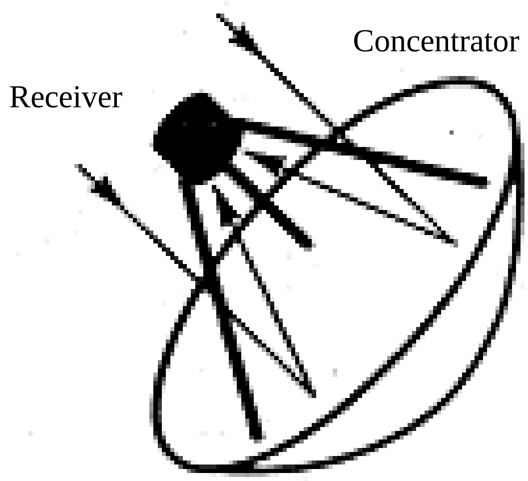

Figure 10 Parabolic dish concentrator [27]

2.3 Traditional *Areke* Production

Although, traditional *areke* production methods are the same the recipe or ingredients they use are different from location to location and individual to individual, however, in general they commonly use the same feedstock for *difedif* preparation- mixture of *enkuro* (cooked corn flour), malted wheat, and ground gesho (*Rhamnus prinoides*) leaves. Malted wheat is a germinated wheat grain which is used as yeast to convert broke down starch-sugar in to alcohol or ethanol. *Enkuro* is cooked corn flour prepared by grounding corn kernels into flour and slurried/mixed with water then cooked. Gesho (*Rhamnus prinoides*) leaf is believed to have similar function as hop plant used in brewery industry. Hop is one of the ingredients used for bittering, flavoring and aroma imparting agent for beer brewing and also used as bacteriostatic activity to inhibit the growth of most microorganisms [23]. The mixture of these inputs is kept in the container for fermentation until distillation time reaches.

2.3.1 Difedif Preparation Process

Generally, in traditional *areke* distillation *difedif* preparation process is divided into three phases. In the first phase mixture of ground gesho (*Rhamnus prinoides*) leaves and water is kept for four to five days which is known as *tenses* and then after in second phase *enkuro* made up of ground corn or other cereals slurred with water and cooked, ground malt-germinated barley or wheat (*bikil*) and more water is added to the mixture. The mixture is left for fermentation for four to five days, at this stage the mixture is known as *difedif* (figure 8) then in the third phase fermented *difedif* is distilled by heat supply from biomass burning to distillation apparatus.

2.3.2 Traditional *Areke* Distillation Apparatus

Traditional *areke* distillation system generally comprises the following components: distillation pot made of clay with thickness of approximately 8-12mm, pot lid made of clay, condensate tube made of bamboo, distillate collector flask and condenser tub-made of clay filled with cooling water. The distillation pot is placed on either three stone support or on stove made with the shape (usually rounded) of the pot to increase heat delivery to pot and increase efficiency, where one side has small opening which aids the supply of firewood and burning of the fuel (Figure 9).

Figure 11 Photograph of *difedif* ready for distillation

There are also improved *areke* distillation stoves (figure 10) which has separate fuel and air inlets [9]. The fuel and air inlet and combustion chambers are made of refractory bricks which can withstand high temperature and gives strength to stove *(Ibid)*.

Figure 12 Multiple traditional *areke* distillation stove (rounded shape to hold the shape of pot) [9]

Figure 13 Improved *areke* distillation stoves [9]

2.3.3 Condensate Tube

In traditional *areke* distillation process the condensate tube made of bamboo with approximate internal diameter of 60mm is used. The condensate tube has small opening at one end where bamboo tube having smaller diameter is inserted and connects the collector flash with the pot, while the larger opening at the other end is inserted in to the opening on the lid of distillation pot. The small opening on the condensate tube has approximate diameter of 20mm.

2.3.4 Cooling System

In traditional *areke* distillation the condenser system comprises the following three components: -cooling tub made of clay filled with cooling water, tie rope and the distillate collector flask. The distillate collector is immersed up to its neck into the water filled tub. One end of condensate tube made of bamboo is inserted into the opening of distillate collector flask, while the other end is inserted into the outlet of the distillate pot. After condensate tube is inserted into the flask and the flask is inserted in the cooling water, it will be tied down to the tub by tie rope to prevent the movement. The evaporate coming from the *difedif* in distillate pot flows through the condensate tube and enters into the collecting flask. The hot steam that enters into the flask cools by releasing the heat to the cooling water in the cooling tub. When the cooling water in the tub gets hot, it will be drained and replaced by cool water if the flask is not already full of distillate-areke. The photograph of cooling system is shown in figure 14.

2.3.5 Traditional *Areke* Distillation Procedures

After washing distillation pot *difedif* will be poured to the pot. Depending on amount of distillate or *areke* required the amount of *difedif* added into the pot varies. In some places of the country 8 (eight) liters of *difedif* is added to obtain 1(one) liter of distilled *areke* (data used for the design of the system in this thesis, this data is obtained from one of *areke* distilling household found in *Kechene Medanialem*, Addis Ababa*)* with 40% alcohol content. While in other place of the country 12 (twelve) liters of *difedif* is added to the pot to obtain 2 (two) liters of distilled *areke*.

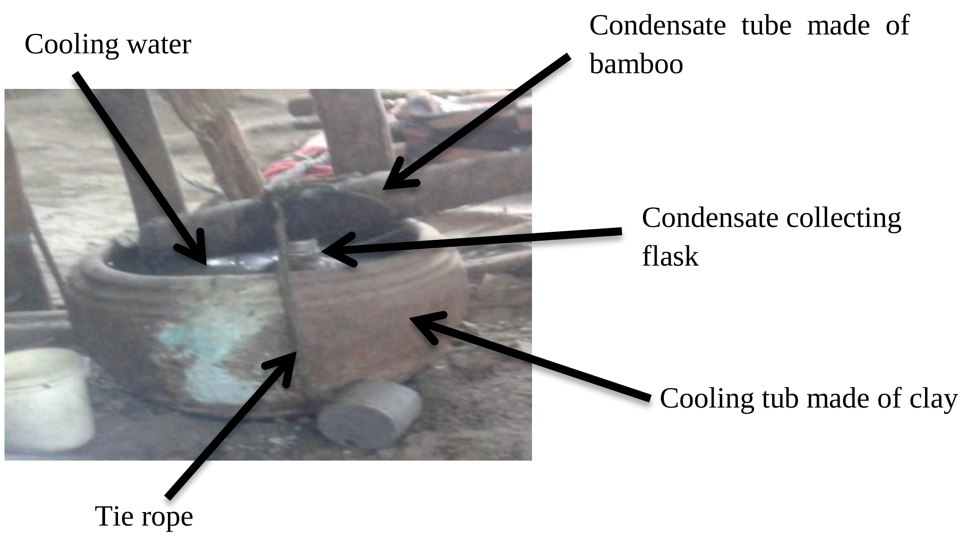

Figure 14 Photograph of traditional *areke* distillation cooling system

After the pot filled with the required amount of *difedif*, it will be placed on three stone stove and agitated-while heat is supplied under the pot by firewood burning, until the temperature reaches at which the evaporate can be seen through the pot opening. Then when evaporate seen through the pot opening the system will be sealed. Clay lid will be placed on the opening of the pot to prevent evaporate from escaping to the atmosphere and the condensate tube will be inserted to the lid opening, through where alcohol and water mixture distillate steam flows and enters into the condensate collector flask. If multiple pots are used at the same time single distillate collector can be used or single pot can be used with single collector flask. Cloth soaked into *difedif* is used as a sealing the space between the lid and pot opening to prevent evaporate leakage. The evaporate (mixture of alcohol and water) which enters into collector flask will be cooled by releasing heat to cooling water filled in the condenser. After the system is sealed the heat supply or fire must be controlled by controlling the amount of wood feed in order to avoid the *difedif* in the pot from burning, sticking to the bottom of the pot and reduce the percentage of water in the final distillate-*areke*.

Figure 15 Photograph of *difedif* undergoing pre-heating process before sealed

If the *difedif* gets overheated, the final output or *areke* will change its color and it will be wasted. The system will be continuously inspected for leakage and correction measures taken. They check the distillate amount by weighing by hand the distillate collector if they feel heavy; they think the collector is full and time to end the distillation process. Then the leftover stillage, known as *atella* will be used as feed for livestock. According to the data obtained from local *areke* distillers one round distillation takes on average from 2:30 to 3:00 hours.

Figure 16 Photograph of single sealed traditional distillation stove

CHAPTER THREE

DESIGN CALCULATION OF PARABOLIC DISH

3.1 Theoretical Background

Some processes require delivering heat with high temperature which is not possible with all types of solar heat collectors. This can be achieved by decreasing the area by which heat losses occur. Solar concentrator is one of the systems used to deliver solar radiation energy with high temperature. Solar concentrator is a device which concentrates solar radiation energy on a larger surface onto a smaller surface. Total system which consist the concentrator and receiver system is known as solar collector. The concentrator is the component of the collector system which directs solar radiation onto the receiver surface. Receiver is the part of the collector system where incident radiation reflected from the concentrator is absorbed and useful energy is transferred to the working fluid.

High temperature absorbed by the receiver is dependent on the concentration ratio of the collector. Increasing ratios mean increasing temperatures at which energy can be delivered and increasing requirements for precision in optical quality and positioning of the optical system [6].

Concentration ratio, C of solar collector is defined as the ratio of the area of aperture to the area of the receiver.

The aperture area $, A_a$ is the opening area of the concentrator at which solar incident from the sun is intercepted.

Absorber area $, A_{ab}$ is the total area of surface of the absorber that receives the incoming reflected radiation from concentrator.

The concentration ratio is given by:

$$C = \frac{A_a}{A_{ab}} \qquad (1)$$

The optical efficiency is defined as the ratio of the energy absorbed by the absorber to the energy incident on the concentrator aperture and for most concentrator it ranges between 0.6 to 0.7 [11]. The optical efficiency , η_o is given by:

$$\eta_o = \frac{Q_{abs}}{A_a I_b} \quad (2)$$

Where,

Q_{abs} is energy absorbed by the absorber.

I_b is solar beam radiation.

The thermal efficiency is defined as the ratio of the useful energy delivered to the energy incident at the concentrator aperture. For parabolic dish solar *areke* distiller including evaporation of alcohol and water is given by:

$$\eta_{th} = \frac{m_{dT} c_{pw}(T - T_o) + m_e * L_e + (m_{dT} - 0.05 m_{dT}) * c_{pw}(T - T_o) + m_w * L_w}{I_b A_a} \quad (3)$$

Where,

m_{dT} is total mass of *difedif* (7kg).

c_{pw} is the specific heat of water, $\frac{J}{kg.K}$.

T is evaporation temperature of alcohol (i.e. 70.4^oC in Addis Ababa).

T_o is the initial temperature of *difedif* (ambient temperature is considered for design calculation, 20 ^oC).

m_e is mass of ethanol (0.35kg).

L_e is latent heat of vaporization of ethanol, $\frac{kJ}{kg}$.

m_w is mass of distilled water (0.56kg).

L_w is latent heat of vaporization of water, $\frac{kJ}{kg}$.

In equation 3,

1st term is sensible heat gain of difedif.

2nd term is latent heat of vaporization of ethanol.

3rd term is sensible heat gain of the remaining difedif after 0.35kg of ethanol is evaporated.

4th term is latent heat of vaporization of water.

The instantaneous thermal efficiency of a solar concentrator may be calculated from an energy balance on the absorber. The useful energy delivered by a concentrator is given by:

$$Q_u = \eta_o A_a I_b - U_L(T_{ab} - T_a)A_{ab} \tag{4}$$

$$\eta = \frac{Q_u}{A_a I_b} = \eta_o - \frac{U_L(T_{ab} - T_a)A_{ab}}{A_a I_b} \tag{5}$$

Where,

U_L is overall heat loss coefficient

T_{ab} is absorber surface temperature

T_a is ambient temperature

3.2 Atmospheric Pressure

The boiling point of any given liquid depends on atmospheric pressure of any given location. Since the atmospheric pressure of any location depends on the altitude of given place the pressure at sea level must be corrected to the required altitude. For altitudes between 0 and 10,973m the standard atmosphere is expressed by [24]:

$$p = p_o(1 - \frac{BZ}{T_o})^{5.26} \tag{6}$$

Where,

p_o= standard atmospheric pressure at sea level

Z= altitude, m or ft (Addis Ababa, 2400m)

T_o=518.69°R=288.16 K=15°C

B=0.003566°R/ft=0.00650 K/m

3.3 Sizing Parabolic Dish Solar Collector System

The amount of heat required from parabolic dish solar distiller is that it will heat about 8 liters of *difedif* from ambient temperature to the evaporation temperature of alcohol 70.4 ℃ and water 92°C in Addis Ababa plus the enthalpy of vaporization of alcohol and water.

3.3.1 Absorber Sizing

Absorber or receiver is element of solar collector system where the radiation is absorbed and converted into some other useful energy form-heat.

The absorber is considered to be spherically shaped with flat bottom surface, having outside diameter d_o, internal diameter d_i, and with uniform thickness of $t = 8mm$.

Assuming volume of the absorber, V_a is to be equal to the volume of the *difedif* to be boiled in one round ($\mathrm{i.e.}\ \mathrm{V_d} = 8\ \mathrm{liters} = 0.008\mathrm{m}^3$).

Volume of sphere is given by:

$$V_a = \frac{4\,\pi * r_i^3}{3} \tag{7}$$

$$\mathrm{r_i} = \sqrt[3]{\frac{3 * 0.008}{4 * \pi}} = 0.124\mathrm{m}$$

$$d_i = 2\,r_i = 0.248m$$

Where,

d_o Outside diameter of absorber

d_i Inside diameter of absorber

r_i Internal radius of the absorber sphere

V_d Volume of *difedif* equal to volume of absorber

Effective surface area of the absorber, A_a

$$A_a = 4\pi {r_o}^2 \tag{8}$$

Where,

r_o Is outside radius of absorber sphere is equal to 132mm

$$A_a = 0.22m^2$$

Assuming the reflected ray only reaches the bottom surface of the absorber (i.e. 50% of the total area) effective surface area of the absorber will be:

$$A_a = 0.11m^2$$

3.3.2 Areke Preparation Analysis

The following data is obtained from the survey conducted on one of *areke* distiller's household in *Kechene Medanialem*, Addis Ababa. According to w/o Kebebush Kidane from *Kechene Medanialem*, Addis Ababa her income is dependent on local *areke* production. The following inputs are needed to prepare *difedif*:

(***N.B***: The amount of all inputs will vary depending on the amount of *areke* required).

For 20kg of corn meal, 12kg of *bikil* (germinated wheat), 2kg of ground gesho leaf and water (5 liters of water is needed to prepare *tenses* and additional 80 liters of water is added to prepare mixture of-gesho, *bikil* and corn meal-*difedif*). Approximately total 85 liters of water is required to prepare the *difedif*, assuming water in the *enkuro* is completely removed during cooking.

Total mass of *difedif*, m_{dT} is equal to the sum of mass of corn (m_c), mass of gesho (m_g), mass of *bikil* (m_b) and mass of water (m_w).

$$m_{dT} = m_c + m_g + m_b + m_w \quad (9)$$

$$m_{dT} = 119kg$$

Where,

Density of water, ρ_w=1kg/L

Density of wheat (malted flour), ρ_y=673kg/m^3

Density of gesho flour, ρ_g=769kg/m^3 (density of any flour)

(*Source: Bulk Density Chart*, *Anval*)

Total volume of the *difedif*, V_T is the sum of volume of all inputs

$$V_T=V_c+V_g+V_b+V_w \quad (8)$$

$$V_T = 138l$$

$$V=m/\rho$$

Where,

V_c is volume of corn

V_g is volume of gesho

V_b is volume of *bikil*

V_w is volume of water

3.3.3 Sizing Parabolic Dish Reflector

Reflector that is surface of revolution (circular concentrator) of parabola, known as paraboloid is used to direct radiation to receiver on a point.

Volume of *difedif* to be distilled starting from morning 8:00AM to 5:00PM (assumed uniform throughout the day for design simplicity) is 24 liters to obtain 3 liters of *areke* with alcohol content of 44% in three cycles (i.e. in each round 8 liters of *difedif* is distilled to obtain 1 liter of *areke* with 44% of alcohol content, within 3 hours).

To obtain 1 liter of *areke* with one cycle, 8 liters of *difedif* is used. Total volume difedif (i.e. 138l) can be distilled approximately 17 times. 17 liters of *areke* with alcohol content of 44% can be obtained from 138 liters of *difedif*.

The ethanol yield from a large production plant is about 1 liter ethanol from 2.69kg of corn grain [29]. Hence, 7.4 liters of ethanol can be obtained from 20kg of corn grain. For 17 cycle of distillation with 44% of alcohol and 56% of water was obtained. In 138L of *difedif* 38.4% is a mixture of corn meal, ground gesho and *bikil*, while 61.6% is water. One liter of *difedif* contains 0.384 liters (mixture of corn, gesho, *bikil* and alcohol) and 0.616 liters of water. Hence, 8 liters of *difedif*, contains 3.072 liters (mixture of corn, gesho, *bikil* and alcohol) and 4.928 liters of water.

Volume of each ingredient in 1liter of *difedif* is:

Gesho= 3/138 = 0.022l

Bikil= 18/138= 0.13l

Corn= 32/138=0.232l

Water= 85/138= 0.616l

Volume of each ingredient in 8l of *difedif* is:

Gesho= 0.176l

Bikil= 1.04l

Corn= 1.856l

Water= 4.928l

Mass of each ingredient in 8 liters of *difedif* is:

Gesho= 0.176l*0.769kg/l=0.14kg

Bikil= 1.04l*0.673kg/l=0.7kg

Corn= 1.856l*0.625kg/l=1.16kg

Water= 4.928l*1kg/l=4.93kg.

Total mass of 8 liters of *difedif* is 6.93kg~7kg.

After complete distillation assuming 0.44 liter of alcohol in the 8 liters of *difedif* is completely removed, the leftover stillage contains 2.6232l (mixture of corn, *bikil* and gesho) and 4.368 liters of water. Final distillate, in 1liter of *areke* contains 44% alcohol and 56% of water.

Mass of ethanol, m_e in 1 liter of *areke* is given by:

$$m_e = \rho_e * V_e \quad (9)$$

$$m_e = 0.35\text{kg}$$

Where,

ρ_e is density of ethanol i.e. 0.790kg/l.

V_e is volume of ethanol in 1liter of *areke* i.e. 0.44l.

Mass of distilled water, m_{we} in 1liter of *areke* is given by:

$$m_{we} = \rho_w * V_w \quad (10)$$

$$m_{we} = 0.56\text{kg}$$

Where,

ρ_w is density of water i.e. 1kg/l

V_w is volume of water in 1 liter of distilled *areke* i.e. 0.56l

NB: The amount of water present in *areke* determines the quality of the final product. On average local *areke* contains 40 % to 45% of alcohol content. When the amount of water in the *areke* increases, the quality (power) of *areke* will decrease.

3.3.4 Energy Balance

3.3.4.1 Expected thermal performance of the system

Useful energy absorbed by the *difedif*, Q_u

$$Q_u = \eta_{th} I_b A_a \tag{11}$$

Where,

η_{th} is thermal efficiency of solar concentrator

A_a is aperture area of concentrator

I_b is solar beam radiation

Most solar concentrator's thermal efficiency, η_{th} ranges from 40%-60% [11] [12]. Average solar radiation intensity of Addis Ababa is $500W/m^2$ and assumed to be uniform throughout the day. Let aperture diameter, D_a of the concentrator is 1.6m. Average $\eta_{th} = 0.5$.

Aperture area, A_a

$$A_a = \frac{\pi * {D_a}^2}{4} \tag{12}$$

$$A_a = 2m^2$$

$$Q_u = 0.5 * 500 * 2 = 500W$$

Absorbed energy by absorber, Q_{abs}

$$Q_{abs} = \eta_o A_a I_b = \frac{\eta_o}{\eta_{th}}(\eta_{th} A_a I_b) = \frac{\eta_o}{\eta_{th}} Q_u \tag{13}$$

$$Where, \eta_o\ is\ optical\ efficiency\ solar\ concentrator$$

The optical efficiency of most solar concentrators lies between 0.6 and 0.7 [11]. Taking the lowest value, $\eta_o = 0.6$

$$Q_{abs} = \frac{0.6}{0.5}500 = 600W$$

The useful energy for one cycle of distillation of *areke* is calculated by:

$$Q_u = Q_{u1} + Q_{u2} + Q_{u3} + Q_{u4} \tag{14}$$

Where,

Q_{u1} is the heat energy required to raise the sensible temperature of *difedif* of mass, m_{dT} from ambient temperature, T_o=20^{o}C to boiling temperature of alcohol in Addis Ababa, T=70.4^{o}C. Q_{u2} is heat energy required to evaporate 0.35kg of alcohol to vapor.

Q_{u3} is heat energy required to raise the sensible temperature of the remaining mass of *difedif* after 0.35kg of alcohol distilled.

Q_{u4} is heat energy required to evaporate 0.56kg of water to steam.

$$Q_{u1} = m_{dT}c_{pw}(T - T_o) = \eta_{th}I_bA_at_1 \tag{15}$$

$$t_1 = \frac{m_{dT}c_{pw}(T - T_o)}{\eta_{th}I_bA_a} = \frac{7 * 4180 * (70.4 - 20)}{0.5 * 500 * 2} = 2949.802s \approx 50min$$

Note: Because of unavailability of c_p data of *difedif* and mixture of *difedif* contains high percentage of water; c_{pw} value of water is used as c_p of *difedif* for calculation.

Where,

t_1 is the time required to raise temperature of 7kg of *difedif* from 20^{o}C to 70.4^{o}C.

$$Q_{u2} = m_e * L_e = \eta_{th}I_bA_at_2 \tag{16}$$

$$t_2 = \frac{m_e * L_e}{\eta_{th}I_bA_a} = \frac{0.35 * 919 * 10^3}{0.5 * 500 * 2} = 643.3s \approx 11min$$

Where,

$L_e(919kJ/kg)$ is the latent heat of vaporization of ethanol at 70.4^{o}C and t_2 is the time required to convert 0.35kg of alcohol to vapor.

$$Q_{u3} = (m_{dT} - 0.05m_{dT}) * c_{pw}(T - T_o) = \eta_{th} I_b A_a t_3 \quad (17)$$

$$t_3 = \frac{(m_{dT} - 0.05m_{dT}) * c_{pw}(T - T_o)}{\eta_{th} I_b A_a} = \frac{6.65 * 4180 * (92 - 70.4)}{0.5 * 500 * 2} = 1200.83s \approx 21min$$

Where,

t_3 is the time required, after 0.44l or 0.35kg alcohol distillation the remaining mass of *difedif* temperature to reach from 70.4^{o}C to 92^{o}C (evaporation temperature of water in Addis Ababa)

$$Q_{u4} = m_w * L_w = \eta_{th} I_b A_a t_4 \quad (18)$$

$$t_4 = \frac{m_w * L_w}{\eta_{th} I_b A_a} = \frac{0.56 * 2257 * 10^3}{0.5 * 500 * 2} = 2527.84s \approx 43min$$

Where,L_w(2257kJ/kg) is the latent heat of vaporization of water at 92^{o}C

t_4 is the time required to convert 0.56kg of water to steam.

Estimated total time required for one cycle of distillation will be:

$$T_d = t_1 + t_2 + t_3 + t_4 \quad (19)$$

$$T_d = 50min + 11min + 21in + 43min = 125\ minutes\ or\ 2\ hours\ and\ 5\ minutes$$

Concentration ratio, C

$$C = \frac{A_a}{A_{ab}} \quad (20)$$

$$C = \frac{2}{0.22} = 9.1$$

Where,

A_a Aperture area

A_{ab} Absorber area

Focal length, $\boldsymbol{f}$ the solar concentrator is always most angle tolerant when the focal height is one fourth of the aperture length regardless of the target size [1].

$$f = \frac{1}{4} D_a \tag{22}$$

$$f = \frac{1.6}{4} = 0.4m$$

Height/Depth of dish, h

$$h = \frac{{D_a}^2}{16f} \tag{23}$$

$$h = \frac{1.6^2}{16 * 0.4} = \frac{2.56}{6.4} = 0.4m$$

Volume of parabola, V

$$V = \frac{1}{2}\left(\pi\left(\frac{D_a}{2}\right)^2 h\right) \tag{24}$$

$$V = \frac{1}{2}\left(\pi(\frac{1.6}{2})^2 * 0.4\right) = 0.402m^3$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

After parabolic dish collector is designed and constructed the test was conducted for three different days to measure distillate amount and for one day to measure the temperature variation of the *difedif* with time. In all three different days the same amount of *difedif* (i.e. 2.5 liters) was used to conduct the test to measure the distillate amount approximately the same amount of measurement was obtained. The test to measure the temperature variation of the *difedif* with time was conducted from 11:15AM to 3:00PM on January 24, 2015. The test was conducted on December 30, 2014 from 9:51AM to 1:00PM, December 31, 2014 from 9:45AM to 12:45PM and January 24, 2015 from 11:15AM to 8:15PM to measure the distillate amount. The temperature variation with time was measured only for one day the measured data is given in the table 1 and the variation with time is represented by graph shown in figure 17.

4.1 Temperature variation of the *difedif* in the absorber pot with time

During test for temperature variation of the *difedif* temperature reading was taken from 11:15AM to 3:00PM at the interval of 15 minutes. The following table shows the temperature variation of the *difedif* within each interval of 15 minutes.

Table 1 Temperature variation of *difedif* in the pot of 24^{th} January, 2015

Measurement	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Time	11:15 AM	11:30 AM	11:45 AM	12:00 PM	12:15 PM	12:30 PM	12:45 PM	1:00 PM	1:15 PM	1:30 PM	1:45 PM	2:00 PM	2:15 PM	2:30 PM	2:45 PM	3:00 PM
Temp (^oC)	17.5	23.5	37	46	65	70	76	70.5	70.5	80	82	76	80.3	83	83	92

It is observed that from table 1 the *difedif* temperature variation started to increase from its initial value of 17.5^{o}C at 11:15AM. At 7^{th} column the temperature of the *difedif* reached 76^{o}C and falls down to 70.5^{o}C boiling point temperature of alcohol this is because the sun was vertically overhead radiation intensity was high. The *difedif* approximately took 1 hour and 15 minutes to reach the boiling point temperature of ethanol in the *difedif* to start evaporation. After disassembling the collector system within three hours, the leftover stillage or *atella* in the absorber pot was left on focal point for additional temperature reading. After 45 minutes the stillage or *atella* temperature was reached between 83^{o}C and 92^{o}C.

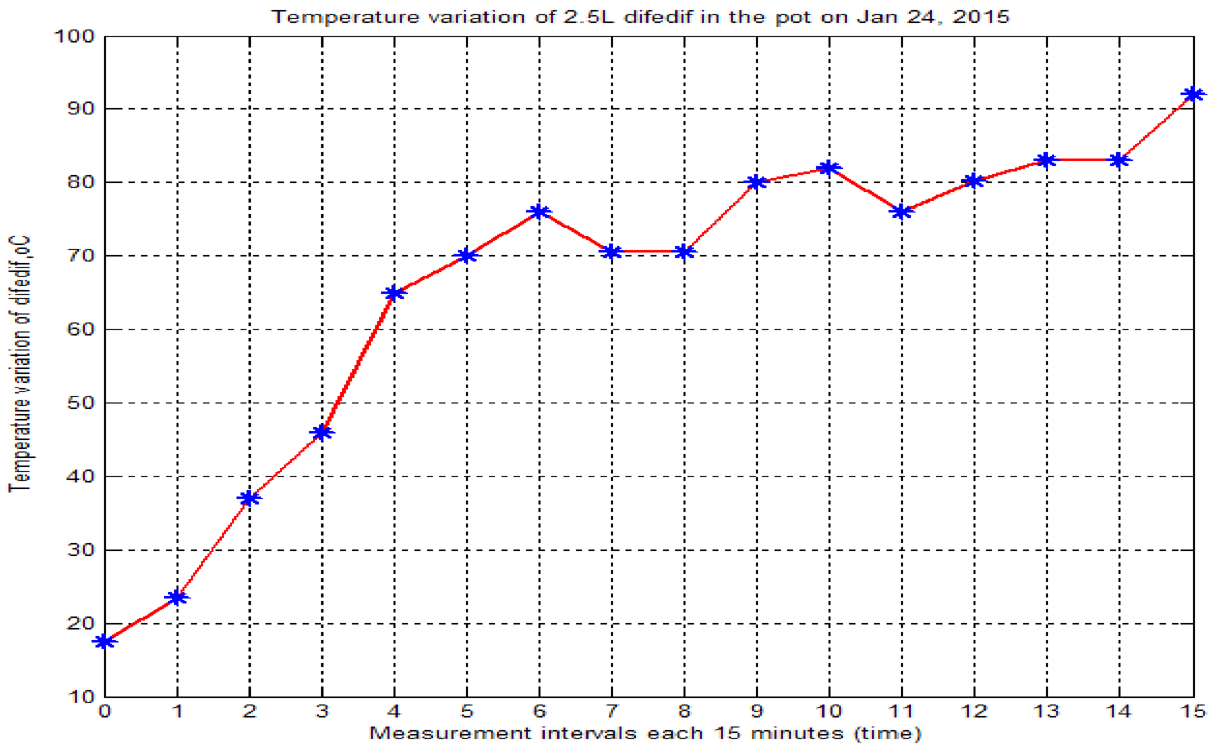

Figure 17 Temperature variation of *difedif* on Jan 24, 2015 (11:15AM to 3:00PM)

4.2 Instantaneous efficiency of the collector

Due to malfunctioning of solar radiation measuring instruments the radiation data measured by Aklilu Tesfamicheal on November 2, 2004 was used to calculate the instantaneous efficiency of the test. On this day the maximum temperature reached 22.65^{0}C at 2:41pm and radiation reached 1.0357kW/m^{2} around the noon. The sunrise was at 7:00 am and sunset was at 5:30 PM. The measured data is given in the figure 18.

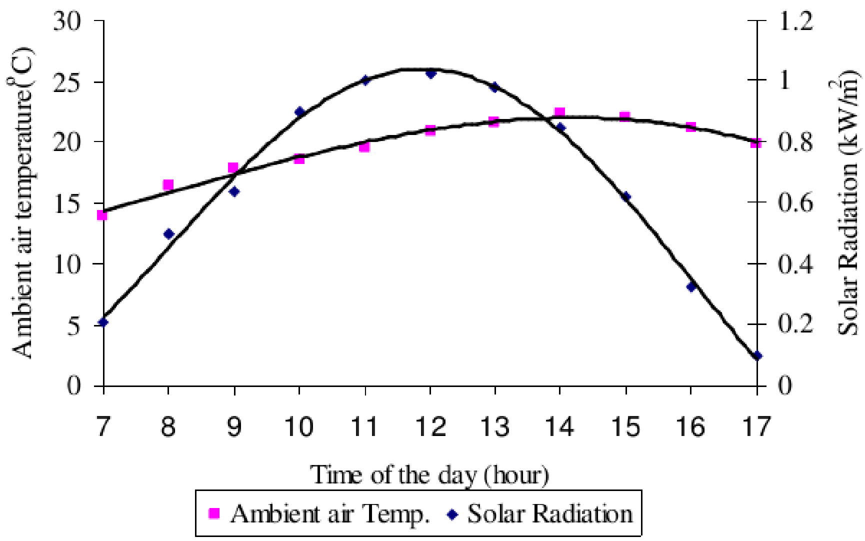

Figure 18 Weather data for the test period: measured total solar radiation and ambient temperature obtained from the pyranometer and temperature sensor [28]

The instantaneous efficiency of the collector is given by:

$$\eta = \frac{Q_u}{A_a I_b t} * 100$$

Where,

Q_u is useful heat delivered to the *difedif*

t is time

I_b is total solar radiation on the aperture surface of concentrator

A_a is solar concentrator aperture area

From above given radiation data and taken measurements calculations the thermal efficiencies of 35%-38% were obtained and the overall performance of the distiller is satisfactory.

4.3 Distillate amount of a*reke*

After the collector system is constructed the test were conducted on three different days to measure the distillate amount of *areke* from 2.5 liters of *difedif* in the absorber pot. The tests of the results are summarized in the following table 2.

It is observed that almost the same amount of distillate *areke* was obtained from three different test days. As indicated in the table 2 on December 30, 2014, 0.28 liters of *areke* having specific gravity of 0.92 was obtained from 2.5 liters of *difedif* within 3 hours of distillation period.

Table 2 Results of test of distillate amount of *areke* for three different days

Date and Time	*Difedif* amount used, l	Duration, hours	Distillate amount obtained, l	Weather condition during distillation	Specific gravity of *Areke*
Dec 30,2014 9:51am-1:00pm	2.5	3	0.28	Clear sky	0.92
Dec 31, 2014 9:45am-12:45pm	2.5	3	0.3	Clear sky	0.92
Jan 24, 2015 11:15am-2:15pm	2.5	3	0.2	Fairly cloudy condition	0.92

The atmospheric condition during the test in this day was clear sky the solar intensity was good. Also the same amount of distilled *areke* was obtained during second test on December 31, 2014 from the same amount of *difedif* filled in the absorber pot with alcohol content of 44%. Amongst the three days of the test January 24, 2015 results the lowest amount of distilled *areke*. This low value was as a result of the cloudiness of the weather condition on that day. Figure 20 shows the amount of distilled *areke* during the test using solar parabolic dish distiller system. Some amount of *areke* was spilled during the specific gravity test and fire test from each container.

The alcohol content of distilled *areke* in each day was measured in AAIT chemical lab using hydrometer and micrometer to determine the specific gravity of the *areke*-mixture of ethanol and water. Equal value of alcohol content was observed during the test. The specific gravity of 0.92 was recorded during hydrometer test. Based on recorded specific gravity the alcohol content of 44% was read from property table [25].

Figure 20 Photograph of distilled *areke* using parabolic dish distiller

The alcohol content of local *areke* distilled by firewood was measured for comparison and gives value of 0.93 which has alcohol content of 40% almost closer to the solar energy distilled *areke*. Locally firewood distilled *areke* was bought from the same house where *difedif* for test was purchased. The photograph of specific gravity measurement using hydrometer is illustrated in figure 21.

Figure 21 Specific gravity measurement of *areke* using hydrometer

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this study design and development of parabolic dish solar collector for local *areke* distillation is presented. Specially designed clay pot is used as absorber surface; where *difedif* is filled and absorb heat reflected by the concentrator surface. The test was conducted for three different days to measure the distillate amount and temperature variation of the *difedif*. Almost the same amount of distillate was collected during each test. The test conducted on parabolic dish solar collector showed satisfactory result. It was possible to reach the boiling temperature of alcohol in the *difedif* within 1 hour and 30 minutes of time. Maximum of 0.3 liters were obtained from 0.25 liters of *difedif* in absorber pot. Hence, using solar energy as a substitute or support for local *areke* distillation process with the design of appropriate solar energy capturing systems it is possible to mitigate the negative impacts on human health, environment and economy due to biomass burning for *areke* distillation. This work was only a beginning and the results were only a starting point to improve the developed *areke* distillation unit further study is required.

5.2 Recommendations

1. The biggest challenge during this thesis work was the shortage of documented previous research data on the area of traditional *areke* production analysis; there is no detail analysis of *areke* production process and no recorded data for easy reference. Therefore, in order to fill the shortage of data united efforts are required from students, researchers, NGOs, governments and different stake holders to conduct research on traditional *areke* distillation processes.
2. In this thesis clay pot was used as an absorber element during the test. Hence, the relation between other materials as a receiver element and *areke* distillation process

can be further analyzed. If positive result is obtained, may be the distillation time can be minimized and overall performance could be improved.

3. Using highly reflective glass mirror as a reflective surface might improve the overall performance of the distillation system.
4. The shortage of necessary measuring instruments (data loggers, pyranometer, sensors, etc.) was the limitation during the test. Hence, with availability of necessary test instruments detail analysis of the distillation system could be done.
5. In this thesis spherically shaped with flat bottom surface absorber clay pot was used. Using parabolic shaped absorber surface might improve the overall performance of the distillation system.
6. In this thesis clay pot was used as an absorber element. Different material shows different properties depending on the radiation type (wavelength). The response of clay pot to solar and biomass radiation could be studied in details. Due to data shortage the analysis is not included in this thesis.

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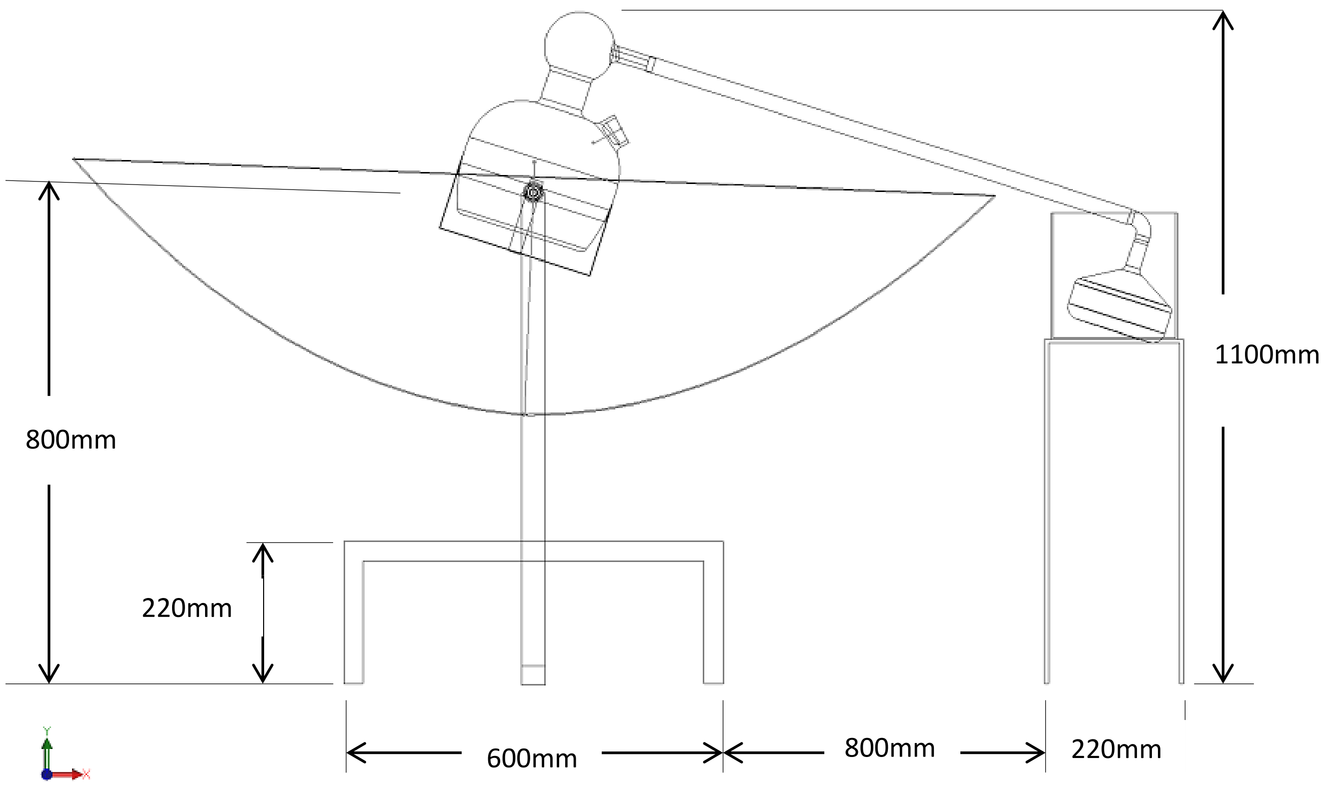
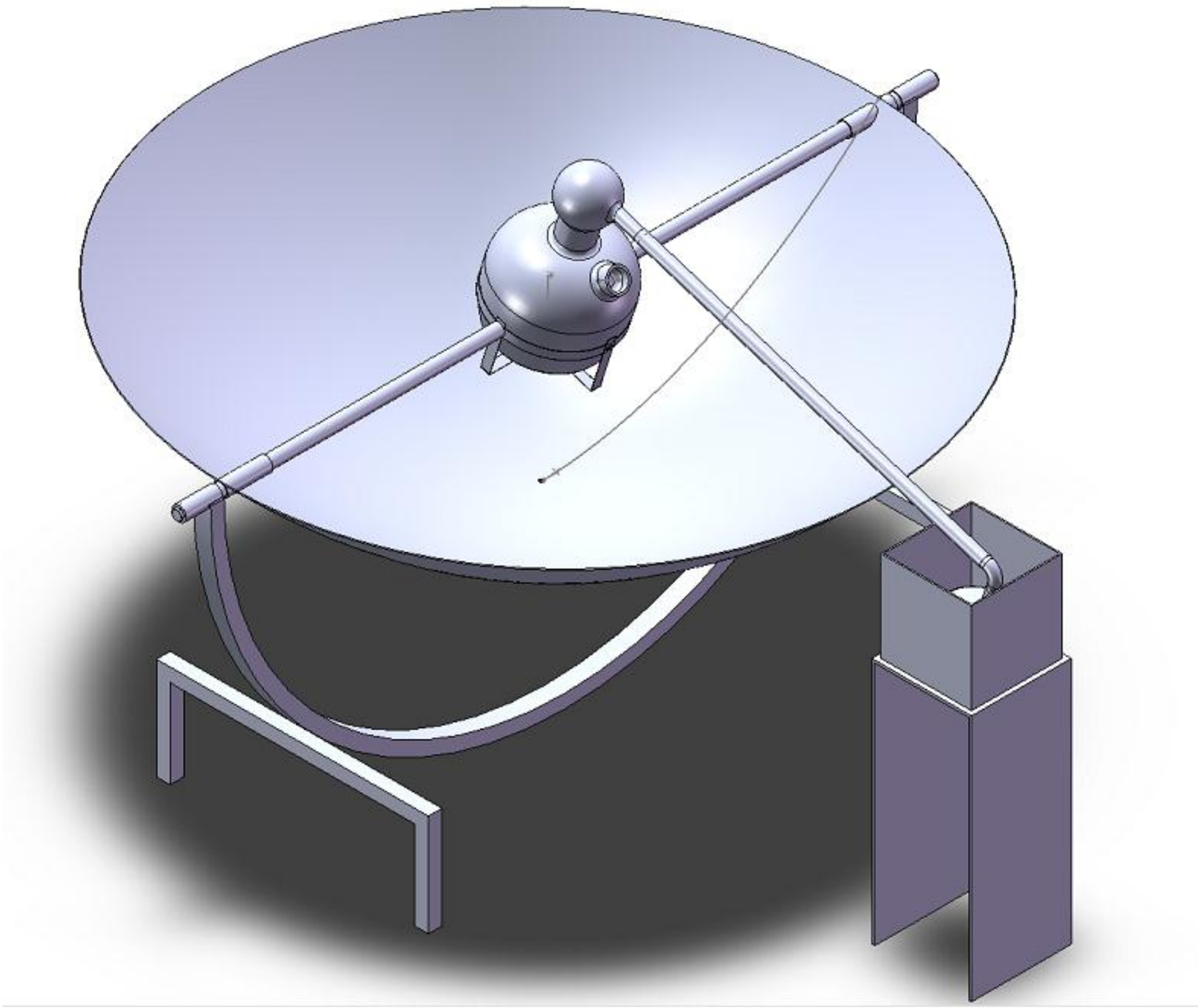
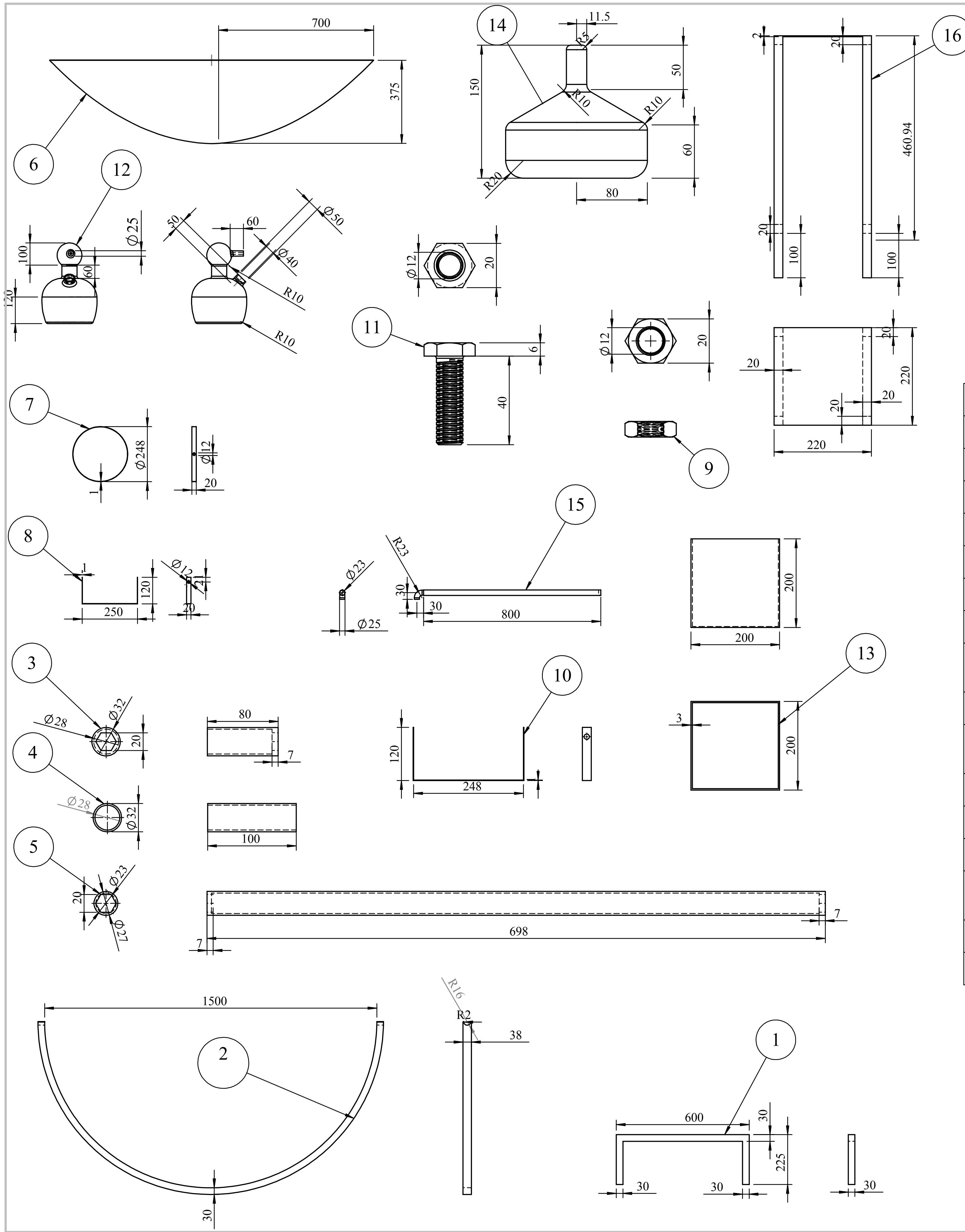
APPENDIX

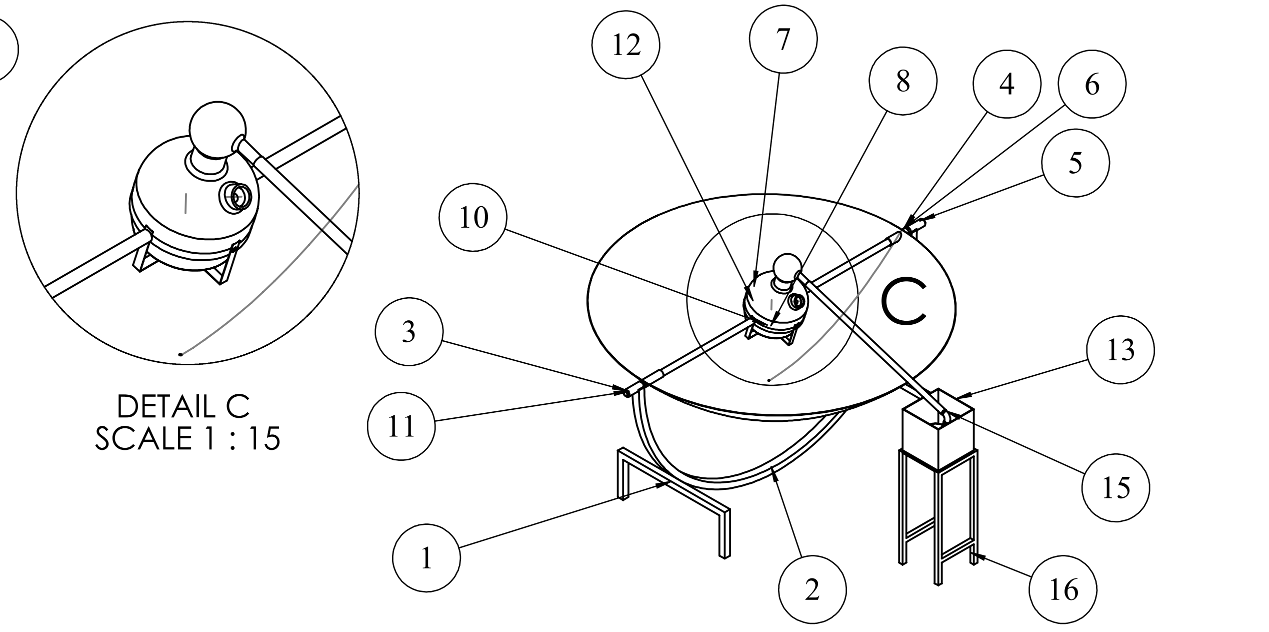


Assembled drawing of parabolic dish solar concentrator system



Pictorial drawing of parabolic dish solar concentrator system





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	leg		2
2	frame		1
3	small pipe		2
4	medium pipe		2
5	large pipe		2
6	Dish		1
7	pot supporting ring		1
8	pot supporting plate 1		1
9	nut1		4
10	pot supporting plate 2		1
11	bolt		2
12	absorber pot		1
13	cooling tub		1
14	condensate collector		1
15	condensate tube		1
16	tub table		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS

AAIT

	NAME	SIGNATURE	DATE
DRAWN	Adane Kassa		
CHK'D			
APPV'D			

TITLE: Detail drawing of parabolic dish solar concentrator

DWG NO. 1 | A3

SCALE:1:1 | SHEET 1 OF 1