ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF GRADUATE STUDIES

DESIGN, FABRICATION AND EXPERIMENTAL INVESTIGATION OF IMPROVED BIOMASS AREKE DISTILLATION STOVE

DIRIBA BEKELE

A THESIS SUBMITTED TO THE SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING IN PARTIAL FULFILLMENT OF THE DEGREE OF MASTERS OF SCIENCE IN MECHAMICAL ENGINEERING (THERMAL STREAM)

Advisor: - Kamil Dino Adem (PhD)

February, 2019

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Thermal & Energy Conversion Chair

THESIS APPROVAL SHEET

The following graduate school members certify that this student has successfully presented the necessary written final thesis and oral presentation for partial fulfillment of the thesis requirements for the Degree of Master of Science in Thermal Engineering.

Name Diriba Bekele Signature______________ Date________.

Approved by

Advisor:

Name Kamil Dino Adem (PhD) Signature______________ Date________.

Internal Examiner:

Name____________________________ Signature______________Date________.

External Examiner:

Name____________________________ Signature______________ Date________.

School Dean:

Name Yilma T. (PhD) Signature______________Date________.

Declaration

Author would like to declare that the work which is presented in this thesis entitled "Design, Fabrication and Experimental investigation of improved biomass Areke distillation stove" is original work of his own, has not been submitted elsewhere for a degree/diploma and that all sources of material used for the thesis have been duly acknowledged.

___________________   ___________________

Diriba Bekele   Date

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

_____________________________   __________________ .

Kamil Dino Adem (PhD) (Advisor)   Date

`

ABSTRACT

Areke is a traditional alcoholic beverage which is distilled from fermentation of cereals; malt (*beqil*), *gesso* which gives flavor to the *Areke* with addition of water. Traditional stoves are widely used across various regions of Ethiopia. Mostly, three stone biomass *Areke* stove is the dominant stove used for *Areke* distillation. But traditional and three-stone fires cause serious health issues and their high fuel consumption leads to deforestation problems. The aim of this study was to design and make experimental investigation of improved biomass *Areke* distillation stove to improve thermal efficiency of the stove and consequently reduce the wastage of heat energy during the distillation process. In order to quantify the amount of heat loss accounted in three stone and improved biomass *Areke* distillations stove intensive experimental investigation was made, and data obtained was analytically analyzed. In addition to that, Controlled Cooking was used to evaluate the performance of the *Areke* stoves. An experienced cook/brewer was hired to prepare and distill *Areke* using the two types of stoves three stone, and improved *Areke* stoves. The fuel used for all the tests has on average a size of 40mm x 40mm x 1000mm. The moisture content of the fuel wood used for the test was around 14%. The test room has a size of 2.5m x 3.5m x 2.5m. Considering the three stone *Areke* stove as a reference, the specific fuel consumption improvement or fuel use reduction of improved *Areke* stove is 45 %. Similarly, time to brew/cook reduction is 50% in using improved *Areke* stove. The heat loss accounted in the improved biomass *Areke* distillation stove was also quantified and the system encountered 505 W heat losses. The thermal efficiency of the improved biomass Areke distillation stove was 25% while that of the three-stone fire for Areke distillation was 11 %. This shows an increase of the efficiency by nearly 56 % compared to the three-stone fire. In replacing the existing three stone, the improved *Areke* stove will bring increase in thermal efficiency, reduction of fuel use and reduce total distillation time using biomass in addition to the indoor air pollution load for the women and child in households.

Keywords: *Areke*, Distillation, Heat loss, Specific fuel consumption

ACKNOWLEDGMENT

First and foremost, Author take this opportunity to give glory to the almighty God without which the completion of this work would have been impossible.

Author would like to thank Kamil Dino Adem (PhD) for his expert guidance, constructive comments, suggestions and encouragement without which this work could have not been completed.

Author would also show his gratitude to Ing Wondowson Bogale (PhD) to borrow instrument for his experimental investigation and also very pleased to thank Abdulkadir Aman (PhD) for giving related literature to his study and for his valuable comments and advice. In addition, Author would like to thank all AAIT mechanical engineering workshop staffs for their collaboration, guidance, kindness and support during experimental tests.

Author also grateful to his mother w/o Motu Chala from Mojo city, for her willingness and cooperation to sale ready *difedif* for distillation throughout the test and helping to understand the traditional *Areke* distillation method and procedures.

Last but not least, I would like to thank my all friends for their support, passion and love.

Table of Contents

Abstract ii

Acknowledgment iii

List of figures vi

List of tables vii

CHAPTER ONE 1

Introduction 1

1.1. *Areke* distillation process 3

1.2. Problem of statement 4

1.3. Objective of the research 4

1.4. Scope of study 6

1.5. Significance of study 6

CHAPTER TWO 7

Literature Review 7

2.1. *Areke* Fermentation 8

2.1.1. *Terra-Areke* (Ordinary) 8

2.1.2. *Dagim-Areke* (redistill) 8

2.2. Properties of alcohol 9

2.3. *Areke* distillation stove in Ethiopia's Case 10

2.4. Benefit of using improved *Areke* distillation stove 14

2.5. Traditional *Areke* distillation apparatus 15

2.6. Controlling system of Areke distillation process 16

2.7. Cooling System 17

CHAPTER THREE 18

Materials and Methods 18

3.1. *Areke* preparation analysis 19

3.2. Discription of the *Areke* stove 20

3.3.Traditional *Areke*distillation procedure……………………………………………21

3.4.Testing location……………………………………………………………........... 22

3.6. Fuels tested..……….…………………………………………………..................24

3.7. Experimental setup……………………………………………………………..25

3.8. Controlled Cooking Test……………………………………………………… 26

3.9. Thermal Analysis of Three Stone and Improved Biomass *Areke* Distillation Stove……………………………………………………………………............. 28

3.10. Average temperature variation of the stove body……………………………… 28

3.10.1. Thermal Efficiency…………………………...…………………………28

3.11.Heat transfer and energy balance for modified(improved) stove……...41

3.11.1. Heat gain from gases to the pot bottom…………………………………..47

3.11.2. Heat gain to the side of the pot…………………………………………..50

3.11.3. Heat loss from skirt surface……………………………………………..52

CHAPTER FOUR……………………………………………………………...58

Result and Discussion……………………………………………………………58

4.1. Analytical design…………………………………………………………58

4.2. Experimental test………………………………………………………….....61

4.3. Specific fuel consumption……………………………………………………61

4.4. Average brewing time………………………………………………………...62

4.5. Performance comparisons……………………………………………………...63

CHAPTER FIVE……………………………………………………………...65

Conclusion and Recommendation……………………………………………………65

Reference……………………………………………………………………………67

List of figures

Figure 1: Biogas *Areke* distillation Stove

Figure 2: Experimental setup,

Figure 3:Methodology

Figure 4: Biomass *Areke* distillation stove,

Figure 5: Solar concentrator

Figure 6: Biogas *Areke* distillation stove,

Figure 7: Traditional *Areke* distillation apparatus

Figure 8: Process of traditional condensation.

Figure 9: a) Malt of wheat b) Leaves of gesso (Rhamnus prinoides) c) *difedif* ready for Distillation

Figure 10: *Areke* difedif undergoing pre-heating process before sealed and Process of Traditional *Areke* distillation

Figure 11: Schematic diagram for *Areke* Processing

Figure 12: *Areke* Processing Unit at Arsi-negele

Fig 13: Testing equipment's

Figure 14: Fuel wood collected from forest & purchased from market

Figure 15: Component of modified biomass *Areke* distillation stove

Figure 16: Result obtained from traditional *Areke* stove analytical analysis.

Figure 17: Result obtained from improved *Areke* stove analytical analysis.

Figure 18: Average Specific Fuel Consumption (3SAS, TAS and IAS)

Figure 19: Average brewing time (3SAS, TAS and IAS)

Figure 20: Distillation time and fuel consumption comparison

List of tables

Table 1: Grade of various ethyl alcohols

Table 2: Summary of the literature review

Table 3: Types cereals and corresponding amount used for preparation of sorghum mash

Table 4: Measured temperature of IAS and 3TAS

Table 5: stove data for analytical design calculation

Table 6: Summarized values of heat transfer model

Table 7: Summarized values of heat transfer model

Nomenclature

Symbol	**Meaning**
A	Area
E	Energy
m	Mass
T	Temperature
C_p	Specific heat
d	Diameter
t	Time
V	Velocity
T	Temperature
K	Thermal conductivity
f	Friction factor
J	View factor
Q	Heat transfer
LHV	Lower heating value of wood

HHV	Higher heating value of char
h	Heat transfer coefficient
h_{fg}	Enthalpy of vaporization of water
ΔT	Change in temperature from initial to final
LHV	Net calorific value of char
L	Thickness
P_1	Dry mass of empty pot
∞	Ambient Fluid (air) Temperature
N_u	Nusselt number
P	Static Pressure
P_r	Prandtl number
Re	Reynolds number
R	Resistance

Greek letters

σ	Stefan-Boltzmann constant
α	Absorptivity
ε	Emissivity
μ	Viscosity
ρ	Density

Subscripts

i	Initial
f	Final
a	Ambient
b	Boiling point

s	Surface
Char	Charcoal
e	Evaporated

ABBREVIATIONS

3SAS	Three stone *Areke* stove
TAS	Traditional *Areke* stove
IAS	Improved *Areke* stove

CHAPTER ONE

Introduction

In many countries in the globe there are numerous traditional alcoholic beverages which are produced and consumed at the local level. Such types of drink production seem especially common in many African countries, where a wide variety of alcoholic beverages can be found. Ethiopia has a diversified rich cultural heritage in terms of food and beverages, being the oldest country in the world. A variety of foods and beverages are consumed in different parts of the country. Among the beverages, local alcoholic drinks are consumed by the society. The local alcoholic drinks such *as Tella, Tej, Areke, Karibo, and Korefe* are the popular drinks in Ethiopia. Their alcohol contents various from low to high. That is, *Tella* has an alcohol content of 2- 4 % and *Tej* has 7 – 11 % while *Areke* has an alcohol content of up to 4 5% (Admassie, 2010).

Areke is a traditional alcoholic beverage which is distilled from fermentation of cereals; malt (*bikil*), *gesso* which gives flavor to the *Areke* with addition of water (Admassie, 2010). It resembles *tella* except that the fermentation is more concentrated (Fite, 1991). Desta (1977) also explained that *Terra-Areke* is colorless, clear, local alcoholic beverage which is distilled from a fermentation of *Yeareke-tinsis*. *Yeareke-tinsis* is prepared by mixing powdered *gesso* leaves and powdered *bikil* (1:2 ratios) with water to give a mixture of free flowing consistency which will be put aside to ferment for about five days. To achieve these tasks, they mostly use the traditional three stone biomass stove for Areke distillation. For distilling 1 liter of *Areke*, 2.65 kg of wood is required (Mohammed, 2008).

Areke production and marketing have both positive and negative aspects. This is crystal clear particularly from the perspective and wellbeing of women, who are the major actors, and from the wellbeing and socioeconomic development of the communities in which it is produced. *Areke* production provides tens of thousands of women or more with the only opportunity of livelihood, and this is a very important matter. *Arek*e is commonly distilled by poor women who can only employ archaic, energy inefficient and polluting methods of production that affect their health and also contribute to the progressive denuding of the vegetation cover of the land (Admassie, 2010).

In Ethiopia, most people use three-stone fires for *Areke* distillation applications. When used indoors, these biomass *Areke* stoves lead to severe health issues because the smoke is vented into the home and pollutants concentration increases due to inadequately ventilated rooms causing chronic lung diseases, acute respiratory problems as well as vision problems. The main victims are usually women and young children, who are often carried on the mother's back while *Areke* distillation. These traditional wood fires also imply a high risk of burns and scalds especially on children. Furthermore, because the heat is allowed to escape into the open air rather than heating the cooking vessel, three-stone fires have a low thermal efficiency of around 11 % [4]. This implies a high fuel consumption which results in an increase of the amount of wood harvested and related deforestation.

A number of efforts are underway to improve the performance of traditional biomass *Areke* stoves. In early stages of development, the focus was on improving specific parts of the stove such as the grate, skirt and insulation. However, nowadays, researches focus on reducing the emissions and increase the energy efficiency. For this reason, improved metal shield biomass stoves are receiving more attention [5].

This paper focuses mainly on the role of *Areke* stoves in reducing emissions, eliminating drudgery, and improving overall quality of life. The work is carried out to design improved biomass *Areke* stove and performance of improved biomass *Areke* stove is evaluated using thermal efficiency, distillation duration and specific fuel consumption. The controlled cooking test (CCT) demonstrates improvement in specific fuel consumption and total distillation duration of improved biomass *Areke* stove in comparison with three stone *Areke* stove.

1.1. *Areke* distillation process

Areke is a traditional home-distilled beverage that is made from an assortment of cereals such as wheat, sorghum and maize, and has a high level of ethanol. In its original state it is pure spirit with a neutral taste, and clear, colorless appearance. As *Areke* is a pure – grain alcoholic beverage, its production involves the following ingredients:

- Mixture of cereals that are prepared in different forms to provide the natural sugar needed for fermentation.
- Malt (*biqil*), which is made by soaking wheat in pure water and allowing it to germinate and is then halted from germinating further by drying with hot air.
- *gesso*, the shiny-leaf buckthorn- which gives flavor to the *Areke*
- Water is a vital element of *Areke* production, used in every single step right up to the end.

In most of *Areke* processing areas, malted wheat is bought from the market place and used. In exceptional circumstances, the distillers themselves were found to do the malting process.

The process of *Areke* production goes through three major stages:

- *Metenses* refers to the preparation of *tinsis* (sort of starter mash), which is usually a mixture of malt, *gesso* and water. And then the resulting mixture kept overnight for 4-5 days in a closed container which gives mash (*tinsis*).
- *Medfedef* is the process of adding *Inkuro* into the prepared *tinsis* and left to ferment for five days in warm zone and for twelve days on cold zone – giving the *difedif*.
- Distilling (*Mewtat*/extracting) this is the only uniform stage in all *Areke* distillers' community in the *Areke* production process. The prepared *difedif* can be poured portion by portion, to the distillation pot and finally it is distilled.

In the case of *Areke* production, the distillation pot is placed on the three stone biomass stove, then the distillation pot is filled with the specific amount of *difedif* and then heat was supplied to the bottom of the pot. This will continue until the temperature reach's at which the Evaporate can be seen through the pot opening. After the Evaporate seen through the pot opening, the pot lid will be placed on the opening of the distillation pot to seal the distillation pot and connect it to the bamboo pipe. Finally the distillate pipe is connected with collecting flask and water and alcohol mixture distillate steams flows through this connection and store in the collecting flask. The evaporate which is mixture of alcohol and water will cooled in condenser tub by releasing heat to the cooled water in the cooling tub. It takes about 2-2 1/2 hours to distill a clay pot of *difedif* into colorless, clear, locally drinkable alcoholic liquor *Areke*.

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].

In Ethiopia, in addition to the already existing burden on natural resource imposed by the use of traditional biomass for cooking, the processing and production of alcoholic beverages such as local liquor(Areke), local beer (*Tela*), *Korefe*, *Borde*, *Shameta* and others place further threat on the environment and human health.

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 2.6kg 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 improve biomass stove as a replacement or as a support to three stone biomass stove 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 inefficient biomass Areke stove is deteriorating household economy and damages the environment [3].

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 that is believed to address the environmental as well as human health impacts of utilization of traditional biomass[9]. However, the improved stoves to meet people's most basic cooking and Areke distillation needs are out of the reach of the majority Areke distiller's community, especially for those in rural areas. Their access to improved stoves is also very limited. But, 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.

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 study will design improved biomass Areke distillation stove as a substitute of traditional biomass Areke stove. The study was carried out to design, make experimental investigation and produce CCT test report on traditional and improved Areke stove. A standard procedure, CCT was used to evaluate the performance of the Areke stoves.

1.3. Objective of the research

The general objective of this research is to design and make experimental investigation of an improved biomass stove for *Areke* distillation process as an alternative approach to traditional *Areke* distillation methods.

The specific objective of the research includes:

- To analyze heat loss encountered in a three stone fire biomass *Areke* distillation stove.
- To design improved biomass *Areke* stove.
- To manufacture the improved biomass *Areke* stove.
- To conduct performance test for the improved and three stone fire *Areke* stoves.
- To conduct energy balance on the improved biomass *Areke* stove for future improvements.

1.4. Scope of Work

This thesis work attempts to cover the design and experimental investigation of improved biomass *Areke* distillation stove and loss accounted in an improved and three stone biomass stove. Besides, the task focuses on undertaking at least six controlled cooking tests on the three stone and improved *Areke* distillation stoves (three on each version of the stove). Finally, the researcher shall strive to identify and suggest areas of further technical improvement on the improved *Areke* stove for further optimization.

CHAPTER TWO

Literature Review

In nearly all areas of the world, some type of alcoholic beverage native to its region is prepared and consumed. In Africa, fermented alcoholic beverages are consumed in different occasions such as marriage, naming and rain making ceremonies (Zvauya et al., 1997), at festivals and social gatherings, at burial ceremonies and settling disputes (Steinkraus, 1983). They are also used as medicines for fever by adding barks or stems of certain plants (Okafor, 1972). Fermented beverages produced from cereals usually referred to as beers while those produced from fruits are classified as wines (Pederson, 1979).

Kenyan Muratina and uragua are drunk largely at festivals and social gatherings (Harkishore, 1997). Palm wines are fermented and consumed under different parts of the world. Palm wine has special place in traditional celebrations and ceremonies such as marriages, burials, and settling disputes (Ayenor, 1972). In West Africa in addition to their use as beverages, palm wine are also used as medicines for fever and other ailments by adding barks or stems of certain pants (Okafor, 1972).

Ethiopia is a country rich in cultural diversity. The variety of foods and beverages processed and consumed among the various ethnic groups are manifestations of this diversity. Ethiopia is one of the countries where a wide variety of traditional fermented beverages are prepared and consumed. The various traditional fermented beverages are produced on a fairly small scale and usually for local consumption. Among Ethiopian fermented beverages are varieties of *Tella*, *Tej*, *borde*, Areke, *Keribo*, *korefe* consumed in Ethiopia, Admassie, (2010).

Areke is a distilled beverage. It is a colorless, clear, traditional alcoholic beverage which is distilled from fermentation products prepared in almost the same way as *tella* except that the fermentation mass in this case is more concentrated (Fite et al., 1991). *Areke* is usually brewed in rural and semi-urban areas and is used more commonly by farmers and semi-urban dwellers than by people who live in the cities.

In cities, those who drink *Areke* are predominantly lower class people or those who have become dependent on alcohol and cannot afford to buy industrially produced alcohol (WHO, 2004).

The production of alcohol in Ethiopia in factories traces back to the beginning of the 20th century. Today, there are above ten Distilleries, *Fincha*, *Mekanisa*, *Akaki*, *Sebeta* and *Balezaf* are the widely known distilleries. *Fincha* which is under Fincha Sugar Factory produces 8 million liters of technical alcohol per annum for domestic and export market; the other four are autonomous plants producing both potable and technical alcohols with annual total production of about 2.8 million liters, Teffera, (2007).

2.1. *Areke* Fermentation

Areke is a traditional alcoholic beverage which is distilled from fermentation of cereals; malt (beqil), gesho, which gives flavor to the Areke with addition of water (Admassie, 2010). Desta, (1977) also explained that *Areke* is colorless, clear, local alcoholic beverage which it resembles tella except that the fermentation is more concentrated. Areke is commonly distilled by poor women who can only employ archaic, energy inefficient and polluting methods of production that affect their health and also contribute to the progressive denuding of the vegetation cover of the land.

Traditionally *Areke* is classified into two: *Terra-Areke* and *Dagim-Areke*.

2.1.1. *Terra-Areke* (Ordinary)

Terra-Areke is colorless, clear, local alcoholic beverage which is distilled from a fermentation of Yeareke-tinsis. Desta, (1977) reported that, Yeareke-tinsis is prepared by mixing powdered gesho leaves and powdered bikil (1:2 ratio) with water to give a mixture of free flowing consistency which will be put aside to ferment for about five days. ASSAYE, (2018) reported the average alcohol content of *Terra-Areke* is 37.22 %.

2.1.2. *Dagim-Areke* (redistill)

Dagim-Areke is a stronger type of terra-Areke, which is prepared in the same way as terra-Areke, except that the distillation process is allowed to proceed for a shorter period of time, or three volumes of Terra-Areke are redistilled to give about one volume of Dagim-Areke (Desta, 1977). Assaye, (2018) reported that, the average alcohol content of *Dagim-Areke* is 48 %.

2.2. Properties of alcohol

Ethyl alcohol, CH_3CH_2OH, is one of the Oxygen-containing organic chemicals. It is a volatile, flammable, and a colorless chemical compound. It is a monohydric primary alcohol and it boils at 78.5 °C. It is miscible with water in all proportions. Ethanol that is completely free of water is called absolute ethanol, (Ayanie, 2011). Table 1 Shows that the various grades of ethyl alcohol.

Table 1 Grade of various ethyl alcohol (Teffera, 2007).

Category	Grade	Typical Use
Industrial alcohol	96.5	As solvent, fuel, and also as raw material for Production of numerous chemical products.
Denatured spirit	88	Generally used as heating and lighting
Fine alcohol (either Hydrous and anhydrous)	96-96.5	It is used mainly for Pharmaceutical and cosmetic Preparation and for human consumption.
Absolute anhydrous Alcohol and pure product of pharmaceutical grade	99.7-99.8	It is a water-free ethyl alcohol used as engine fuel

Alcohols are important industrial and commercial applications. Principally important commercial alcohols include Methanol, Ethanol, Isopropanol and Ethylene Glycol. Ethanol, or Ethyl Alcohol, is used as a solvent, fuel additive, and in lotions, tinctures, perfumes and medicines. Ethyl alcohol is a versatile product which can be used for various purposes, mainly as solvent, beverages, and raw material for making hundreds of chemicals, such as aldehydes, ethyl acetate, acetic acid, glycols, ethyl chloride, and many other organic compounds, (Teffera, 2007). Ethanol has been described as a psychoactive agent and it produces a variety of physiological and behavioral effects.

The units of measurement commonly used in reporting ethyl alcohol production are the proof gallon or Gay Lussac degree (^oGL) which is equal to the percent by volume of ethanol. The Proof is twice of the Gay Lussac degree. The various category of ethyl alcohol its typical applications are presented in the above table.

2.3. *Areke* distillation stove in Ethiopia's Case

In Ethiopia, biomass is the major source of energy for *Areke* distillation process. Biomass based source of energy is gained from three sources; energy crop, agricultural residues and forestry residuals. These types of energy source needs good efficient biomass conversion method to modernize and upgrade energy production.

In most of *Areke* distiller's community in our country, *Areke* distillation is carried out using three stone open fire biomass stove in which fires surrounded by three *gulicha*. The heat released from fuel to the pot will be lost through the exhaust gases from wood fuel, the sides and radiation and convection losses from the pot surface. The main disadvantage of three stone biomass stove is its inefficiency and causes health problems to the community's and affects the environment.

In enclosed biomass *Areke* distillation stove three medium sized stone are used to support the distillation pot and half part of stove is closed. This kind of traditional *Areke* distillation biomass stove are more efficient than the three stone biomass *Areke* distillation stove and used by most *Areke* distiller's community due to reduction of fuel wood consumption than the three stone stoves. The heat produced in the stove will be lost in three ways. These are: through the sides, from pot surface by convection and radiation and through the exhaust gases from wood fuel.

Few researchers have conducted research in the area of designing and improving new technologies for Ethiopian local *Areke* distillation process. So far some findings have been published and some of the thesis paper are reviewed and evaluated in the following paragraph.

Mohammed (2008) was the first researcher to study the effect of *Areke* production on the ecology. The result of his study shows that 87 % of respondents are participated in *Areke* production. The consumption rate of fuel wood for *Areke* distiller is 76kg per day and for non-distillers 17kg per day. And he finally concluded that this high fuel wood consumption rate by *Areke* distillers leads the country to environmental degradation.

Gezahegne (2008) introduced new efficient *Areke* distillation stove and assessed the potential benefit of efficient fuel saving stove towards reduction of fuel wood consumption. The result of improved stove had shown that, time taken for distillation can be reduced by

22% and fuel wood consumption can be reduced by 4.4%. But had not be done the heat transfer analysis of the improved stove. Figure 1 shows the improved biomass *Areke* distillation stove at Arsi Negelle.

Figure 1: Biomass *Areke* distillation stove, (Gezahegne, 2008)

Solomon (2011) investigated the potential of solar energy for *Areke* distillation. The finding of his experiment have shown that, using solar energy the average boiling point of *Areke* is 74 ^{o}C and it took 2 1/2 hrs. To reach at this boiling temperature this is more than the time needed to boil pure ethanol.

Kassa (2015) presented using solar parabolic collector for *Areke* production process. The main objective of this thesis was designing, modeling and testing of parabolic dish solar collector for local *Areke* distillation process. To collect the solar energy an aperture diameter of 1.6m, depth of 0.4m and focal length of 0.4m of parabolic collector was designed. The parabolic dish is designed to obtain 3 liters of *Areke* with alcoholic content of 44% from 24 liters of *defidef* per day. This was done from 8:00Am – 5:00Pm. It took 3hrs for one cycle of distillation process and the test is done in three different days. The test result showed to obtain 0.25 liters of *Areke*, with 44 % of alcoholic content, it needs 2.5 liters of *defidef* and it took 3 hours on the average to reach boiling point temperature of 70.4 ^{o}C. Figure 2.2 shows the test setup of the parabolic collector used for *Areke* distillations.

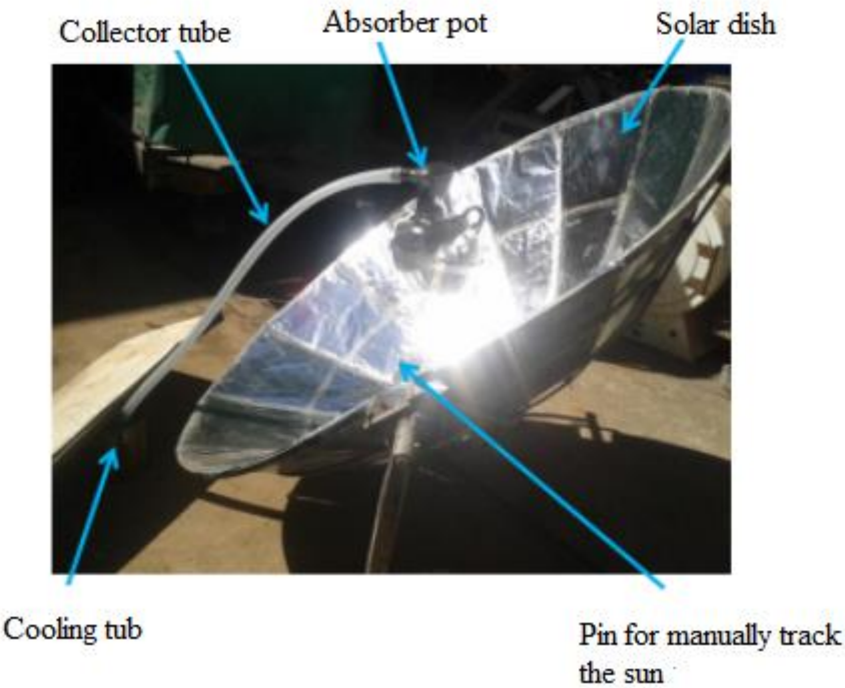


Figure 2: Solar concentrator, (Kassa, 2015)

Abebaw (2010) focused on the potential of biogas energy in supplementing the household energy needs for *Areke* production in Arsi-Negelle. The result of his study revealed that from the households who participated on production of *Areke* in Arsi-Negelle, 97.8 % of the households have an average of five cattle per household.

If sustainable biogas are implemented the dependency on biomass for *Areke* production in Arsi-Negelle can be reduced by 28 %. This is done by replacing 19,769 tons of fuel wood annually.

Analytically designing the biogas stove for minimum gas consumption and high efficiency, fabrication and experimental testing is done. In addition to this economic projection of biogas utilization in *Areke* distillation is evaluated. According to the conclusion of the researcher the overall efficiency of the stove evaluated through water boiling test is found to be 54.8 % , 43.6 % at higher flame intensity and relatively lower flame intensity respectively and it is economically feasible with a payback period of a little over three years. The stove showed a remarkable reduction in time taken for distilling a pot of distill and which is nearly half of the time it took to distill a pot of distill and using wood (Demissie, 2016). Figure 3 shows the improved biogas *Areke* distillation stove.

Figure 3: Experimental setup of biogas *Areke* distillation stove (Demissie, 2016)

Kamil Dino (2019), focused mainly to facilitate, conduct, analyses and produce CCT test report on traditional and improved *Areke* stove. A standard procedure, CCT was used to evaluate the performance of the *Areke* stoves. Considering the three-stone *Areke* stove as a reference, the specific fuel consumption improvement or fuel use reduction of *Mirt Areke* stove is 51 %. Similarly, time to brew/cook reduction is 52 % in using *Mirt Areke* stove. In the case of CO, PM2.5, and PM10, the percentage reduction is 29 %, 53 %, and 52 %, respectively. This literature was used for validation of CCT result of this research. Figure 4 shows the modified biomass *Mirt Areke* distillation stove.

Figure 4: Modified *Mirt Areke* Stoves, Kamil Dino (2019)

Almost in all literature review, most of the researcher focuses on the impact of *Areke* production on the environment and human health by measuring emission of CO and PM during distillation process of *Areke*. In addition, some of the researcher focuses on the potential assessment of solar and biogas energy in supplementing the household energy needs for *Areke* production. However, no one can deal on the heat loss accounted on the Areke production process.

Thus, this paper focuses mainly on the role of *Areke* stoves in reducing emissions, eliminating drudgery, and improving overall quality of life. The work is carried out to design improved biomass *Areke* stove and performance of improved biomass *Areke* stove is evaluated using thermal efficiency, distillation duration and specific fuel consumption. The controlled cooking test (CCT) demonstrates improvement in specific fuel consumption and total distillation duration of improved biomass *Areke* stove in comparison with the traditional *Areke* stove.

2.4. Benefit of using improved *Areke* distillation stove

Improving the traditional biomass *Areke* distillation stove in a way that the stove will be more efficient in terms of cost effective, Energy expenditure has positive advantage in improving the living standard of the *Areke* distillers community, in making safe environment for the country and safe to use (in terms of health of the user). Thus, improved *Areke* distillation stove will:

- Reduce the pollution caused by incomplete combustion gases. This is done because of the energy stored in combustible gas can be released as a heat.
- Improve heat transfer efficiency: by transferring the heat generated in the stove to the content of the distillation pot efficiently.
- Control efficiency: so that only the heat needed for distillation of *Areke* is generated.
- Improve household outcomes: through reduction of effort in distillation and energy collection, concentrations of smoke and indoor air pollution.
- External benefits include:
- Reduced GHG and less pressure on forest and energy resources.

2.5. Traditional *Areke* distillation apparatus

Traditional *Areke* distillation process generally composed of distillation pot made of clay with thickness of 8.2-12.5mm, pot lid made of clay Bamboo, distillate collector flask, and condenser tub-made of clay filled with cooled water.

2.5.1. Areke distillation pot

Areke distillation pot is made of clay used to store difedif during distillation process. This distillation pot if placed on the stove with distilled difedif and the heat was supplied to the bottom of the pot to get the final distilled *Areke*. Figure 5 shows apparatus used to distill local Ethiopian *Areke*.

Figure 5: Traditional *Areke* distillation apparatus (Kassa, 2015)

2.5.2. Pot lid

A small head cap component of traditional *Areke* distillation still which is used to

Seal the distillation pot and connect it to the bamboo pipe.

2.5.3. Bamboo pipe

Bamboo pipe of internal diameter 60mm around which a wet rope is coiled, and forms the joint of traditional still through which the condensing alcohol vapor travels from the boiling distillation pot to the distillate collector flask.

2.5.4. Distillate collector flask

This flask 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.

2.5.5. Condenser tub

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*.

2.6. Controlling system of Areke distillation process

After the distillation pot is closed by distillation pot lid heat supply under the pot is must be controlled to avoid burning of *difedif* in the pot, to get high quality *Areke* and to reduce percentage of water in the final distilled *Areke*. If this is not done the difedif in the pot gets over heated and the distillate *Areke* changes its color and finally it is wasted. The system will be continuously checked for leakage and to take correction measures if something wrong is happened during distillation process.

They check the distillate amount of *Areke* by weighting by hand the collector flask. I f the collector flask is heavy they think that the collector flask is full and it is time to finish the distillation process. Then leftover *atella* inside the distillation pot will be used as food for cows, sheep’s, goats and etc.

2.7. Cooling System

In traditional *Areke* distillation the condenser system composed of *koda* (collector flask), *wadiat* (cooling tub) made of clay filled with cooling water, Flat rope (stone). The koda is inserted into cooled water filled *wadiat*. One end of bamboo is inserted into the opening of the distillate pot, while the other end is inserted into the opening of the *koda*. Then, the *koda* is pushed down to the water filled *wadiat* by flat stone to prevent the fluctuation or movement. The evaporate coming from the *difedif* in distillate pot flows through the bamboo and enters into the *koda*.

The hot steam that enters into the *koda* cools by releasing the heat to the cooling water in the *wadiat*. When the cooling water in the *wadiat* gets hot, it will be drained and replaced by cool water if the flask is not already full of distillate-*Areke*. Figure 6 shows cooling system of distilled *Areke*.

Figure 6: Process of traditional condensation. (Kassa, 2015)

.

CHAPTER THREE

Materials and Methods

3. Preparation of *Areke difedif*

For distillation, different distillers used different cereals and different proportion of inputs to prepare *difedif*, but the production process they followed is similar for different products. For this particular study, *Areke difedif* preparation process is goes through two major stages.

- ***Metenses*** refers to the preparation of *tinsis* (sort of starter mash), which is usually a mixture of malt, *gesso* and water. And then the resulting mixture kept overnight for 4-5 days in a closed container which gives mash (*tinsis*).
- ***Medfedef*** is the process of adding *Inkuro* into the prepared *tinsis* and left to ferment for five days in warm zone and for twelve days on cold zone – giving the *difedif*.

Figure 7: a). Malt of wheat b). Leaves of *gesso* (Rhamnus prinoides) c) *difedif* ready for

Distillation

3.1. Determination of the amount of Areke difedif

The amount of raw materials (cereals +water) used for preparation of this particular sample (*Areke difedif*) is described from the Table (3). Total mass m_d of *Areke difedif* is sum of mass of *bikil* (m_b), mass of *inkuro* (m_i), mass of *gesso* (mg) and mass of water (mw). Given by: Given by:

$$m_d = m_b + m_i + m_g + m_w \qquad Eqn\ 3.1$$

$$= 40kg$$

Total volume of this Areke difedif, v_t is the sum of volume of all inputs, given by:

$$v_b = \frac{m_b}{\rho_b} = 7.64\ L$$

$$v_g = \frac{m_g}{\rho_g} = 3.9\ L$$

$$v_i = \frac{m_i}{\rho_i} = 21.53\ L$$

$$v_w = \frac{m_w}{\rho_w} = 16\ L$$

Total volume of Areke difedif will be expressed as:-

$$v_d = v_b + v_g + v_i + v_w = 49\ L$$

Where,

Density of bikil (malt) of wheat, ρ_b = 0.72

Density of flour of gesso, ρ_g = 0.769

Density of Inkuro (flour of sorghum), ρ_i = 0.72

Density of water, ρ_w = 1

Table 3, types of cereals and corresponding amount used for preparation of *Areke difedif*

Inputs used	Amount used (Kg)	Total amount of *difedif*
Wheat for *bikil* (malt)	5.5	
Gesso	3	
Inkuro	15.5	
Water	16	40 g

The data which is listed in Table 3 were obtained from the measurement conducted during fermentation of two of *Areke* distiller's household, around Arsi-Negelle town and 40 Kg Areke difedif sample is more than enough for experimental investigation of this thesis study.

3.2. Description of the *Areke* stove

Generally, Areke distillation process is time consuming activity compared to other household cooking practices. In the case of a single Areke processing unit, a single pot with single bamboo pipe and metal canteen will be used for distilling the Areke.

As shown in figure 9 the prepared difedif will be poured into a pot (insera) where the pot is supported by three stones, and a slow constant fire is applied to the pot.

This stove is used for a single pot processing while a number of pots will be arranged to produce Areke in a single room. Figure 9 shows the single pot Areke processing using three stone biomass stove.

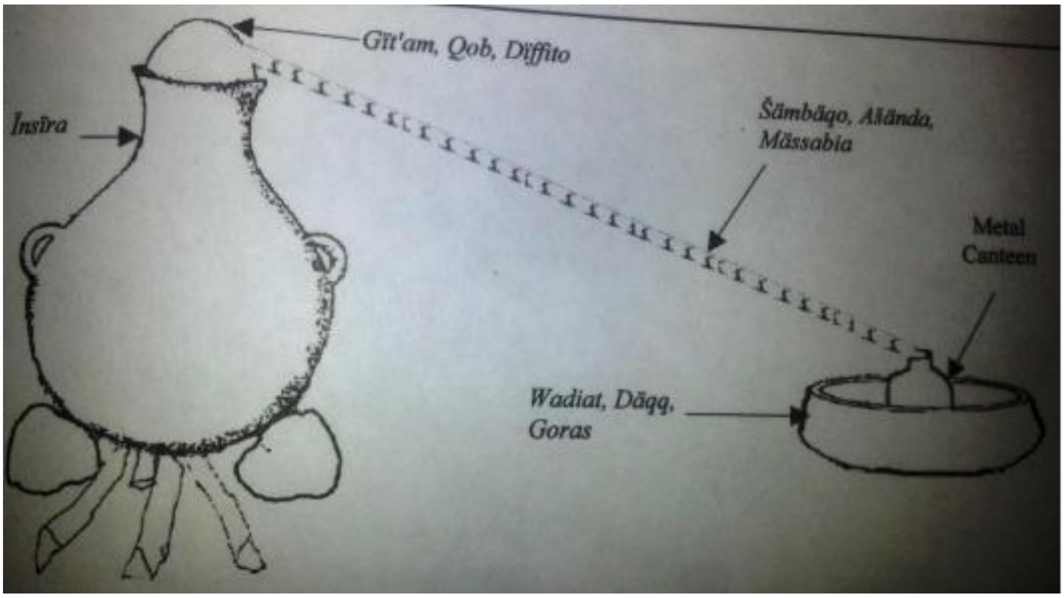


Figure 8: Schematic diagram for *Areke* Processing**,** (Admassie, 2010)

3.3. Traditional *Areke* distillation procedure

In the case of *Areke* production, the distillation pot is placed on the three stone biomass stove, then the distillation pot is filled with the specific amount of *difedif* and then heat was supplied to the bottom of the pot. This will continue until the temperature reach's at which the Evaporate can be seen through the pot opening. After the Evaporate seen through the pot opening, the pot lid will be placed on the opening of the distillation pot to seal the distillation pot and connect it to the bamboo pipe. Finally the distillate pipe is connected with collecting flask and water and alcohol mixture distillate steams flows through this connection and store in the collecting flask. The evaporate which is mixture of alcohol and water will cooled in condenser tub by releasing heat to the cooled water in the cooling tub. It takes about 2-$2^{1/2}$ hours to distill a clay pot of *difedif* into colorless, clear, locally drinkable alcoholic liquor *Areke*. Figure 8 shows the *Areke difedif* undergoing pre-heating process before sealed and process of *Areke* distillation.

Figure 9: a) *Areke difedif* undergoing pre-heating process before sealed, b) Process of traditional *Areke* distillation

3.4. Visual Inspection

The traditional biomass *Areke* distillation stoves were first photographed (Figure 10) and visually inspected. The attributes were measured during the visual inspection as an input data for improved biomass *Areke* distillation stove are number of holes in grate, internal and outer diameters of the stove, depth of the stove, dimensions and area of air inlet port. Figure 10 shows traditional biomass *Areke* distillation stoves visually inspected.

Figure 10: Areke Processing Unit at Arsi-negle, (Mohammed, 2008)

3.5. Testing Location

The test was performed at Mojo city in a single household over a 12 days period from 20 Sep 2019. All tests were conducted in an enclosed shed in ambient conditions. Since the testing facility is well organized with the necessary instruments, the test had been conducted at the premises by purchasing an *Areke* brewer from the nearby town, Arsi-Negelle. The actual room where the test was performed has a dimension of 2 m x 3m x 2 m.

3.5.Instruments used for the test

Instruments used to conduct the CCT includes:-

- digital balance
- moisture content measuring device
- stop watch
- thermometer
- Charcoal pan and spatula.

Figure 11 shows the Instrument used to conduct the test.

Figure 11: Instruments used to conduct the test

3.6. Fuels Tested

The feedstock used for the experiment was eucalyptus tree wood cut into small pieces and sun dried for at least one week to reduce the moisture content. This type of wood is commonly used for *Areke* distillation in *Areke* distiller community of Ethiopia. Figure 12 shows the type of fuel wood used for *Areke* processing during the test.

Figure 12: Fuel wood collected from forest & purchased from market

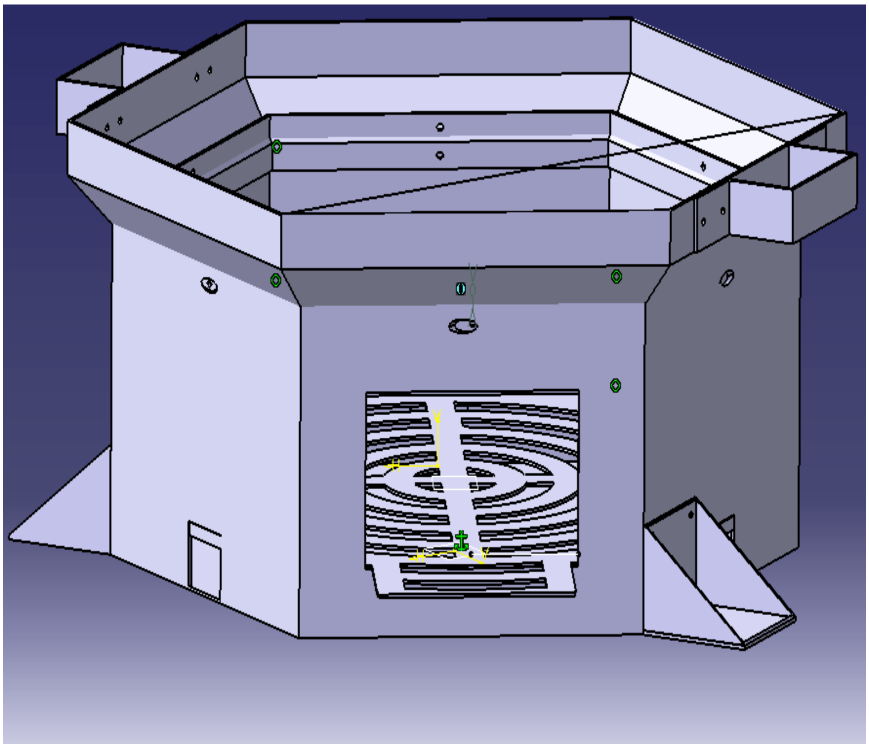
Table 4 shows the characteristics of the wood, experimentally determined at Geological Survey of Ethiopia according to ASTM standard (Materials, 1983).

Table 4: Physical and thermal characteristics of wood (Eucalyptus) (Materials, 1983).

Characteristics	Biomass (Eucalyptus)
Size (mm × mm × mm)	40 × 40 × 1000
Bulk density (kg m^{-3})	480
Moisture content (% wb)	14
Volatile matter (% db)	80.81
Ash content (% db)	0.54
Fixed carbon (% db)	13.02
lower calorific value (MJ kg^{-1})	18.70

3.7. Experimental Set-up, Improved biomass Areke Stove

The design of the *improved biomass Areke* distillation stove is based on the Berkeley Darfur biomass cook stove design for institutional cooking developed at Darfur, Sudan. The stove is made up of five components. The five components are: pot skirt, handle, stove body, grate, and legs. The stove is manufactured in the AAiT mechanical workshop. The improved stove is made to accommodate a 350mm diameter of pot size which is typical size used in most *Areke* distillers households. The stove combustion chamber is cladded with sheet metal on the inside and with fiberglass insulation on the outside. The stove has non-removable skirt. Outer diameter of the stove is 350 mm; inner diameter of the stove 300 mm, height of stove 265mm, total height from the floor up to pot skirt 350 mm, grate width 154mm, and grate length 317 mm. Figure 13 shows the assembled improved stove.



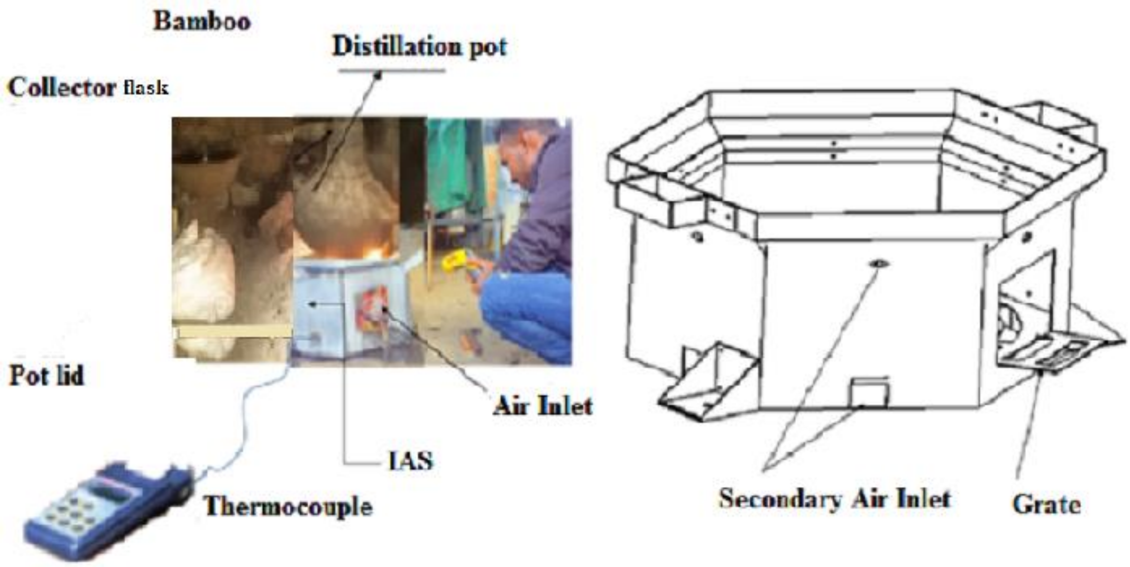


Figure 13: Experimental Setup

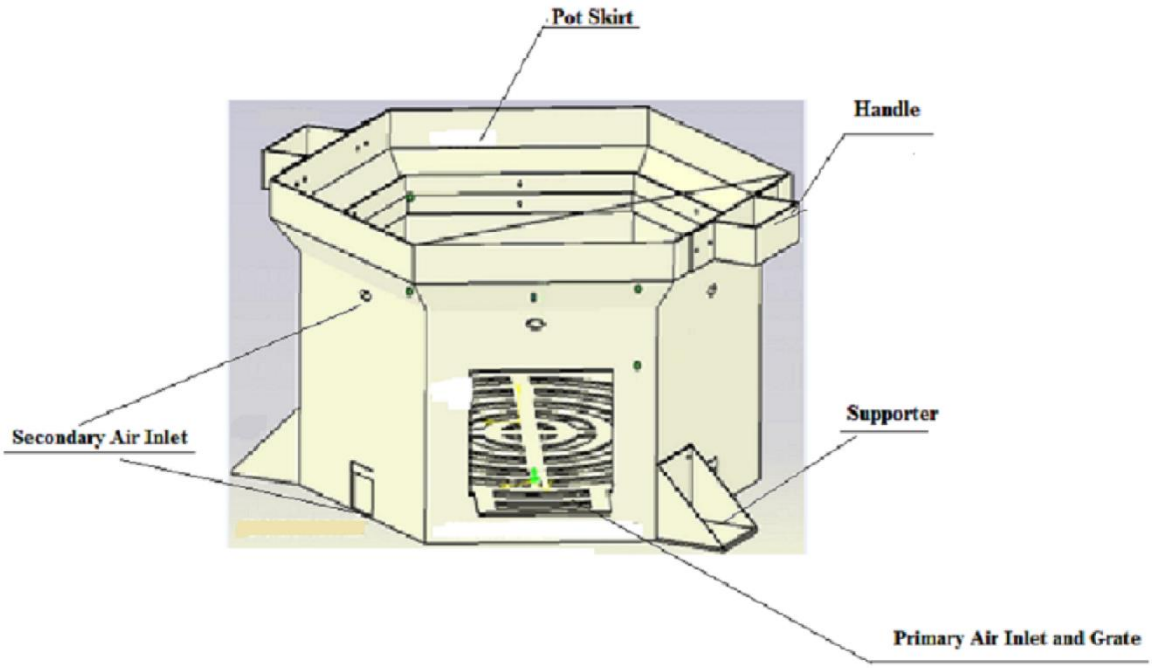


Figure 14: Parts of Biomass Improved Areke distillation Stove

3.8. Controlled Cooking Test for *Areke* distillation

For this test, CCT protocol prepared by Rob Bailis for Household Energy and Health Program, Shell Foundation, (Version 2.0) will be used to evaluate the performance of Areke stoves. The protocol is designed to assess the performance of the improved Areke stove relative to the common or traditional Areke stove that the improved model is mean to replace. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking task that the local people do every day. However, the tests are designed in a way that minimizes the influence of other factors and allows for the test conditions to be reproduced. To conduct this test first expected to contact an experienced traditional *Areke* distiller to provide the necessary supplies and complied.

3.8.1. Testing procedure

I. Before starting the test

a. Prepare pre-weighted bundle of wood and average dimension of the wood
b. The type of pot used and record its shape, size and empty weight of the pot used.
c. Record local conditions such as air temperature (^oC), wind condition and local boiling point of alcohol (^oC).
d. Weight of container for charcoal
e. Type of stove used

II. During the test

a. Start burning the fuel wood charged to the stove.
b. Start the time in second as starting of distillation process, min.
c. Measure the temperature variation of the stove body and difedif with in 20 min time gap.

III. After the test

a. Weight of fuel wood used (Initial and final), g
b. Weight of charcoal with container, g
c. Weight of pot with distilled difedif
d. Finish time of distillation process, min

3.9. Performance calculations

Analysis of energy utilized for Areke distillation

Energy utilized is the amount of heat energy used to distill Areke to the required quality without including the loss accounted during the distillation process. It is the sum of total energy gain through convection and radiation. The mass of evaporated difedif can be obtained from the difference between the initial weight of difedif and the final distilled difedif. The energy utilized to distill Areke is computed by using Eqn (3.2).

$$E_u = Q_{conv-gain} + Q_{rad-gain} \qquad Eqn\ (3.2)$$

Determination of Specific fuel consumption

The amount of fuel used to brew a gram of Areke was calculated for all the two stoves, calculated according to the controlled cooking stove testing protocol [22]. Equations 3.3, 3.4 and 3.5 were used to calculate the equivalent fuel wood (fd), net weight of food (Wf) and SFC:

$$fd = \left(f_f - f_i\right) * \left(1 - (1.12 * m)\right) - 1.5 * \Delta Cc \qquad Eqn\ (3.3)$$

Where,

f_d = Equivalent dry wood consumed

f_f = Final weight of fuel wood (wet basis) (grams)

f_i = Initial weight of fuel wood (wet basis) (grams)

m = Wood moisture content (% - wet basis)

ΔCc = Weight of char remaining (grams)

$$Wf = P_f - P \qquad Eqn\ (3.4)$$

$$SCc = \frac{F_d}{Wf} * 1000 \qquad Eqn\ (3.5)$$

Where,

F_d = Equivalent dry wood consumed [Grams]

W_f = Total weight of distilled *difedif* [grams]

Calculation of Thermal efficiency

The thermal efficiencies of both three-stone fire and improved biomass Areke distillation stove were calculated as the ratio of useful energy to the net energy input. The thermal efficiency was calculated using Eq 5:

$$\eta = \frac{m_{Areke} \times C_{p,Areke}(T_{distill} - T_{difedif}) + m_{eva} h_{fg}}{HV_{fuel} - m_{chair}(m_{fuel} HV_{char}} \qquad Eqn\ (3.6)$$

3.10. Analysis of Principal Heat Gain and Heat Loss Encountered in Three Stone and Improved Biomass *Areke* Distillation Stove

In *Areke* distillation stove heat energy is gained by transfer of heat from flame to pot bottom and to the sides of the pot and heat energy is lost to stove body and to the ambient by convection and radiation mode of heat transfer. In order to increase the heat transfer to the pot, the overall heat transfer coefficient, h, area exposed to the flame and flue gases, A, and flame temperature, T, need to be increased. Overall heat transfer coefficient, h, is mainly composed of convective and radiative heat transfer coefficients. The physics that govern the behavior of *Areke* distillation stove are rooted in thermodynamics, further explained using principles of heat transfer.

In this chapter the researcher analyzed the principal heat gain and heat loss encountered both in the three stone and improved biomass *Areke* distillation stove depending on surface temperature measured during experimental analysis. In addition energy balance (energy loss and gain) is calculated and their result is discussed.

3.10.1 Average temperature variation of the stove body

During the experimental test, the average temperature variation of the three stone biomass *Areke* distillation stove was taken from 12:00 Am to 8 Am LT. Table 5 shows measured data for Energy balance calculation.

Table 5: Measured temperature of IAS and 3TAS

Measured surfaces (K)	Improved *Areke* stove	Three stone *Areke* stove
Average temperature of flame	943	873
Average temperature of outside the combustion Chamber	333	-
Average temperature of pot surface	303	333
Average temperature of pot skirt	323	-
Average surface temperature of wood	370	370
Ambient temperature	299	299

In addition to that, the study "improved biomass *Areke* stove for Household identified a number of factors that would affect the efficiency of a stove; the stoves tested in this study have dimensions obtained during visual inspection. Table 6 shows stove data obtained during visual inspection used for analytical design calculations.

Table 6 stove data for analytical design calculation

Parameters	Dimensions (mm)
Outer diameter of the stove is	350
inner diameter of the stove	300
height of stove	265
total height from the floor up to pot skirt	350
grate width	154
grate length	317

Height of air gap b/n the pot and drip pan	27.5
Inner radius of skirt, R_{in}	420
Outer radius of skirt	420.4

3.11. Heat transfer and energy balance for three stone *Areke* distillation stove

In three stone *Areke* distillation stove heat energy is gained by transfer of heat from flame to pot bottom and heat energy is lost to the surrounding from flame and pot surface by convection and radiation mode of heat transfer. Figure 15 shows energy balance of three stone biomass Areke distillation stove.

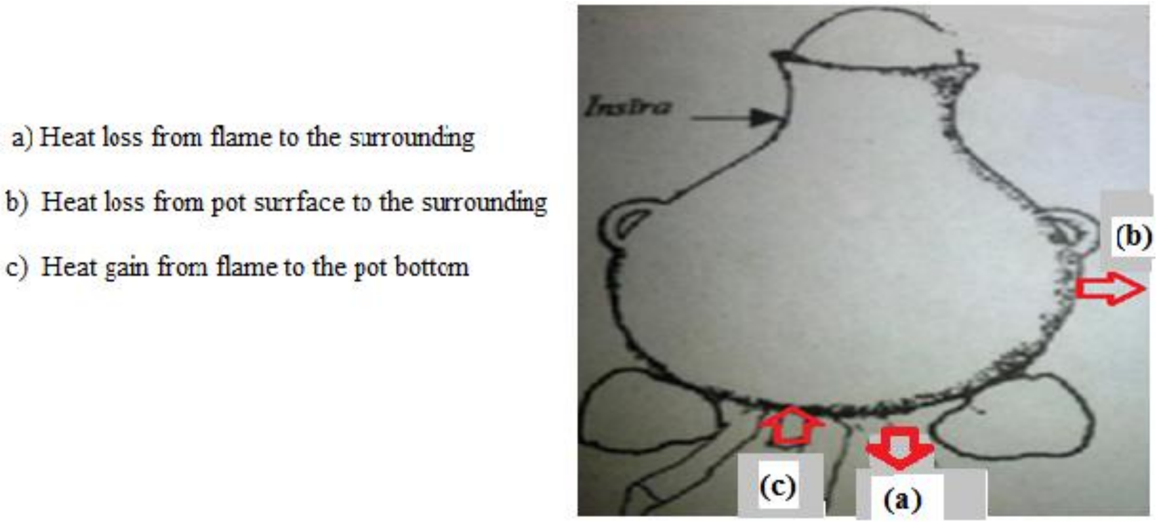


Figure 15: schematic of energy balance of a three stone *Areke* distillation stove

3.11.1. Heat loss from flame to the ambient

Heat loss from flame to the stove body was carried out due to the energy released by the combustion of fuel, a certain amount goes to the pot bottom which is partially absorbed by distillation pot and partially lost to the ambient. Therefore, heat is lost from gases to the ambient through convection and radiation.

Convection heat loss from flame to the ambient air

In this case heat was lost from gases to the stove body due to the transfer of heat from gases to the stove body and stove body gets heated up.

Properties of air

- ✓ μ_o = 1.71 * 10^{-5} kg/m.s, nominal absolute viscosity of air at 1atm and T_o =273 K
- ✓ $R_{universal}$ = 8.3143 J/k.mol, Universal gas constant
- ✓ M_{mass} of air = 28.97 gm/mol, Molar mass of air
- ✓ P_{atm} = 76 kpa = 1.01325 *10^5 pa

Properties of Air

- ✓ Thermal conductivity of gas K_{gas} = 10.5 *10^{-2} w/m.k
- ✓ Specific heat of gas $C_{p,gas}$ = 1007 J/kg.k

The area (A) for convective heat transfer is calculated by using equation (4.1)

$$A_c = \pi DL = \mathbf{0.25m^2} \quad (3.6)$$

Rate of convection from gases to the wall of stove is conveniently expressed by using equation (5.2) (Wiley, 2002), (Hill, 2003).

$$Q_{conv} = h_s A_c (T_{gas} - T_s) \quad (3.7)$$

Where,

h_s = Convection heat transfer coefficient

A_c =Convective heat transfer area, m^2

T_{gas} = Temperature of gas, K

T_s = Average inner stove surface temperature, K

Convective heat transfer coefficient through clay body of the stove will be calculated by using equation (5.3) (Wiley, 2002).

$$h_s = \frac{N_u K_{gas}}{D_s} \quad (3.8)$$

Where,

N_u = Nusselt number

K_{gas} = Thermal conductivity of the fluid (gas), w/m.k

D_s = Effective chamber diameter, m

The empirical correlation for the average Nusselt number (N_u) in natural convection was shown in equation (5.4) (Wiley, 2002).

$$N_u = 1.86Re^{1/3}Pr^{1/3}\left(\frac{D}{L}\right) \quad (3.9)$$

Reynolds's number approximation for fully developed internal flow will be expressed using (5.5) (Zube, 2010).

$$R_e = \frac{\rho_{gas}V_{gas-stack}D_s}{\mu_{gas}} \quad (3.10)$$

Where,

$$R_{air} = \frac{R_{universal}}{M_{-mass\ air}} = 286.997\frac{J}{kg}.k$$

$$\rho_{gas} = \frac{P_{atm}}{R_{air}T_{gas}} = 0.4\ \frac{Kg}{m^3}$$

$$V_{gas} = \frac{\dot{m}_{stove}}{\rho_{gas}A_s} = 0.075\ {}^{m}/_{s}$$

And $\mu_{gas} = \frac{\mu_o T_{gas}}{T_o} = 5.47 \times 10^{-5}\frac{kg}{m}.s$

Therefore,

$$R_e = \frac{\rho_{gas}V_{gas}D_s}{\mu_{gas}}$$

$$= 165$$

For Reynolds number less than 2300, the flow is laminar flow.

Prandtl number which is the ratio of thermal dissipation conduction can be expressed by using equation (5.6) (Zube, 2010).

$$pr = \frac{\mu_{gas}C_{P-gas}}{K_{gas}} = 0.52 \quad (3.11)$$

Therefore, Average nusselt number is calculated as:

$$N_u = 1.86Re^{\frac{1}{3}}Pr^{\frac{1}{3}}\left(\frac{D}{L}\right)^{\frac{1}{3}} = 8.54$$

Therefore, $h_s = \frac{N_u K_{gas}}{D_s} = 2.99\ W/m$

Convection heat loss from gasses to the stove surface can be determined using equation 3.6

$$\dot{Q}_{con} = h_s A_s (T_{gas} - T_s)$$

$$= 114\ W$$

Radiation heat loss from flame to the surrounding

Heat loss from flame to the surrounding was carried out due to radiation heat transfer between the flames of the gases and surrounding air, there will be radiation loss to the surrounding. This amount of radiated heat loss can be determined by using equation (4.7) (Zube, 2010):-

Radiation heat loss from put surface to surrounding can be obtained as,

$$Q_{rad} = \varepsilon \sigma A_{ch} ({T_f}^4 - {T_\infty}^4) \qquad (3.12)$$

Where,

A_{ch} = Effective inner surface area of stove = $\frac{\pi D^2}{4} = 0.0071 m^2$

T_f = Average temperature of flame, K

T_∞ = surrounding temperature. K

Stefann boltzman constant, $\sigma = 5.67 * 10^{-8}$

The net heat loss from gases to the surface of the stove at average temperature of flame and wood will be given by equation (4.7):-

$$\dot{Q}_{rad} = 315\ W$$

3.11.2. Heat loss from spherical round ceramic pot surface to the surrounding

Heat loss in the surface of *Areke* distillation pot was carried out due to the flame at sides of the distillation pot emitted to the surface of spherical round ceramic pot and gets heated up.

Therefore, heat is lost from spherical round ceramic pot surface to the surrounding through radiation and convection.

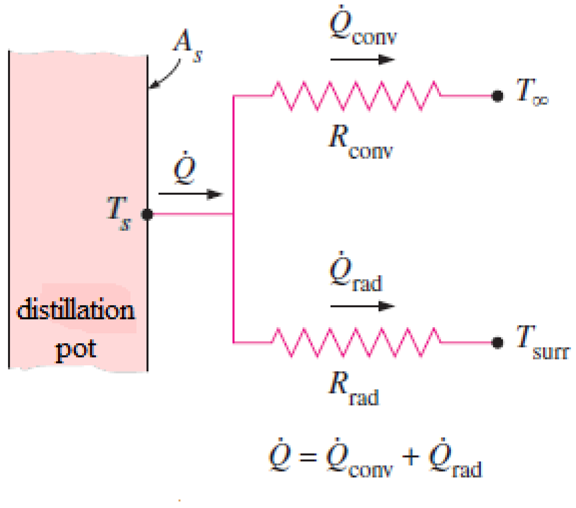


Figure: Convection and Radiation resistances at a pot surface.

Convection heat loss from the pot surface

In this case thermal energy was lost from the surface of the pot to the cold environment by the bulk movement of the air.

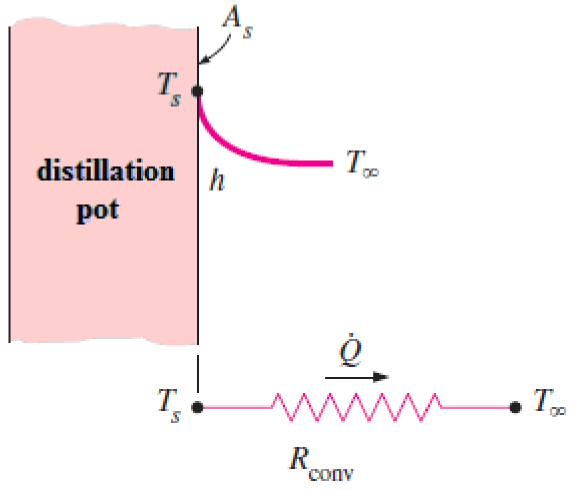


Figure: Convection resistance at a pot surface.

Film temperature, $T_f = \frac{501+299}{2} = 400k$

Properties of air at film temperature

$\nu = 26.41 * 10^{-6} m^2/s$ $P_r = 0.69$

$k = 33.8 * 10^{-3} \frac{w}{m}.k$ $\beta = 2.5 * 10^{-3} k^{-1}$

Surface area of spherical round ceramic pot can be calculated using equation below by assuming 50% of heat is lost to the surrounding from the whole surface area of spherical round ceramic pot.

$A_s = 4\pi r^2 = 0.5 * 0.283 m^2 = 0.1415\, m^2$

Convection heat loss from stove surface can be defined as:

$$Q_{conv} = hA_p(T_s - T_\infty) \quad (3.13)$$

Where,

h = convection heat transfer coefficient, $w/m^2.k$

A_s = Surface area of stove, m^2

T_s = Average temperature of the stove, k

T_∞ = temperature of the air sufficiently far from the surface, k

Convective heat transfer coefficient over pot surface can be determined as:

$$h_p = \frac{N_u K}{L}$$

Where,

h_c = convective heat transfer coefficient, $w/m^2.k$

N_u = nusselt number

K = thermal conductivity, w/m.k

L = characteristic height, m

Empirical correlation for the average nusselt number for natural convection are defined by eqn (Wiley, 2002).

$$N_u = 0.59 {Ra_L}^{1/4} \quad (10^4 \leq Ra_L \leq 10^9)$$

$$N_u = 0.1 {R_a}^{1/3} \quad (10^9 \leq Ra_L \leq 10^{13})$$

Rayleigh number(Ra_L) is the product of Grashof and Prandtl numbers:

$$Ra_L = Gr_L p_r = \frac{g\beta(T_p - T_\infty)L_c{}^3}{v^2}.P_r$$

$$= 1.32 \times 10^3$$

Therefore, average nusselt number is calculated as;

$$N_u = 0.59 Ra_L{}^{\frac{1}{4}} = 63.241$$

Hence, $h_s = \frac{N_u K}{L}$

$$= 8.1 \frac{w}{m^2}.k$$

Convection heat loss from pot surface to surrounding can be obtained as:

$$Q_{conv} = hA_s(T_p - T_\infty)$$

$$= 232\ W$$

Radiation heat loss to the surrounding

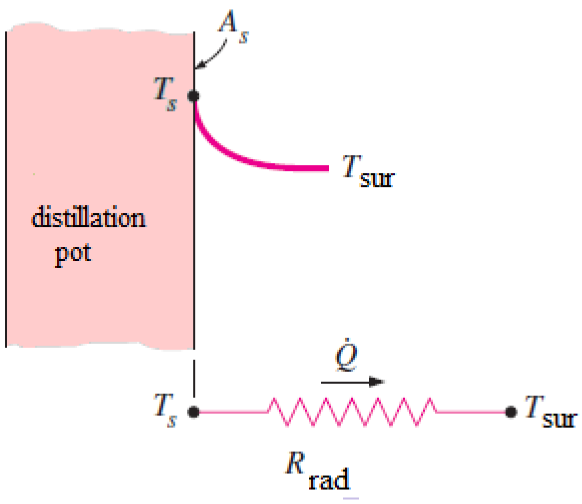


Figure: radiation resistance at a pot surface.

Radiation heat loss from put surface to surrounding can be obtained as,

$$Q_{rad} = \varepsilon\sigma A_p(T_p{}^4 - T_\infty{}^4)$$

Where,

$\varepsilon =$ is emissivity of pot surface(Ceramic), $= 0.72$)

$\sigma =$ stefan − Boltizmann constant, $= 5.67 \times 10^{-8} \frac{w}{m^2}.K^4$

$A_p =$ surface area of pot

$T_p =$ is average surface temperature of pot

$T_\infty =$ is surrounding temperature

Therefore, the net energy emitted from pot surface to the surrounding at temperature (T_∞) can be determined as;

$$Q_{rad} = \varepsilon\sigma A_p\left(T_p{}^4 - T_\infty{}^4\right)$$

$$= 18\,W$$

3.11.3. Heat gain from gases to the pot bottom

Net of heat loss from flame to the stove body, the remaining energy goes towards the pot with its contents and to the sides of the pot. Depending on the resistance offered to this heat flow by the pot and contents, a fraction of this energy flows into the pot and its contents, and the remainder is goes to surroundings, primarily as flue gas and direct radiation losses. Therefore heat was transferred from flame to pot bottom by convection and radiation.

Convection heat gain from gases to pot bottom

In this case heat energy was gain due to the transfer heat from gases to pot bottom and the pot gets heated up.

Properties of air at film temperature

- ✓ Specific capacity of air, (assumed constant value at T=850K),
- ✓ $C_{p\text{-}gas} = 1.11 * 10^3$ J/kg.k
- ✓ Thermal conductivity of gas (increases with temperature),

$$K_{gas} = \left(\frac{0.0047}{K} \times T_{gas} + 1.9403\right).10^{-2}\frac{w}{m}.k = 0.06\frac{w}{m}.k$$

The distillation pot is considered to be spherically shaped having outside diameter d_o = 350mm, and with thickness of t = 8mm.

Effective surface area of the distillation pot $A_{p\ will}$ be:

$$A_P = 4\pi {r_o}^2 = 0.38m^2$$

And $\quad A_{pot-gap} = \pi d_p L_{pot-gap} = 0.026m^2$

Where,

r_o = is the outside radius of the distillation pot

Assuming the reflected gases (flames) only reaches 50% of the total area, effective surface area of the distillation pot will be $0.192m^2$.

Effective gas velocity flowing through pot is:-

$$V_{gas-pot} = \frac{m_{stove}}{\rho_{gas} A_{pot-gap}} = 0.21\ {}^{m}/_{s}$$

Reynolds's number approximation for fully developed internal flow can be obtained as:-

$$Re_{pot-gap} = \frac{\rho_{gas} V_{pot-gap} d_p}{\mu_{gas}}$$

$$= 466.67$$

The flow through pot gap is less turbulent than in stack.

Pradntl number, $p_r = \frac{\mu_{gas} C_{P-gas}}{K_{gas}} = 0.52$

Stagnation Nusselt number for fully developed internal flow will be obtained as:

$$N_{u-D} = 1.86 Re^{\frac{1}{3}} Pr^{\frac{1}{3}} \left(\frac{D}{L}\right)^{\frac{1}{3}}$$

$$= 12.2$$

Convective heat transfer coefficient can be calculated as:

$$h_{con-pot} = \frac{N_u K_{gas}}{d_{pot}}$$

$$= 4.26 \frac{w}{k}.m^2$$

Accounting for combustion and therefore flame radiation can increase the magnitude of the convective heat transfer coefficient anywhere from 2.3-3.4× (Viskanta.R, 1993). This is more realistic expression of impinging flame jet flow exhibited in stove.

$$h_{con-low\ flame} = 2.3h_{conv-pot} \tag{3.14}$$

$$= 9.8\frac{w}{k}.m^2$$

$$h_{con-high\ flame} = 3.4h_{conv-pot} \tag{3.15}$$

$$= 14.5\frac{w}{k}.m^2$$

Assuming high flame, $h_{con-pot} = 14.5\frac{w}{k}.m^2$

Temperature of flame exposed to pot bottom will be calculated from the total heat loss to wall of stove before the hot gases make it to pot bottom$Q_{stove-losses}$ **(Zube, 2010).**

$$Q_{stove-losses} = \dot{m}_{gas}C_{p-gas}(T_{gas} - T_{gas-exposed\ to\ pot\ bottom}) \tag{3.16}$$

Where,

$$\dot{m}_{stove} = mass\ flow\ rate\ of\ the\ gas\ (flame)$$

From this equation, it is possible to determine temperature of the gas exposed to pot bottom. Therefore temperature of the gas exposed to pot bottom will be determined using equation (3.12):-

$$T_{gas-exposed\ to\ pot\ bottom} = T_{gas} - \frac{Q_{stove-losses}}{m_{flow-in\ stove} \times C_{P-gas}} \tag{3.17}$$

$$T_{gas-exposed\ to\ pot\ bottom} = 752\ K$$

Convection heat transfer from gasses to pot bottom can be obtained as:-

$$Q_{cov-pot\ bottom} = h_{con-pot}A_p(T_{gas-exposed\ to\ pot\ bottom} - T_{pot-surface})$$

$$= 398\ W$$

Radiation heat transfer from flame to pot bottom

Heat loss from gases to the pot bottom was carried out due to radiation heat transfer between the flame of the gases and pot bottom. Therefore, there will be radiation heat transfer (gain) towards the pot bottom. Assuming pot is a black body (i.e.$\varepsilon = \sigma = 1$), radiation is directionally independent and reflectivity of flame is negligible.

Total radiation heat transfer goes (supplied) to pot bottom from flame of the gases can be obtained by using equation (3.13) (Wiley, 2002):-

$$Q_{rad-flame\ to\ pot} = A_{flame} F_{flame} \sigma_{stefan} (\varepsilon_{flame} 4_{flame-a} - T^4{}_{flame-b}) \qquad (3.18)$$

Data obtained from experiment

- ✓ Average temperature of emitting area, $T_{flame-a} = 763k$
- ✓ Average temperature of pot surface, $T_{flame-b} = 365.5k$
- ✓ Effective area intercepted by pot bottom

Variable simplification for view factor calculation

$$S_{flame-view} = 1 + \frac{1+\left(\frac{R_{flame-b}{}^2}{L_{flame}{}^2}\right)}{\left(\frac{R_{flame-a}{}^2}{L_{flame}{}^2}\right)} = 2.55$$

Therefore, view factor can be determined by using:-

$$F_{flame\ in-out} = \frac{1}{2}\left[S_{flame-view} - \left(S_{flame-view}{}^2 - 4\left\{\frac{R_{flame-in}}{R_{flame-out}}\right\}^2\right)\right]$$

$$= 0.349$$

Therefore, radiation heat transferred to the pot bottom surface will be:-

$$Q_{rad-flame\ to\ pot} = A_{flame} F_{flame} \sigma_{stefan} (\varepsilon_{flame} 4_{flame-a} - T^4{}_{flame-b}) = 412\ W$$

Table 6 summarizes the total heat loss and heat gain calculations made on the previous sections.

Table 6: Summarized values of heat transfer mode**l**

Modes of heat	Values calculated for traditional Areke Distillation stove (W)
<u>Heat Gain</u>	
Convection	
To pot bottom	398
Radiation	
To pot bottom	412
Total heat energy gain	810
<u>Heat losses</u>	
Convection	
From flame to ambient	114
From pot surface to ambient	232
Radiation	
From pot surface to the surrounding	315
From pot surface to the surrounding	18
Total heat energy loss	679
Total Heat Energy Generated in the system =	1489 W

Figure 16 shows Sankey diagram of three stone biomass *Areke* distillation stove

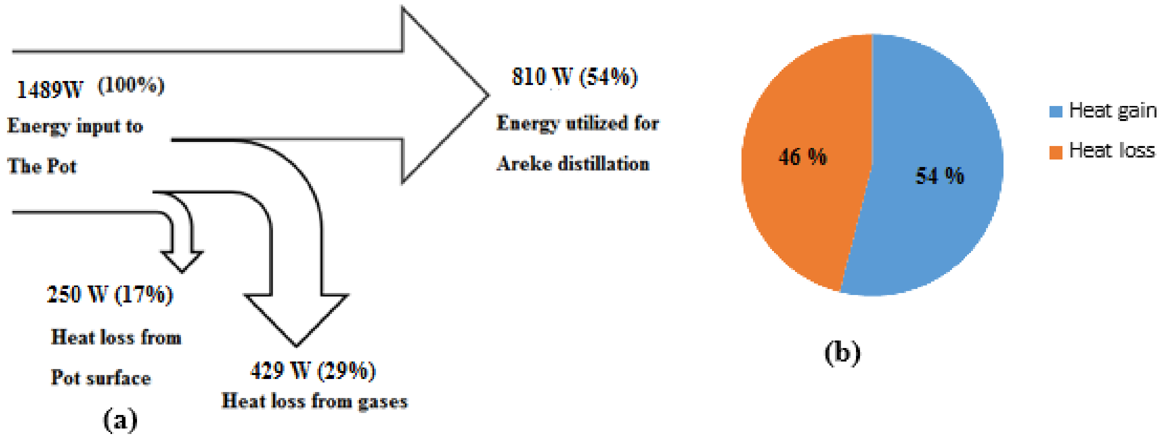


Figure 16: Result obtained from analytical analysis. (a) Energy Sankey diagram of traditional biomass *Areke* distillation stove (b) Percentage description of total heat loss gain accounted in the three stone biomass *Areke* distillation stove.

The result from analytical analysis of the loss accounted in the Areke distillation process shows, total heat loss of three stone biomass Areke distillation stove was 679 W with from flame to the surrounding accounts major loss (429 W of total loss) from the system and 250 W heat loss from pot surface to the environment. Thus, useful energy (the amount of energy utilized for Areke distillation using traditional biomass stove) 810 w was obtained by subtracting all loss encountered in the system from the total (1479w) heat energy generated in the system for each Areke distillation cycle.

3.12. Heat transfer and energy balance for modified (improved) Areke stove

In improved biomass *Areke* distillation stove heat energy is gained by transfer of heat from flame to pot bottom and to the side of pot surface and heat energy is lost to stove body and to the ambient by convection and radiation mode of heat transfer. Figure 16 shows energy balance of improved biomass *Areke* distillation stove

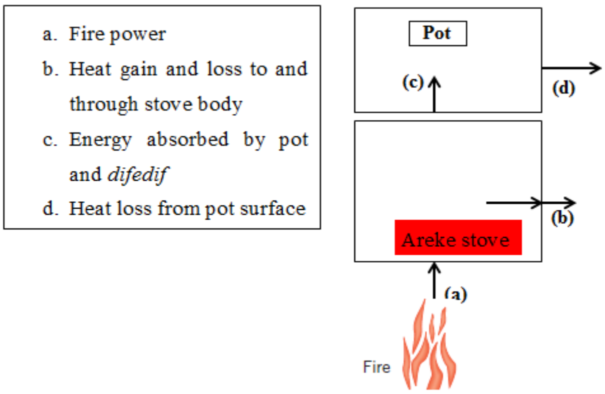


Figure17: Schematic of energy balance of improved *Areke* stove

3.12.1. Heat loss from Stove body

In this case heat is transferred from the flames to the stove combustion chamber and then lost from wall of stove combustion chamber to the ambient by the bulk movement of the air through convection and radiation.

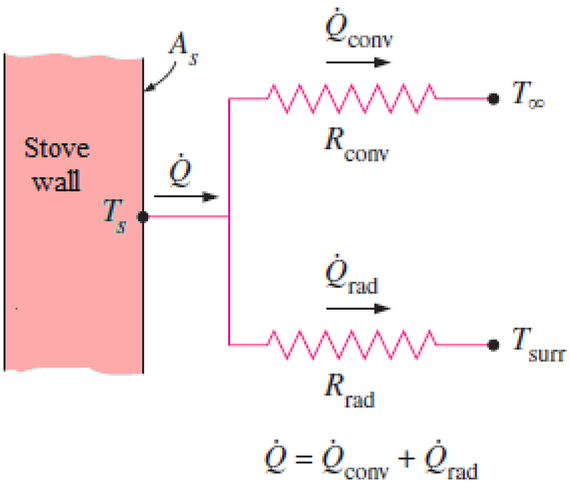


Figure: convection and radiation resistance at a stove wall

Convection heat loss from stove combustion chamber

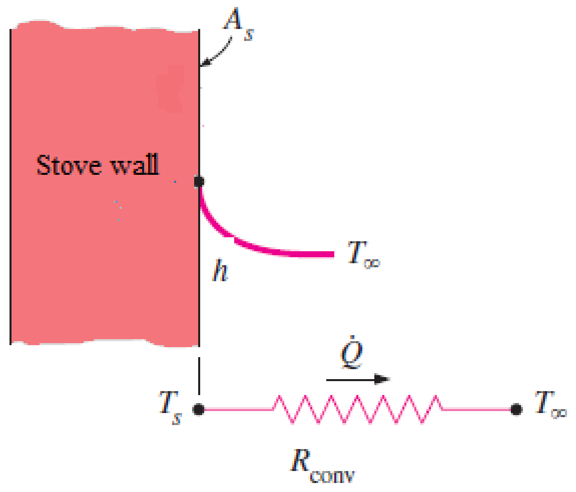


Figure: convection resistance at a stove wall

Film temperature, $T_f = \frac{T_\infty + T_s}{2} = 410$ K

Properties of air at film temperature

$v = 26 * 10^{-6} m^2/s$ $\quad\quad$ $P_r = 0.699$

$k = 33.8 \times 10^{-3} \frac{w}{m}.k$ $\quad\quad$ $\beta = 2.5 * 10^{-3} k^{-1}$

Convective heat transfer area of the stove, $A_c = \pi DL = 0.291 m^2$

Convection heat loss from pot surface can be defined as:

$Q_{conv} = hA_c(T_p - T_s)$

Where,

h = convection heat transfer coefficient, $w/m^2.k$

A_s = heat transfer surface area of the stove, m^2

T_p = Average temperature of the plate surface, k

T_∞ = temperature of the air sufficiently far from the surface, k

Convective heat transfer coefficient over pot surface can be determined by eqn:

$h_p = \frac{N_u K}{L}$

Where,

h_c = convective heat transfer coefficient, w/m^2.k

N_u = nusselt number

K = thermal conductivity, w/m.k

L = characteristic height, m

Empirical correlations for the average nusselt number for natural convection are defined by eqn;

$N_u = 0.54 Ra_L{}^{1/4} \qquad (10^4 \leq Ra_L \leq 10^9),$

$N_u = 0.11 R_a{}^{1/3} \qquad (10^9 \leq Ra_L \leq 10^{13})$

Rayleigh number ($\boldsymbol{Ra_L}$) is the product of Grashof and Prandtl numbers:

$Ra_L = Gr_L p_r = \frac{g\beta(T_p - T_\infty) L_s{}^3}{v^2} . P_r$

$= 9.11 \times 10^5$

Therefore, average nusselt number is calculated as,

$N_u = 0.54 Ra_L{}^{\frac{1}{4}}$

$= 16.7$

Therefore, $h_p = \frac{N_u K}{L} = 2.35$

Convection heat loss from stove to the surrounding can be obtained as:

$Q_{conv} = hA_c(T_s - T_\infty)$

$= 152 \text{ W}$

Radiation heat loss from stove body

Thermal energy is the transfer of energy due to electromagnetic wave. It is continuously emitted by all matter whose temperature is above absolute zero and increase with increasing temperature of the body (Wiley, 2002).

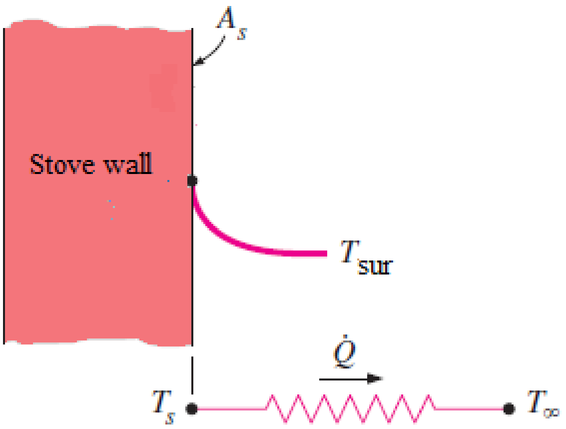


Figure: radiation resistance at a stove wall

Radiation heat loss from stove surface to surrounding can be obtained as,

$Q_{rad} = \varepsilon\sigma A_p({T_s}^4 - {T_\infty}^4)$

Where,

$\varepsilon =$ is emissivity of stove body(stainless steel)

$\sigma =$ stefan − Boltizmann constant, $= 5.67 \times 10^{-8} \frac{w}{m^2}.K^4$

$A_p =$ surface area of stove $= 6 \times h^2 = 0.41\ m^2$

$T_p =$ is average surface temperature of stove

$T_\infty =$ is surrounding temperature

Therefore, the net energy emitted from stove surface to the surrounding at temperature (T_∞) can be determined as;

$Q_{rad} = \varepsilon\sigma A_p({T_p}^4 - {T_\infty}^4)$

$= 163\ W$

3.12.3. Heat gain from gases to the pot bottom

Net of heat loss from gases to the stove body, the remaining energy goes towards the pot with its contents and to the sides of the pot. Depending on the resistance offered to this heat flow by the pot and contents, a fraction of this energy flows into the pot and its contents, and the remainder is goes to surroundings, primarily as flue gas and direct radiation losses. Therefore heat was transfer from gases to pot bottom by convection and radiation.

Convection heat transfer from gases to pot bottom

In this case heat energy was gain due to the transfer heat from gases to pot bottom and the pot gets heated up.

Properties of air at film temperature

- ✓ Specific capacity of air, $C_{p\text{-}gas}$ = 1097.68 J/kg.k
- ✓ Thermal conductivity of gas , K = 0.05633 w/m.k

Assume the space created by pot gap and stoves drip pan behaves like two parallel plates. Effective surface area of the distillation pot A_p will be:

$$A_{P-bottom} = 4\pi r^2 = 0.19\text{m}^2$$

And $$A_{pot-gap} = \pi D_{pot} L_{pot-gap} = 0.03\text{m}^2$$

Density of the gas will be:

$$\rho_{gas} = \frac{P_{atm}}{R_{air} T_{gas}} = 0.4 \frac{Kg}{m^3}$$

Estimated gas velocity flowing through pot gap area is:-

$$V_{gas-pot} = \frac{m_{stove}}{\rho_{gas} A_{pot-gap}} = 0.18 \, ^{m}/_{s}$$

$$\mu_{gas} = \frac{\mu_o T_{gas}}{T_o} = 5.44 \times 10^{-5} \frac{kg}{m}.s$$

Hydraulic diameter definition between two parallel plates D_h = 2h pot gap = 55mm

Reynolds's number approximation for fully developed internal flow can be obtained as:-

$$Re_{pot-gap} = \frac{\rho_{gas} V_{pot-gap} D_h}{\mu_{gas}}$$

$$= 714.8$$

The flow through pot gap is less turbulent than in stack.

Pradntl number, $p_r = \frac{\mu_{gas} C_{P-gas}}{K_{gas}} = 1.1$

Stagnation Nusselt number for fully developed internal flow will be obtained as:

$$N_{u-D} = 1.86 Re^{\frac{1}{3}} Pr^{\frac{1}{3}} \left(\frac{D}{L}\right)^{\frac{1}{3}} = 8.74$$

Convective heat transfer coefficient can be calculated as:

$$h_{con-pot} = \frac{N_u K_{gas}}{d_{pot-b0ttom}} = 1.4 \frac{w}{k}.m^2$$

Accounting for combustion and therefore flame radiation can increase the magnitude of the convective heat transfer coefficient anywhere from 2.3-3.4× (Viskanta.R, 1993). This is more realistic expression of impinging flame jet flow exhibited in stove.

$$h_{con-low\ flame} = 2.3 h_{conv-pot}$$

$$= 3.22 \frac{w}{k}.m^2$$

$$h_{con-high\ flame} = 3.4 h_{conv-pot}$$

$$= 4.76 \frac{w}{k}.m^2$$

Assuming high flame, $h_{con-pot} = \mathbf{4.76 \frac{w}{k}.m^2}$

Temperature of gas exposed to pot bottom will be calculated from the total heat loss to wall of stove before the hot gases make it to pot bottom$Q_{stove-losses}$.

$$Q_{stove-losses} = \dot{m}_{stove} C_{p-gas} \left(T_{gas} - T_{gas-exposed\ to\ pot\ bottom}\right)$$

From this equation, it is possible to determine temperature of the gas exposed to pot bottom. Therefore temperature of the gas exposed to pot bottom will be determined using equation (3.12):-

$$T_{gas-exposed\ to\ pot\ bottom} = T_{gas} - \frac{Q_{stove-losses}}{m_{flow-in\ stove} \times C_{P-gas}}$$

$T_{gas-exposed\ to\ pot\ bottom} = 690\ K$

Convection heat transfer from gasses to pot bottom can be obtained as:-

$$Q_{cov-pot\ bottom} = h_{con-pot}A_{p-bottom}(T_{gas-exposed\ to\ pot\ bottom} - T_{pot-surface})$$

$$= 234\ W$$

Radiation heat transfer from flame to pot bottom

Heat loss from gases to the pot bottom was carried out due to radiation heat transfer between the flame of the gases and pot bottom. Therefore, there will be radiation heat transfer (gain) towards the pot bottom. Assuming pot is a black body (i.e.$\varepsilon = \sigma = 1$), radiation is directionally independent and reflectivity of flame is negligible.

Total radiation heat transfer goes (supplied) to pot bottom from flame of the gases can be obtained by using equation (5.13):-

$$Q_{rad-flame\ to\ pot} = A_{flame}F_{flame}\sigma_{stefan}(\varepsilon_{flame}4_{flame-a} - T^4{}_{flame-b})$$

Effective emitting flame areas,

$$A_{flame-a} = \pi R^2{}_{flame} = 0.13m^2$$

Effective area intercepted by pot bottom

$$A_{flame-b} = \pi R_{flame-b}{}^2 = 0.0962m^2$$

Variable simplification for view factor calculation

$$S_{flame-view} = 1 + \frac{1+\left(\frac{R_{flame-b}{}^2}{L_{flame}{}^2}\right)}{\left(\frac{R_{flame-a}{}^2}{L_{flame}{}^2}\right)} = 2.55$$

Therefore, view factor can be determined by using:-

$$F_{flame\ in-out} = \frac{1}{2}\left[S_{flame-view} - \left(S_{flame-view}{}^2 - 4\left\{\frac{R_{flame-in}}{R_{flame-out}}\right\}^2\right)\right]$$

$$= 0.349$$

Therefore, radiation heat transferred to the pot bottom surface will be:-

$$Q_{\text{rad-flame to pot}} = A_{\text{flame}} F_{\text{flame}} \sigma_{\text{stefan}} (\varepsilon_{\text{flame}} T4_{\text{flame-a}} - T^4{}_{\text{flame-b}})$$

$$= 544 \text{ W}$$

3.12.4. Heat gain to the side of the pot

Convection heat to the side of the pot surface

Convection heat transfer to side of the pot using pot skirt

$$Q_{\text{conv-sides}} = h_{\text{conv-sides}} A_{\text{sides}} (T_{\text{gas-exposed to pot bottom}} - T_{\text{pot}})$$

Gas temperature as it exits the pot gap and travels up the sides of the pot.

$$Q_{\text{pot-losses}} = \dot{m}_{\text{flow-in stove}} C_{\text{p-gas}} (T_{\text{gas}} - T_{\text{gas-exposed to pot}})$$

$$= 455 \text{ W}$$

$$T_{\text{gas-2}} = T_{\text{gas-exposed to pot bottom}} - \frac{Q_{\text{pot-losses}}}{\dot{m}_{\text{in-stove}} C_P}$$

$$= 496 \text{ K}$$

$t_{\text{skirt}} = 6\text{omm}$ Thickness of the air gap between the pot skirt and pot

$h_{\text{skirt}} = 90\text{mm}$ Height of pot skirt from bottom of pot

$D_i = D_{\text{pot}} = 300\text{mm}$ $\quad$ $D_0 = D_i + t_{\text{skirt}} = 420\text{mm}$

$$A_{\text{side}} = \pi D_{\text{pot}} h_{\text{skirt}} = 0.085\text{m}^2$$

Hydraulic diameter of circular tube annulus formed by pot skirt and pot

$$D_o = D_o - D_i = 120\text{mm}$$

Reynolds's number approximation for fully developed internal flow can be obtained as:-

$$R_e = \frac{\rho_{\text{gas}} V_{\text{pot-gap}} D_h}{\mu_{\text{gas}}}$$

$$= 158.82$$

Pradntl number, $p_r = \frac{\mu_{gas} C_{P-gas}}{K_{gas}} = 1.1$

Stagnation Nusselt number for fully developed internal flow will be obtained as :

$$N_{u-D} = 1.86 Re^{\frac{1}{3}} Pr^{\frac{1}{3}} \left(\frac{D_h}{h_{skirt}}\right)^{\frac{1}{3}} = 11.44$$

Convective heat transfer coefficient can be calculated as:

$$h_{con-pot} = \frac{N_u K_{gas}}{D_{pot}} = 2.14 \frac{w}{k}. m^2$$

Assuming high flame, $h_{con-sides} = 3.4 h_{conv} = 7.276$

$$Q_{conv-sides} = h_{conv-sides} A_{sides} \left(T_{gas-exposed\ to\ pot\ bottom} - T_{pot}\right)$$

$$= 165\ W$$

Radiation reflected from skirt to pot surface

The rate at which radiation leaves flames and is intercepted by skirt is determined by:

$$Q_{radfrom\ pot\ support} = A_{flame\ to\ skirt} F_{flame\ to\ pot\ skirt} J_{flame\ to\ skirt}$$

$$\rho_{pot\ support} = 1 - \varepsilon_{pan} = 0.18$$

$$J_{flame-drip\ pan} = T_{flame}{}^4 \varepsilon_{flame} \sigma_{stefan}$$

$$= 25{,}043.132$$

Variable simplification for view factor calculation

$$S_{flame-view} = 1 + \frac{1 + \left(\frac{R_{flame-in}{}^2}{L_{flame}{}^2}\right)}{\left(\frac{R_{flame-out}{}^2}{L_{flame}{}^2}\right)}$$

$$= 2.03$$

Therefore, view factor can be determined by using:-

$$F_{flame\ in-out} = \frac{1}{2}\left[S_{flame-view} - \left(S_{flame-view}{}^2 - 4\left\{\frac{R_{flame-in}}{R_{flame-out}}\right\}^2\right)\right]$$

$$= 0.92$$

For emission and reflected irradiation from flame to skirt surface.

$$Q_{rad\ from\ skirt} = A_{flame\ to\ pot\ skirt} F_{flame\ to\ skirt} J_{flame\ to\ skirt}$$

$$= 99\ W$$

3.12.5. Heat loss from skirt surface

Heat loss in the surface of skirt was carried out due to the flame at sides of the pot emitted to the surface of skirt and gets heated up. Therefore, heat is lost from skirt surface to the environment through radiation and convection.

Convection heat loss from the stove skirt surface

In this case thermal energy was lost from the surface of the stove skirt to the cold environment by the bulk movement of the air.

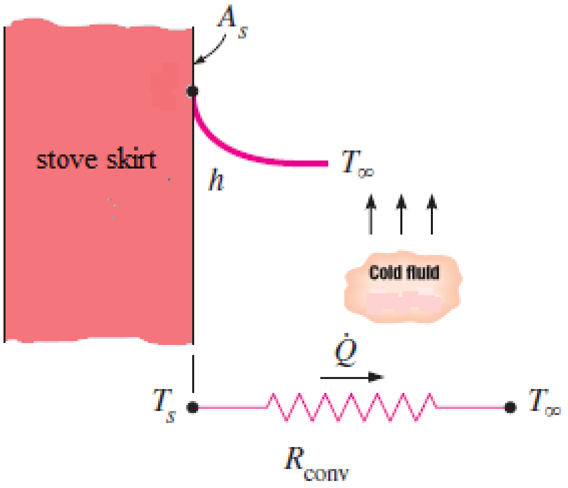


Figure: Convection resistance at a stove skirt surface

Film temperature, $T_f = \frac{406+299}{2} = 352.5k$

Properties of air at film temperature

$\upsilon = 5.5122 * 10^{-5} m^2/s$ $\quad\quad$ $P_r = 0.694$

$k = 47.357 * 10^{-3} \frac{w}{m}.k$ $\quad\quad$ $\beta = 2.89 * 10^{-3} k^{-1}$

Convection heat loss from stove skirt can be defined as:

$$Q_{conv} = hA_{skirt}(T_{skirt} - T_{\infty})$$

Where,

h = convection heat transfer coefficient, w/m^2.k

A_{skirt} = Surface area of stove, m^2

T_{skirt} = Average surface temperature of the stove skirt, k

T_{∞} = temperature of the air sufficiently far from the surface, k

Convective heat transfer coefficient over pot skirt can be determined by eqn:

$$h_{skirt} = \frac{N_u K}{L}$$

Where,

h_c = convective heat transfer coefficient, w/m^2.k

N_u = nusselt number

K = thermal conductivity, w/m.k

L = characteristic height, m

Empirical correlation for the average nusselt number for natural convection is defined by eqn [38, 39].

$$N_u = 0.59{Ra_L}^{1/4} \quad\quad (10^4 \leq Ra_L \leq 10^9)$$

$$N_u = 0.1{R_a}^{1/3} \quad\quad (10^9 \leq Ra_L \leq 10^{13})$$

Rayleigh number(Ra_L) is the product of Grashof and Prandtl numbers:

$$Ra_L = \frac{g\beta(T_{skirt} - T_{\infty}){L_c}^3}{v^2}.P_r = 6.93 \times 10^8$$

Therefore, average nusselt number is calculated as;

$$N_u = 0.59 Ra_L^{\frac{1}{4}} = 95.72$$

Hence, $h_s = \frac{N_u K}{L} = 5.04 \frac{w}{m^2}.k$

Convection heat loss from pot surface to surrounding can be obtained as:

$$Q_{conv} = hA_{skirt}(T_{skirt} - T_\infty)$$

$$= 65 \text{ W}$$

Radiation heat loss from pot skirt

In this case thermal energy was lost from the surface of the stove skirt to the cold environment by the bulk movement of the air.

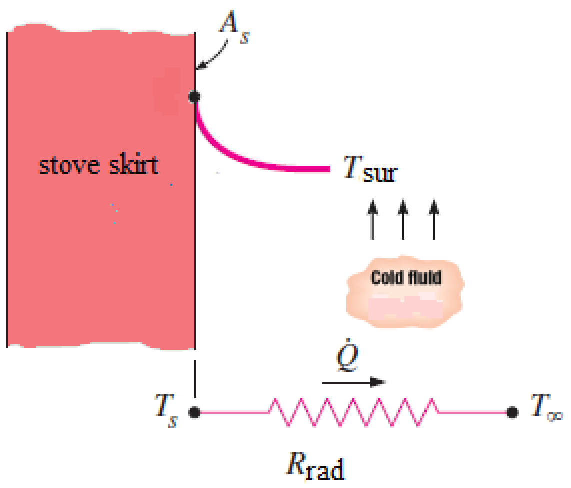


Figure: radiation resistance at a stove skirt

Radiation heat loss from pot skirt surface to cold environment can be obtained as,

$$Q_{rad} = \varepsilon \sigma A_{skirt}({T_{skirt}}^4 - {T_{sur}}^4)$$

Where,

ε = is emissivity of pot skirt(steel = 0.96)

σ = stefan − Boltizmann constant, $= 5.67 \times 10^{-8} \frac{w}{m^2}.K^4$

A_{skirt} = surface area of pot

T_{skirt} = is average surface temperature of pot

T_∞ = is surrounding temperature

Therefore, the net energy emitted from pot surface to the surrounding at temperature (T_∞) can be determined as;

$$Q_{rad} = \varepsilon\sigma A_p\left({T_p}^4 - {T_\infty}^4\right)$$

$$= 125\ W$$

Table 7 summarizes the total heat loss and heat gain calculations made on the previous sections.

Table 7: Summarized values of heat transfer model

Modes of heat	Values calculated for Improved biomass *Areke* Distillation stove (W)
<u>Heat Gain</u>	
Convection	
To pot bottom	234
To side of pot surface	165
Radiation	
To pot bottom	544
To side of pot	99
Total heat energy gain	1042
<u>Heat losses</u>	
Convection	
To stove combustion chamber	152
To ambient	65
Radiation	
To stove combustion chamber	163
To ambient	125
Total heat energy loss	505
Total Heat Energy Generated in the system =	1547

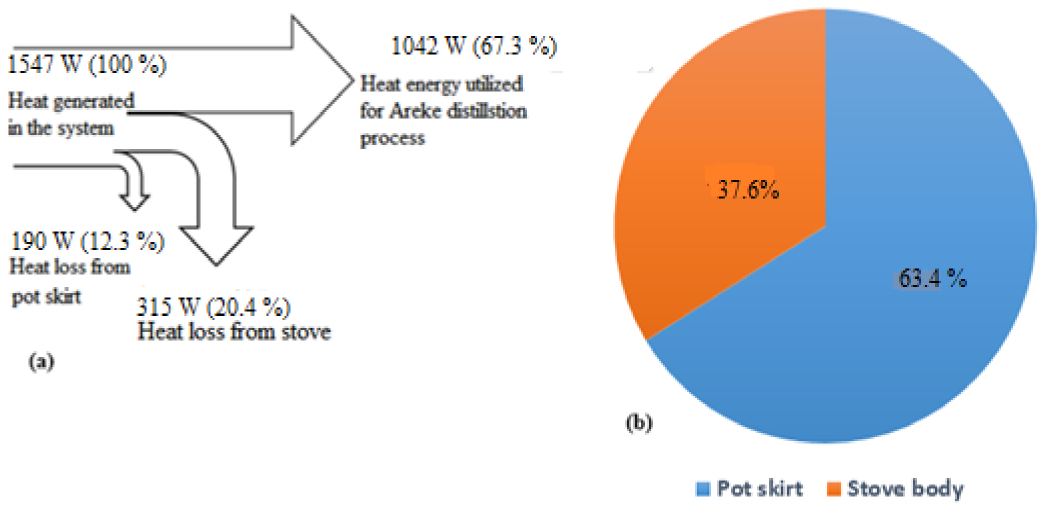


Figure 18: Result obtained from analytical analysis. (a) Energy Sankey diagram of improved biomass *Areke* distillation stove (b) Percentage description of total heat loss accounted in the improved *Areke* distillation stove

The result from analytical analysis of the loss accounted in the Areke distillation process shows, total heat loss of improved biomass *Areke* distillation stove was 505 W with heat loss from pot skirt to ambient accounts major loss (190 W of total loss) from the system and 315w heat loss from stove to the environment. Thus, useful energy (the amount of energy utilized for *Areke* distillation using traditional biomass stove) 1042 W was obtained by subtracting all loss encountered in the system from the total (1547 W) heat energy generated in the system for each *Areke* distillation cycle.

CHAPTER FOUR

Result and Discussion

In this section the results obtained from the analytical design and experiment presented and discussed against literatures and previous studies. Since the results of the analytical design calculations are already provided in the previous section here only the summery is presented. But the results of the experiment is elaborated in detail in this section and discussed.

4.1. Results of analytical design

The improved *Areke* stove is constructed with the fabrication values listed in the table 5. For quantifying the heat loss accounted in the *Areke* distillation process average temperature of all measurement at each surface of the *Areke* stove and distillation pot was used. In the analytical calculation the heat transfer to the pot bottom and to the side of pot surface is considered as heat gain, while the heat transfer to the environment was considered as heat loss. Table 8 shows results of analytical calculation of three stone and improved biomass *Areke* distillation stove.

Table 8: The results of the analytical design calculation

Parameters	Three stone *Areke* stove (W)	Improved *Areke* stove (W)
Total energy generated in the system	1489	1547
Total heat energy utilized for *Areke* - Distillation process	810	1042
Total heat energy loss	679	505
Thermal efficiency	11.2%	25.6%

The result of analytical calculation shows from 1547 W heat energy generated in improved biomass *Areke* distillation stove 550 W heat is lost to the surrounding and 1042 W energy is used for *Areke* distillation process. Compared to the traditional biomass *Areke* distillation stove, the improved biomass *Areke* distillation stove improves the thermal efficiency by 14.4 %.

4.2. Thermal efficiency

The thermal efficiency of the present improved biomass Areke distillation stove was 25% while the efficiency of the three-stone fire for Areke distillation was 11 % (Table 9). This shows an increase of the efficiency of around 100% compared to the three-stone fire. These results are slightly lower but in good agreement with those presented by other authors. Yang, (2010) tested the Berkeley Darfur cook stove and found an average efficiency of 28% using biomass. The lower efficiency found for the improved biomass Areke distillation stove could be explained because of the differences between the Areke distillation process and the cooking process. This result obtained by using equation 4:15-4:19.

Table 9. Thermal efficiency of improved biomass Areke distillation stove compared with three- stone fire stove.

No	Description	Type of Areke distillation stove	
		Improved Areke Stove	Three stone Areke stove
		Average	Average
1	$m_{intial-difedif}$ (L)	8	8
2	$m_{final-difedif}$ (L)	6	6.5
2	t (min)	70	105
3.	$T_{difedif}$ (^oC)	78.5	78.5
4	$T_{intial-difedif}$ (^oC)	20	20
5	h_{fg} (kJ/kg)	18700	18700
6	m_{wood} (kg)	1.8	2.65
7	U (J)	$6 * 10^3$	$4 * 10^3$
8	Q_{rate} (W)	12	8
9	E_{in} (J)	14	12
10	E_{out}	6	4
11	$Q_{total} = Q_{rad} + Q_{conv}$	1574	1489
12	$E_{consumed}$ (kJ)	3744	3870
13	**Energy** $_{\mathbf{in\ fuel}}$	4072	3870
14	Energy supplied for distillation	6169	13,296
15	Thermal efficiency = $\frac{Q_{total}}{E_{in-fuel}}$	25 %	11.2%

4.3. Energy utilized for *Areke* distillation process

Energy utilized is the amount of heat energy used for Areke distillation process without including the loss accounted during the distillation process. It is the sum of total energy gain through convection and radiation. Therefore, the amount of energy utilized for *Areke* distillation process using the improved *Areke* stove can be obtained as:

$$E_u = Q_{conv-gain} + Q_{rad-gain}$$

From 1547 W, the amount of heat energy utilized for each *Areke* distillation process using improved *Areke* stove was obtained as 1042 W heat energy which account 68 % of total energy supplied to the system. However, from1489 W the amount of heat energy utilized for each *Areke* distillation process using three stone *Areke* stove was 810 W which accounts 54 % of total energy supplied to the system.

4.4. Results of Experimental test

The experimental test which is a Controlled Cooking Tests conducted as it was stated in the methodology of the study are presented below. In this experiment three tests have been conducted for each stove. The pot weighs 7 Kg and the initial temperature of the distilland was 20.8^0C. For the first round test initial the pot was put on the *Areke* stove empty until it warms up then the level to which it heats up was checked by pouring some water in to it. Then the distilland was poured in to the pot and kept open until it boils while it has been steered before the distillation tube is put in place and sealed then left until the distillation is over.

4.5. Specific fuel consumption

The amount of fuel used to distill a gram of *Areke* was calculated for all the two stoves (three stone and improved *Areke* stoves). In this case, a total of 6 tests were considered for evaluation of the performance in terms of fuel use and time to brew and for enclosed *Areke* stove it is taken from literature. Figure 19 shows the specific fuel consumption for three-stone, enclosed and improved biomass *Areke* stoves.

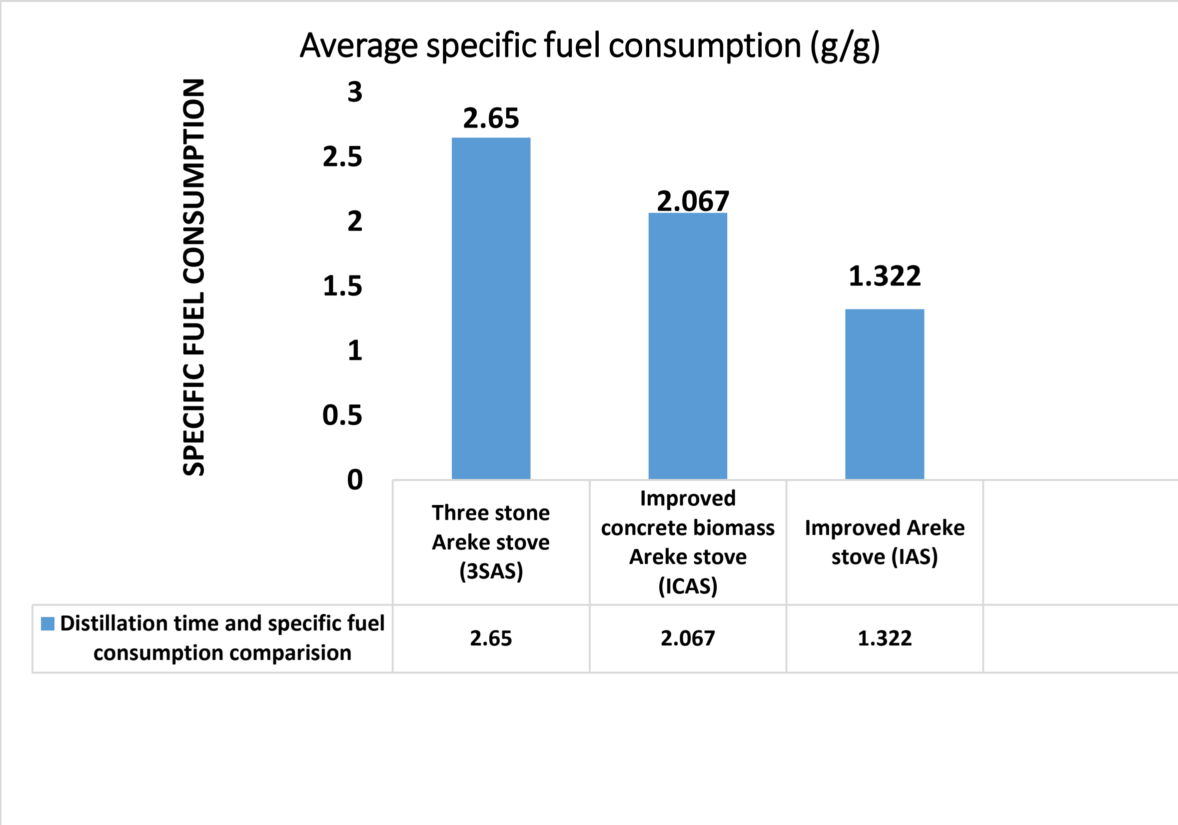


Figure 19: Average Specific Fuel Consumption (3SAS, TAS and IAS)

The traditional *Areke* stove has a reduction of 36% in specific fuel consumption compared to three stone fire while improved biomass *Areke* distillation stove showed a reduction of 45% compared to the three stone *Areke* stove. This is advantage which will be gained if the three-stone *Areke* stoves are to be replaced with improved *Areke* stoves.

4.6. Average brewing time

The time to distil *Areke* is also an important indicator of stove performance. Depending on local conditions and individual preferences, stove users may value this indicator more or less the same as fuel consumption indicator. This is calculated as a simple clock difference between start and finish of the *Areke* processing activity. Figure 20 indicates the average time and its percentage improvement compared to three stone *Areke* stove.

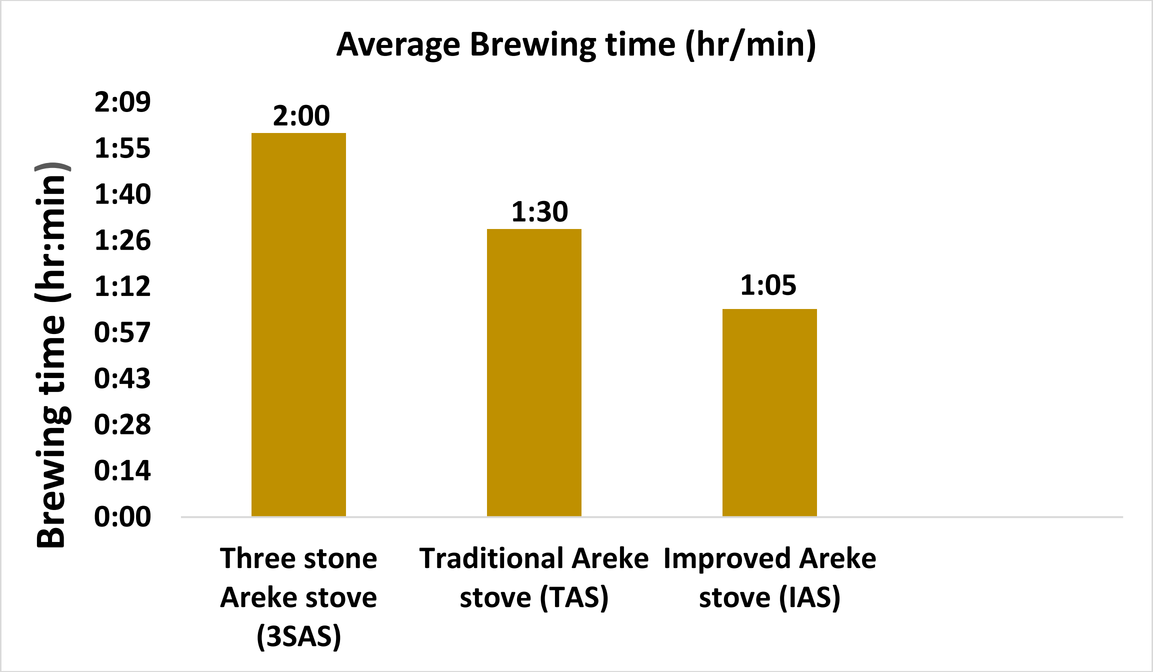


Figure 20. Average brewing time (3SAS, TAS and IAS)

Comparing the traditional *Areke* stove with the three stone, there was a reduction of 30 minutes in terms of time for *Areke* distillation. Improved *Areke* stove reduces the time required for brewing nearly by half compared to three stone *Areke* stove. This performance is due to the metal shield around the fire which improved the thermal efficiency by reducing heat loss via convection and radiation. This is really one of the improvements in using the improve biomass *Areke* distillation stove.

4.7. Performance comparisons

The experimental test result of the newly designed and manufactured improved biomass *Areke* stove showed a remarkable performance as compare to the performances of stoves tested in studies conducted previously. Figure 21 shows distillation and fuel consumption comparisons of improved *Areke* stove with studies conducted previously.

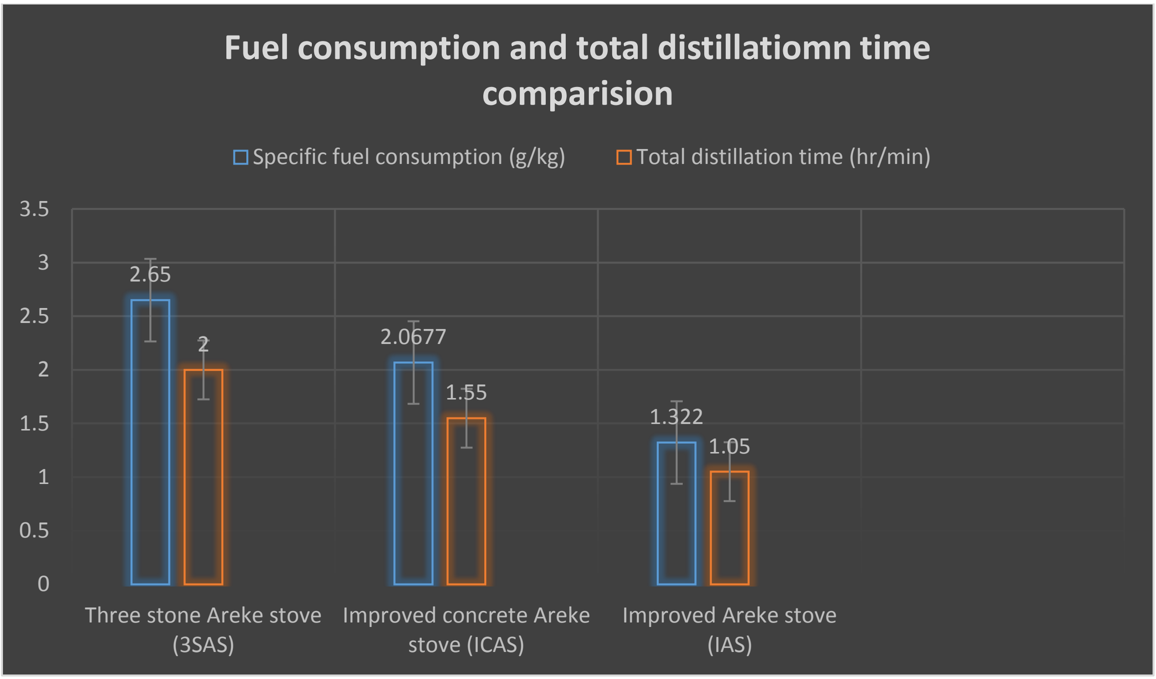


Figure 21: Distillation time and fuel consumption comparison

Comparing the newly improved biomass *Areke* stove with the three stone, there was a reduction of 50 % and 45 % in terms of time and fuel consumption for *Areke* distillation respectively. The improved *Areke* stove has a thermal efficiency of 25% and the three stone *Areke* stove has a thermal efficiency of 11.2%. This performance is due to the metal shield around the fire which improved the thermal efficiency by reducing heat loss via convection and radiation. There was 4 % and 22 % reduction in terms of time and fuel consumption respectively for *Areke* distillation using concrete improved *Areke* stove as compared to three stone *Areke* stove (Gezahegne, 2008). Compared with the 3-stone fire and improved concrete *Areke* stove, improved biomass *Areke* stove has a faster time to distill, better thermal efficiency, and lower specific fuel consumption. The improved stove is simple, portable, durable and low cost, and has benefits over traditional three stone stoves and improved concrete *Areke* stove.

CHAPTER FIVE

Conclusion and Recommendation

5.1. Conclusion

In this work the design and experimental investigation of improved biomass *Areke* distillation has been carried out. Its performance is compared with that of a three-stone fire usually used for *Areke distillation*. First, for quantifying the loss accounted both in the three stone and improved *Areke* stove intensive experimental investigation was made, and the improved *Areke* stove accounts 505 W heat loss and from the total heat loss accounted in the system. The average thermal efficiency achieved was 25% which is higher than three-stone fire (11.2%). The stove performances were evaluated from multiple perspectives because efficiency by itself is not a comprehensive indicator of performance. The controlled cooking test result indicated that improved *Areke* stove reduces 45% fuel used compared with three stone *Areke* stove. In a similar manner, the total distillation time of improved *Areke* distillation stove is reduced by 50% as compared to three stone *Areke* stove. The 3-stone arrangement had the highest specific fuel consumption, this implies that it consumes the most fuel; it also had high visible smoke emissions compared to the improved *Areke* stove tested. This first attempt to develop an *improved biomass Areke distillation* stove achieved promising results and, if improved and widely distributed, it could contribute to reduce deforestation, emissions and health problems caused by elevated concentrations of pollutants in the kitchen when using inefficient three-stone fires.

5.2. Recommendation

Based on the results of the Controlled Cooking Test (CCT), carried out in this study, the improved *Areke* stove can be recommended as cost effective alternatives to the 3-stone *Areke* stove.

. The following points are recommended for future works.

- To get more improved efficiency, the effect of pot skirt on heat transfer efficiency has to be analyzed by CFD and also the effect of gap between top part surface used to hold pot supports or mouth of flame outlet and pot bottom should be analyzed for this *Areke* distillation stove geometry.

- The efficiency value gained from analytical calculation of new geometry has to be validated with CFD simulation test result.
- It is also recommended researchers to include the indoor air pollution tests to verify the amount of harmful gases exhibited with kitchen.

The test conducted on improved biomass *Areke* stove could be used as a baseline performance data for future improvements. The stove could further be improved after having undergone a number of production and producers feedbacks

Reference

Abebaw, A. (2010). The Potential of Biogas Energy in supplementing the Household Energy needs for Areke production, case of Arsi Negele District, Oromia Regional State.

Admassie, Y. A. E. A. (2010). The *Areke* Dilemma: The Socioeconomics of Traditional Distilled Alcohol production, Marketing, and Consumption in Ethiopia.

Ashenafi. M, M. T. (2001). Some microbiological and nutritional properties of Borde and Shamita. Ethiop. J. Health Dev., 9, 105-110.

Assaye, m. (2018). Studying thermodynamic properties and increasing ethanol concentration in local distilled ethiopian areki.

Ayanie, A. K. (2011). Bioethanol Production And Optimization Test From Agricultural Waste: The Case Of Wet Coffee Processing Waste (Pulp)," A Thesis Submitted To The School Of Graduate Studies, Addis Ababa University In The Partial Fulfillment Of The Requirement For The Award Degree of Masters Of Science In Environmental Science,.

Ayenor, K. S. a. M., J. S. (1972). The sap of Elaeis guineensis Jacq. As raw material for alcoholic fermentation in Ghana. In: Handbook of Indigenous Fermented Foods. Steinkraus KH (ed). Marcel Dekker, Inc. New York, pp 315 – 328.

Bailis, R. (2004). Controlled Cooking Test (CCT).

Demissie, S. W. (2016). Design, Fabrication and Testing of Biogas Stove for 'Areke' Distillation:The case of Arsi Negele, Ethiopia, Targeting Reduction of Fuel-Wood Dependence.

Desta, B. (1977). A survey of the alcoholic contents of traditional beverages. Ethiopian Medical Journal, 15, 65–68.

Fite, A. T., A. Urga, K, and Seyoum, E. (1991). Methanol, fuel oil and ethanol contents of some Ethiopian traditional alcoholiv beverages. Ethiopian Journal of Science, 14, 19-27. (et al).

Gadaga, T. (1999). A review of traditional fermented foods and beverages of Zimbabwe. International Journal of Food Microbiology, 53(1), 1–11. https://doi.org/10.1016/S0168-1605(99)00154-3.

Gezahegne, G. (2008). Evaluating The Efficiency Of Improved Local Liquor (Areke) Distilling Stove By Measuring The Indoor Air Emission, MSc Thesis, Addis Ababa University, Addis Ababa.

Harkishore, K. M. (1997). Kenyan urwuga In: Handbook of Indigenous Fermented Foods. Steinkraus KH (ed). Marcel Dekker, Inc. New York, pp.338 – 340.

Hill, M. (2003). Cengel, Yunus A. Heat transfer a practical approach.

Kassa, A. (2015). Investigation of parabolic dish solar concentrator for local Areke distillation.

Mohammed, N. (2008). Impact of „Katikala" production on the Degradation of Woodland Vegetation and Emission of CO and PM during Distillation in Arsi-Negele Woreda, Central Rift Valley of Ethiopia, MSc Thesis, Addis Ababa University, Addis Ababa.

Okafor. (1972). The microbiological basis of a method for palm-wine preservation. J Appl. Bacteriol, 43, 159-161.

Solomon, H. (2011). Potential of solar energy for areke production. MSc thesis submitted to Addis Ababa University, School of Graduate Studies, and Environmental Science Program.

Teffera, B. (2007). Cleaner Production Assessment In The Ethiopian Alcohol Industries A Case Study In The Sebata Alcohol & Liquor Factory," A Thesis Submitted To The School Of Graduate Studies Of Addis Ababa University In Partial Fulfillment Of The RequirementFor The Degree Of Master Of Environmental Engineering.

Usinger, J. (1996). Manual on Simple Monitoring Techniques for the Control of Indoor air and Combustion Quality Standards in Developing Countriesî. GTZ GMBH, Echborn.

Viskanta.R. (1993). 11. Heat Transfer to Impinging Isothermal Gas and Flame Jets. Elsevier Science Publishing Co., Inc., 1993, Experimental Thermal and Fluid Science, Vol. 6.

Wiley, J. (2002). Incropera, Frank P. and DeWitt, David P. Introduction to Heat Transfer.

Zube, D. J. (2010). Heat Transfer Efficiency Of Biomass Cook Stoves.

Zvauya, R., Mygochi, T., Parawira, W.,. (1997). Microbiological and biochemical changes occurring during production of masvusvu and mangisi, traditional Zimbabwean beverages. Plant Foods for Human Nutr., 51, 43- 51.

APPENDIX 1: CONTROLLED COOKING TEST IN EXCEL

TEST 1:

I. INPUT PARAMETERS FOR EXCEL Bailis, R. (2004)

SHELL FOUNDATION HEH PROJECT CONTROLLED COOKING TEST

DATA AND CALCULATION FORM

Shaded cells require user input; unshaded cells automatically display outputs

Qualitative data

Name(s) of Tester(s)	Dirriba Bekele	Type of stove: Stove 1	raditional Three Stone Biomass Areke Distillation Stove
		Type of stove: Stove 2	Improved Biomass Areke Distillation Stove
Test Number	One	Location	Addis Ababa, Ethiopia
Date		Wood species	Eucalyptus Globulus (Southern Blue Gum, Fever Tree)

Quantitative testing conditions	data	units	variable		data	units
Avg dimensions of wood (length x width x height)	4*4*100	cm	--	Empty weight of Pot # 1	7,000	g
Wood moisture content (% - wet basis)	14%	%	m	Empty weight of Pot # 2		g
Local boiling point of water	79	ºC	T_b	Empty weight of Pot # 3		g
(default value is 100 ºC - correct if local value differs)				Weight of container for char	500	g

Other comments on test conditions

II. INITIAL TEST CONDITIONS FOR TRADITIONAL STOVE

CCT-Test 1 for the Traditional Three Stone Biomass Areke Distillation Stove

Wind conditions: moderate wind

Air temperature: 21.5 ºC

Shaded cells require user input; unshaded cells automatically display outputs

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for distillation	g	5000	f_i	2500	f_f	
Weight of charcoal+container	g			700	c_c	
Weight of Pot # 1 with distilled difedif	g			8000	$P1_f$	
Weight of Pot # 2 with distilled difedif	g				$P2_f$	
Weight of Pot # 3 with distilled difedif	g				$P3_f$	
Time	min		t_i	100	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of distilled difedif	g	1000	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	1808	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	200	$\Delta c_c = k - c_c$	Total cooking time	min	100	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	1808	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

CCT-2 for the Traditional Three Stone Biomass Areke Distillation Stove

Wind conditions: moderate wind

Shaded cells require user input; unshaded cells automatically display outputs

Air temperature: 20.5 °C

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for distillation	g	5000	f_i	2600	f_f	
Weight of charcoal+container	g			675	c_c	
Weight of Pot # 1 with distilled difedif	g			8000	$P1_f$	
Weight of Pot # 2 with distilled difedif	g				$P2_f$	
Weight of Pot # 3 with distilled difedif	g				$P3_f$	
Time	min		t_i	95	t_f	

CALCULATIONS			Formula
Total weight of distilled difedif	g	1000	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$
Weight of char remaining	g	175	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	1761	$f_d = (f_f - f_i)*(1-(1.12*m)) - 1.5*\Delta c_c$
Specific fuel consumption	g/kg	1761	$SC = \frac{f_d}{W_f}*1000$
Total cooking time	min	95	$\Delta t = t_f - t_i$

CCT-3 for the Traditional Three Stone Bioı

Wind conditions: moderate wind

Shaded cells require user input; unshaded cells automatically display outputs

Air temperature: °C

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for distillation	g	5000	f_i	2800	f_f	
Weight of charcoal+container	g			600	c_c	
Weight of Pot # 1 with distilled difedif	g			8000	$P1_f$	
Weight of Pot # 2 with distilled difedif	g				$P2_f$	
Weight of Pot # 3 with distilled difedif	g				$P3_f$	
Time	min		t_i	120	t_f	

CALCULATIONS			Formula
Total weight of distilled difedif	g	1000	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$
Weight of char remaining	g	100	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	1705	$f_d = (f_f - f_i)*(1-(1.12*m)) - 1.5*\Delta c_c$
Specific fuel consumption	g/kg	1705	$SC = \frac{f_d}{W_f}*1000$
Total cooking time	min	120	$\Delta t = t_f - t_i$

III. INTIAL TEST CONDITION FOR IMPROVED AREKE STOVE

CCT-1 for the IMPROVED AREKE STOVE

Wind conditions: moderate wind

Air temperature: 26 °C

Shaded cells require user input; unshaded cells automatically display outputs

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	5000	f_i	2800	f_f	
Weight of charcoal+container	g			800	c_c	
Weight of Pot # 1 with cooked food	g			8000	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Time	min		t_i	80	t_f	

CALCULATIONS	Units	Value	Formula
Total weight of food cooked	g	1000	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$
Weight of char remaining	g	300	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	1405	$f_d = (f_i - f_f)*(1-(1.12*m)) - 1.5*\Delta c_c$

CALCULATIONS	Units	Value	Formula
Specific fuel consumption	g/kg	1405	$SC = \frac{f_d}{W_f}*1000$
Total cooking time	min	80	$\Delta t = t_f - t_i$

CCT-2 for the IMPROVED AREKE STOVE

Wind conditions: moderate wind

Air temperature: 26 °C

Shaded cells require user input; unshaded cells automatically display outputs

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	5000	f_i	2950	f_f	
Weight of charcoal+container	g			725	c_c	
Weight of Pot # 1 with cooked food	g			8000	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Time	min		t_i	70	t_f	

CALCULATIONS	Units	Value	Formula
Total weight of food cooked	g	1000	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$
Weight of char remaining	g	225	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	1391	$f_d = (f_i - f_f)*(1-(1.12*m)) - 1.5*\Delta c_c$

CALCULATIONS	Units	Value	Formula
Specific fuel consumption	g/kg	1391	$SC = \frac{f_d}{W_f}*1000$
Total cooking time	min	70	$\Delta t = t_f - t_i$

CCT-3 for the **IMPROVED AREKE STOVE** Wind conditions: moderate wind

Shaded cells require user input; unshaded cells automatically display outputs Air temperature 26 °C

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	5000	f_i	2900	f_f	
Weight of charcoal+container	g			900	c_c	
Weight of Pot # 1 with cooked food	g			8000	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Time	min		t_i	60	t_f	

CALCULATIONS			Formula
Total weight of food cooked	g	1000	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$
Weight of char remaining	g	400	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	1171	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$

CALCULATIONS			Formula
Specific fuel consumption	g/g	1171	$SC = \frac{f_d}{W_f} * 1000$
Total cooking time	min	60	$\Delta t = t_f - t_i$

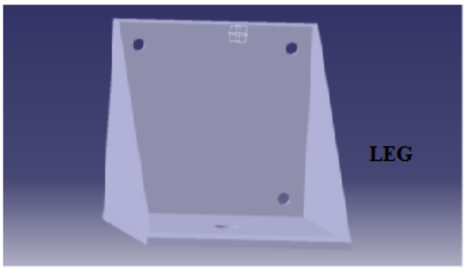
IV. RESULT OBTAINED

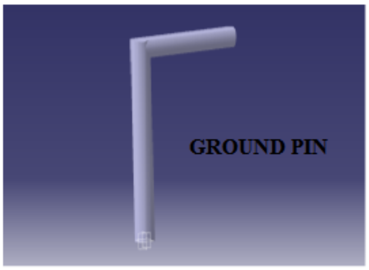
1. CCT results: Stove 1	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of distilled difedif	g	1,000	1,000	1,000	1,000	-
Weight of char remaining	g	200	175	100	158	52
Equivalent dry wood consumed	g	1,808	1,761	1,705	1,758	52
Specific fuel consumption	g/g	1,808	1,761	1,705	1,758	52
Total cooking time	min	100	95	120	105	13

2. CCT results: Stove 2	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	1,000	1,000	1,000	1,000	-
Weight of char remaining	g	300	225	400	308	88
Equivalent dry wood consumed	g	1,405	1,391	1,171	1,322	131
Specific fuel consumption	g/g	1,405	1,391	1,171	1,322	131
Total cooking time	min	80	70	60	70	10

Comparison of Stove 1 and Stove 2		% difference	T-test	Sig @ 95% ?
Specific fuel consumption	g/g	45.12%	5.35	YES
Total cooking time	min	40%	3.66	YES

APPENDIX 2: COMPONENT OF IMPROVED AREKE STOVE





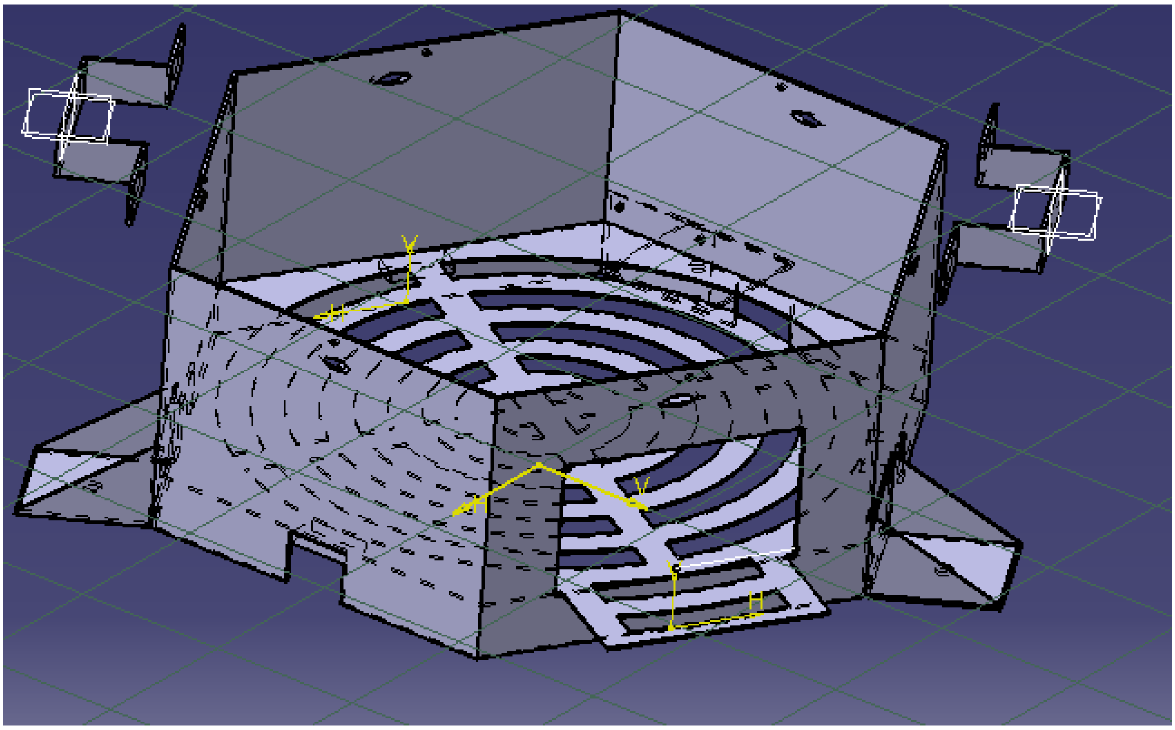
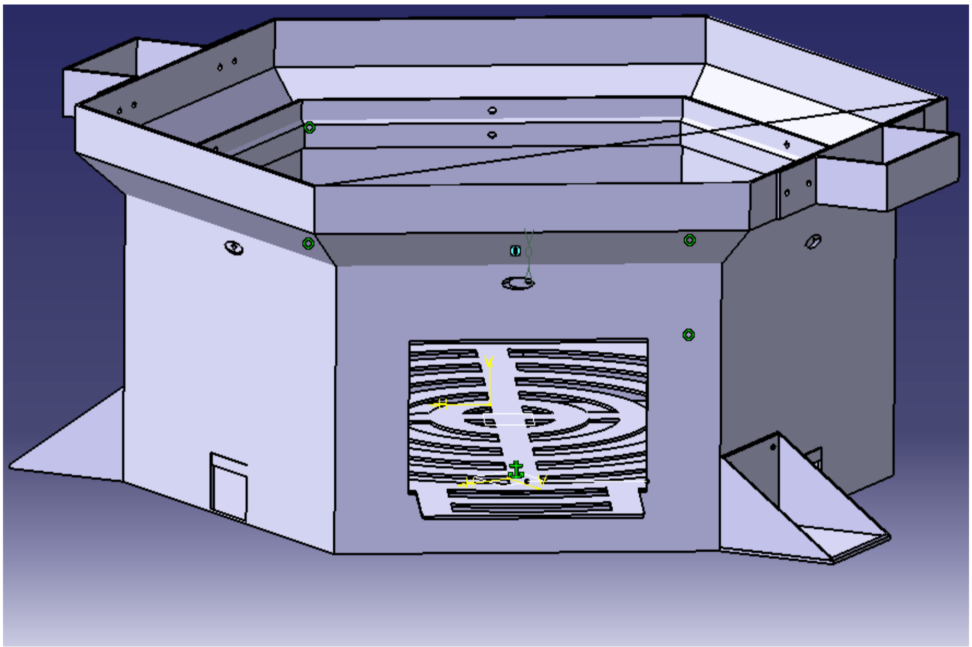


FIGURE: STOVE BODY



3D VIEW OF ASSEMBLED IMPROVED AREKE STOVE

APPENDIX 3:- CONCEPT SELECTION

Concept selection is the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development.

There is seven-step process that leads the team through the concept selection activity. The steps are:

- Generating concept
- Preparing the selection criteria
- Rate the concepts
- Rank the concepts
- Combine and improve the concepts
- Select one or two concepts
- Refine on the result and the process

Concept generation

The purpose of generating concept is to have different options for what we want to do. In this stage different drawings are prepared and one will be selected at the final.

Concept A

One of the improved biomass Areke distillation pot is a single-pot concrete stove, which is shown in Figure 1. It is made of concrete and consists a great and a chimney. On the front side, it has an ash hole and a square shape fuel feeding hole is situated on the left side. All types of biomass fuel can be used in this Areke distillation stove during the whole year.

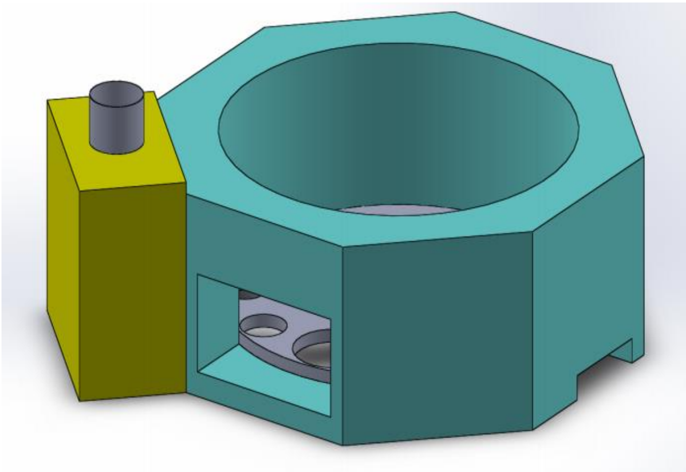


Figure 1: Concrete stove

Concept B:

The "Improved Areke distillation Stove" are designed and built to assist better combustion and heat transfer, for reducing emissions and increasing efficiency performance; while still ensuring lower cost and ease of use. A few common ICS design strategies are placing a metal grate under the burning fuel, provision of specific and low density heat walls for enclosing fire, use of insulation for reducing thermal losses, and designing properly sized channels for forcing heat to the bottom of the distillation pot.

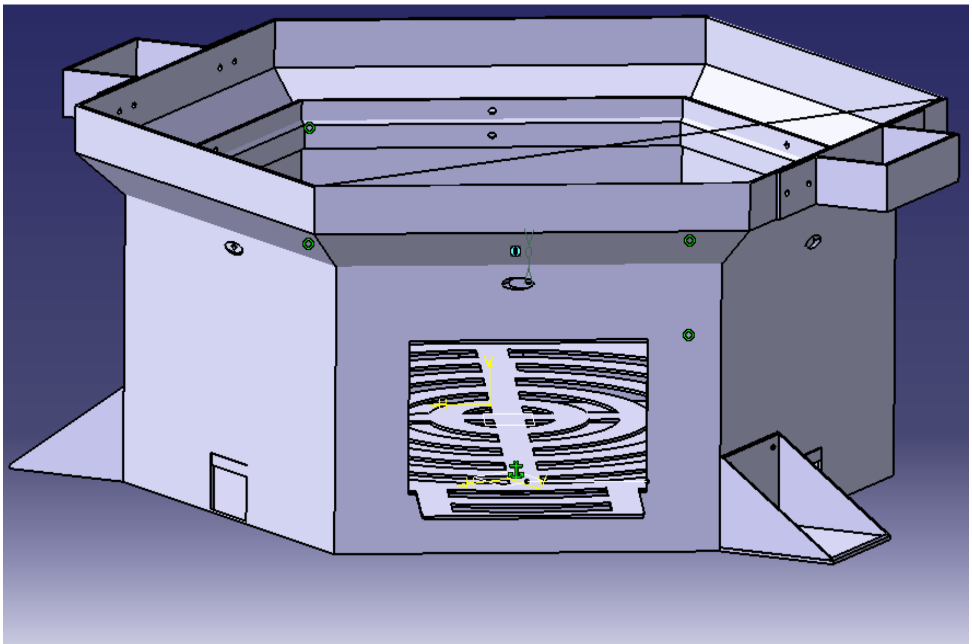


Figure 2: Improved metal stove

Concept C:

Figure 3 shows the single-mouth Areke distillation stove, which is used easily due to its portable nature along with low-cost facility. It can be used for indoor and outdoor cooking. Structure, grate and lid for covering the ash outlet are the main parts of the improved stove and it is usually constructed by using clay.

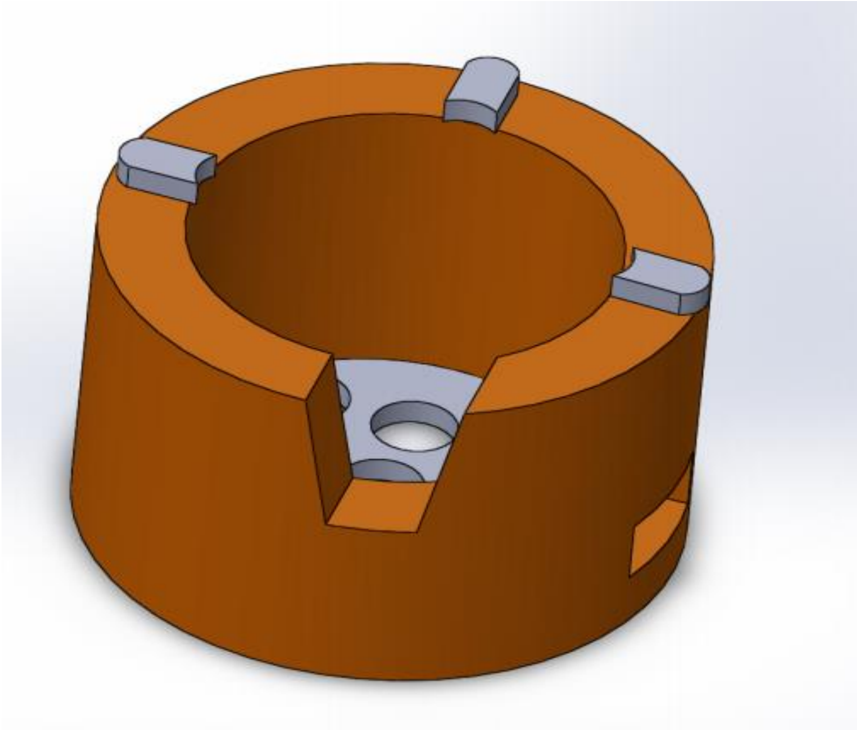


Figure 3: Improved clay stove

Table: Summary of the generated concept selection

	Concepts		
Selection criteria	**A** **Concrete stove**	**B** **Improved metal stove**	**C** **Clay stove**
- Ease of handling	-	+	+
-Ease of use	0	+	+
-Designed to burn wood	+	+	+

- Durability	+	-	0
-Ease of manufacture	-	+	-
- Cost	-	+	0
- Portability	-	+	+
- Designed to minimize heat loss	+	+	+
Sum +'s Sum 0's Sum –'s	3 1 4	7 1 1	5 3 1
Net scores Ranks Continue?	-1 3 No	6 1 Yes	4 2 No

Note: - The concept-screening matrix, the team rated the concepts against the reference concept using a simple code (+ for "better than," 0 for "same as," – for "worse than") in order to identify concepts for further consideration

Therefore based on concept selection criteria concept B is selected as the final improved biomass Areke distillation stove.

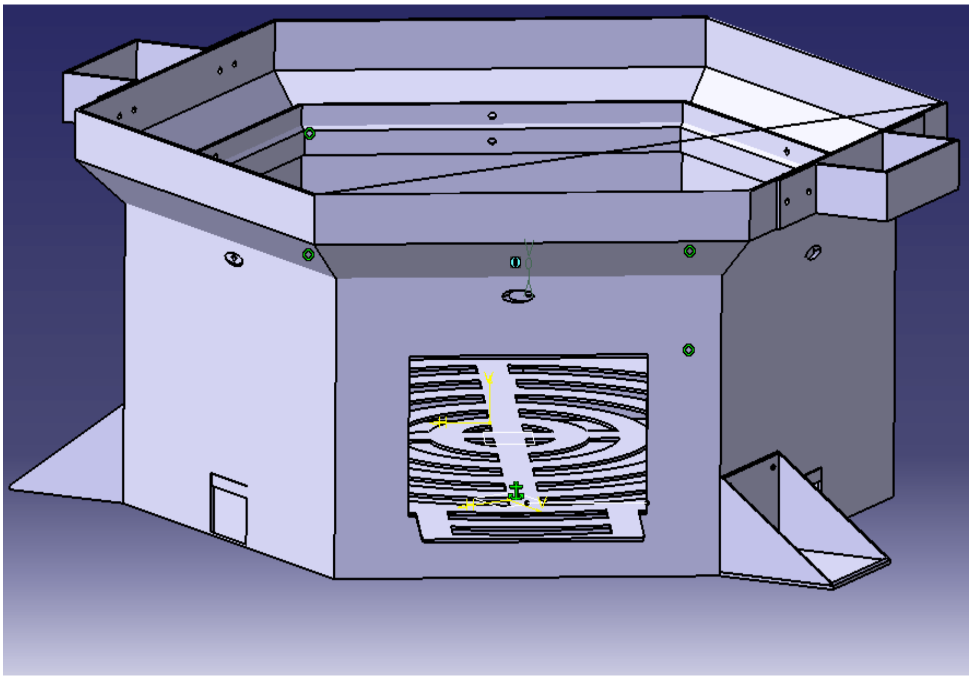


Figure 4: Selected concept